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Effective control of root rot enhances seedling production in artichoke using safe compounds

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ABSTRACT

The investigation centered on the efficacy of essential oils in seedling production and the induction of resistance against globe artichoke root rot caused by *Fusarium solani* and *Rhizoctonia solani*. The study encompassed *in vitro*, and greenhouse experiments conducted during 2022 and 2023. The results from treatments of varying concentrations indicated that mint oil and fulvo copper yielded the most substantial inhibition, outperforming other treatments and the control group. Both light and scanning electron microscopy observations unveiled discernible alterations in the morphology of *F. solani* spores, showcasing a loss of plasmolysis of mycelia, and *R. solani* hyphae exhibited signs of degradation when treated with fulvo copper. Mint oil, clove oil, fulvo copper, and the chemical fungicide (Maxim and Rhizolex-T) were notably successful in considerably diminishing the root rot percentage and disease severity among treated artichoke seedlings compared to alternative treatments and untreated controls. Remarkably, fulvo copper demonstrated the highest enhancement in bud's number for both *F. solani* and *R. solani* cases. Moreover, treated seedlings exhibited significant growth improvements in terms of leaf count, leaf length, root and plant length, fresh weight, as well as dry matter, Crude Protein (%), Total Carbohydrate (%), Total Phenols (%), Chlorogenic Acid, and Total Chlorophyll in artichoke seedlings. Nutritional components like N (%), P (%), K (%), and Ca (%) contents showed pronounced increments upon treatment with fulvo copper. The function of defense-related enzymes, such as polyphenol oxidase, peroxidase, and catalase, demonstrated heightened levels in response to the increasing application of fulvo copper, showcasing a substantial contrast to untreated plants.

Keywords: Globe artichoke seedling, Fusarium, Rhizoctonia, Eessential oil, Resistance-inducer.

INTRODUCTION

Globe artichoke is a highly esteemed vegetable in Egypt for fresh consumption, processing, and exportation. Seedlings are one of the propagation methods of globe artichoke to shorten the vegetative growth stage to early flowering especially in some late-production cultivar (Concerto cv). Egypt, ranking second globally and first in the Arab world, heavily relies on globe artichoke production as a source of income for its farmers and export industry. Cultivating over 17,000 hectares and yielding 400.000 tons annually (FAO, 2021), globe artichoke contributes significantly to the country's agricultural economy. However, one of the major challenges affecting artichoke production is the prevalence of fungal diseases such as Verticillium wilt, powdery mildew, grey mold, white mold, and *Fusarium* spp., leading to yield reduction.

While chemical pesticides have proven effective in pest and disease control, their adverse impact on the environment and non-target organisms cannot be ignored. As a solution to mitigate the harmful effects of chemical residues, the shift towards pesticide alternatives, including biocides, plant extracts, and essential oils, has gained momentum. Essential oils, recognized as natural antifungal agents, present an alternative avenue for combating plant diseases (El-Sharaky and Shala, 2018). Notable examples include clove, cumin, thyme, and peppermint oils, which have been investigated for their antimicrobial and antifungal properties.

Clove oil, featuring the active compound eugenol, demonstrates potent antifungal attributes that effectively combat fungal diseases in plants. Additionally, the application of clove oil has been correlated with increased leaf count and plant height (Elsisi and Shams, 2019). Cumin essential oil exhibits antifungal activity against various postharvest fruit pathogens, including *Aspergillus flavus*, *Penicillium italicum*, and *Botrytis cinerea* (Esmail *et al.,* 2016), showing potential for disease management. Similarly, thyme essential oil, characterized by its chemical polymorphism, displays efficacy against both bacteria and yeasts, as well as microscopic filamentous fungi (Lucia *et al.,* 2021).

A prominent strategy in integrated plant disease control involves stimulating internal resistance through the use of inducers, encompassing biotic and abiotic substances. These include hydrogen peroxide, potassium sorbate, and organic acids like fulvic acid. Hydrogen peroxide, a versatile household liquid, has demonstrated the ability to stimulate plant resistance against diseases, notably effective against common fungal ailments like powdery mildew. Its mechanisms involve activating enzymes such as peroxidase, catalase, and polyphenol oxidase, which bolster plant defenses against pathogen infections while enhancing lignin and suberin content (Abd El-Hai *et al.,* 2017). Similarly, potassium sorbate impedes the growth and sporulation of various fungi, including *Botrytis cinerea* (Smilanick, 2012).

Fulvo copper, an organic compound, emerges as a viable solution for controlling downy mildew, early blight, late blight, root rot, and wilt diseases. Application of foliar sprays containing copper results in noticeable improvements in plant characteristics such as height, leaf number, chlorophyll content, and overall weight, as well as enhanced nitrogen, phosphorus, and potassium content in leaves (Al-Hasan, 2019; Badr *et al.,* 2020). Phenolic compounds assume essential roles in plant processes, including pigmentation, growth, reproduction, and resistance to pathogens. They contribute significantly to plant resistance against fungal attacks by inducing disease resistance (Lattanzio *et al.,* 2006). Chlorogenic acid, a pivotal phenolic compound, safeguards plant tissues against oxidative stress and pathogen invasions (Telles *et al.,* 2017). The central objective of this study is to assess the influence of select safe compounds on the mitigation of root rot diseases in artichoke seedlings.

MATERIAL AND METHODS

The experiment was carried out during the two successive seasons of 2022 and 2023 in Horticulture Research greenhouse in Dokki, Horticultural Research Institute, Agriculture Research Center, Egypt. Stumps (old crowns) were used as a propagation material and there were planted under greenhouse condition (black siren 63 % shading) in polyethylene bags 25 cm diameter containing beat moss and vermiculite (1:1) in mid-June to mid-August (8 weeks) during both seasons. Propagation materials of globe artichoke Concerto CV were taken from the Horticultural Research Institute, Agriculture Research Center, Egypt. The experiment was conducted to study the effect of some safety compounds in controlling root rot of globe artichokes. The experimental plot was 15 bag including one seedling/pot, each treatment content three plots.

Isolation, Purification, and Identification of Pathogenic Fungi:

Pathogenic strains of *Fusarium solani, Rhizoctonia solani*, and *Macrophomina* sp. were isolated from naturally infected globe artichoke plants exhibiting symptoms of root rot. Samples were collected from various locations within cultivated areas in Dokki, Giza, Kaha, El Qanater El-khayria, El Qalyubia governorate, Egypt. Based on their shape and microscopic features, the isolated fungus was identified after being purified using the hyphal tip procedure. The Plant Pathology Research Institute (PPRI), ARC, Giza, Egypt's Mycological Research and Disease Survey Department verified the identification of the pathogen isolates by Sneh et al. (1991) and Leslie and Summerell (2006). At 4±1°C, the pathogenic isolates were cultured on a potato dextrose agar (PDA) medium.

Pathogenicity Test:

By growing isolates in autoclaved bottles containing (100 gm sorghum, 50 gm sand, and 80 ml water), the pathogens *F. solani* and *R. solani* were inoculated. For two hours, the sandy loam soil was autoclaved at 121°C. 30-centimeter diameter plastic pots were sterilized with 5% formalin and allowed to stand for two days to allow the formalin to completely evaporate. The prior inoculum was added to each pot at a rate of 3% of the soil weight to carry out the soil infestation. Plant seeds in every container for seven days following soil infestation in a controlled greenhouse environment with 25 ± 2^{o}C and 65 ± 5 humidity. Each treatment was carried out in five duplicates, and a control treatment was planted in pots filled with soil that was devoid of pathogens and sandy loam.

Treatments:

Commercial essential oils of cumin, mint, clove, and thyme were utilized in this study and were obtained from the Chemical Industrial Development Company (CID), Egypt. Potassium sorbate and H_2O_2 were obtained from the Chemical Elgomhoria company. While, organic matter, fulvic acid obtained from Microbiology Dep. Soil, Water and Environment Research Institute. ARC and Fulvo Copper a commercial organic product containing the active ingredient Copper hydroxide was obtained from Top Fert Industrial Chemicals Co., Wady Elnatron, Egypt, Dose 0.9 ml/L. Chemical commercial fungicide Maxim containing the active ingredients (Mefenoxam 3.5% and Fludioxonil 3.5%) was obtained from Syngenta Chemical Co., and Rhizolex-T, a commercial fungicide product (Rizolex-T 50 WP) containing the active ingredient Tolcfos-methyl was obtained from Sumitomo Chemical Co., Ltd., Osaka, Japan.

***In Vitro* Treatments against *F. solani* and *R. solani*:**

The fungal isolates were cultured on PDA medium for 7 days. Plugs of 5mm were taken and recultured onto PDA plates of 9 cm diameter, treated with 8 substances (H_2O_2, potassium sorbate, mint oil, cumin oil, thyme oil, clove oil, fulvic acid, fulvo copper) and two fungicides (Maxim for *F. solani* and Rhizolix-T for *R. solani*). Control plates with 5mm plugs of *F. solani* and *R. solani* grown on PDA were used.

Greenhouse Experiments:

Forty-five bags (pots) were used for each treatment filled by the infested soil with the pathogenic agent's inocula were done as mentioned above in the section of pathogenicity test. All pots were irrigated 3 times through the seven days. H_2O_2, potassium sorbate, mint oil, cumin oil, thyme oil, clove oil, fulvic acid, fulvo copper and fungicide (Maxim and Rhizolex-T) were used in this experiment at 1ml in all oils, 2.0 ml in case of H_2O_2 and Fulvic acid and 2 g/l in potassium sorbate, while, fulvo copper used rate 0.9 ml/l, compared with fungicides Maxim and Rhizolex-T on recommended concentration of 2ml and 2g/l, respectively, started with planted propagation materials and repeated every 10 days.

Disease Assessment:

Root rot assessment was conducted based on a scale 0-4 used by Hwang and Chang (1989). The root rot index was calculated using the ratings assigned to each category of root discoloration. The scale 0-4, with minor modification as follow: 0 = healthy roots, 1 = 1-9%, 2 >= 9-39%, 3 >= 39-69% and 4 >= 69% and above of root discoloration. Root discoloration was recorded at the end of the experiment and calculated according to the following formula:

$$\text{Root rot index} = [\text{total of all ratings} / (\text{total number of plants} \times 4)] \times 100$$

Assessment of buds several globe artichoke seedlings:

Assessment of the effect of the tested treatments on the bud's number of globe artichoke seedlings through numeric new shoots beside globe artichoke seedlings.

Enzyme Activity Assay:

The enzyme activity of defense enzymes (catalase, peroxidase, and polyphenol oxidase) in treated artichoke plants was evaluated. Fresh artichoke leaves were homogenized, and enzyme activities were measured using a spectrophotometer. freshly treated globe artichoke leaves were homogenized at 4 ^{0}C in 3 ml of 50 mM TRIS buffer (pH 7.8), containing 1 mM EDTA-Na_2 and 7.5% polyvinylpyrrolidone. The homogenates were centrifuged (12,000 rpm, 20 min, 4 ^{0}C), and the enzyme activity was estimated at 25 C, using a typical UV-160A spectrophotometer. Catalase (CAT), peroxidase (POX), and polyphenol oxidase (PPO) activities were measured, as demonstrated by Aebi (1984) Hammerschmidt *et al*. (1982) and Malik and Singh (1980), respectively.

Light and Scanning Electron Microscopy:

Light microscope (Leica DM1000) examination was used to study the effect of fulvo copper on *R. solani* (mycelial) and *F. solani* (hyphae and spores). Photographing by microscope was done at the Vegetable Diseases Research Dept. Plant Pathology Research Institute. Agricultural Research Center. (ARC). Giza. Egypt.

According to Harley and Ferguson's (1990) methods, small pieces of agar were cut at the margin of the causals, fulvo copper and transferred for dehydration before being sputter-coated with gold to investigate the interaction between the causals of globe artichoke root rot and fulvo copper. Scanning electron microscopy (SEM) JEOL JSM 6510 lv, Faculty of Agriculture, Mansoura University, was used for examination and photography in order to evaluate the effect of fulvo copper on *F. solani* and *R. solani*.

Vegetative Growth Characteristics:

Five plants were taken from each experimental unit at the end of nursery (after eight weeks) to determine leaves number, leaf length (cm), root length (cm), plant length (cm), plant fresh weight (gm) and dry matter (gm) as well as survival plant percentage (%).

Chemical Composition of Leaves:

Chemical composition of seedlings leaves *i.e.*, Nitrogen, Phosphorus, Potassium and Calcium (%) were determine according to Pregl (1945), John (1970), Brown and Lilleland (1946) and Nielsen (2010), respectively. Total carbohydrates (%) Block et al (1985), chlorogenic acid (mg/gm D.W.) , total phenols (%) were determined according to Pinto *et al*. (2008) by using HPLC and Meda *et al*. (2005), respectively and chlorophyll content was measured by portable leaf chlorophyll meter (Minolta SPAD-502, Japan) to determine the greenness or relative content of leaves to analyze the photosynthetic pigments according to A. O. A. C. (2000) and Torres-Netto *et al*. (2005), as well as crude protein was calculated as nitrogen content x 6.25.

Statistical Analysis:

All experiments utilized a complete randomized block design. Statistical analyses, including analysis of variance (ANOVA) and Pearson correlation tests, were conducted using software tools (WASP and SPSS V.22) to assess relationships between measured parameters.

RESULTS

Frequency of the isolated fungi from diseased globe artichoke plants:

Fungi isolates obtained from diseased artichoke roots were subjected to purification and identification based on their cultural and morphological characteristics, leading to the identification of *Fusarium* spp. (Mart.) Sacc, *Rhizoctonia solani* Kühn, and *Macrophomina phaseolina* (Tassi) Goid. Notably, the number of isolates obtained from El Qanater Elkhayria district (8 isolates) exceeded those isolated from the Kaha and Dokki districts (7 and 6 isolates, respectively). Among the identified fungi, *R. solani* exhibited the highest occurrence across all three districts. In terms of colony frequency, *R. solani* displayed the highest rate with 10 colonies, followed by 8 colonies of *F. solani* and 3 colonies of *M. phaseolina* **Table (1)**

Table 1. Fungi isolated from roots of diseased globe artichoke plants

location / Isolated fungi	Dokki		Kaha		El Qanater Elkhayria		Total isolates
	No. fungal colony	Frequency %	No. fungal colony	Frequency %	No. fungal colony	Frequency %	
F. solani.	2.0 b	33.3	3.0 a	42.9	3.0 b	37.5	8.0
R. solani	3.0 a	50.0	3.0 a	42.9	4.0 a	50.0	10.0
M. phaseolina	1.0 c	16.7	1.0 b	14.2	1.0 c	12.5	3.0
Total isolates	6.0	100.0	7.0	100.0	8.0	100.0	21.0

- Values in the same column followed by the same letter are not significantly different *at P < 0.5* level.

GC-MS Analysis of essential oils:

The tested plant oils contained active components, revealing the presence of forty-four fractions in mint oil, thirty-three fractions in cumin oil, twenty-nine fractions in thyme oil, and forty-four fractions in clove oil.

Analysis of mint oil using GC-MS revealed the existence of various components including Menthone (42.97%) and Menthol (27.64%), as well as isomenthone, carvone, piperidone oxide, D-limonene, and eucalyptol. Meanwhile, cumin oil displayed the highest relative concentration of Beta-cumin aldehyde (11.77), carotol (5.47), 1-butenyl-thiophene (4.39), and phenanthrene methanol (3.85). Thyme oil analysis unveiled compounds such as 1,8-cineol (23.96), phenol 1-methyl ethyl (20.54), n-hexadecenoic acid (16.17), and Alpha-terpinenyl acetate (14.5). Similarly, clove oil constituents were identified through GC-MS analysis, with eugenol (55.6), eugenol acetate (20.45), caryophyllene (14.84), and α-humolene (2.75) being prominent.

Effect of some treatments on linear growth of *F. solani* and *R. solani:*

The impact of various treatments with different concentrations (0.5, 1.0, 2.0 ml/l) including H_2O_2, potassium sorbate, mint oil, cumin oil, thyme oil, clove oil, fulvic acid, fulvo copper, and two fungicides (Maxim and Rhizolex) on the linear growth of *F. solani* and *R. solani*, compared to the fungicide, is presented in Table (2), as well as Figures (1) and (2). The findings indicated that mint oil, fulvo copper, and the fungicide (Maxim) significantly inhibited the growth of *F. solani* at all three concentrations (0.0, 0.0, 0.0 cm at a concentration respectively, Except the mint oil which scored 3.9 at concentration 0.5), resulting in a reduction percentage of 100%, compared to other treatments and the untreated control. Similarly, mint oil, fulvo copper, fulvic acid, cumin oil, and the fungicide (Rhizolex-T) achieved the highest reduction in linear growth of *R. solani* (0.0, 2.3, 4.2, 4.8, and 1.2 cm at a concentration of 2ml/l, respectively), when compared to other treatments and the untreated control. The reduction percentages for these treatments were 100%, 74.4%, 53.3%, 46.7%, and 86.7%, respectively.

Table 2. Effect of some safety compounds on linear growth of *F. solani* and *R. solani* isolated from artichoke plants *in vitro* after 7 days.

Treatment	Concentration (ml/l)	L. G* *Fusarium solani*	Inhibition %	L. G *Rhizoctonia solani*	Inhibition %
H_2O_2	0.5	9.0 a	0.0	9.0 a	0.0
	1	9.0 a	0.0	8.8 ab	2.2
	2	9.0 a	0.0	8.6 b	4.4
Potassium sorbate	0.5	9.0 a	0.0	9.0 a	0.0
	1	9.0 a	0.0	8.2 c	8.9
	2	8.3 b	7.8	7.6 b	15.6
Mint oil	0.5	3.9 c	56.7	1.9 n	78.9
	1	0.0 d	100	0.0 p	100
	2	0.0 d	100	0.0 p	100
Cumin oil	0.5	9.0 a	0.0	5.8 f	35.6
	1	9.0 a	0.0	5.1 g	43.3
	2	9.0 a	0.0	4.8 h	46.7
Thyme oil	0.5	9.0 a	0.0	8.7 b	3.3
	1	9.0 a	0.0	7.4 de	17.8
	2	9.0 a	0.0	6.9 e	23.3
clove oil	0.5	9.0 a	0.0	9.0 a	0.0
	1	9.0 a	0.0	8.3 c	7.8
	2	9.0 a	0.0	7.8 d	18.7
Fulvic acid	0.5	9.0 a	0.0	9.0 a	0.0
	1	9.0 a	0.0	6.8 e	24.4
	2	9.0 a	0.0	4.2 j	53.3
Fulvo copper	0.5	0.0 d	100	4.6 hi	48.9
	1	0.0 d	100	2.8 l	68.9
	2	0.0 d	100	2.3 m	74.4
Fungicide (Maxim)	0.5	0.0 d	100	-	-
	1	0.0 d	100	-	-
	2	0.0 d	100	-	-
Fungicide (Rizolex T)	0.5	-	-	3.2 k	64.4
	1	-	-	2.2 m	75.6
	2	-	-	1.2 o	86.7
control		9.0 a	100	9.0 a	0.0
L.S.D at 0.05		0.312		0.211	

- Values in the same column followed by the same letter are not significantly different *at* $P < 0.5$ level.
L.G*= Linier growth

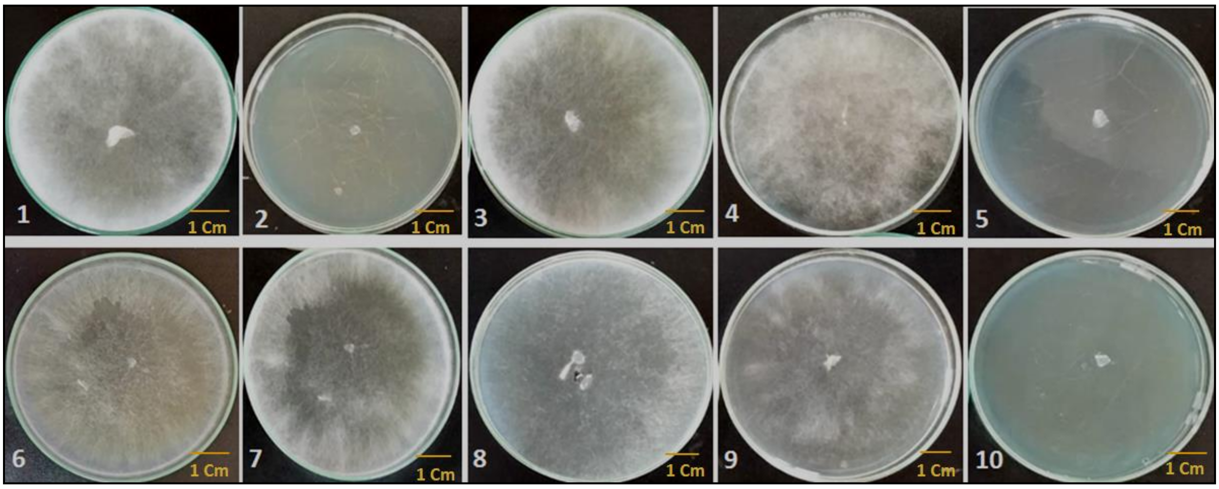

Fig. 1. Effect of some safety compounds and chemical fungicides on the radial growth of *F. solani,* 1 = Control, 2 = fungicide, 3 = H_2O_2, 4 = Potassium sorbate, 5= Mint oil, 6= cumin oil, 7= Thyme oil, 8= clove oil, 9 = fulvic acid and 10 = fulvo cupper.

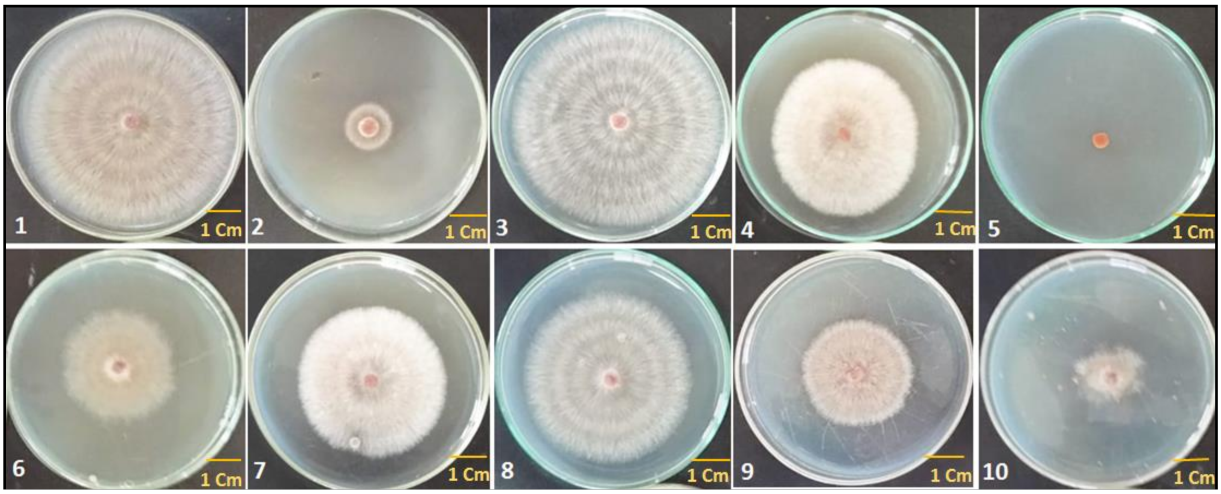

Fig. 2. Effect of some safety compounds and chemical fungicide on the radial growth of *R. solani,* 1 = Control, 2 = fungicide, 3 = H_2O_2, 4 = Potassium sorbate, 5= Mint oil, 6= cumin oil, 7= Thyme oil, 8= clove oil, 9 = fulvic acid and 10 = fulvo cupper.

Microscopic Observations:

Examinations conducted under a light microscope on *F. solani* mycelia and spores that were treated with fulvo copper revealed distinct changes, including the contraction, collapse, and abnormal morphology of the treated plant's hyphae (Fig. 3B), when compared to the untreated *F. solani* (control Fig. 3A). Similar findings were observed in the case of fulvo copper-treated *R. solani* (Fig. 5B), in contrast to the control (Fig. 5A). Utilizing a scanning electron microscope to scrutinize fungal structures extracted from globe artichoke roots subjected to fulvo copper treatment unveiled notable anomalies and modifications in the mycelia and spores of *F. solani* (Fig. 4B), contrasting with the untreated control (Fig. 4A). Additionally, twisting, plasmolysis of mycelia and spores, as well as shrinkage and collapse, were also evident (Fig. 4B). Conversely, globe artichoke plants treated with fulvo copper displayed the collapse and shrinkage of mycelia (Fig. 6B), when compared to the untreated control (Fig. 6A).

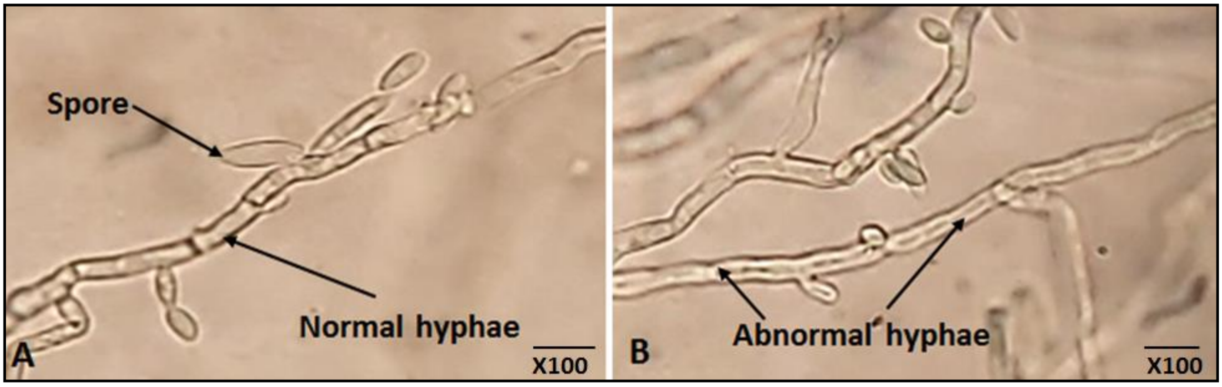

Fig. 3. Light microscopy examination of fulvo copper effects against *F. solani*, (**A**) control, (**B**) treated with fulvo copper.

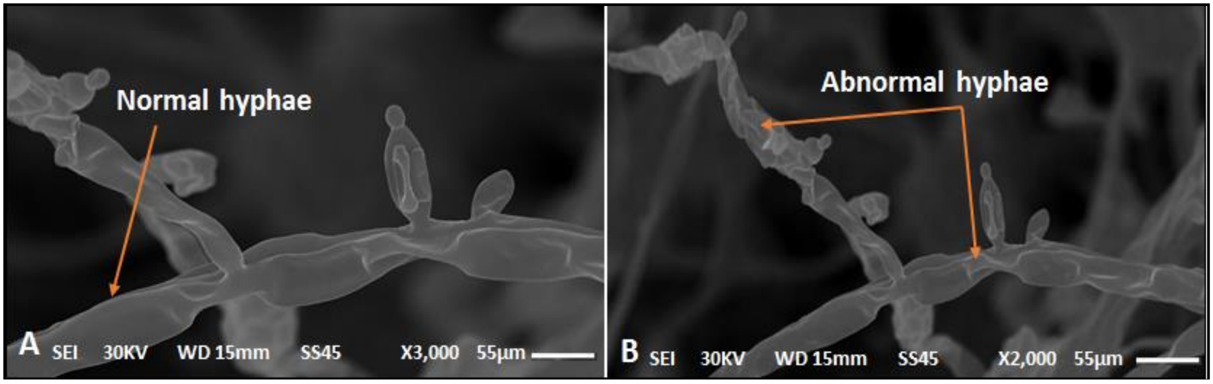

Figure 4. Scanning Electron Microscopy of fulvo copper effects against *F. solani*, (**A**) control, (**B**) treated with fulvo copper.

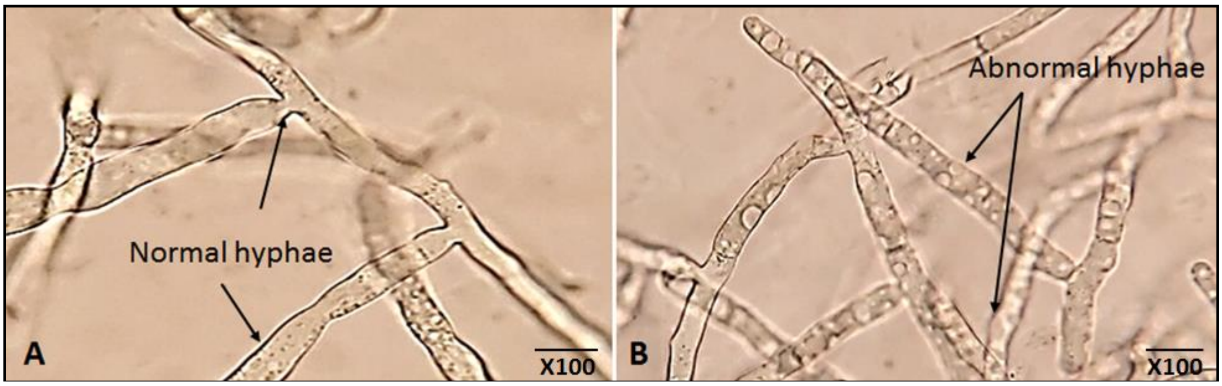

Figure 5. Light microscopy examination of fulvo copper effects against *R. solani*, (A) control, (B) treated with fulvo copper

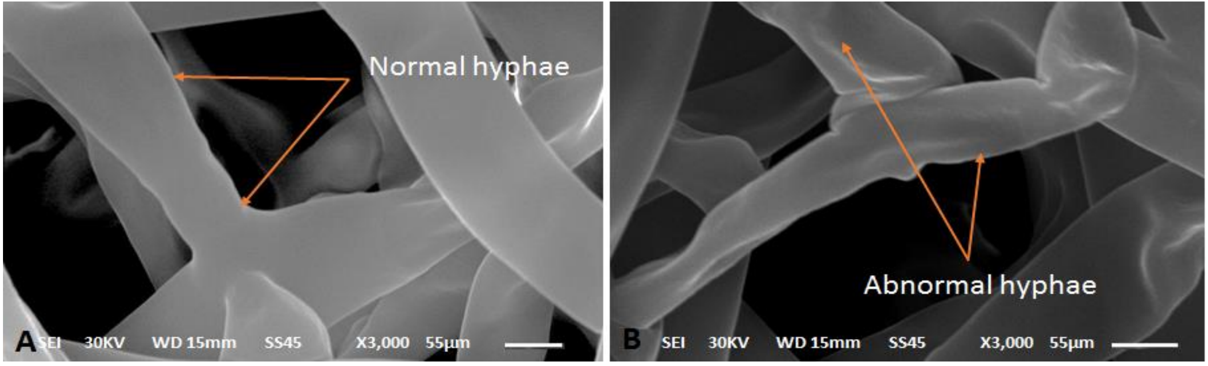

Fig. 6. Scanning Electron Microscopy of fulvo copper effects against *R. solani*, (A) control, (B) treated with fulvo copper.

Effect of some safety compounds on *F. solani* and *R. solani* in globe artichoke seedlings under greenhouse condition:

The impact of some treatments, in comparison to the recommended fungicide, on the severity of root rot disease in globe artichoke seedlings treated under greenhouse conditions is summarized in Table (3). The findings indicate that mint oil, clove oil, fulvo copper, and the chemical fungicide exhibited significant reductions in both root rot percentage and disease severity during seasons 2022 and 2023 in the treated globe artichoke seedlings when compared to the other treatments and the untreated control. The highest effectiveness in terms of root rot percentage and the least disease severity value with *F. solani* was observed in the case of fulvo copper, achieving 73.5 and 20.0%, respectively in first season, while the second season achieved 73.2 and 21.2%, respectively. Following this, mint oil achieved 72.9 and 71.7% root rot reduction with disease severity of 21.3 and 22.4% through two seasons, clove oil reached 69.73 and 69.6% reduction with 22.7 and 24.1% disease severity, all for *F. solani* infection. Conversely, with *R. solani* the results also demonstrated during two seasons that fulvo copper, mint oil, cumin oil, and clove oil displayed the least disease severity rates at (19.3, 20%), (19.7, 19.8%), (22.7, 23.4%), and (27.3, 29.2%), respectively, and exhibited the highest efficacy percentages of 80.7%, 80%), (80.3, 80.2%), (77.3, 76.6%), and 72.7, 70.8%), respectively.

Table 3. Effect of some safety compounds on *F. solani* and *R. solani* in artichoke plants under greenhouse.

Treatment	Disease severity%				Efficacy%			
	F. solani		*R. solani*		*F. solani*		*R. solani*	
	2022	2023	2022	2023	2022	2023	2022	2023
H_2O_2	27.3	29.6	23.7	26.2	63.6	62.6	76.3	73.8
Potassium sorbate	70.3	73.4	67.7	68.5	6.27	7.3	32.3	31.5
Mint oil	21.3	22.4	19.7	19.8	72.9	71.7	80.3	80.2
Cumin oil	67.3	69.1	22.7	23.4	10.25	12.8	77.3	76.6
Thyme oil	43.3	44.2	56.7	58.1	42.27	44.2	43.3	41.9
Clove oil	22.7	24.1	27.3	29.2	69.73	69.6	72.7	70.8
Fulvic acid	51.3	52.0	36.7	38.1	31.6	34.3	63.3	61.9
Fulvo copper	20.0	21.2	19.3	20.0	73.5	73.2	80.7	80.0
Fungicide*	18.7	20.3	14.3	16.1	75.06	74.4	85.7	83.9
Control	75.0	79.2	100	100	0.0	0.0	0.0	0.0
L.S.D $_{at\ 0.05}$	A= 0.875 B= 0.398 AXB=1.244		A= 0.641 B= 0.284 AXB= 0.912					

- Values in the same column followed by the same letter are not significantly different *at* $P < 0.5$ level.

* = Fungicide Maxim with *F. solani* and Rhizolex-T with *R. solani*.

Effect of some safety compounds on bud number on global artichoke plants:

The data provided in Table (4) demonstrates that the application of fulvo copper resulted in the highest bud's number, reaching 5.0 in the case of *F. solani* and 3.67 in the case of *R. solani*. Following this, the treatments that yielded favorable bud numbers for *F. solani* were H_2O_2, thyme oil, clove oil, fulvic acid, and mint oil, in that order. Conversely, for *R. solani*, some treatments performed particularly well in promoting buds' number, specifically cumin oil, H_2O_2, and thyme oil, respectively.

Table 4. Effect of some safety compounds on bud's number on globe artichoke seedlings under greenhouse.

Treatment	Buds number	
	F. solani	***R. solani***
H_2O_2	4.67	2.33
Potassium sorbate	1.67	1.33
Mint oil	2.33	2.67
Cumin oil	1.33	2.67
Thyme oil	3.33	2.0
Clove oil	3.0	2.34
Fulvic acid	2.67	2.0
Fulvo copper	5.0	3.67
Fungicide*	5.67	4.0
Control	0.67	0.67
L.S.D. $_{\text{at 0.05}}$	A= 0.296 & B= 0.177 & AXB= 0.415	

- Values in the same column followed by the same letter are not significantly different *at* $P < 0.5$ level.
* = Fungicide Maxim with *F. solani* and Rhizolex-T with *R. solani*.

Effect of some safety compounds on plant growth parameter on globe artichoke seedlings:

About the impact of treating globe artichoke seedlings with various safe components, including potassium sorbate, hydrogen peroxide, fulvic acid, fulvo copper, as well as natural oils such as mint, cumin, thyme, and clove oils, alongside two types of fungicides, on the growth of the seedlings, encompassing factors such as survival rate, leaf number and length, seedling length, fresh weight, total chlorophyll, and dry matter, the data presented in Table (5) reveals intriguing findings.

The data highlights that the highest survival percentage of seedlings occurred when grown in media previously infected with *Rhizoctonia* fungus, showing significant differences during the second season compared to *Fusarium* infection. Remarkably, hydrogen peroxide treatment led to the highest survival rate among all treatments in both experimental seasons.

Analyzing the effect of the safe components and the two types of fungi on seedling survival, the data suggests that hydrogen peroxide notably enhanced the survival percentage of seedlings exposed to both *Fusarium* and *Rhizoctonia* fungi across both seasons.

Turning to the influence of the safe components and fungal types on the vegetative growth characteristics of globe artichoke seedlings, Table (5) portrays intriguing trends. The highest values for leaf number, seedling length, leaf length during both growth seasons, as well as total chlorophyll during the second season, were observed in seedlings grown in media infected with *Fusarium* fungus compared to those infected with *Rhizoctonia*. In contrast, an increase in root length, seedling fresh weight, and dry matter during both seasons, along with total chlorophyll in the first season, was noticed in seedlings grown in media infected with *Rhizoctonia* fungus. Further examination of the data reveals that the application of fulvo copper significantly affected leaf number and plant length during both seasons dry matter during the second season. In contrast, thyme oil led to a notable increase in dry matter during the second season. Clove oil treatment exhibited a substantial increase in leaf length and seedling fresh weight across both seasons. Notably, mint oil contributed to a significant root length increases during both seasons. Moreover, an increase in total chlorophyll was evident in the first season through the use of fungicide, while the second season saw a similar effect with the use of potassium sorbate.

Taking into account the interactive effects, the data in Table (5) uncovers intriguing insights. Treating seedlings infected by either Fusarium or Rhizoctonia with fulvo copper resulted in a higher number of leaves. Moreover, the application of fulvo copper to seedlings infected with Fusarium led to increased seedling and leaf lengths compared to other treatments. Interestingly, fresh weight in Rhizoctonia-infected seedlings increased with fulvo copper treatment, outperforming other treatments. Furthermore, seedlings infected with Fusarium and treated with Maxim fungicide exhibited heightened root length. Meanwhile, mint oil or thyme oil treatments were associated with increased dry matter in Rhizoctonia-infected seedlings when compared to other treatments. Chlorophyll content (SPAD) enhancement in leaves was observed in seedlings infected with Rhizoctonia fungus when treated with Rizolex-T or potassium sorbate.

Table 5. Effect of some safety compounds on plant growth promoter on globe artichoke seedlings infected with *F. solani* and *R. solani* during two seasons 2022 and 2023.

	treatment	**Survival plant percentage (%)**		**Leaves number/ plant**		**Leaf length (cm)**		**Root length (cm)**		**Plant length (cm)**		**Plant fresh weight (gm)**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
F. solani		68.00	65.33	7.40	7.20	23.63	25.56	10.70	12.63	34.13	39.13	188.37	156.10
R. solani		57.00	56.33	6.71	5.56	22.16	24.23	11.40	12.90	33.43	32.63	188.03	219.17
L.S.D at 0.05		**N.S**	**8.95**	**N.S**	**0.94**	**0.14**	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**	**44.23**
	H_2O_2	97.50	93.33	8.00	7.33	21.66	23.66	14.33	16.33	16.33	31.83	140.17	156.50
	Pot. Sor.	33.33	34.16	6.50	5.50	19.66	21.66	8.66	10.66	10.66	31.50	109.33	160.33
	Mint oil	61.66	60.83	6.33	5.66	22.16	24.50	17.83	19.50	19.50	33.33	177.33	206.00
	Cumin oil	51.66	53.33	7.00	5.83	24.33	26.33	14.00	14.16	14.16	31.50	166.17	191.00
	Thyme oil	70.00	66.66	7.00	6.16	21.16	23.83	9.16	11.16	11.16	31.66	185.00	200.33
	Clove oil	76.66	75.83	6.00	6.33	26.83	28.83	8.33	10.33	10.33	31.83	207.67	220.00
	Fulvic acid	52.50	65.66	7.33	6.50	26.50	28.50	8.83	10.83	10.83	39.16	178.17	205.50
	Fulvo cop.	70.00	63.33	9.66	8.50	26.00	27.00	8.66	10.00	10.00	44.00	201.00	225.17
	fungicide	63.33	62.50	8.50	8.83	26.16	28.16	15.66	17.66	17.66	39.66	201.50	231.67
	control	50.00	41.66	4.25	3.16	14.50	16.50	5.00	7.00	7.00	19.33	54.67	79.83
L.S.D. at 0.05		**11.36**	**8.12**	**1.51**	**2.40**	**4.62**	**4.50**	**2.93**	**3.58**	**3.58**	**4.21**	**43.41**	**19.57**
F. solani	**H_2O_2**	96.66	91.66	7.00	5.66	21.33	23.33	11.66	13.66	13.66	34.66	107.67	122.67
	Pot. Sor.	31.66	31.66	6.33	4.66	20.66	22.66	8.33	10.33	10.33	32.33	74.00	87.33
	Mint oil	33.33	31.66	6.33	4.33	21.66	23.66	20.00	22.00	22.00	30.00	129.00	159.33
	Cumin oil	33.33	35.00	7.00	4.66	22.33	24.33	12.00	13.33	13.33	35.66	144.67	198.67
	Thyme oil	70.00	75.00	6.00	5.00	23.33	26.66	10.33	12.33	12.33	27.66	139.00	154.67
	Clove oil	70.00	70.00	6.00	5.66	30.66	32.66	8.33	10.33	10.33	25.33	189.33	204.33
	Fulvic acid	70.00	78.33	6.33	5.66	26.00	28.00	5.33	7.33	7.33	42.66	154.00	170.00
	fulvo cop.	70.00	68.33	9.33	8.00	34.00	34.00	6.00	8.00	8.00	49.00	159.33	177.33
	Rhizolex T	66.66	53.33	8.33	8.00	22.00	24.00	20.33	22.33	22.33	45.00	211.33	242.67
	control	31.66	28.33	4.50	4.00	14.33	16.33	4.66	6.66	6.66	19.00	52.67	84.00
R. solani	**H2o2**	98.33	95.00	9.00	9.00	22.00	24.00	17.00	19.00	19.00	29.00	172.67	190.33
	Pot. Sor.	35.00	36.66	6.66	6.33	18.66	20.66	9.00	11.00	11.00	30.66	144.67	233.33
	Mint oil	90.00	90.00	6.33	7.00	22.66	25.33	15.66	17.00	17.00	36.66	225.67	252.67
	Cumin oil	70.00	71.66	7.00	7.00	26.33	28.33	16.00	15.00	15.00	27.33	188.33	223.33
	Thyme oil	70.00	58.33	8.00	7.33	19.00	21.00	8.00	10.00	10.00	35.66	231.00	246.00
	Clove oil	83.33	81.66	6.00	7.00	23.00	25.00	8.33	10.33	10.33	38.33	226.00	235.67
	Fulvic acid	35.00	35.00	8.33	7.33	27.00	29.00	12.33	14.33	14.33	35.66	204.33	241.00
	fulvo cop.	70.00	58.33	10.00	9.00	18.00	20.00	11.33	12.00	12.00	39.00	242.67	273.00
	Rhizolex T	90.00	96.66	8.66	9.66	30.33	32.33	11.00	13.00	13.00	34.33	191.67	220.67
	control	33.33	30.00	4.00	2.33	14.66	16.66	5.33	7.33	7.33	19.66	56.67	75.67
L.S.D at 0.05		**20.03**	**13.40**	**2.56**	**3.32**	**6.20**	**6.39**	**4.01**	**5.45**	**5.45**	**6.38**	**59.33**	**48.07**

L.S.D at 0.05 = low significant differences at 5%.

Impact of various treatments on the determination of dry matter and nutrient levels in globe artichoke seedlings:

The assessment of nutrients such as nitrogen, phosphorus, potassium, and calcium content were carried out, along with evaluating the impact of fungal infection treatments on chemical components within globe artichoke seedling leaves. This encompassed parameter like nitrogen, phosphorus, potassium, calcium, proteins, and carbohydrates, as well as active compounds such as total phenols and chlorogenic acid. The data provided in Table (6) elucidates significant findings. In terms of fungal infection effects on nutrient content, the data reveals that leaves of seedlings infected with Rhizoctonia showcased higher levels of nitrogen, phosphorus, potassium, and calcium compared to those infected with Fusarium. Particularly, during the first season, notable differences in nitrogen and phosphorus content were observed.

Regarding the influence of safety components on the nutrient content of globe artichoke seedling leaves, Table (6) highlights intriguing trends. Nitrogen content significantly increased when fungicide was employed during the first season, surpassing other treatments. During the second season, the same treatment exhibited a substantial increase compared to other treatments, except for the fulvo copper treatment. Notably, fulvo copper usage resulted in the highest phosphorus content, demonstrating significant differences from other treatments except the fungicide treatment. Additionally, fulvo copper application led to a significant increase in potassium content in seedling leaves, compared to other treatments except fulvic acid during the first season. During the second season, the highest potassium content was recorded when potassium sorbate was employed, exhibiting a significant difference from the untreated control. Moreover, calcium content was highest in seedling leaves treated with fulvo copper during the first season, indicating a significant increase compared to the untreated treatment. In the second season, fungicide treatment led to the highest calcium content, followed closely by fulvo copper, with no significant differences between them.

Table 6. Effect of safety compounds on dry matter, N contents, P contents, K contents and Ca contents (%) on globe artichoke seedlings infected with *F. solani* and *R. solani* during two seasons 2022 and 2023.

	treatment	**Dry matter (%)**		**N contents (%)**		**P contents (%)**		**K contents (%)**		**Ca contents (%)**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
F		14.50	15.06	1.87	1.99	0.327	0.355	3.14	2.77	1.86	1.71
R		15.92	16.02	2.26	2.19	0.433	0.440	3.15	2.96	1.95	1.90
LSD at 0.05		**N.S**	**N.S**	**0.31**	**N.S**	**0.049**	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**
	H_2O_2	15.35	15.50	1.52	1.80	0.296	0.291	2.40	2.69	1.87	1.61
	Pot. Sor.	15.17	15.29	1.80	2.02	0.290	0.320	3.48	3.22	1.86	1.79
	Mint oil	15.55	15.82	2.07	1.90	0.333	0.260	3.25	2.60	1.89	1.77
	Cumin oil	15.17	15.15	1.80	1.79	0.345	0.453	2.81	2.77	1.49	1.64
	Thyme oil	15.87	15.99	2.16	2.01	0.365	0.463	2.70	2.74	1.94	1.86
	Clove oil	14.98	15.67	1.71	2.24	0.331	0.380	3.49	2.60	1.96	1.85
	Fulvic acid	15.71	15.78	2.34	2.19	0.438	0.455	3.63	3.21	2.15	1.83
	Fulvo cop.	15.00	16.10	2.73	2.62	0.665	0.605	3.79	3.14	2.09	2.02
	Fungicide	14.86	15.44	3.11	2.65	0.573	0.570	3.28	3.22	2.09	2.03
	control	14.46	14.67	1.39	1.66	0.165	0.180	2.65	2.45	1.72	1.65
LSD at 0.05		**0.85**	**0.88**	**0.84**	**0.87**	**0.092**	**0.092**	**0.79**	**0.67**	**0.28**	**0.27**
F. solani	**H_2O_2**	14.94	14.66	1.20	1.78	0.173	0.166	2.41	2.55	1.78	1.38
	Pot. Sor.	14.37	14.50	1.23	2.17	0.203	0.150	3.50	3.15	1.91	1.58
	Mint oil	13.90	15.65	2.16	1.79	0.206	0.203	2.98	2.54	1.97	1.49
	Cumin oil	14.66	14.42	1.59	1.73	0.300	0.403	2.53	2.33	1.43	1.56
	Thyme oil	14.97	15.51	2.17	1.92	0.310	0.460	2.78	2.69	1.68	1.87
	Clove oil	14.85	15.06	1.33	1.80	0.326	0.363	3.80	2.40	2.10	1.85
	Fulvic acid	14.50	15.22	2.33	2.09	0.280	0.363	3.62	2.78	1.93	1.58
	Fulvo cop.	14.07	15.90	1.70	2.68	0.693	0.663	3.77	3.03	2.08	2.21
	Maxim	14.60	15.08	2.67	2.31	0.623	0.616	3.51	3.92	2.11	1.95
	control	14.17	14.58	1.31	1.63	0.156	0.166	2.54	2.31	2.59	1.63
R. solani	**H_2O_2**	15.76	16.34	1.84	1.81	0.420	0.416	2.39	2.83	1.96	1.84
	Pot. Sor.	15.97	16.07	2.38	1.86	0.376	0.490	3.45	3.30	1.81	2.00
	Mint oil	17.20	15.99	1.98	2.02	0.460	0.316	3.53	2.65	1.81	2.05
	Cumin oil	15.68	15.87	2.01	1.86	0.390	0.503	3.10	3.22	1.55	1.73
	Thyme oil	16.77	16.47	2.14	2.11	0.420	0.466	2.63	2.79	2.20	1.84
	Clove oil	16.77	16.28	2.10	2.68	0.336	0.396	3.18	2.81	1.82	1.86
	Fulvic acid	15.11	16.34	2.36	2.29	0.596	0.546	3.64	3.63	2.36	2.08
	Fulvo cop.	15.93	16.30	2.76	2.57	0.636	0.546	3.82	3.26	2.10	2.83
	Rhizolex T	15.11	15.80	2.56	2.99	0.523	0.523	3.06	2.53	2.07	2.11
	control	14.75	14.76	1.48	1.69	0.173	0.193	2.76	2.59	1.85	1.66
LSD at 0.05		**1.79**	**1.54**	**1.16**	**1.34**	**0.131**	**0.144**	**1.14**	**1.00**	**0.52**	**0.46**

L.S.D at 0.05 = low significant differences at 5%.

Exploring the interaction between safety components and fungal types, the data in Table (6) unveils insightful correlations. The highest nitrogen content in leaves was observed when Rhizolex-T was employed on Rhizoctonia fungus during both seasons. Additionally, the application of fulvo copper to treat Fusarium fungus led to a notable increase in phosphorus content in leaves, compared to the untreated treatment in both seasons. Regarding potassium content, the usage of fulvo copper with Rhizoctonia fungus exhibited the highest levels during the first season. In the second season, applying Maxim fungicide to Fusarium-infected plants significantly increased potassium content compared to the untreated treatment. Furthermore, utilizing fulvic acid with Rhizoctonia fungus led to increased calcium content during the first season, while the highest calcium content was attributed to fulvo copper treatment with Fusarium fungus during the second season.

Effect of some safety compounds on chemical contents on globe artichoke seedlings:

The impact of various treatments on chemical contents in globe artichoke seedlings, including proteins, total carbohydrates, total phenols, and chlorogenic acid, was examined. Data presented in Table (7) provides valuable insights into these effects.

Table 7. Effect of some safety compounds on Crude Protein (%), Total Carbohydrate (%), Total phenols (%), Chlorogenic acid, and Total chlorophyll on globe artichoke seedlings infected with *F. solani* and *R. solani* during two seasons 2022 and 2023

	treatment	**Crude Protein (%)**		**Total Carbohydrate (%)**		**Total phenols (%)**		**Chlorogenic acid mg/g D.W.**		**Total chlorophyll (SPAD)**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
F. solani		11.70	12.46	59.16	59.60	2.89	2.94	2.61	2.74	51.00	49.35
R. solani		14.14	13.69	60.23	60.41	3.04	2.85	2.74	2.73	53.25	49.32
LSD $_{\text{at 0.05}}$		**1.98**	**4.64**	**0.92**	**0.770**	**N.S.**	**0.08**	**0.11**	**N.S.**	**N.S**	**N.S**
	H_2O_2	9.51	11.25	61.38	61.61	3.25	3.06	2.89	2.89	53.35	52.35
	Pot. Sor.	11.27	12.62	59.93	59.89	2.98	2.71	2.59	2.28	55.60	53.90
	Mint oil	12.96	11.92	59.06	58.69	2.87	2.80	2.80	2.60	52.41	49.23
	Cumin oil	11.27	11.24	58.52	60.10	2.75	2.90	2.35	2.75	53.70	50.70
	Thyme oil	13.50	12.60	58.79	59.06	2.83	3.12	2.75	2.78	53.48	52.71
	Clove oil	10.72	14.03	58.91	58.88	2.83	2.80	2.58	2.72	46.96	44.48
	Fulvic acid	14.66	13.71	59.45	59.93	2.92	2.70	2.81	3.15	53.28	49.00
	Fulvo cop.	17.10	16.41	61.77	60.85	3.44	3.07	3.15	2.81	50.71	46.96
	Fungicide	19.49	16.59	59.30	61.75	2.91	2.80	2.94	2.95	57.76	54.08
	control	8.72	10.40	59.87	59.30	2.88	3.01	2.07	2.42	44.00	39.91
LSD $_{\text{at 0.05}}$		**5.28**	**5.49**	**0.988**	**1.092**	**0.33**	**0.28**	**0.40**	**0.41**	**5.09**	**3.88**
F. solani	**H_2O_2**	7.52	11.14	61.82	61.26	3.00	3.08	2.73	2.98	50.80	52.56
	Pot. Sor.	7.66	13.58	58.34	59.03	2.93	2.79	2.50	2.38	51.16	51.53
	Mint oil	13.52	11.22	59.82	59.19	2.93	2.83	2.64	2.44	52.06	49.93
	Cumin oil	9.97	10.85	58.15	59.85	2.72	2.86	2.19	2.68	51.56	49.76
	Thyme oil	13.60	12.02	59.29	59.13	2.71	3.19	2.42	2.64	51.83	54.36
	Clove oil	8.33	11.27	59.05	58.35	2.84	2.84	2.52	2.58	55.83	54.36
	Fulvic acid	14.58	13.08	58.53	59.22	2.98	2.69	3.08	3.21	54.06	49.83
	Fulvo cop.	16.91	16.75	60.87	60.12	3.16	3.10	3.06	2.71	45.30	41.36
	Maxim	16.72	14.47	57.96	61.28	2.96	3.01	2.89	3.10	54.63	50.76
	control	8.18	10.22	58.83	58.61	2.64	3.02	2.11	2.69	43.03	39.00
R. solani	**H_2O_2**	11.50	11.35	60.95	61.97	3.49	3.04	3.06	2.81	55.90	52.13
	Pot. Sor.	14.87	11.66	61.52	60.76	3.02	2.63	2.69	2.19	60.03	56.26
	Mint oil	12.41	12.62	58.29	58.18	2.80	2.77	2.95	2.77	52.76	48.53
	Cumin oil	12.56	11.62	58.90	60.34	2.78	2.94	2.52	2.81	55.83	51.63
	Thyme oil	13.39	13.18	58.30	59.00	2.95	3.04	2.73	2.93	55.13	51.06
	Clove oil	13.12	16.79	59.77	59.42	2.83	2.75	2.64	2.85	38.33	34.60
	Fulvic acid	14.75	14.35	60.38	60.64	2.86	2.72	2.54	3.10	52.50	48.16
	Fulvo cop.	17.29	16.08	62.67	61.59	3.72	3.04	3.24	2.91	56.13	52.56
	Rhizolex T	22.25	18.70	60.64	62.22	2.86	2.58	3.00	2.81	60.90	57.40
	control	9.27	10.58	60.91	60.00	3.13	3.00	2.02	2.14	44.96	40.83
LSD $_{\text{at 0.05}}$		**7.28**	**8.39**	**1.540**	**1.60**	**0.48**	**0.38**	**0.55**	**0.72**	**7.68**	**6.90**

L.S.D at 0.05 = low significant differences at 5%.

When considering fungal infection effects on chemical content, the data showcases intriguing patterns. Seedlings infected with Rhizoctonia exhibited the highest protein content in leaves compared to those infected with Fusarium. This increase was consistent across both seasons, with significant differences observed during the first season. Moreover, Rhizoctonia infection led to a significant increase in carbohydrate content across both seasons. In terms of total phenols, the highest levels were recorded in leaves infected with Rhizoctonia during the first season. However, during the second season, infection with Fusarium resulted in a significant increase in phenols content. Additionally, Rhizoctonia infection treatment significantly increased chlorogenic acid content in leaves compared to Fusarium infection treatment during the first season. Conversely, during the second season, Fusarium infection treatment yielded a non-significant increase in chlorogenic acid content compared to Rhizoctonia infection treatment.

Utilizing fungicide resulted in a significant increase in protein content compared to the untreated treatment during both seasons. Meanwhile, the application of fulvo copper followed by hydrogen peroxide significantly increased the total carbohydrate content in leaves compared to other treatments in both seasons. Total phenols content showed significant increases with the use of fulvo copper and thyme oil during the first and second seasons, respectively, compared to the untreated treatment. Furthermore, employing fulvo copper and fulvic acid led to significant increases in chlorogenic acid content during the first and second seasons, respectively, compared to the untreated treatment.

Examining the interaction between treatment and fungal infection, the data in Table (7) reveals notable trends. Using Rhizolex T treatment with Rhizoctonia-infected plants significantly increased protein content in seedling globe artichoke leaves during both seasons. In terms of total carbohydrates, treating plants infected with Rhizoctonia with fulvo copper followed by Rhizolex T yielded the highest levels during the first and second seasons, respectively. Similarly, the application of fulvo copper to Rhizoctonia-infected plants led to a significant increase in total phenols compared to Rhizolex T treatment during the first season. Meanwhile, thyme oil treatment for Fusarium-infected plants resulted in the highest total phenols content in leaves during the second season. Lastly, using fulvo copper to treat Rhizoctonia-infected seedlings significantly increased chlorogenic acid content in leaves compared to the untreated treatment during the first season. In the second season, the highest chlorogenic acid content was attributed to fulvic acid treatment for Fusarium-infected plants.

Effect of some safety compounds on enzyme activities in globe artichoke seedlings:

The impact of various treatments and the recommended fungicide on the activity of defense enzymes in treated artichoke plants is outlined in Table 8. The data provided in Table 8 highlights significant effects, showing that treatments such as fulvo copper, clove oil, hydrogen peroxide (H_2O_2), and fulvic acid notably increased the activities of defense-related enzymes namely, catalase, peroxidase, and polyphenol oxidase in treated globe artichoke seedlings compared to the untreated control. These effects were observed in cases of infection by both *F. solani* and *R. solani.*

Specifically, the highest enzyme activity levels were observed with the fulvo copper treatment. For *F. solani* infection, the activity levels were 32.8 (catalase), 1.238 (peroxidase), and 0.132 (polyphenol oxidase), while for *R. solani* infection, they were 29.7 (catalase), 1.103 (peroxidase), and 0.129 (polyphenol oxidase). Following closely, the fulvic acid treatment demonstrated substantial enzyme activity levels of 31.4 (catalase), 1.003 (peroxidase), and 0.112 (polyphenol oxidase) in the case of *F. solani* infection, and 28.4 (catalase), 1.007 (peroxidase), and 0.118 (polyphenol oxidase) in the case of *R. solani* infection. These results indicate that treatments involving fulvo copper, clove oil, hydrogen peroxide, and fulvic acid play a role in enhancing the defense mechanisms of the globe artichoke seedlings against infections caused by *F. solani* and *R. solani.*

Table 8. Effect of some safety compound on enzyme activities in globe artichoke seedlings under greenhouse infected with *F. solani* and *R. solani*.

Treatment	**Enzyme activity**					
	CAT mM H_2O_2 g^{-1} FW Min^{-1}		POX mM H_2O_2 g^{-1} FW Min^{-1}		PPO µ mol /min^{-1} g^{-1} (FW)	
	F. solani	***R. solani***	***F. solani***	***R. solani***	***F. solani***	***R. solani***
H_2O_2	30.2	28.9	1.123	1.111	0.098	0.098
Potassium sorbate	31.7	29.4	1.024	1.009	0.089	0.091
Mint oil	29.7	27.3	1.091	1.012	0.138	0.089
Cumin oil	25.2	24.6	0.989	0.978	0.081	0.088
Thyme oil	26.8	24.9	0.971	0.972	0.083	0.082
Clove oil	31.2	28.3	0.992	0.983	0.087	0.088
Fulvic acid	31.4	28.4	1.003	1.007	0.112	0.118
Fulvo copper	32.8	29.7	1.238	1.103	0.132	0.129
Fungicide	23.9	19.2	0.823	0.571	0.062	0.059
Control	19.3	15.1	0.572	0.472	0.046	0.043
L.S.D at 0.05	A= 0.500 & B= 0.222& AXB= 0.716		A= 0.041 & B= 0.022 & AXB= 0.068		A= 0.007 & B= 0.006 & AXB= 0.013	

- Values in the same column followed by the same letter are not significantly different *at $P < 0.5$* level.

DISCUSSION

The findings of the present research reveal a significant reduction in the linear growth and inhibition percentage of root rot (*F. solani* and *R. solani*) on globe artichoke (*Cynara scolymus*, L) when treated with mint oil, fulvo copper, and Maxim fungicide at concentrations of 0.5, 1, and 2 ml/l, respectively. These outcomes align with the observations made by Sarkhosh (2017), who reported that thyme, cinnamon, and mint oils effectively suppressed the mycelial growth of *F. solani*. Notably, the inhibitory effect of thyme oil was specifically pronounced at lower concentrations for *F. solani*. Furthermore, the study found that mint oil displayed notable efficacy in inhibiting the *in vitro* mycelial growth of various fungi, including *F. solani*, particularly at a concentration of 1600 µl/l. In a similar vein, Zambonelli *et al.* (1996) demonstrated the strong control potential of essential oil derived from a distinct thyme species, *Thymus vulgaris*, against the mycelial growth of four different phytopathogenic fungi, including *F. solani*.

In the context of this study, it was observed that mint oil could completely halt the mycelial growth of the targeted pathogens (*F. solani* and *R. solani*). However, this inhibitory effect was achieved at a considerably higher concentration of 2000 µl/l in comparison to the control treatment. Similar observations were made by Moghaddam et al. (2013), who found that essential oil from the same mint species exhibited the highest efficacy in inhibiting the *in vitro* mycelial growth of three different fungal species at a concentration of 1600 µl/l.

Examinations conducted using light and scanning electron microscopes revealed that fulvo copper exerted an impact on the size, shape, and caused a shrinking effect on treated hyphae and spores of *F. solani*, as well as the mycelium of *R. solani*. These findings align with the observations made by Kamel *et al.* (2022), where they noted that microscopic evaluations displayed aberrant shapes, shrinking, and collapsing of conidia, accompanied by twisting and plasmolysis of spores and hyphae of F. solani when exposed to Copper Oxide Nanoparticles.

The data presented in this study demonstrated that hydrogen peroxide (H_2O_2) yielded noteworthy outcomes in terms of peroxidase, polyphenol oxidase, and catalase activities. These findings are consistent with the research conducted by Mahmoud *et al.* (2016), and Walters (2007). These studies have collectively observed induced resistance in plants against pathogens, characterized by an active defense mechanism reliant on the activation of physical or chemical barriers in response to abiotic agents. These agents sensitize plants to react swiftly following infection, leading to the accumulation of phytoalexins, phenols, lignification, and the activation of key enzymes like peroxidase, polyphenol oxidase, catalase, and chitinase. Abiotic inducers like hydrogen peroxide (H_2O_2) have shown the ability to trigger resistance against damping-off and root rot diseases in plants like lentils and peanuts (Mahmoud *et al.,* 2016). Studies by Khalifa *et al.* (2007) indicated that soaking lupine seeds in these inducers, especially at low concentrations of H_2O_2, significantly reduced disease parameters and increased the proportion of healthy surviving plants. The involvement of H_2O_2 in induced disease resistance is believed to stem from the activation of enzymes such as peroxidase, polyphenol oxidase, catalase, and B-1, 3-glucanase, all of which serve to shield plants against pathogen invasion. Furthermore, research by Martinez *et al.* (2000) suggested that hydrogen peroxide also stimulates the synthesis of lignin and suberin, along with the activation of peroxidase and chitinase enzymes, thereby fortifying the plant's defense mechanisms. Moreover, H_2O_2 acts on pathogens either by direct inhibition or by generating reactive free radicals with antimicrobial properties (Peng and Kuc, 1992). Lu and Higgins (1999) noted that H_2O_2 can notably impede the growth of pathogenic fungi, with effective concentrations that are considerably lower than those causing harm to plant cells. Various studies have even suggested that acting at relatively low concentrations of H_2O_2 could be a driving factor in triggering the expression of genes associated with defense responses. On a different note, El-Mohamedy *et al.* (2014) observed in field trials that the most substantial reductions in root rot disease caused *by F. solani, R. solani*, and *Sclerotium rolfsii* in terms of incidence and disease severity were achieved in tomato plants treated with potassium sorbate. They also found that potassium sorbate was particularly effective in enhancing growth parameters, yield, and the quality of tomato fruits when compared to control treatments. The risk of resistance development in the pathogen population was likely low.

The information showed that the effectiveness of fulvic acid (FA) in lessening the effects of *F. solani* and *R. solani* was assessed. The current study demonstrated a significant reduction in *F. solani* growth when fulvic acid was applied *in vitro*, Afifi *et al* (2017). Fulvic acid was shown by Moliszewska and Pisarek (1996) to have the ability to suppress *Fusarium culmorum* and *Alternaria alternata* in the PDA medium. When FA was applied to cucumber plants grown in naturally infested soil, the percentage of disease severity was significantly lower than with control treatments. Fulvic acid, according to Hahlbrock and Scheel (1989), is mainly made up of a mixture of phenolic compounds, which are essential to plant defense mechanisms. Additionally, fulvic acid is rich in sulfur, which makes it a potential agent, according to Kamel *et al.* (2014).

The results obtained indicated that treating globe artichoke seedlings infected with *F. solani* and *R. solani* using fulvo copper effectively reduced disease severity percentages and yielded good efficacy rates. These findings align with Keller *et al.* (2018), who reported that copper compounds have been successful in combating crop diseases caused by certain fungi and bacteria. These compounds are cost-effective, and the risk of resistant pathogen strains emerging is low due to their multiple toxic sites of action. Evans et al. (2007) found that copper is essential for the formation of key plant defense proteins, such as plastocyanin, peroxidase, and copper multiple oxidases, in response to pathogen infections. Nevertheless, Although, copper-containing compounds were once successfully used as fungicides in agriculture, they are now known to be dangerous pollutants. In agriculture, copper salts are frequently used to manage bacterial and fungal diseases (Mapper *et al.,* 1984). Copper, being a key micronutrient, plays a pivotal role in the growth and development of plants and contributes to disease resistance. Kamel et al. (2022) discovered that copper oxide nanostructures exhibited promising antifungal activity against *F. solani* under laboratory conditions. Similarly, Khatami et al. (2019) illustrated significant inhibition of *F. solani* cultures by copper oxide nanoparticles. These findings are consistent with studies by Khatami *et al.* (2019), which highlighted the high potential of Cu_2O nanoparticles for controlling soil-borne fungi such as *F. solani* and *F. oxysporum*. Furthermore, copper oxide (Cu O) and copper oxide (Cu_2O) are widely used as antimicrobial agents due to their remarkable efficacy against a broad spectrum of microbes (Xiong *et al.* 2015). The unique crystal shapes and large surface areas of these compounds enhance their potency (Stoimenov *et al.* 2002). Copper compounds continue to be employed as fungicides for wood protection and disease prevention (Franich, 1988). From another perspective, copper oxide serves as a non-toxic, inorganic antimicrobial agent that inhibits the growth of various microorganisms (Babaei *et al.* 2017). Additionally, copper's role as a fertilizer appears to contribute to host defense mechanisms (Elmer *et al.* 2018). Addition soil of hydrogen peroxide leads to increase the rate of free oxygen around area of roots spread which increment the rooting activity and this reflected to product healthy plants. Deng *et al.* (2012) and Abd Elhady *et al.* (2021) showed that injecting hydrogen peroxide increased the root's activity, which was evident in the soil, and enhanced the root's characteristics and activities, which were brought on by an increase in the root's absorption of nutrients and water. They also disclose how hydrogen peroxide initiates accidental rooting in soil. Fulvic acid is a chelating substance that facilitates the absorption of elements into the soil and thus improves plant vegetative growth, El shoraky *et al.* (2018). Also, it increases root growth and spread which leads to improved absorption of elements and is reflected in vegetative growth.

In addition, fulvic increases the formation of energy compounds in plant cells and enhances photosynthesis which increases carbohydrates, dry matter of leaves, and active substances as total phenols and chlorogenic acids. (Aiken and McKnight 1985). Indicated that the application of fulvic acid had a significant effect on several leaves per plant and foliage dry weight. These findings could be attributed to fulvic acid's beneficial effects on plant leaves and foliage dry weight, which can be explained by the fact that it has the lowest molecular weight and the ability to easily bond minerals and other elements into its molecular structure, causing the elements to resolve and become mobilized fulvic complexes. Fulvic acid also typically carries at least seventy mineral and effect elements as part of its molecular complexes. According to (El- Metwaly 2020), fulvic acid had the highest P and K contents. These findings could be explained by the fact that fulvic acid, a major component of premium foliar spray fertilizers, can promote the uptake of nutrients from plant surfaces into plant tissues and aid in their penetration into plant parts. It can also. According to Alhasany *et al.* (2019), this could be because applying copper treatment promotes root growth, which enhances the plant's ability to absorb certain nutrients from the soil, such as nitrogen, and increases the amount of this nutrient in the leaves of the plant. Another possible explanation for this could be that the copper treatment encourages the growth of elongated roots, which in turn helps to configure the total number of radicals that can utilize and optimizing water and nutrients, ultimately increasing plant height. Fulvic acids were shown to enhance the concentrations of Ca in tomato leaves by increasing root growth, which was observed to increase nutrient uptake (Zhang *et al.,* 2021). The effect is explained by the acidity of fulvic acids, which lowers the growth medium's pH and increases the nutrients' bioavailability. They also conclude that the increases were caused by improvements to the root structure. An additional factor in the promotion of biomass and the accumulation of carbohydrates that benefit plants was the increase in nutrient uptake. (Clifford *et al.* 2017) and (Kwang Kim and Un Park 2019) revealed that the production of several significant compounds, including flavonoids and flavonoids, occurs via the phenylpropanoid reaction pathway, which is how chlorogenic acids are biosynthetically generated from phenylalanine. Copper is necessary for many different enzyme systems and activates some plant enzymes that are involved in the synthesis of lignin. It is also necessary for photosynthesis, vital for plant respiration, and helps the plant metabolize proteins and carbohydrates. The presence of copper in cultivation media evoked an elevation of free chlorogenic acid, and treated plants may have partially correlated with the accumulation of free phenolic acids. This could be because copper spraying enhances root growth, which increases the plant's ability to absorb certain nutrients from the soil, such as nitrogen, and increases the amount of nitrogen in the plant's leaves Hussein and Rabie (2009) confirmed this finding. This finding was consistent with that of Korzeniowska and Glubiak (2011) and may have been caused by copper's function in raising the nitrogen content of plants, which in turn increased the amount of chlorophyll in the leaves.

CONCLUSION

The study investigated how well essential oils worked to produce seedlings and protect against globe artichoke root rot, which is caused by Fusarium solani and Rhizoctonia solani. The best results were found for fulvo copper and mint oil in terms of preventing root rot and reducing the severity of the condition. Leaf count, length, fresh weight, dry matter, crude protein, total carbs, phenols, chlorogenic acid, and total chlorophyll all showed substantial growth benefits as a result of the treatment. Enzymes involved in defense functioned better after fulvo copper was applied.

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المكافحة الفعالة لعفن الجذور يعزز إنتاج الشتلات في الخرشوف باستخدام مركبات آمنة

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أظهرت الدراسة فعالية الزيوت العطرية ومحفزات النباتات على انتاج الشتلات ومكافحة مرض عفن الجذور في الخرشوف الذى يسببه فطريات *Rhizoctonia solani*, *Fusarium solani* وقد بينت التجارب التي اجريت في المعمل والصوبة خلال موسمي الدراسة 2022 و2023 ذلك, وأوضحت النتائج أن استخدام تركيزات مختلفة من زيت النعناع والفالفو كوبر قد أعطى أعلى نسبة تثبيط للمرض بالمقارنة بالمواد الأخرى المستخدمة للمكافحة. كما اوضح الميكروسكوب الإلكتروني فقدان الحيوية لجراثيم فطر *F. solani* وهيفات فطر *R. solani.* كما اوضحت النتائج نجاح زيت النعناع وزيت القرنفل والفالفوكوبر والمبيدات محل الدراسه بشكل ملحوظ في تقليل نسبة وشدة مرض عفن الجذور بين شتلات الخرشوف بالمقارنة بالمواد الأخرى المستخدمة وبالمقارنة بالكنترول في تجارب الصوبة. ومن اللافت للنظر أن الفولفوكوبر أعطى أعلى نسبة تنشيط لعدد البراعم في الشتلات تحت ظروف العدوى بال *F. solani* و *R. solani*. علاوة على ذلك أظهرت النباتات المعاملة تحسينات كبيرة في النمو من حيث عدد الأوراق وطول الورقة وطول الجذور والنبات والوزن الطازج وكذلك الوزن الجاف, النسبة المئوية للبروتينات الكلية وإجمالي الكربوهيدرات وإجمالي الفينولات وحمض الكلوروجينيك وإجمالي الكلوروفيل في نباتات الخرشوف كما أظهرت المكونات الغذائية مثل محتوى النيتروجين والفوسفور والبوتاسيوم والكالسيوم زيادات بنسب واضحة عند المعاملة بالفالفو كوبر كما ظهر نشاط عالي للإنزيمات المرتبطة مثل الكتاليز والبيروكسيديز والبولي فينول أوكسيديز بالمقارنة بمعامله الكنترول.

الكلمات المفتاحية: شتلات الخرشوف, الفيوزاريوم , الرايزوكتونيا , الزيوت العطريه , استحثاث المقاومه.