Induction of Resistance in Eggplant (*Solanum melongena* L.) Using Edible Mushroom (*Agaricus bisporus*) Extract and Biosynthesized Nano-Magnesium against White Mold Caused by *Sclerotinia sclerotiorum*

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Abstract

This study evaluated the efficacy of alcoholic and aqueous extracts of the edible mushroom *Agaricus bisporus*, biosynthesized nano-magnesium, and their combinations in inducing resistance in two eggplant (*Solanum melongena L.*) cultivars, Jawhara and Barcelona, under infection with *Sclerotinia sclerotiorum*. A factorial experiment (two cultivars × eight treatments) was arranged in a randomized complete block design with three replications. Relative polyphenol oxidase (PPO) activity, plant dry weight, leaf area, and fruit firmness were measured. Significant effects of treatments, cultivars, and their interaction were detected for all traits. The alcoholic extract + biosynthesized nano-magnesium treatment produced the highest mean relative PPO activity (3.117 AU at 420 nm) and did not differ significantly from the alcoholic extract alone (3.102 AU at 420 nm), whereas the healthy control recorded the lowest value (0.340 AU at 420 nm). Among infected plants, biosynthesized nano-magnesium and alcoholic extract + biosynthesized nano-magnesium produced high dry weights (20.97 and 20.58 g, respectively), comparable with the healthy control (21.25 g). The alcoholic extract + aqueous extract treatment produced a leaf area of 182.4 cm^2, comparable with the healthy control (184.8 cm^2). The aqueous extract + biosynthesized nano-magnesium treatment produced the highest fruit-firmness mean among infected plants (10.58 kgf cm^{-2}), which was comparable with the healthy control (11.17 kgf cm^{-2}). Barcelona had higher means for relative PPO activity, leaf area, and fruit firmness, whereas Jawhara had a higher dry-weight mean. These findings indicate that *A. bisporus* extracts and biosynthesized nano-magnesium can enhance selected biochemical and growth-related responses of infected eggplant plants; however, direct disease-incidence and disease-severity measurements are needed to confirm disease-suppression efficacy.

Keywords: *Agaricus bisporus*; biosynthesized nano-magnesium; eggplant; induced resistance; polyphenol oxidase; *Sclerotinia sclerotiorum*; white mold.

1. Introduction

Eggplant (*Solanum melongena* L.) is an economically and nutritionally important vegetable crop in the family Solanaceae, particularly in warm and temperate regions. In Iraq, eggplant is cultivated in open fields and under protected conditions. Food and Agriculture Organization data confirm its importance as a widely cultivated vegetable crop, especially in Asia [1].

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Eggplant is affected by numerous plant pathogens, including fungi, bacteria, viruses, and nematodes, as well as insect and non-insect pests. These biotic constraints can reduce plant growth, yield, and produce quality. White mold, caused by *Sclerotinia sclerotiorum*, is an important fungal disease of many crops. This broad-host-range necrotrophic pathogen can cause substantial losses in the field and during storage. Its pathogenicity is associated with several virulence factors, particularly oxalic acid and cell-wall-degrading enzymes, which promote tissue maceration, penetration, and colonization [2].

White mold management has frequently relied on chemical fungicides. Repeated or inappropriate fungicide use, however, may contribute to environmental contamination, adverse effects on beneficial microorganisms, and selection for fungicide-resistant pathogen populations. Consequently, interest has increased in safer alternatives, including natural extracts, biological agents, and nanomaterials, that may stimulate plant defenses and reduce the adverse effects of infection.

Edible mushroom extracts are among the promising natural products investigated for this purpose. *Agaricus bisporus* contains phenolic compounds, flavonoids, polysaccharides, and other constituents with antioxidant and antimicrobial activities. These bioactive compounds may directly inhibit microorganisms or indirectly support plant physiological status and induced-resistance responses under biotic stress [3–5].

Nanomaterials have also received increasing attention in crop production and plant protection. Magnesium is an essential macronutrient and the central atom of the chlorophyll molecule; it also participates in photosynthesis, energy transfer, and enzyme activation. Applying magnesium in nano-form may improve its availability and utilization and may help plants tolerate biotic stress [6–8].

Defense-related enzymes, including polyphenol oxidase (PPO), are useful biochemical indicators of plant responses to pathogens and resistance-inducing treatments. PPO catalyzes the oxidation of phenolic compounds and contributes to the formation of defense-related products that can strengthen tissues and restrict pathogen development. Evaluating relative PPO activity together with dry weight, leaf area, and fruit firmness can therefore provide evidence of biochemical and physiological responses to *S. sclerotiorum* infection and the applied treatments [9].

This study aimed to evaluate alcoholic and aqueous extracts of *A. bisporus*, biosynthesized nano-magnesium, and their combinations as resistance-inducing treatments in the eggplant cultivars Jawhara and Barcelona under *S. sclerotiorum* infection. Their effects on relative PPO activity, plant dry weight, leaf area, and fruit firmness were assessed.

2. Materials and Methods

2.1 Study Site

The study was conducted during the 2025–2026 growing season in the Plant Protection laboratories and plastic house of the College of Agriculture, University of Tikrit, Iraq.

2.2 Instruments and Materials

The principal instruments included an analytical balance, water distiller, magnetic stirrer, autoclave, centrifuge, spectrophotometer, incubator, drying oven, laminar-flow cabinet, water bath, refrigerator, leaf-area meter, and fruit-firmness tester. The materials included sodium hypochlorite, 70% ethanol, an antibiotic, potato dextrose agar (PDA), magnesium nitrate, and sodium hydroxide.

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2.3 Preparation of Reagents for the PPO Assay

Phosphate buffer was prepared according to Mahadevan and Sridhar [10] from two stock solutions. Stock solution A was prepared by dissolving 53.65 g of disodium hydrogen phosphate in distilled water and bringing the final volume to 1 L. Stock solution B was prepared by dissolving 27.8 g of sodium dihydrogen phosphate in distilled water and bringing the final volume to 1 L.

To prepare 100 mL of phosphate buffer at pH 6.0, 6.1 mL of stock solution A was mixed with 43.8 mL of stock solution B, and the volume was brought to 100 mL with sterile distilled water. Catechol substrate was prepared by dissolving 0.025 g of catechol in 100 mL of the phosphate buffer.

2.4 Preparation of Potato Dextrose Agar

Potato dextrose agar was prepared by dissolving 39 g of commercial PDA powder in 1 L of distilled water. The medium was heated with continuous stirring until completely dissolved, dispensed into glass flasks, and autoclaved at 121°C and 15 psi for 15 min. After cooling to approximately 40°C, the antibiotic was added at 250 mg L^{-1}. The medium was poured into sterile Petri dishes and allowed to solidify.

2.5 Isolation and Purification of *Sclerotinia sclerotiorum*

Eggplant tissues showing typical white mold symptoms, including wilting, basal stem rot, and white fungal mycelium, were collected and transported to the Plant Pathology Laboratory in sterile polyethylene bags.

The infected tissues were washed under running tap water, cut into 0.5–1.0-cm pieces, surface-disinfested with sodium hypochlorite, rinsed with sterile distilled water, and dried on sterile filter paper. Tissue pieces were placed on PDA and incubated at 25 ± 2°C until fungal growth developed.

Hyphal tips from emerging colonies were transferred to fresh PDA plates to obtain pure cultures. The isolate was identified as *S. sclerotiorum* on the basis of its cultural and microscopic characteristics.

2.6 Preparation of *Agaricus bisporus* Extracts

Fruiting bodies of *A. bisporus* were obtained from the mushroom farm of the College of Agriculture, University of Tikrit. They were dried, ground to a fine homogeneous powder, and used to prepare alcoholic and aqueous extracts.

2.6.1 Alcoholic Extract

The alcoholic extract was prepared by mixing dried *A. bisporus* powder with 70% ethanol. The mixture was allowed to extract and was then filtered through suitable filter paper. The filtrate was concentrated at low temperature and stored until use.

2.6.2 Aqueous Extract

For the aqueous extract, 5 g of *A. bisporus* powder was added to 50 mL of distilled water. The mixture was heated at 60°C for 15 min with continuous stirring, cooled to room temperature, and filtered to obtain a clear extract free of suspended particles.

2.7 Preparation of Biosynthesized Nano-Magnesium

Biosynthesized nano-magnesium was prepared by a green-synthesis procedure using *A. bisporus* extract. The extract was gradually mixed with magnesium nitrate solution under continuous stirring, and the pH was adjusted by the gradual addition of sodium hydroxide. The mixture was maintained in a water bath at 50–55°C for 24 h. A color change and milky turbidity were taken as indications of nanoparticle formation.

After the reaction, the mixture was centrifuged for 15 min. The supernatant

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was discarded, and the precipitate was washed three times with distilled water and once with ethanol to remove impurities and unreacted materials. The precipitate was dried at 60°C for 4–8 h and stored in sterile, tightly sealed containers. The procedure followed Umaralikhan and Jafar [11], with modifications appropriate to the sample.

2.8 GC–MS Analysis of the Extract

The chemical constituents of the extract were analyzed by gas chromatography–mass spectrometry (GC–MS) using a Shimadzu GCMS-QP2010 Plus instrument (Japan). A 1-µL sample was injected in split mode. Separation was performed on a 30-m non-polar InertCap 1 capillary column (100% dimethylpolysiloxane). Helium (99.999% purity) was used as the carrier gas at a flow rate of 13.6 mL min^{-1}.

The oven temperature was initially set at 100°C and held for 1 min, increased at 17°C min^{-1} to 150°C and held for 4 min, and then increased at 9°C min^{-1} to 250°C and held for 1 min. The reported total run time was 20.61 min. Mass spectra were acquired over m/z 30–900 at an ionization energy of 72 eV. Compounds were identified by comparison with spectra in the instrument library, following the cited GC–MS source [12].

2.9 Plastic-House Experiment

The experiment was conducted in the plastic house of the Department of Plant Protection, College of Agriculture, University of Tikrit, during the 2025–2026 growing season. The soil was irrigated and tilled, and a drip-irrigation system was installed. The plastic house was treated with 4% formaldehyde solution and kept closed for 7 days.

After sterilization, the plastic house was opened and ventilated for 3 days to dissipate formaldehyde residues. Seedlings of the Jawhara and Barcelona cultivars were then transplanted according to the experimental design.

2.10 Experimental Design and Treatments

A two-factor factorial experiment was arranged in a randomized complete block design with three replications. Factor A comprised two eggplant cultivars (Jawhara and Barcelona), and factor B comprised the following eight treatments:

1. Infected control
2. Healthy control
3. Alcoholic extract of *Agaricus bisporus*
4. Aqueous extract of *Agaricus bisporus*
5. Biosynthesized nano-magnesium
6. Alcoholic extract + aqueous extract
7. Alcoholic extract + biosynthesized nano-magnesium
8. Aqueous extract + biosynthesized nano-magnesium

The treatment effects on relative PPO activity, plant dry weight, leaf area, and fruit firmness were evaluated under *S. sclerotiorum* infection, except for the healthy-control plants. Peroxidase (POD) activity was not measured in the present study.

2.11 Artificial Inoculation with *Sclerotinia sclerotiorum*

Eggplant plants were artificially inoculated after reaching the selected growth stage. A sterile tool was used to make an approximately 2-cm longitudinal slit in the stem, and a sclerotium with attached fungal mycelium was placed in the wound.

The inoculation site was wrapped with Parafilm to maintain moisture and prevent desiccation, thereby promoting infection and symptom development. The procedure was based on Petzoldt and Dickson [13].

2.12 Measured Traits

2.12.1 Relative Polyphenol Oxidase Activity

Relative polyphenol oxidase (PPO) activity was determined in eggplant leaves using catechol as the substrate in phosphate buffer at pH 6.0. The absorbance resulting from catechol oxidation was measured at 420 nm using a spectrophotometer. PPO activity was expressed as relative absorbance units at 420 nm (AU at 420 nm), and the resulting values were used to compare treatment-induced biochemical responses under *S. sclerotiorum* infection.

2.12.2 Plant Dry Weight

At the end of the experiment, plants were carefully uprooted and the roots were washed to remove adhering soil. Plant samples were dried in an oven until a constant weight was reached and then weighed on an analytical balance. Dry weight was expressed in grams per plant.

2.12.3 Leaf Area

Fully expanded representative leaves were collected from each treatment and replication and measured with a leaf-area meter. Leaf area was expressed in square centimetres (cm^2), and the treatment mean was calculated.

2.12.4 Fruit Firmness

Fruit firmness was measured on representative fruits from each treatment and replication using a fruit-firmness tester. Measurements were taken from the equatorial region of each fruit, and the mean value was calculated for each treatment. Fruit firmness was expressed as kilogram-force per square centimetre (kgf cm^{-2}) and was used as an indicator of tissue firmness under infection and treatment conditions.

2.13 Statistical Analysis

Data were subjected to factorial analysis of variance appropriate for a randomized complete block design using SPSS. Treatment, cultivar, and treatment × cultivar effects were tested, and means were compared using the least significant difference (LSD) test at $P \leq 0.05$.

3. Results and Discussion

3.1 Effect of Treatments on Relative Polyphenol Oxidase Activity

Table 1 shows significant effects of treatment, cultivar, and their interaction on relative PPO activity. The alcoholic extract + biosynthesized nano-magnesium treatment recorded the highest treatment mean (3.117 AU at 420 nm), but it did not differ significantly from the alcoholic extract alone (3.102 AU at 420 nm). Biosynthesized nano-magnesium and aqueous extract + biosynthesized nano-magnesium recorded means of 2.603 and 2.360 AU at 420 nm, respectively, whereas the aqueous extract alone produced the lowest mean among the inducing treatments (1.174 AU at 420 nm).

The infected control recorded a significantly higher relative PPO mean (1.355 AU at 420 nm) than the healthy control (0.340 AU at 420 nm), indicating that infection itself activated PPO. Nevertheless, the alcoholic extract, alone or combined with biosynthesized nano-magnesium, produced a stronger response than infection alone.

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Table 1. Effects of Agaricus bisporus extracts, biosynthesized nano-magnesium, and their combinations on relative polyphenol oxidase activity (AU at 420 nm) in eggplant infected with Sclerotinia sclerotiorum.

Treatment	**Jawhara**	**Barcelona**	**Treatment mean**
Infected control	1.043	1.667	1.355
Healthy control	0.067	0.613	0.340
Alcoholic extract	3.090	3.113	3.102
Aqueous extract	0.508	1.840	1.174
Biosynthesized nano-magnesium	2.263	2.943	2.603
Alcoholic extract + aqueous extract	1.760	1.913	1.837
Alcoholic extract + biosynthesized nano-magnesium	2.603	3.630	3.117
Aqueous extract + biosynthesized nano-magnesium	2.733	1.987	2.360
Cultivar mean	**1.759**	**2.213**	**1.986**

LSD (0.05)	Treatment	**Cultivars**	**Interaction**
	0.6331	**0.2238**	**0.4476**

Polyphenol oxidase is an important defense-related enzyme because it oxidizes phenolic compounds and contributes to products associated with tissue strengthening and restriction of pathogen development. Recent reviews emphasize the role of PPO in plant defense against pathogens and herbivores [9].

The high PPO response to the alcoholic extract may be associated with its ability to solubilize phenolic and other bioactive constituents of *A. bisporus*. Studies of *A. bisporus* extracts have documented antioxidant and antimicrobial compounds [3–5]; although these studies do not directly demonstrate induced resistance in eggplant, they provide indirect support for the biological activity of the extracts.

The response to alcoholic extract + biosynthesized nano-magnesium may reflect complementary effects of mushroom-derived bioactive compounds and magnesium nutrition. Reference [8] showed that MgO nanoparticles can influence plant defense responses under disease stress; however, comparisons should be interpreted cautiously because nanoparticle composition, size, dose, and host–pathogen systems may differ.

Barcelona recorded a significantly higher cultivar mean for relative PPO activity (2.213 AU at 420 nm) than Jawhara (1.759 AU at 420 nm). The highest interaction value occurred in Barcelona treated with alcoholic extract + biosynthesized nano-magnesium (3.630 AU at 420 nm), whereas the lowest value occurred in the healthy-control Jawhara plants (0.067 AU at 420 nm). This result demonstrates a cultivar-dependent biochemical response to the resistance-inducing treatments.

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Sclerotinia sclerotiorum is a broad-host-range necrotroph whose pathogenicity involves oxalic acid, cell-wall-degrading enzymes, and secreted proteins [2]. Enhanced relative PPO activity may represent one component of the induced defense response; however, PPO activity alone does not directly quantify disease suppression.

3.2 Effect of Treatments on Plant Dry Weight

Treatment, cultivar, and treatment × cultivar effects on plant dry weight were significant (Table 2). The healthy control had the highest numerical treatment mean (21.25 g), whereas the infected control had the lowest mean (7.95 g), demonstrating the adverse effect of infection on dry-matter accumulation.

Among infected plants, biosynthesized nano-magnesium (20.97 g) and alcoholic extract + biosynthesized nano-magnesium (20.58 g) produced the highest dry-weight means and were statistically comparable with the healthy control. The aqueous extract alone produced the lowest mean among the inducing treatments (10.02 g).

Table 2. Effects of Agaricus bisporus extracts, biosynthesized nano-magnesium, and their combinations on plant dry weight (g plant⁻¹) of eggplant infected with Sclerotinia sclerotiorum.

Treatment	**Jawhara**	**Barcelona**	**Treatment mean**
Infected control	7.87	8.03	7.95
Healthy control	22.60	19.90	21.25
Alcoholic extract	18.97	18.43	18.70
Aqueous extract	11.70	8.33	10.02
Biosynthesized nano-magnesium	24.03	17.90	20.97
Alcoholic extract + aqueous extract	11.00	14.97	12.99
Alcoholic extract + biosynthesized nano-magnesium	22.33	18.83	20.58
Aqueous extract + biosynthesized nano-magnesium	12.20	14.48	13.34
Cultivar mean	**16.34**	**15.11**	**15.72**

LSD (0.05)	Treatment	**Cultivars**	**Interaction**
	2.233	**0.789**	**1.579**

The low dry weight of the infected control may be attributed to tissue damage and disruption of physiological processes by *S. sclerotiorum*. Oxalic acid and cell-wall-degrading enzymes can impair tissue integrity, water and nutrient relations, and photosynthetic performance, thereby reducing dry-matter accumulation [2].

The dry-weight response to biosynthesized nano-magnesium may be related to the central role of magnesium in chlorophyll formation, enzyme activation, photosynthesis, and energy transfer. Magnesium availability is closely associated with plant growth, dry-matter production, and photosynthetic efficiency [6,7,14].

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The nano-form may increase the availability or utilization efficiency of magnesium and may support plants under disease stress. Liao et al. [8] reported that MgO nanoparticles modified defense responses and reduced disease severity in another host–pathogen system, although direct extrapolation to the present material and pathosystem requires caution.

The alcoholic extract also increased dry weight relative to the infected control. This response may be associated with the bioactive and antioxidant constituents reported in *A. bisporus* extracts [4,5], but the specific mechanism in eggplant requires further investigation.

Jawhara had a significantly higher dry-weight mean (16.34 g) than Barcelona (15.11 g). The highest interaction mean was recorded for biosynthesized nano-magnesium × Jawhara (24.03 g), whereas the lowest was recorded for aqueous extract × Barcelona (8.33 g). This indicates that dry-matter responses depended on both cultivar and treatment.

3.3 Effect of Treatments on Leaf Area

Treatment, cultivar, and treatment × cultivar effects on leaf area were significant (Table 3). The healthy control had the highest numerical mean (184.8 cm²), whereas the infected control had the lowest mean (65.7 cm²), demonstrating substantial suppression of leaf expansion by infection.

Among infected plants, alcoholic extract + aqueous extract produced the highest leaf-area mean (182.4 cm²), which was statistically comparable with the healthy control. Alcoholic extract + biosynthesized nano-magnesium and alcoholic extract alone produced means of 167.5 and 161.6 cm², respectively. The aqueous extract alone had the lowest mean among the inducing treatments (117.2 cm²).

Table 3. Effects of Agaricus bisporus extracts, biosynthesized nano-magnesium, and their combinations on leaf area (cm²) of eggplant infected with Sclerotinia sclerotiorum.

Treatment	**Jawhara**	**Barcelona**	**Treatment mean**
Infected control	49.4	81.9	65.7
Healthy control	192.5	177.0	184.8
Alcoholic extract	148.0	175.1	161.6
Aqueous extract	110.6	123.9	117.2
Biosynthesized nano-magnesium	133.2	144.3	138.8
Alcoholic extract + aqueous extract	194.2	170.7	182.4
Alcoholic extract + biosynthesized nano-magnesium	182.0	153.1	167.5
Aqueous extract + biosynthesized nano-magnesium	89.8	151.0	120.4
Cultivar mean	**137.5**	**147.1**	**142.3**

LSD (0.05)	Treatment	**Cultivars**	**Interaction**
	15.58	**5.51**	**11.02**

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The marked reduction in leaf area in the infected control may reflect tissue injury, impaired water and nutrient relations, and reduced photosynthetic capacity caused by *S. sclerotiorum*. Its necrotrophic activity, including oxalic-acid production and secretion of cell-wall-degrading enzymes, can restrict plant growth and leaf development [2].

The response to the combined alcoholic and aqueous extracts may be associated with a broader spectrum of compounds extracted across solvents of different polarity. *Agaricus bisporus* contains phenolics, polysaccharides, β-glucans, and antioxidant compounds [3–5]. This interpretation remains a hypothesis because the active constituents responsible for the plant response were not individually tested.

Improved leaf area following alcoholic extract + biosynthesized nano-magnesium may also reflect complementary effects of mushroom-derived compounds and magnesium nutrition. Magnesium supports chlorophyll formation and photosynthetic processes, and nano-formulation may affect nutrient availability under stress [6–8].

Barcelona had a significantly higher leaf-area mean (147.1 cm^2) than Jawhara (137.5 cm^2). The highest interaction mean occurred with alcoholic extract + aqueous extract × Jawhara (194.2 cm^2), whereas the lowest occurred in infected-control Jawhara plants (49.4 cm^2). Thus, leaf-area responses depended on cultivar, treatment, and their interaction.

3.4 Effect of Treatments on Fruit Firmness

Treatment, cultivar, and treatment × cultivar effects on fruit firmness were significant (Table 4). The healthy control had the highest numerical mean (11.17 kgf cm^{-2}), whereas the infected control had the lowest mean (7.00 kgf cm^{-2}), indicating that infection reduced fruit firmness.

Among infected plants, aqueous extract + biosynthesized nano-magnesium produced the highest mean (10.58 kgf cm^{-2}), which was statistically comparable with the healthy control. Biosynthesized nano-magnesium and alcoholic extract + aqueous extract produced means of 9.75 and 9.67 kgf cm^{-2}, respectively. The aqueous extract alone produced the lowest mean among the inducing treatments (8.17 kgf cm^{-2}).

Table 4. Effects of Agaricus bisporus extracts, biosynthesized nano-magnesium, and their combinations on fruit firmness (kgf cm^{-2}) of eggplant infected with Sclerotinia sclerotiorum.

Treatment	Jawhara	Barcelona	Treatment mean
Infected control	6.83	7.17	7.00
Healthy control	11.17	11.17	11.17
Alcoholic extract	9.17	9.50	9.33
Aqueous extract	7.33	9.00	8.17
Biosynthesized nano-magnesium	10.00	9.50	9.75
Alcoholic extract + aqueous extract	9.33	10.00	9.67
Alcoholic extract + biosynthesized nano-magnesium	8.00	10.17	9.08

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Treatment			**Jawhara**	**Barcelona**	**Treatment mean**
Aqueous extract + biosynthesized nano-magnesium			10.67	10.50	10.58
Cultivar mean			**9.06**	**9.62**	**9.34**
LSD (0.05)	Treatment	**Cultivars**	**Interaction**		
	1.097	**0.388**	**0.775**		

The reduction in fruit firmness in the infected control may be associated with the capacity of *S. sclerotiorum* to degrade cell walls and weaken tissue cohesion. Oxalic acid, cell-wall-degrading enzymes, and secreted proteins facilitate tissue disintegration and fungal colonization [2].

The response to aqueous extract + biosynthesized nano-magnesium may reflect combined effects of water-soluble mushroom constituents and magnesium nutrition. Magnesium contributes to photosynthesis, carbohydrate production, and tissue growth, whereas nano-formulation may influence nutrient utilization and defense responses [6–8].

Improved firmness may also be associated with defense-related oxidation of phenolic compounds. Nevertheless, the relationship between PPO activity and fruit firmness was not tested statistically in this study; therefore, it should be regarded as a possible explanation rather than a demonstrated causal relationship [9].

Barcelona had a significantly higher fruit-firmness mean (9.62 kgf cm^{-2}) than Jawhara (9.06 kgf cm^{-2}). The healthy control produced the highest interaction value in both cultivars (11.17 kgf cm^{-2}), whereas infected-control Jawhara plants produced the lowest value (6.83 kgf cm^{-2}). These results indicate cultivar-dependent maintenance of fruit firmness under infection and treatment conditions.

4. Conclusions

The alcoholic extract + biosynthesized nano-magnesium treatment produced the highest relative PPO activity (3.117 AU at 420 nm) and was statistically comparable with the alcoholic extract alone (3.102 AU at 420 nm), indicating strong activation of this biochemical defense marker.

Among infected plants, biosynthesized nano-magnesium and alcoholic extract + biosynthesized nano-magnesium produced the highest dry-weight means (20.97 and 20.58 g, respectively), both comparable with the healthy control.

The alcoholic extract + aqueous extract treatment maintained leaf area (182.4 cm^2) at a level statistically comparable with the healthy control (184.8 cm^2).

The aqueous extract + biosynthesized nano-magnesium treatment produced the highest fruit-firmness mean among infected plants (10.58 kgf cm^{-2}), which was statistically comparable with the healthy control (11.17 kgf cm^{-2}).

Cultivar responses differed: Barcelona had higher relative PPO activity, leaf area, and fruit firmness, whereas Jawhara had higher plant dry weight. Overall, the treatments improved selected biochemical and growth-related traits under infection. Because disease incidence and severity were not reported, the results should not be interpreted as direct proof of white mold control.

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5. Recommendations

Agaricus bisporus extracts and biosynthesized nano-magnesium warrant further evaluation as components of resistance-induction strategies for eggplant, but their disease-control efficacy should be confirmed using direct measurements of disease incidence and severity.

Future experiments should test clearly defined concentrations, application rates, and treatment timings to determine dose–response relationships and identify the most effective treatments.

Additional eggplant cultivars should be evaluated to identify genotypes that respond consistently to the treatments and tolerate *S. sclerotiorum* infection.

Other defense-related variables, including peroxidase (POD), catalase (CAT), total phenolic content, and additional oxidative-stress markers, should be assessed to clarify the mechanisms of induced resistance.

The experiments should be repeated across seasons and locations, with appropriate nanoparticle characterization and direct disease assessments, to establish the stability, safety, and practical value of the treatments.

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