Effect of *Brassica nigra* extract on growth and physiological activities of *Solanum lycopersicum* plant infected with *Fusarium solani* fungi

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Abstract

The present work aims to study the growth alterations, productivity, physiological metabolic activities, and some antioxidant enzymes as a result of chemical antagonism of *Brassica nigra* root extract on tomato plants infected with *F solani* fungus. The extract of *B. nigra* root interfering with the fungus had a favorable impact on percentage of germination and some growth parameters of 20- and 60-day-old tomato plants. Also, it was observed that the total carbohydrates, protein, and chlorophyll a and b increased in tomato plants treated with the extract alone or overlapping with *F. solani* in contrast to the control while antioxidant enzymes upregulated in the case of plants infected with the fungus alone. There was a noticeable raise in the N, P, K, Ca, Mg, and Fe contents of the infected plants treated with the *B. nigra* extract at the age of 90 days. The tomato plant productivity and quality of the fruits treated with the *B. nigra* extract improved, either alone or with the fungus. It was found that *B. nigra* root extract had a positive effect by increasing the growth criteria, physiological activities, growth, productivity, and quality of tomato fruits and also by mitigating the harmful effects of *F. solani* fungus on tomato plants.

Keywords: tomato, antioxidant, fusarium, extract, growth

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Introduction

It is possible to find a lot of nutritionally beneficial (carbohydrates, lipids, protein, vitamins, and minerals) and phytochemically beneficial (glucosinolates, isothiocyanates, flavonoids, and phenolics) components in *Brassica* plants (Paul et al., 2019). Seeds, stems, roots, flower buds, and sprouts of these plants have all been ingested and used historically (Cartea and Velasco, 2008; Dejanovic et al., 2021; Kapusta-Duch et al., 2012; Paul et al., 2019). *B. nigra* plant was frequently praised for its beneficial effects on health due to its high concentrations of glucosinolates (Wang et al., 2016) and phenolic compounds (Duthie et al., 2000), which promote a variety of physiological processes, including antioxidant and anti-inflammatory activity, control the production of enzymes, and participate in apoptosis and cell cycle control (Paul et al., 2019). Allelochemicals used to make natural herbicides and manage a variety of weeds are believed to have fewer negative effects on the environment. Allelochemicals released into the environment may additionally have an effect on various types of plants. For example, glucosinolates can be used to prevent weeds from growing (Fenwick et al., 1983). It is usually not the glucosinolates themselves that exert biological effects, but rather

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the byproducts of enzymatic hydrolyses, such as organic cyanides (CN), oxazolidinethiones (OZT), ionic thiocyanate (SCN-), and isothiocyanates, ITC. (Bangarwa et al., 2011).

Thioglucosidases, also known as "myrosinases," come into contact with glucosinolates. The breakdown of the glucose-sulfur connection allows for rearrangement and the generation of biocidal catabolites such as isothiocyanates (Al-Turki and Dick, 2003; Clarke, 2010; Dai and Lim, 2014; Popova and Morra, 2014, 2017). Plants, nematodes, insects, and fungi are all destroyed by glucosinolates released into the rhizosphere (Larkin and Griffin, 2007; Bressan, et al., 2009; Hopkins et al., 2009; Boydston et al., 2011; Avato et al., 2013; Yu and Morishita, 2014).

Allelopathy is a key ecological phenomenon that affects how productive plants are in agricultural practices and vegetational compositions (Tukey, 1969). This is done by influencing plant growth (Rice, 1984). It is recognized as a self-defense tactic when utilized to help plants protect themselves against invasive insects and other surrounding plants (Lovett, 1991). It has a profound impact on community organization, plant variety, and species' capacity for adaptation (Chou and Lee, 1991). The acetate and shikimic acid pathways produce secondary metabolites known as allelochemicals, and they belong to a number of chemical families of phenolic acids, coumarins, flavonoids, terpenoids, alkaloids, and sulfurides, among others (Jiang, 2018, Narwal and Tauro, 1994)

The mechanism was considered to be driven by unique biochemical interactions between plants. However, the propensity of plant species to produce allelopathy may also injure other living organisms such as bacteria and insects (Maqbool et al., 2013). A recent study in this field has discovered the relevant facts.

Siva (2008) observed that leaf extracts from numerous medicinal herbs increased growth metrics (root and shoot lengths, fresh and dry weights of both root and shoot) on *Solanum melogena* L plants treated with *Fusarium oxysorum* vs *Fusarium* alone treated plants. They also discovered that *Adhatoda vasica*, *Jatropha curcas*, and *Sapindus emarginatus* leaf extracts inhibited mycelial growth of *Fusarium oxysporum* f. sp. *Melongenae matuo* and *Ishigami* by 100% in water, ethanol, and acetone, and plant extracts of 17 different angiosperms inhibited mycelial growth by 60% to 98%.

According to Rehman et al. (2019) *Brassica* species produce a wide range of allelochemicals that have a significant impact on target plant growth and development. *Brassica* species produce endogenous plant growth regulators such as brassinosteroids, which are a steroidal chemical family required for plant growth and development (Mandava et al., 1981). Glucosinolates are produced by *Brassica* species and accumulate in healthy plants before being released when the plant is injured (Bagger et al*.,* 1999; Bending and Lincoln 1999; Warton et al., 2001).

The majority of *Brassica* species, according to Mayton et al*.* (1996) possess a mechanism for producing and releasing allelochemicals that are poisonous to pests, illnesses, and their vectors. For instance, allyl isothiocyanate produced from the leaf tissues of *Brassica* species effectively reduced potato dry rot (*Fusarium sambucinum*).

Brassinolide was found by Fuiji et al., (1991) to accelerate ripening and increase grain yield in rice. Brassinolide foliar spray has also been confirmed to boost soybean root nodule formation (Terakado et al., 2005). Similarly, a smaller dose of brassinolide enhanced root nodulation, root length, and pod yield in common bean (*Phaseolus vulgaris* L.) (Upreti and Murti, 2004).

Plant extracts of *Azadirachta indica*, *Atropha belladona*, *Calotropis procera*, *Ocimum basilicum, Eucalyptus amygdalina*, *Ailanthus excelsa*, and *Lantana camera* inhibited *Fusarium* mycelial development (Bansal and Gupta, 2000). *Brassica carinata* and *Brassica calyicina* extracts exhibited high antifungal activity, and the extracts with the strongest inhibitory effect on *Brassica carinata* had a high total phenolic content, acidity, and pH values (Rongai et al., 2015).

According to Fierro et al., (2013), *F. oxysporum* resistance to commercially available fungicides, as well as the frequent use of synthetic fungicide

treatments, mandates the development of innovative management strategies.

The *Brassicaceae* family has been identified to have antimicrobial chemicals. All *Brassica rapa* extracts demonstrated dose-dependent antifungal activity at various dosages. Root-derived extract revealed inhibition percentages greater than 45% between 10 and 0.1 g/l. Stem-leaf and seed-derived extracts inhibited the enzyme quite well (> 30% and > 35%, respectively) in the same concentration range.

When compared to the untreated control, fourteen plant extracts were efficient in inhibiting the radial growth of *F. oxysporum* f.sp. *lycopersici*, according to Rongai et al., (2015). Extracts from six plant families (*Alliaceae*, *Brassicaceae*, *Lythraceae*, *Lamiaceae*, *Solanaceae*, and *Verbenaceae*) were similarly shown to have excellent antifungal activity against *F. oxysporum* f.sp. *lycopersici*, completely preventing conidial germination.

Brassica carinata, according to Avita (2013), contains a high concentration of glucosinolates, which generate cytotoxic compounds with antifungal activity when digested by enzymes. Carbon disulfide, dimethyl disulfide, dimethyl sulfide, and methanethiol, which contain compounds generated during the breakdown of glucosinolates, may play an important role in fungal suppression. *Brunfelsia calycina* is a *Solanaceae* plant that contains alkaloids, flavonoids, saponins, tannins, and glycosides.

Sesquiterpenes substantially inhibit *F. oxysporum* mycelia growth and spore germination, according to Abdelgaleil et al. (2011), and this antifungal effect is based on the permeability of fungus cellular walls. The interactions of sesquiterpenes with the -SH group of amino acids, proteins, and enzymes are also known to be important in their bioactivity. Furthermore, phenolic compounds found in the *Lythraceae*, such as punicalagin and ellagic acid, may be responsible for inhibiting fungal mycelia growth.

The goal of the present study was to use a safe *B. nigra* root extract to reduce the detrimental effects of *F. solani* on the tomato plant.

Materials and Methods

Plant material

Brassica nigra, plants were obtained from the Giza, Egypt, Agricultural Research Center and *Solanum lycopersicum* (Tomato cv. Gawaher Hybrid.) seeds were supplied by Al-Basatin Research Institute, Giza, Egypt. The healthy grains were examined for unity of size and form before being thoroughly cleaned with 2.5% sodium hypochlorite for five minutes and immersed in pure distilled water.

Preparation of aqueous extracts

Brassica nigra root was washed thoroughly, cut into thin slices, and dried in the air for five days until completely dry. It was then ground in an electric grinder into very fine particles, sieved with an No. 80 mesh sieve, and a 7% aqueous extract was prepared (as a result of testing several percentages as a preliminary test) by soaking in distilled water for three days at room temperature using a shaking machine. Through a double-layered filter paper, filtration was conducted (Whatman No.1). In the control treatment, distilled water was used in the experiment for comparison with other treatments.

Fungus

The fungus strain YMM20 was identified from the Beheira Governorate's agricultural land in Egypt. It was determined to be *F solani* based on its molecular and morphological characteristics (Identifiers of MN960159's GenBank entries). We frequently subcultured on a PDA slant at 28 ℃, pure YMM20 colonies and after that, maintained them at 4 ℃.

Inoculum preparation of YMM20

F. solani YMM20 was grown on PDA Petri plates, and then they were incubated at 28 On PDA Petri plates for five days. Using an isolation loop and sterile deionized water was used in 15 ml the fungal culture was scraped. In order to get the necessary inoculum, supply of 4.5×10^6 conidia/ml in suspension, the spores were collected and counted with the aid of a hemocytometer.

Table 1
The employed soil sample's physiochemical criterion

PH	EC (m mohs cm^{-1})	Soil Texture	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	CO_3^{2-}	HCO_3^-	SO_4^{2-}
7.4	0.71	Sand/Clay 31.53%/68.47	0.39	6.9	2.21	2.9	4.12	1.79	4.3	2.34

Germination and seedling experiment

S. lycopersicum seedlings were germinated at 23 ± 2 ℃ in 0.02 m^2 plastic pots containing 780 g of sandy soil disinfected through acid washing. Part of the seeds under study were treated by soaking in *B. nigra* root extract for 24 hours at room temperature and the control seeds were treated by soaking in distilled water for 24 hours.

The seeds treated with the extract were divided into two groups. The first group contained the uninfected seeds (Ext.), and the second group contained the seeds after being infected with *F. solani* (fungus + Ext.), by soaking them in spore suspension for one minute with mechanical vibration. The seeds soaked in distilled water were divided into two sections. The first section was control (C.), and the second section contained the seeds after being infected with *F. solani* (fungus). Each group was grown in a plastic pot including 10 seeds with three replicas irrigated with the same volume of distilled water and kept in the darkness for two days. The seedlings were then exposed to 10:14 hours (light/darkness) photoperiod in the growth chamber. The seeds were collected after 20 days to assay growth parameters and the percentage of germination, radicle and plumule lengths, and fresh and dry weights.

Pot experiment

In order to achieve realism in the effect within the study (where electrical conductivity of extract of 1:5 soil at 25 ℃ was 0.71 m mohs cm^{-1} and dirt suspension with a pH of 1:5 was 7.4), sand-clay soil 12 v/v as a clay soil sample was randomly collected from agricultural lands from the surface layer (0-35 cm) in the middle of the delta. In addition, the sand was washed with hydrochloric acid and distilled water. The properties of the soil are presented in Table 1.

Five seedlings were sown into the pots after being divided into four groups (Control, Ext., Fungus and Fungus + Ext). A sample of irrigated soil at a depth of 10 centimeters was weighed, and the weight value was compared to that of completely dry soil from the same mixture as a control, so as to figure out the percentage of the water content of all pots, just prior to the date of irrigation, which was fairly constant. Irrigation was carried out in fixed quantities until the beginning of the saturation level for each pot, with pot places changing daily. The entire growth period was spent without the use of any pesticides, fungicides, or herbicides.

Estimation of photosynthetic pigments

Fresh leaf weights from the previous sixty days were immediately homogenized and centrifuged for 15 minutes at 3000 XG in 5 ml of 85% cold acetone, before they were stored in a refrigerator for one day. A suitable volume of the acetone extract was diluted at 663, 644, and 452.5 nm, and its color intensity was measured (Metzner et al., 1965). The following equations were applied for calculating the pigment concentration of the experimental plants:

10.3 E663 - 0.918 E 644= chlorophyll (a)

3.87 E633 - 19.7 E 644= chlorophyll (b)

Carotenoids = 4.2 E 452.5 - (0.0264 chlorophyll a + 0.426 chlorophyll b)

In terms of fresh weight, pigment fractions were represented as µg/g.

Estimation of total carbohydrates and proteins

Employing a buffer of borate (28.63 g of boric acid, 29.8 g of potassium chloride, and 3.5 g of sodium hydroxide in one liter of filtered water), aliquots (100 mg) of finely powdered 60-day-old tomato plant dry shoot and root were extracted. Before centrifuging for 15 minutes at 3000 xg, the pH was adjusted to 8.0 and allowed to stand for 24 hours at 4 ℃. For the purpose of estimating the amount of polysaccharides, the residue was washed

repeatedly and dried at 80 ℃. In order to assay total carbohydrates and proteins, the supernatant and residue washings were collected. The carbohydrate sugars were extracted in a buffer of borate (pH 8) as 0.1 g dry mass 10 cm^{-3} buffers.

Carbohydrate sugars were quantified using (Nelson, 1944), modified in some ways made by (Naguib, 1963). Modifications included the addition of 10 mg of unwet plant matter to a borate salt buffer after extraction, along with 0.2 ml of 0.1 % (w/v) enzyme and 0.1 milliliter of acetate buffer (six milliliters of 0.2 N acetic acid and four milliliters of 0.2 N Na- acetate), made to three milliliters according to (Classics Lowry et al., 1951).

Antioxidant enzymes assays

To measure antioxidant enzyme activities, 0.5 g of a sample fresh plant leaves were immediately crushed in liquid nitrogen at 4 ℃, and 50 mM cold phosphate buffer was added, 8 ml of which were homogenized with a pH of 7.0 (Beauchamp and Fridovich, 1971). Centrifuging the homogenates at 4000 rpm for 20 minutes separated the mixtures. The supernatant was incubated at -80 ℃ and further utilized as a raw extract for enzymatic analyses.

Peroxidase (POX) activity [EC 1. 11. 1. 7]

The reaction mixture contained 0.5 ml of diluted enzyme, 1.5 ml of 0.05 M pyrogallol, and 0.5 ml of 1% H_2O_2. Thirty second intervals of the 420 nm absorbance variations were recorded for 3 min. The changes in absorbance in terms of $min^{-1}g^{-1}$ of leaf tissue served as an indicator of enzyme activity (Hammerschmidt et al., 1982).

Catalase (CAT) activity [EC 1. 11. 1. 6]

Initially disappearing rates of H_2O_2 and tetra-guaiacol, respectively, were used to test for catalase (Kato and Shimizu, 1987). H_2O_2's coefficient of extinction (40 mM cm^{-1} at 240 nm), which is used to determine activity, was used to assess the change in absorbance brought on by the reduction in H_2O_2 at 420 nm.

Polyphenol oxidase (PPO) [EC 1. 10. 3. 1]

According to the methodology outlined by Mayer et al. (1966), a reaction mixture containing 1.5 ml of 0.1 M sodium phosphate buffer and 200 µL of enzyme extract were prepared (pH 7.0). To begin the reaction, 200 µL of 0.01 M catechol were added. Variations in terms of increases in absorbance at 495 nm were recorded at 10-second intervals over the course of 1 minute. Changes in absorbance in gram per minute of leaf tissue were used to express PPO activity.

Determination of mineral contents

The mineral content of roots and shoots of 90-day-old tomatoes were assessed. In order to determine the minerals, the mixed acid-digestion method was utilized, as stated in (Allen et al., 1974). Half a gram of oven-dried plant samples was mixed using 3 ml of hydrogen peroxide and 5 ml of nitric acid. The mixture was heated gently until the whole mixture turned to a clear solution without charring. After that, distilled water was used to dilute the solution to a constant amount (50 ml). The amount of potassium, magnesium, calcium, and iron minerals present in the extract were determined spectrophotometrically through measuring atomic absorption and flame emission (Model Perkin Elmer 2380 Atomic Absorption Spectrophotometer).

Determination of nitrogen

An estimate of the nitrogen content was made following Tetlow and Wilson (1964). The digested samples were titrated against 0.6 N NaOH using few drops of phenolphthalein as an indicator until a faint pink color appeared. Thereafter, 1 ml of phenol-sodium nitroprusside reagent was added and mixed with 1 ml of sodium hydroxide-sodium hypochlorite reagent. A water bath was used to incubate the combination at 37 ℃ for 15 min, which was then diluted to 10 ml, and by using a spectrophotometer, optical density was determined at 630 nm.

Table 2
Effect of *Brassica nigra* root extract on percentage of germination, fresh and dry weights, and radicle and plumule lengths of 20-day old *Solanum lycopersicon cv* seedlings infected with –ve and +ve *Fusarium solani* fungus

Treatments	Germination (%) ±SD	Seedling FW (g) ±SD	Seedling DW (g) ±SD	Plumule length (cm) ±SD	Radicle length (cm) ±SD
Control	99.33 ± 0.47 ^{A}	3.78 ± 0.08 ^{A}	0.36 ± 0.02 ^{A}	6.50 ± 0.41 ^{A}	3.17 ± 0.12 ^{A}
Ext.	99.67 ± 0.47 ^{A}	3.73 ± 0.09 ^{A}	0.36 ± 0.02 ^{A}	6.33 ± 0.24 ^{A}	3.10 ± 0.216 ^{A}
Fungus	67.67 ± 1.25 ^{C}	1.76 ± 0.14 ^{C}	0.15 ± 0.01 ^{C}	4.27 ± 0.21 ^{B}	1.93 ± 0.05 ^{C}
Fungus + Ext.	91.00 ± 1.41 ^{B}	2.58 ± 0.14 ^{B}	0.27 ± 0.01 ^{B}	4.87 ± 0.12 ^{B}	2.70 ± 0.08 ^{B}

Means that do not share a letter are significantly different: FW: fresh weight, DW: dry weight, Ext: *Brassica nigra* root extract.

Determination of phosphorus

Using the molybdenum blue technique, phosphorus was measured (following Allen et al. (1974). One ml of the digested samples extract was titrated against 8 N NaOH solution using phenolphthalein indicator until the faint pink color appeared followed by the addition of 1 ml ammonium molybdate reagent (using 400 ml of distilled water, 25 g of ammonium molybdate was dissolved + 280 ml concentrated H_2SO_4). Thereafter, 1 ml stannous chloride reagent (0.5 g stannous chloride dissolved in 250 ml 2% v/v HCl) was added and then diluted to 10 ml and left for 30 min. The absorption was measured spectrophotometrically against blank at 700 nm. Using a calibration curve of standard phosphorus solutions, the phosphorus concentration was calculated as mg/g dm.

Productivity and fruit quality

At physiological maturity, the crop yield was harvested and the yield characteristics were evaluated via measurements for all the treatments including number of fruits per plant, weight of a typical fruit (g), and number of seeds per gram derived as the yield variables. On the other hand, based on the technique developed by Fish et al. (2002), lycopene co tents of tomato fruits were quantified using a spectrophotometer at a wavelength of 503 nm.

Statistical Analysis

The level of statistical significances between treatments were assessed, and Fisher's individual error rate was used in a one-way analysis of variance (ANOVA) design. The least significant difference test (LSD) was used to compare the means at $p<0.05$. Using the Minitab software version 16, three replicas of each experiment were run.

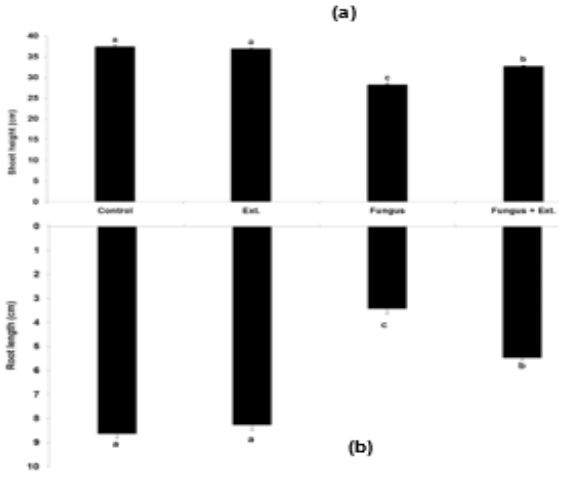

Fig. I. Effect of *Brassica nigra* root extract on shoot height and root length of 60-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus; different letters (a-c) on the bars indicate significant differences according to LSD test ($P \leq 0.05$).

Results

Germinating percentage and growth criteria

Table 2 reveals that the germination percentage of tomato seedlings treated with *B. nigra* root extract was somewhat higher than the control. The interaction of fungus with the extract significantly increased when compared to tomato seedlings infected with fungus alone. When compared to tomato seedlings infected with fungus alone, the interaction of the fungus and *B. nigra* root extract boosted fresh and dry weights and plumule, and radicle lengths.

Pot experiment and growth criteria

Combined treatments of fungus and *B. nigra* root extract increased shoot height and root length of

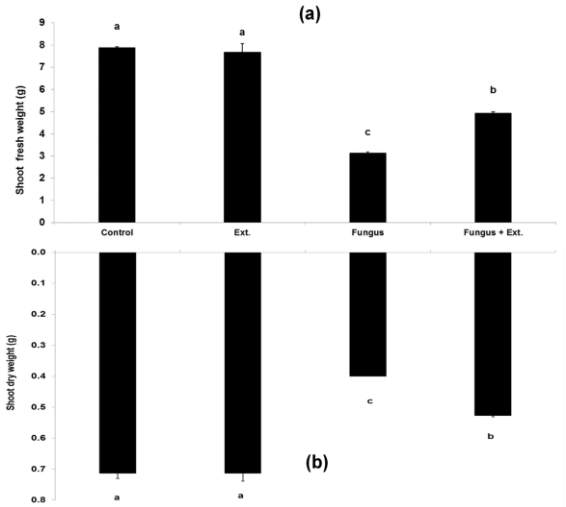

Fig. II. Effect of *Brassica nigra* root extract on shoot fresh and dry weights of 60-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus; different letters (a-c) on the bars indicate significant differences according to the least significant difference (LSD) test (P≤0.05).

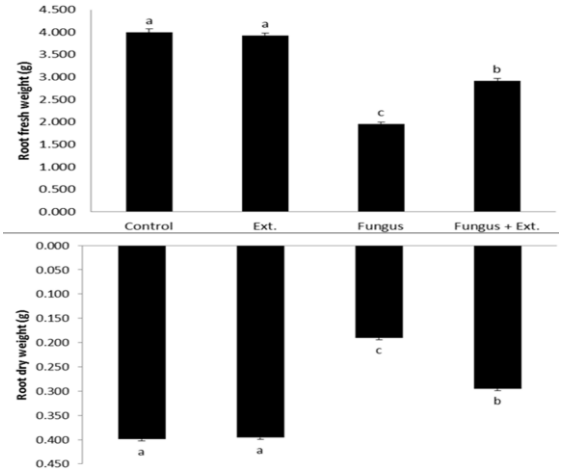

Fig. III. Effect of *Brassica nigra* root extract on root fresh and dry weights of 60-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus; different letters (a-c) on the bars indicate significant differences according to the least significant difference (LSD) test (P≤0.05).

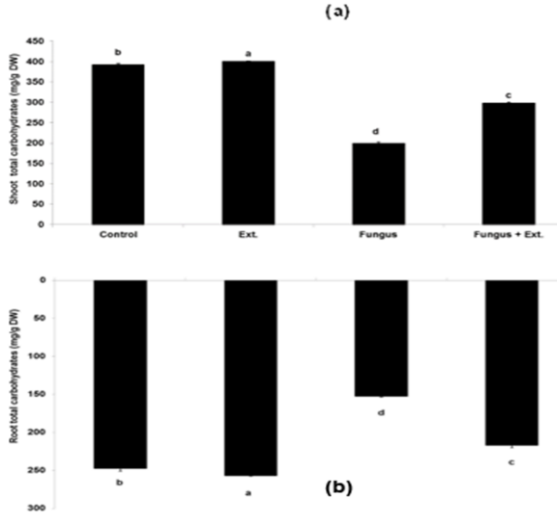

Fig. IV. Effect of *Brassica nigra* root extract on shoot and root total carbohydrates of 60-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus; different letters (a-d) on the bars indicate significant differences according to the least significant difference (LSD) test (P≤0.05).

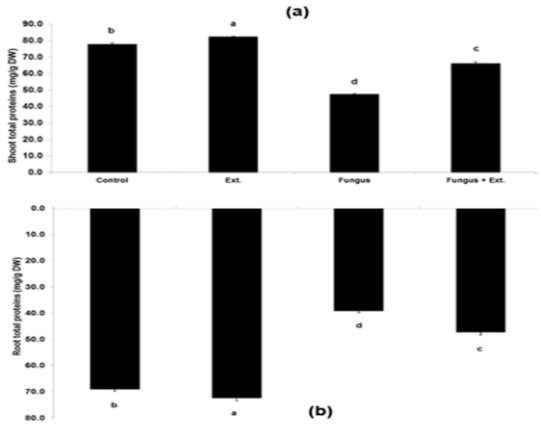

Fig. V. Effect of *Brassica nigra* root extract on shoot and root total proteins of 60-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus; different letters (a-d) on the bars indicate significant differences according to the least significant difference (LSD) test (P≤0.05).

the tomato plants when compared to those infected with the fungus alone (Fig. I). The weights of fresh and dried tomato plant shoots and roots were measured using the same observations (Figs. II and III).

Total carbohydrate contents

Shoot and root total carbohydrates considerably enhanced in tomato plants treated with *B. nigra* root extract compared to controls, with the combination of the fungus and extract having a more noticeable effect than fungus treatment alone (Fig. IV).

Total protein contents

Tomato plants infected with fungus had significantly suppressive total shoot and root proteins, whereas the interaction of *B. nigra* root extract recovered the harmful effect of fungus on tomato plants (Fig. V). The results were also highly

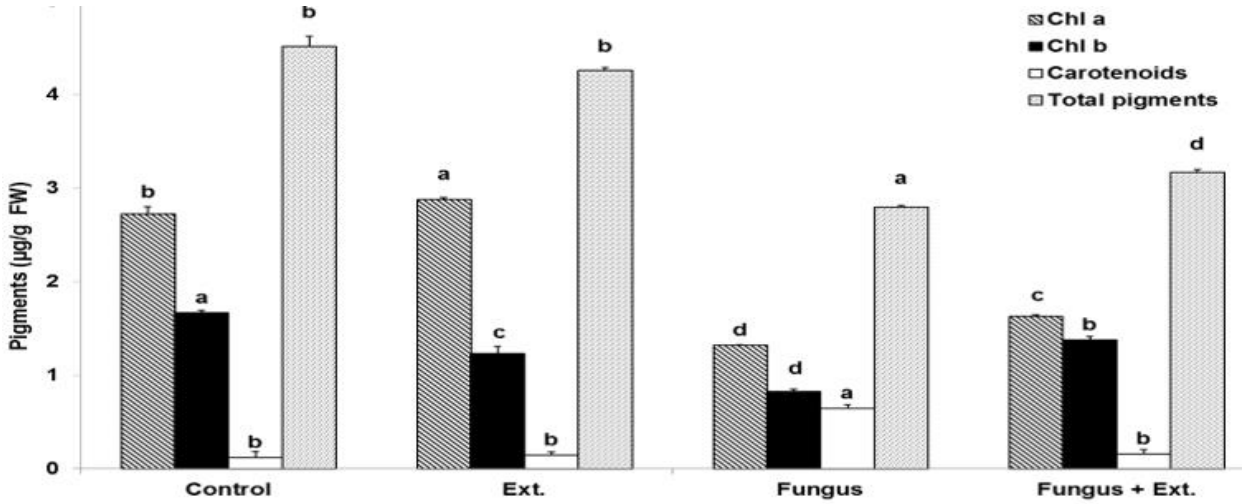

Fig. VI. Effect of *Brassica nigra* root extract on pigment contents of the leaves of 60-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus; different letters (a-d) on the bars indicate significant differences according to the least significant difference (LSD) test (P≤0.05).

visible in plants treated with *B. nigra* root extract without fungus in comparison to the control.

Pigment contents

Chlorophyl *a* contents rose to a greater amount in tomato plants treated with *B. nigra* root extract than in controls, and the results were more noticeable in the interaction of fungus with extract than in plants infected simply with fungus (Fig. VI). Chlorophyl *b* content of tomato plants treated with *B. nigra* root extraction decreased somewhat when compared to the control; however, the combination of a fungus and extract resulted in a significant increase in chlorophyl *b* content when compared to fungus-infected plants.

Carotenoids were substantially higher in tomato plants infected with fungus versus those treated with *B. nigra* root extract in combination with fungus. Total pigments accumulated more in infected tomato plants treated with *B. nigra* root extract than in untreated plants; however, there was a minor drop in total pigments in tomato plants treated with *B. nigra* root extract compared to control.

Activities of antioxidant enzymes

Antioxidant enzyme activities (POX, CAT, and PPO) were higher in tomato plants infected with fungus alone as compared with the tomato plants treated with fungus and *B. nigra* root extraction, with an appreciable increase in enzyme activities in

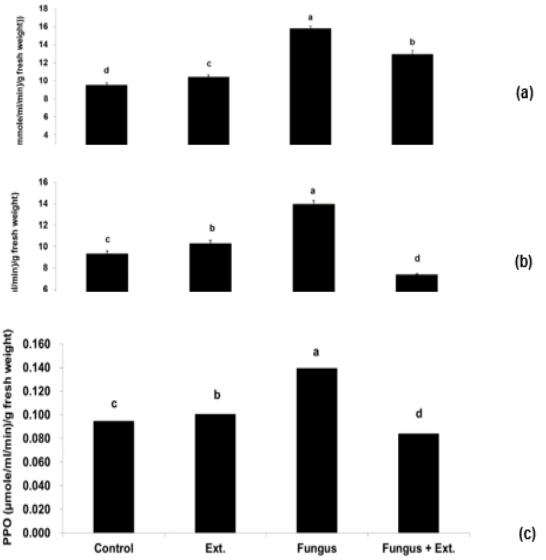

Fig. VII. Effect of *Brassica nigra* root extract on the activities of (a) peroxidase, (b) catalase, and (c) polyphenol oxidase enzymes of the leaves of 60-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus. Different letters (a-d) on the bars indicate significant differences according to the LSD test (P≤0.05).

tomato plants treated with extraction compared to control (Fig. VII. A, b, and c).

Mineral contents

Fig. (VIII) shows that tomato plants treated with *B. nigra* root extraction had a noticeable increase in shoot and root N, P, K, Ca, Mg, and Fe contents when compared to controls. The interaction of fungus with extraction has also recovered the fungus's inhibitory effect on the shoot and root

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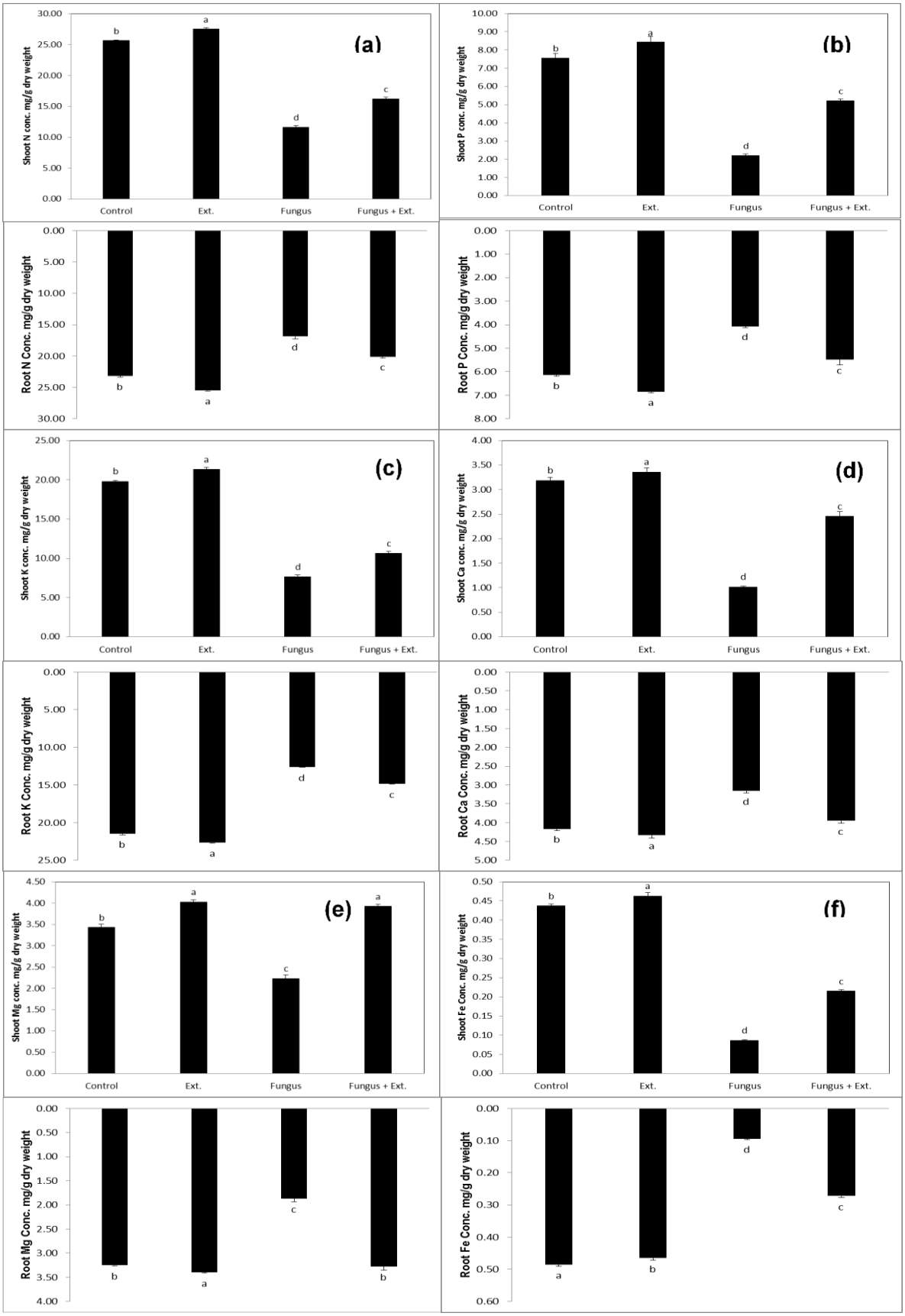

Fig. VIII. Effect of *Brassica nigra* root extract on the shoot and root mineral contents of 90-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus; different letters (a-d) on the bars indicate significant differences according to the LSD test (P≤0.05).

Table 3
Effect of *Brassica nigra* root extract on productivity and fruit quality of 90-day old *Solanum lycopersicon cv* plants infected with –ve and +ve *Fusarium solani* fungus.

Treatments	Number of fruits/plant ±SD	Average fruit weight (g) ±SD	Number of seeds/g ±SD	Lycopene contents (mg.100g^{-1} f.w) ±SD
Control	18.67 ± 0.47 ^{A}	46.17 ± 0.39 ^{A}	160 ± 1.63 ^{A}	3.18 ± 0.05 ^{A}
Ext.	19.33 ± 0.47 ^{A}	47.43 ± 0.33 ^{B}	165 ± 1.70 ^{B}	3.26 ± 0.01 ^{B}
Fungus	3.33 ± 0.47 ^{C}	12.10 ± 0.22 ^{D}	23 ± 0.82 ^{D}	1.10 ± 0.01 ^{D}
Fungus + Ext.	11.67 ± 0.47 ^{B}	38.60 ± 0.54 ^{C}	112.67 ± 1.25 ^{C}	2.51 ± 0.01 ^{C}

Means that do not share a letter are significantly different; Ext: *Brassica nigra* root extract.

nitrogen content increasing by 39.4% and root nitrogen content increasing by 19.2%. The shoot phosphorus content grew by 136.2%, whereas the root phosphorus content increased by 34.6%. Shoot potassium content grew by 39.1%, whereas root potassium content increased by 17.7%. The shoot calcium content grew by 140.2%, whereas the root calcium content increased by 25%. The shoot Mg content rose by 75.8%, whereas the root magnesium content increased by 74.9%. The iron content of the shoot grew by 144.4% while the root iron content increased by 200%.

Productivity and fruit quality

The data in Table 3 revealed a significant increase in average tomato fruit weight, number of seeds per gram, and lycopene content regardless of the number of fruits per plant in tomatoes treated with *B. nigra* root extract compared to the control while the interaction of fungus with *B. nigra* root extraction significantly improved all of the above-mentioned productivity and fruit quality without exception.

Discussion

Fusarium wilt is a soil-borne, systemic, and very destructive tomato disease (McGovern 2015; Ramaiah and Garampalli 2015). Using biological management strategies to manage plant diseases is a promising, cost-effective, and ecologically friendlier strategy. Plant growth-boosting qualities, as well as direct and indirect antagonism mechanisms are responsible for bio control agents' militancy against plant diseases. According to Mazzola et al. (2012), Narender and Ashok (2014), and Taylor et al. (2014), *Brassicas* are among the plant groups having significant Glucosinolate concentration in their tissues. Enzymatic hydrolysis of Glucosinolates produces a variety of Sulphur compounds, some of which hav antibacterial properties. If integrated, these agricultural leftovers lower the number of disease propagules in the soil. Some tomato lines exhibit resistance to the wilt pathogen and can thus be used in the integrated use of beneficial organisms and other bio-intensive disease-suppressing practices, which may improve the level and consistency of control by providing multiple mechanisms of action, a more stable rhizosphere community, and efficacy across a wide range of environmental conditions.

Fungi and fungal communities serve critical functions in soil ecology, and the diversity of fungal communities can be inherently hostile to a variety of plant infections (Gao et al., 2012). Previous research revealed that *Brassica* and *Allium* are bioactive plants capable of producing bioactive substances that may be used to reduce soil-borne pests and illnesses (Xiao et al*.,* 2013; Nagla et al., 2015). In contrast, the study found that suppressing *Rhizoctonia solani* with *Brassica napus* seed meal was connected with particular alterations in soil microbial populations and had nothing to do with glucosinolate levels (Cohen et al., 2005)

The interaction of *F solani* with *B. nigra* extraction resulted in significantly higher fresh and dry weights, plumule, and radicle lengths of tomato seedlings when compared to fungus-infected tomato seedlings alone. These findings agreed with many other researchers' findings (El-Marzoky and Abdel-Sattar, 2008; Hassan et al., 2014; Wang et al., 2017c; Jaber and Alananbe, 2018). Lettuce seedlings' root length, competitiveness for sunlight, competitiveness for nutrients in the soil, and moisture content

dramatically enhanced when exposed to low concentrations of goldenrod leaf extracts (Duke et al., 2006, Prithiviraj et al., 2007). The growth performance of the native species that co-occur can therefore be improved by goldenrod with a degree of light invasion. One theory is that the allelochemicals generated by extracts of goldenrod leaves at low concentrations can cause the production of reactive oxygen molecules during plant cell expansion, which in turn has a favorable impact on lettuce seedlings growth and the germination of seeds (Duke et al., 2006, Prithiviraj et al., 2007). *Fusarium* produces significant disruption in growth hormones, resulting in an obvious deficiency in cell biology (Verma et al., 2019; El-Maraghy et al., 2020). Zhao et al. (2022) discovered that grafted seedlings combined with *Allium fistulosum* and *Brassica juncea* had significantly higher dry weights ($p<0.05$) compared with those planted in untreated replanted soil. Furthermore, plant height, trunk diameter, and branch length were enhanced by 12.72%, 15.42%, 14.67%; 12.06%, 52.88%, and 71.79%, respectively.

The tomato wilt pathogen has a considerable influence on physiological indices of tomato plants (Jamil, 2021). These characteristics were greatly enhanced by *Trichoderma spp.* According to Attia et al. (2022), the first sign of systemic resistance in plants is the use of plant growth-promoting fungi, which reduce the diversity severity percentage while also providing protection against *F. oxysporum*. It can be claimed that an invader with a low degree of invasion can place the native species it coexists with under minimal stress, which will then support the emergence of seedlings and the growth of native species (Ye et al., 2014; Hossain et al., 2016; Wang et al., 2017a; Wang et al., 2017b; Wang et al., 2018). This may be partially linked to hormone influences, which are typically regarded as ecological methods for plant species' responses to outside demand as their main driving force (Takao et al., 2011). According to Attia et al. (2022), tomato plants infected with *F. oxysporum* had a considerable decrease in shoot length (40.4%), root length (85%), and leaf number (50.6%) when compared to healthy control plants. The results showed that extracts of all plant growth-promoting fungus considerably enhanced different growth indices (shoot length, root length, and the number of leaves). Infected plants, on the other hand, exhibited promising recovery when treated with tested fungal isolates (*A.niger*, *A.flavus*, *M.circinelloides*, and *P.oxalicum*). According to Hung and Lee Rutgers (2016), *Aspergillus spp*. stimulates plant development via producing active chemicals. Another study found that *Aspergillus* isolated from the wheat rhizosphere generated numerous plant growth inducers such as IAA, GA, and siderophores, which resulted in phosphate solubilization and increased seed germination percentage and plant height (Pandya et al., 2018). According to Jovii-Petrovi and Jeremi (2016), *Aspergillus* has a 33% inhibitory rate against *F. oxysporum*.

By treating tomato plants with *B. nigra* root extract, shoot height, root length, and fresh and dry weights increased. The outcomes of this study concurred with those of (Guo et al., 2020) who found that the length of the fava bean roots and its dry weight and plant height considerably increased by the exogenous addition of 0.01 $g.mL^{-1}$ wheat stem and leaf extracts in comparison to the control. These parameters were modestly elevated by the exogenously supplied 0.05 $g.mL^{-1}$ wheat stem and leaf extract. Nevertheless, all of the fava bean's growth indicators significantly reduced when 0.1 $g.mL^{-1}$ of wheat stem and leaf extract was applied. The potential of these fungal isolates to generate secondary metabolites that boost plant development and stimulate molecules important for the defense was documented by Chand et al. (2020), Ismail et al. (2020), and Hussain et al. (2021).

In this regard, Guo et al. (2020) reported that fava bean dry weight, root dry weight, main root length, and stem dry weight were all significantly boosted when wheat root extract 0.05 g/mL was applied. The plant height, main root length, stem weight, and root length of the fava bean were significantly reduced when wheat root extract concentration was raised to 0.1 $g.mL^{-1}$, but the other indicators were not significantly affected. *Fusarium oxisporum's* spore germination and mycelial growth were suppressed by the extracts

of fava bean stems, leaves, and roots when used in small doses (Guo et al., 2020)

Comparing the treated group with the untreated control showed that 14 plant extracts were able to inhibit the radial growth of *F. oxysporum* f.sp. *lycopersici*. Alkaloids, flavonoids, and resin in *Rivina humulis*, the known bioactive chemicals that are effective in controlling bacteria and fungi (Joseph and Elvita, 2013).

According to Abdelgaleil et al. (2011), sesquiterpenes considerably reduce the growth of *F. oxysporum's* mycelium and the germination of its spores. This antifungal activity is based on the permeability of fungi's cellular walls.

In the current study, tomato plants with *F. oxysporum* infections displayed a decrease in every growth indicator. This decrease could be the result of the fungus's toxins, which interfere with stomatal function and cause excessive water loss and uncontrolled transpiration, which causes wilted plants. Additionally, a rise in respiration rate and de-compartmentalization brought on by membrane breakdown may be linked to the decline in shoot dry weight (Ahmed et al., 2009). These findings are consistent with those of Hassanein et al. (2008), who discovered that the restriction of growth might also be connected to the buildup and activity of phenolics formed by the breakdown of cell wall lignin, mostly via de-polymerization brought on by fungal elicitors.

B. nigra root extract enhanced total shoot and root carbohydrates. These results are consistent with those obtained by Couée et al. (2006), who reported that soluble sugars play a vital role in how the body reacts to various stresses by acting as signaling molecules for nutrients and metabolites that activate particular or hormonal transduction pathways and significantly alter gene expression. When compared to non-infected controls, total soluble sugars in the leaves and roots of infected tomato plants treated or untreated with biological agents and/or hormonal elicitors decreased 14 days after pathogen inoculation, and then significantly increased to reach their peak value 42 days after infection (El-Khallal, 2007). Treatment with *Arbuscular mycorrhiza* fungi plus jasmonic acid resulted in the highest levels of root soluble carbohydrates; this may be related to higher levels of jasmonic acid in mycorrhiza roots, which may improve the sink-strength of mycorrhizal roots and subsequently increase the production of carbohydrates and their movement into the roots from the shoots (Hause et al., 2002). High chlorophyll content and subsequent higher photosynthetic rate of plants treated with *Arbuscular mycorrhiza* and salicylic acid may be related to the elevated levels of soluble sugars in their leaves. These findings show that the buildup of soluble sugars in tomato plants infected with the disease, particularly those that had been exposed to bioagents and hormone elicitors suggest the relation between activation of systemic resistance and sugar regulation. Plant growth-promoting fungi increase carbohydrates, which play a significant role in physiological protection against numerous pathogens by stimulating hormones and other defense mechanisms, resulting in gene expression alterations (Hosain et al., 2017).

Interaction of *B. nigra* root extraction reversed the damaging effect of *F. solani* on the total shoot and root proteins of tomato plants. In this connection El-Khallal (2007) discussed that *F. oxysporum* infection resulted in a considerable decrease in the quantities of total soluble protein and free amino acids in tomato plant leaves and roots. This decrease grew as the pathogen infection period grew longer. When plants are going through natural senescence during *F. oxysporum* attacks, this may speed up the loss of soluble protein. A decrease in energy requirement may be connected to a delay in the synthesis of the primary nitrogenous chemicals in leaves. As a result, it is challenging to predict how the presence of *F. oxysporum* and/or its metabolites would affect the ability of tissues to conserve energy (Nafie, 2003). Total soluble proteins and total carbohydrates in tomatoes decreased dramatically in response to *F. oxysporum* infection, although total phenols and free proline rose significantly (Attia et al., 2022). When compared to control plants, treatment with *Aspergillus niger*, *Aspergillus flavus*, *Mucor circinelloides*, and *Pencillium oxalicum* elicitors increased total soluble proteins and carbohydrates.

El-Khallal (2007) reported that treatment with the jasmonic acid elicitor alone or in combination with the bio agent *Arbuscular mycorrhiza* fungi had been more effective than all treatments in increasing the amount of free amino acids and total soluble proteins in infected tomato plants. Meuriot et al. (2004) suggested that jasmonate may have an effect on N storages such as soluble proteins and specific VSPs, either directly (transcriptional regulation) or indirectly (through changes in N partitioning). In their study on lupine seedlings, El-Bahay and Moursy (2003) found that salicylic acid exerts its effects on the machinery that produces DNA and RNA at transcriptional and/or translocational levels with magnitudes based on how closely nucleic acid and total soluble protein levels are related in response to the compound. According to El-Khallal (2007), *F. oxysporum* infection predominantly affects the growth of tomato plants, which also experience a reduction in N acquisition as a result of mechanisms for controlling negative feedback. Increasing the rate at which additional amino acids are converted reportedly happens at the expense of soluble proteins, which may be the cause of alterations in tomato plants' total soluble protein concentrations harboring pathogens. Finally, the interaction between the biological agent (*Arbuscular mycorrhiza* Fungi) and the hormone-stimulating agents (Jasmonic Acid and Salicylic Acid) had been successful in treating the symptoms of wilt disease, which were brought on by the infection's metabolic changes. The stimulation of plant defense systems through protein synthesis is one of the indirect impacts of plant growth-promoting fungi in disease eradication (Dufossé, 2006). According to phytochemistry and cell biology findings, physiological immunity is the outcome of a variety of biological processes, including changes in the cell wall and the production of defense-related chemicals such as phytoalexins and proteins involved in pathogenesis (Elsharkawy et al., 2015).

Chlorophyll b levels in tomato plants treated with *B. nigra* root extract were somewhat lower; however, carotenoid levels were much higher in the plants infected with *F. solani* alone compared to the plants treated with a combination of *B. nigra* root extract and fungus. In this connection, Akladious et al. (2015) found that when compared to the healthy control, *F. oxysporum* contaminated tomato plants had significantly reduced levels of total photosynthetic pigments and chlorophyll a and b at the vegetative and blooming stages in their leaves. Total photosynthetic pigments and carotenoid contents in the leaves of both diseased and healthy plants increased after the application of *Ocimum basilicum* extract. The maximum rise in total pigment content was seen during the flowering stage of healthy plants treated with *O. basilicum* extract. This could be due to a factor that has been identified as the current rise in leaf area and number. According to Attia et al. (2022), chlorophyll a and b levels reduced dramatically, whereas carotenoids increased in *Fusarium*-infected plants. On the other hand, infected tomato plants treated with the plant growth-promoting fungus showed a significant increase in the concentration of photosynthetic pigments. Treatment with *Mucor circinelloides* strain had the greatest effect on chlorophyll concentration (Attia et al., 2022). The loss in chlorophyll was effectively characterized by Kyseláková and Prokopová (2011), who observed that infection may be caused by oxidative stress, which damages chlorophyll a; this implies that the plant fails to capture sunlight, and therefore photosynthesis is limited or blocked. When seed treatment with *Trichoderma viride* was utilized, Jamil (2021) discovered that the maximum significant increase in chlorophyll content was 42.56% (3.36 mg/g fresh leaves) in the first year and 45.70% (3.02 mg/g fresh weight) in the following year. Choudhury and Panda (2005), Jahan et al. (2020), and Singh et al. (2021) explained the decrease in chlorophyll pigments as a result of oxidative stress after injury caused by the release of free radicals, causing damage or distortion in the formation of chloroplasts, and this means the plant's failure or inability to capture light and carry out the process of photosynthesis.

The quantity of all pigments used in photosynthetic processes produced by the plants increased when *B. nigra* extract was added to seeds. The extract's function as a catalyst for the enzymes that regulate photosynthetic carbon reduction and protect chloroplast from oxidative

damage may be the cause of this. β-carotene, flavone, phenol, and vitamins, all recognized components of *B. nigra* extract, play crucial photo protective roles in all photosynthetic species by scavenging ROS. As free radical scavengers, carotenoids serve as energy carriers and photo-oxidation defenders, preventing the oxidative destruction of chlorophylls and reducing chlorophyll degradation (Abbas and Akladious, 2013). Increased chlorophyll content caused an increase in net photosynthetic rate, which has a direct influence on plant photosynthetic activity. This is consistent with the findings of Harish et al. (2008) who discovered that *Trichoderma* promoted plant growth by increasing leaf chlorophyll levels, resulting in greater photosynthetic activity.

The antioxidant enzyme activities (peroxidase, catalase, and polyphenol oxidase) of tomato plants infected with fungus were higher than those of tomato plants treated with *B. nigra* extract. These outcomes align with those that were attained by (Akladious et al., 2015) who found that the activities of the enzymes catalase (CAT), peroxidase (POX), ascorbate peroxidase (APX), superoxide dismutase (SOD), and glutathione reductase (GR) were dramatically enhanced by *F. oxysporum* infection during the vegetative and flowering stages. In comparison to CAT and POX activities, the APX and SOD activities were improved more at all treatments. Additionally, soaking the seeds in *O. basilicum* extract prior to sowing significantly boosted the CAT, POX, APX, SOD, and GR activities in both infected and non-infected plants as compared to the control. Infected plants that had received *O. basilicum* extract showed the highest values in these activities. Infected plants had considerably higher levels of oxidative enzymes (POD and PPO) in the study by Attia et al. (2022). Additionally, applying *M. circinelloides* to the infected plants resulted in the greatest rise in POD and PPO activity, followed by *Aspergillus flavus*, *Pencillium oxalicum*, and *Aspergillus niger*. Induced host resistance is shown by increases in the levels of these biochemical and antioxidants (Woo et al., 2014).

When stressed sweet marjoram plants were grown in vegetative rather than flowering stages, Baâtour et al. (2012) detected an improvement in terms of high phenolic contents and antioxidant activities, which indicate a rise in secondary metabolism.

The most prevalent, potent, and water-soluble antioxidant that is not an enzyme, ascorbic acid (vitamin C), works to stop or lessen the harm that ROS causes. In addition to using the APX process to convert H_2O_2 to water, it has the capacity to directly scavenge singlet oxygen, superoxide, and hydroxyl radicals (Abbas and Akladious, 2013). During infection, it is possible to facilitate the species' reactive oxygen metabolism via a number of antioxidant enzymes, including POX and CAT. By facilitating its breakdown into O_2 and H_2O, catalase can shield the cell from the harmful effects of H_2O_2. Increased H_2O_2-scavenging ability and protection from lipid peroxidation are benefits of increased APX activity (Sato et al., 2011). More phenol oxidase enzyme is secreted by the host plant as a defense mechanism when tomato plants are exposed to the pathogen and the antagonist. This could explain why infected plants treated with *O. basilicum* extract showed high levels of enzymatic antioxidant activity (Ojha and Chatterjee, 2012). In addition to direct antagonistic effects, pathogen infection causes the bio control agents to upregulate the activity of a number of defense-related enzymes and molecules against the fungi that cause the damping-off disease. Nahak et al. (2011) found *O. basilicum* essential oil effective, and the stimulatory impact of *O. basilicum* extract on boosting antioxidant enzyme activity in infected tomato plants strongly imply that *F. oxysporum* wilt disease prevention by *O. basilicum* extract involves activating antioxidant defense enzymes (Hanaa et al., 2011). According to Hassan et al. (2014), the use of plant growth-promoting fungus promoted the induction of POD and PPO in *Fusarium*-infected plants. These enzymes generate chemicals that demonstrate the early stages of resistance induction as well as phenolic molecules (Sharma et al., 2019).

In comparison to the control, tomato plants treated with *B. nigra* root extract showed a significant rise in shoot and root N, P, K, Ca, Mg, and Fe contents. Regarding the influence of *B. nigra* extract on mineral contents, El-Khallal

(2007) observed that in tomato plants infected with *F. oxysporum* 42 days after introducing the pathogen, the N and P contents were much lower than those of the non-infected control. If root tissues are already being attacked by pathogens, it may impact the tomato tissues' ability to absorb nutrients and water from the soil, alternatively, they could be extracted from macerated tissues. There may be a connection between this and the decreased uptake of N and P in tomato tissues (Nafie, 2003). Last but not least, increased biomass and photosynthetic rate may be associated to high N and P contents, which may increase tomato plants' susceptibility to wilt disease brought on by *F. Oxysporum*.

While *B. nigra* extract and/or *F. solani* fungi may have raised the amount of K^+ in infected plants, this may slow the spread of *F. solani* and its toxins by blocking the transfer of nutrients from the host to the infection (Nafie, 2003). The integrity of cell membranes may be compromised, increasing permeability, and causing leakage from tissues affected by *F. oxysporum*. This might be a result of all infected plants having less Ca^{2+} in them than non-infected plants, which could be the cause (healthy control). According to Orcutt and Nilsen (2000), calcium may obstruct the uptake of toxic ions from the soil when *F. oxysporum* pathogenesis is present. Hollister et al. (2013) discovered that *Brassica juncea* seed meal treatment significantly impacted soil fungus populations and that its effects might last longer than those conferred on the bacterial community.

The average fruit weight, the number of seeds per gram, and the lycopene content of tomatoes treated with *B. nigra* root extract increased significantly when compared to the control. In this regard, *Brassica* residues at a rate of 25 kg per plot, with or without solarization, were found to dramatically lower the incidence of illness and the cucumber root galling index when compared to the control (Al-Abed et al., 2022). The yield for all treatments (cultivated crops) significantly increased in comparison to the control. However, compared to solarization alone or simply bio fumigation, the results showed that under combined treatment of soil solarization and bio fumigation, there was less root galling frequency and disease. Additionally, compared to the other treatments, utilizing bio fumigation in conjunction with solarization significantly increased the production of cucumbers (Al-Abed et al., 2022).

Al-Abed et al. (2022) demonstrated that broccoli, radish, cabbage, and mustard all showed stronger antifungal activity against *F. oxysporum* than cauliflower, which only inhibited the fungus by 57%. Additionally, they demonstrated that the cultivated *Brassica* had better antifungal properties than the wild *Brassica* did. They showed that employing *Brassica* residues brought about a substantial drop in the severity of the disease and a reduction in root galling when compared to the control (10 % application rate increase). On the other hand, the effects of several plant species on the *Meloidogyne incognit* did not differ significantly from one another. Molla et al. (2012) and Hasan et al. (2020) discovered higher lycopene levels in *Fusarium oxysporum* f. sp. *lycopersic*i-infected tomato plants treated with *T. harzianum*.

The effects of soil solarization and bio fumigation with organic amendments applied as sheep manure and cabbage residues had a positive influence on controlling corky root (*Pyrenochaeta lycopersici*) and nematodes infection, reducing the damage on tomato roots (Moura et al., 2010). A better tomato production resulted from the most efficient management of corky root and nematode. More study is required to develop a unique method for bio fumigating plants that contain GLS using dried pellets of plant material (Lazzeri et al., 2004). According to Jamil (2021), the findings on the efficiency of *Trichoderma spp.* in disease suppression and plant growth augmentation against *Fusarium* wilt of tomato are promising. Compared to the untreated control, using *Trichoderma spp.* in either form significantly ($p<0.05$) improved plant growth and yield indices.

Conclusion

According to the findings of the current study, *B. nigra* contains a strong capability for antioxidants and is applicable to creating innovative use of natural antioxidants to the devastation caused by tomato plant *Fusarium* wilt. Results revealed the positive effects of *B. nigra* root extract on the

harmful effects of *F. oxysporum* on tomato plants by improving some growth parameters, total carbohydrates, and proteins. The content of chlorophyll pigments was increased by using *B. nigra* root extract. It was also found that *B. nigra* root extract can increase the enzymatic antioxidant contents such as peroxidase, catalase, and polyphenol oxidase compared to the control. Furthermore, an increase occurred in mineral content under the *B. nigra* root extract treated or not treated with fungus. The productivity and fruit quality of tomato plants were significantly improved.

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References

Abbas, S. M. and **S. A. Akladious.** 2013. Application of carrot root extract induced salinity tolerance in cowpea (*Vigna sinensis* L.) seedlings. *Pakistan Journal of Botany* 45, 795-806.

Abdelgaleil S.A.M., M.E.I. Badawy, T. Suganuma, and **Kitahara.** 2011. Antifungal and biochemical effects of pseudoguaianolide sesquiterpenes isolated from *Ambrosia maritima* L., *Afr. J. Microbiol. Res*., 5, 3385-3392**.**

Ahmed, Z. M., S. Dawar,M. Tariq. 2009. Fungicidal potential of some local tree seeds for controlling root rot disease. *Pak. J. Bot* 41, 1439-1444.

Akladious, S. A., G. S. Isaac and **M. A. Abu-Tahon .** 2015. Induction and resistance against Fusarium wilt disease of tomato by using sweet basil (*Ocimum basilicum* L) extract. *Canadian Journal of Plant Science* 95, 689-701.

Al-Abed, A., Z. Naser, Y. Dana, B. Al-Shurman, R. Al-Humran. 2022. Study the environment-friendly control methods of soil borne diseases (*Fusarium* and nematode) of cucumber and tomato using the cruciferous plant.

Allen, S. E., H. M. Grimshaw, J.A. Parkinson and **C. Quarmby.** 1974. Chemical analysis of ecological materials. *Blackwell Scientific Publications*.

Al-Turki AI and **WA. Dick .** 2003. Myrosinase activity in soil. *Soil Sci Soc Am J* 67:139–145.

Attia, M.S.,A. M. Abdelaziz, A. A. Al-Askar,A. A. Arishi and **A. M. Abdelhakim** and **A. H. Hashem.** 2022. Plant growth-promoting fungi as biocontrol tool against *Fusarium* wilt disease of tomato plant. *Journal of Fungi*, 8(8), p.775.

Attia, M.S., D. A. El-Wakil, A. H. Hashem and **A. M. Abdelaziz.** 2022. Antagonistic effect of plant growth-promoting fungi against *Fusarium* wilt disease in tomato: in vitro and in vivo study. *Applied Biochemistry and Biotechnology*, 194(11), pp.5100-5118.

Avato P, T. D'Addabbo, P. Leonetti and **MP. Argentieri .** 2013. Nematicidal potential of *Brassicaceae*. *Phytochem Rev*. 12:791–802

Avita E.J. 2013. Phytochemical screening and bioactivity assay of selected South Indian phytolaccaceae, *J. Nat. Life Sci.,* 1, 26-30.

Baâtour, O., I. Tarchoun, N. Nasri, R. Kaddour, J. Harrathi, E. Drawi, M. Mouhiba, B. Nasri-Ayachi, B. Marzouk and **M. Lachaâl.** 2012. Effect of growth stages on phenolics content and antioxidant activities of shoots in sweet marjoram (*Origanum majorana* L.) varieties under salt stress. *African Journal of Biotechnology* 11, 16486-16493.

Bagger CL, S. Buskov,JB Hasselstrom,E. Rosa, H. Sorensen and JC. Sorenson. 1999. Bioactives from *Cruciferous* crops especially glucosinolate derived products produced in pilot plant scale and used as biocides supplementary to synthetic pesticides. Paper presented at International Rapeseed Congress, 10. *International Rapeseed Congress*, 1991, Canberra, Australia

Bangarwa, S. K., J. K. Norsworthy J. D. Mattice and **E. E. Gbur.** 2011. Glucosinolate and isothiocyanate production from Brassicaceae

cover crops in a plasticulture production system. *Weed Science* 59, 247-254.

Bansal, R.K. and **R. K. Gupta.** 2000. Evaluation of plant extracts against *Fusarium oxysporum* wilt pathogen of fenugreek. *Indian Phytopathology*, 53(1), pp.107-108.

Beauchamp, C. and **I. Fridovich,** 1971. Superoxide dismutase: improved assays and an assay applicable to acrylamide gels. *Analytical biochemistry* 44, 276-287.

Bending GD and **SD Lincoln.** 1999. Characterisation of volatile sulphurcontaining compounds produced during decomposition of *Brassica juncea* tissues in soil. *Soil Bio Biochem* 31:695–703

Bharat, N.K. and A. K. **Thakur,** 2014. Bio-intensive management of *Fusarium* wilt of tomato-*A Review. International Journal of Economic Plants*, 1(1), pp.28-35.

Boydston RA, MJ Morra, V Borek, L Clayton and **SF Vaughn.** 2011. Onion and weed response to mustard (*Sinapis alba*) seed meal. *Weed Sci.* 59:546–552

Bressan M, MA Roncato, F Bellvert, G Comte, EF ZaharHaichar, W Achouak and **O Berge O.** 2009. Exogenous glucosinolate produced by *Arabidopsis thaliana* has an impact on microbes in the rhizosphere and plant roots. *ISME J*. 3:1243–1257.

Cartea, M. E. and **P. Velasco, 2008.** Glucosinolates in *Brassica* foods: bioavailability in food and significance for human health. *Phytochemistry reviews* 7, 213-229.

Chand, K., S Shah, J Sharma, MR Paudel and **B Pant,** 2020. Isolation, characterization, and plant growth-promoting activities of endophytic fungi from a wild orchid *Vanda cristata*. *Plant Signal. Behav*. 15, 1744294.

Chou, C.H., Y. F. Lee 1991. Allelopathic dominance of *Miscanthus transmorrisonensis* in an alpine grassland community in Taiwan. *Journal of Chemical Ecology* 17, 2267-2281.

Choudhury, S. and **S.K. Panda,** 2005. Toxic Effects, Oxidative Stress and Ultrastructural Changes in Moss *Taxithelium nepalense* (Schwaegr.) Broth. Under Chromium and Lead Phytotoxicity. *Water Air Soil Pollut*. 167, 73–90.

Clarke DB. 2010. Glucosinolate, structures and analysis in food. *Anal Methods* 2:310–325**.**

Classics Lowry, O., N. Rosebrough, A. Farr and **R. Randall,** 1951. Protein measurement with the Folin phenol reagent. *J Biol Chem* 193, 265-75.

Cohen, M.F.,H. Yamasaki and **M. Mazzola,** 2005. *Brassica napus* seed meal soil amendment modifies microbial community structure, nitric oxide production and incidence of *Rhizoctonia* root rot. *Soil Biol. Biochem*. 37, 1215–1227.

Couée, I.,C. Sulmon, G. Gouesbet and **A. El Amrani,** 2006. Involvement of soluble sugars in reactive oxygen species balance and responses to oxidative stress in plants. *Journal of experimental botany* 57, 449-459.

Dai R and **LT Lim.** 2014. Release of allyl isothiocyanate from mustard seed meal powder. *J Food Sci* 79:E47–E5

Dejanovic, G. M., E. Asllanaj, M. Gamba, P.F. Raguindin, O.A. Itodo, B. Minder, W. Bussler, B. Metzger, T. Muka and **M. Glisic,** 2021. Phytochemical characterization of turnip greens (*Brassica rapa* ssp. *rapa*): A systematic review. *PloS one* 16, e0247032.

Dufossé, L. 2006. Microbial production of food grade pigments. *Food Technol. Biotechnol.* 44, 313–323.

Duke, S. O., N. Cedergreen, E. D. Velini and **R. G. Belz,** 2006. Hormesis: is it an important factor in herbicide use and allelopathy? *Outlooks on Pest Management* 17, 29-33.

Duthie, G. G.,S. J. Duthie and J. A. Kyle, 2000. Plant polyphenols in cancer and heart disease: implications as nutritional antioxidants. *Nutrition research reviews* 13, 79-106.

El-Bahay, M. and **S. Moursy,** 2003. Certain physiological, biochemical and molecular aspects of lupin seedlings as influenced by seed treatment with salicylic acid and gallic acid prior to sowing. *Egypt J. Biotechnol* 13, 157-175.

El-Khallal, S. M. 2007. Induction and modulation of resistance in tomato plants against *Fusarium* wilt disease by bioagent fungi (*Arbuscular mycorrhiza*) and/or hormonal elicitors (jasmonic acid & salicylic acid): 1- Changes in growth, some metabolic activities and endogenous hormones related to defence mechanism. *Aust J Basic Appl Sci* 1, 691-705.

Elsharkawy, M.M.,M. B. Shivanna, M. S. Meera, and M. **Hyakumachi,** 2015. Mechanism of induced systemic resistance against

anthracnose disease in cucumber by plant growth-promoting fungi. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, 65(4), pp.287-299.

Fenwick, G. R., R. K. Heaney, W. J. Mullin and **C. H. VanEtten,** 1983. Glucosinolates and their breakdown products in food and food plants. CRC *Critical Reviews in Food Science and Nutrition* 18, 123-201.

Fierro, J.E., P. Jiménez and **E. D. Coy-Barrera,** 2013. Antifungal activity of *Brassica rapa*-derived extracts against *F. oxysporum*. *Planta Medica*, 79(10), PP. 2.

Fish, W. W.,P. Perkins-Veazie and **J. K. Collins,** 2002. A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. *Journal of food composition and analysis* 15, 309-317.

Fujii S, K., K. Hirai and **H. Saka ,** 1991. Growth-regulating action of brassinolide in rice plants. *ACS Symp Series Am Chem Soc* 474:306–311

Gao, G.P., D. H. Yin,S. J. Chen, F. Xia, J. Yang, Q. Li, and **W. Wang,** 2012. Effect of biocontrol agent Pseudomonas fluorescens 2P24 on soil fungal community in cucumber rhizosphere using T-RFLP and DGGE. *PLoS ONE*. 7, e31806.

Guo, Y., J. LV, Y. Dong and **K. Dong,** 2020. Allelopathy of Wheat and Faba Bean Extracts in an Intercropping System.

Hammerschmidt, R., E. Nuckles and **J. Kuć,** 1982. Association of enhanced peroxidase activity with induced systemic resistance of cucumber to *Colletotrichum lagenarium*. *Physiological Plant Pathology* 20, 73-82.

Hanaa, R. F.,Z. A. Abdou, D. A. Salama, M. A. Ibrahim and **H. Sror,** 2011. Effect of neem and willow aqueous extracts on *Fusarium* wilt disease in tomato seedlings: Induction of antioxidant defensive enzymes. *Annals of Agricultural Sciences* 56, 1-7.

Hassan, N., M. M. Elsharkawy, M. B Shivanna, M.S Meera and **M. Hyakumachi,** 2014. Elevated expression of hydrolases, oxidase, and lyase in susceptible and resistant cucumber cultivars systemically induced with plant growth-promoting fungi against anthracnose. *Acta Agric. Scand. Sect. B—Soil Plant Sci.* 64, 155–164.

Hassanein, N., M.Abou Zeid, K. Youssef and **D. Mahmoud,** 2008. Efficacy of leaf extracts of neem (*Azadirachta indica)* and chinaberry (*Melia azedrach)* against early blight and wilt diseases of tomato. *Aust. J. Basic Appl. Sci* 2, 763-772.

Hause, B., W. Maier, O. Miersch, R. Kramell and **D. Strack,** 2002. Induction of jasmonate biosynthesis in *Arbuscular mycorrhizal* barley roots. *Plant Physiology* 130, 1213-1220.

Hollister, E. B., P. Hu, A. S. Wang, F.M. Hons and **T. J. Gentry,** 2013. Differential impact of brassicaceous and nonbrassicaceous oilseed meals on soil bacterial and fungal communities. *FEMS Microbiol. Ecol*. 83, 632–641.

Hopkins RJ,NM van Dam and **JJA van Loon ,** 2009. Role of glucosinolates ininsect-plant relationships and multitrophic interactions. *Annu Rev Entomol* 54:57–83

Hossain, M., S. Anwar and **R. Nandi, 2016.** Allelopathic effects of *Mikania cordata* on forest and agricultural crops in Bangladesh. *Journal of forestry research* 27, 155-159.

Hossain, M.M., F. Sultana and **S. Islam,** 2017. Plant Growth-Promoting Fungi (PGPF): Phytostimulation and Induced Systemic Resistance. *In Plant-Microbe Interactions in Agro-Ecological Perspectives*; Singh, D., Singh, H., Prabha, R., Eds.; Springer: Singapore, pp. 135–191.

Hung, R. and **S. Lee,** 2016. Rutgers, Chapter 17 - Applications of Aspergillus in Plant Growth Promotion. In V. K. Gupta (Ed.), *New and Future Developments in Microbial Biotechnology and Bioengineering* (pp. 223–227). Elsevier.

Hussain,T.,M. Javed, S. Shaikh,B. Tabasum, K. Hussain, M. S. Ansari, A. Khan and **A. A. Khan,** 2021. Enhancement of Plant Secondary Metabolites Using Fungal Endophytes. In Biotechnological Approaches to Enhance Plant Secondary Metabolites; CRC Press: *Boca Raton*, FL, USA. pp. 61–70.

Ismail AH, AS Mehmood, MU Qadir, MU Husna AI, Hamayun and **NA Khan,** 2020. Thermal stress alleviating potential of endophytic fungus *Rhizopus oryzae* inoculated to sunflower (*Helianthus annuus* L.) and soybean (*Glycine max* L.). *Pak. J. Bot.* 52(5):1857-65.

Jahan, M.S., M. Shah, J. Shirong, G. A.Raziq, B. S. Sheng, S. Yu,W. Golam, J. A. Khairul, P.K.

Rana, 2020. Melatonin alleviates nickel phytotoxicity by improving photosynthesis, secondary metabolism and oxidative stress tolerance in tomato seedlings. *Ecotoxicol. Environ. Saf*. 197, 110593.

Jamil, A. 2021. Antifungal and plant growth promoting activity of *Trichoderma spp*. Against *Fusarium oxysporum* f. sp. *lycopersici* colonizing tomato. *Journal of Plant Protection Research*, pp.243-253.

JIANG, L. 2018. Phytoinhibition and Formulation of Allelopathic Extract of *Mikania micrantha* Kunth ex HBK as pre-emergent weed suppressant against Echinochloa colona (L.) Link. Doctoral Thesis, Universiti Putra Malaysia, 2018.[Google Scholar.[

Joseph, E. and **S. Elvita,** 2013. Phytochemical screening and bioactivity assay of selected South Indian phytolaccaceae. *Journal of Nature and Life Science* 1, 26-30.

Jovičić-Petrović, J., S. Jeremić, I. Vučković, S. Vojnović, A. Bulajić, V. Raičević and **J. Nikodinović-Runić,** 2016. Aspergillus piperis A/5 from plum-distilling waste compost produces a complex of antifungal metabolites active against the phytopathogen *Pythium aphanidermatum*. *Archives of Biological Sciences*, 68(2), pp.279-289.

Kapusta-Duch, J.,A. Kopec, E. Piatkowska, B. Borczak and **T. Leszczynska,** 2012. The beneficial effects of *Brassica* vegetables on human health. *Roczniki Państwowego Zakładu Higieny*, 63(4).

Kato, M. and **S. Shimizu,** 1987. Chlorophyll metabolism in higher plants. VII. Chlorophyll degradation in senescing tobacco leaves; phenolic-dependent peroxidative degradation. *Canadian Journal of Botany* 65, 729-735.

Larkin RP and **TS Griffin,** 2007. Control of soil borne diseases of potato using *Brassica green manures*. *Crop Prot* 26:1067–1077

Lazzeri, L., O. Leoni and **L. Manici,** 2004. Biocidal plant dried pellets for biofumigation. Industrial crops and products 20, 59-65.

Lovett, J. 1991. Changing perceptions of allelopathy and biological control. *Biological Agriculture & Horticulture* 8, 89-100.

Mandava NB, JM Sasse and **JH Yopp,** 1981. Brassinolide, a growth promoting steroidal lactone: activity in selected gibberellin and cytokinin bioassays. *Physiol Plant* 53:453–461

Maqbool, N., A. Wahid, M. Farooq,Z. Cheema and **K. Siddique,** 2013. Allelopathy and abiotic stress interaction in crop plants. Allelopathy. *Springer*, pp. 451-468.

Mayer, A., E. Harel and **R. Ben-Shaul,** 1966. Assay of catechol oxidase—a critical comparison of methods. *Phytochemistry* 5, 783-789.

Mayton HS, C. Olivier , SF Vaughn and **R. Loria ,** 1996. Correlation of fungicidal activity of *Brassica species* with allyl isothiocyanate production in macerated leaf tissue. *J Phytopathol* 86:267–271

Mazzola, M., C. L. Reardon and **J. Brown,** 2012. Initial Pythium species composition and *Brassicaceae* seed meal type influence extent of *Pythium*-induced plant growth suppression in soil. *Soil Biol. Biochem*. 48, 20–27.

McGovern R.J. 2015. Management of tomato diseases caused by *Fusarium oxysporum. Crop Protection* 73: 78–92.

Metzner, H., H. Rau and **H. Senger,** 1965. Untersuchungen zur synchronisierbarkeit einzelner pigmentmangel-mutanten von *Chlorella*. *Planta* 65, 186-194.

Meuriot, F., C. Noquet, J. C. Avice, J. J. Volenec, S. M. Cunningham, T. G. Sors, S. Caillot and **A. Ourry,** 2004. Methyl jasmonate alters N partitioning, N reserves accumulation and induces gene expression of a 32-kDa vegetative storage protein that possesses chitinase activity in *Medicago sativa* taproots. *Physiologia plantarum* 120, 113-123.

Moura, L,I. Queiroz, I. Mourao, L. Brito and J. Duclos, 2010. Effectiveness of soil solarization and biofumigation for the control of corky root and root-knot nematode *Meloidogyne* spp. on tomato. XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): *International Symposium* on 933, pp. 399-405.

Nafie, E. 2003. The possible induction of resistance in Lupinus termis L. against *Fusarium oxysporum* by Streptomyces chibaensis and its mode of action: 1. Changes in certain morphological criteria and biochemical composition related to induced resistance. *Int J Agric Biol* 5, 463-72.

Naguib, M., 1963. Colorimetric estimation of plant polysaccharides. Zucker 16, 15-18.

Nahak, G.,R. Mishra and **R. Sahu,** 2011. Taxonomic distribution, medicinal properties and drug development potentiality of *Ocimum* (Tulsi). Drug Invention Today 3.

Narwal, S. and **P. Tauro,** 1994. Allelopathic problems in Indian agriculture and prospects of research. *Allelopathy in Agriculture and Forestry*; Scientific Publishers: Jodhpur, India, 37-57.

Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. *J. biol. Chem* 153, 375-380.

Ngala, B.M., S. R. Woods, M. A. Back, M.A. Sinigrin degradation and G. pallida, 2015. suppression in soil cultivated with brassicas under controlled environmental conditions. *Appl. Soil Ecol*.95, 9–14.

Ojha, S. and **N. C. Chatterjee,** 2012. Induction of resistance in tomato plants against *Fusarium oxysporum* f. sp. lycopersici mediated through salicylic acid and *Trichoderma harzianum. Journal of plant protection research* 52(2).

Orcutt, D. and **E. Nilsen,** 2000. Influence of plant phytopathogens on host physiology. The Physiology of Plants Under Stress. *Soil and Biotic Factors*. John Wiley & Sons, Inc., USA.

Pandya, N.D., P.V. Desai, H. P. Jadhav and **R. Z. Sayyed,** 2018. Plant growth promoting potential of *Aspergillus sp*. NPF7, isolated from wheat rhizosphere in South Gujarat, India. *Environmental Sustainability*, 1(3), pp.245-252.

Paul, S.,C. A. Geng, T. H. Yang, Y. P. Yang and J.J. Chen, 2019. Phytochemical and health-beneficial progress of turnip (*Brassica rapa*). *Journal of food science* 84, 19-30.

Popova IE, J. S. Dubie and **MJ Morra,** 2017. Optimization of hydrolysis conditions for release of biopesticides from glucosinolates in *Brassica juncea* and *Sinapis alba* seed meal extracts. *Indus Crops* Pro 97:354–359

Popova IE and **MJ Morra,** 2014. Simultaneous quantification of sinigrin, sinalbin, and anionic glucosinolate hydrolysis products in *Brassica juncea* and *Sinapis alba* seed extracts using ion chromatography. *J Agric Food Chem* 62:10687–10693.

Prithiviraj, B., L.G. Perry, D. V. Badri and **J. M. Vivanco,** 2007. Chemical facilitation and induced pathogen resistance mediated by a root-secreted phytotoxin. New Phytologist 173, 852-860.

Ramaiah A.K. and **R. K. H. Garampalli,** 2015. In vitro antifungal activity of some plant extracts against *Fusarium oxysporum* f. sp. *lycopersici*. *Asian Journal of Plant Science & Research* 5 (1): 22–27.

Rehman, S., B. Shahzad, A. A. Bajwa, S. Hussain, A. Rehman, S.A. Cheema, T. Abbas, A. Ali, L. Shah, S. Adkins and **P. Li,** 2019. Utilizing the allelopathic potential of *Brassica species* for sustainable crop production: a review. *Journal of plant growth regulation*, 38, pp.343-356.

Rice, E. 1984. Allelopathy. 2nd (ed.) Acad. Press. Inc. Orlando. Florida, USA.

Rongai, D.,P. Pulcini, B. Pesce and **F. Milano,** 2015. Antifungal activity of some botanical extracts on *Fusarium oxysporum*. *Open Life Sciences*, 10(1).

Sato, Y.,Y. Masut, K.Saito, S. Murayama and **K. Ozawa,** 2011. Enhanced chilling tolerance at the booting stage in rice by transgenic overexpression of the ascorbate peroxidase gene, OsAPXa. *Plant cell reports* 30, 399-406.

Sharma, A., B. Shahzad, A. Rehman, R. Bhardwaj, M. Landi and B. Zheng, 2019. Response of Phenylpropanoid Pathway and the Role of Polyphenols in Plants under Abiotic Stress. *Molecules*, 24, 24-52.

Singh, G.,A. Tiwari, A. Gupta,A. Kumar,P. Hariprasad and **S. Sharma,** 2021. Bioformulation development via valorizing silica-rich spent mushroom substrate with *Trichoderma asperellum* for plant nutrient and disease management. *J.Environ. Manag*., 297, 113278.

Siva, N. 2008. Antifungal effect of leaf extract of some medicinal plants against *Fusarium oxysporum* causing wilt disease of *Solanum melogena* L. *Ethnobotanical leaflets*, 2008(1), p.19.

Takao, L. K., J. P.N. Ribeiro and **M.I.S. Lima,** 2011. Allelopathic effects of *Ipomoea cairica* (L.) Sweet on crop weeds. *Acta Botanica Brasilica* 25, 858-864.

Taylor, F. I.,D. Kenyon and **S. Rosser,** 2014. Isothiocyanates inhibit fungal pathogens of

potato in in vitro assays. *Plant Soil* 382, 281–289.

Terakado J, S Fujihara , S Goto, R Kuratani ,Y Suzuki, S Yoshida and **T Yoneyama,** 2005. Systemic effect of a brassinosteroid on root nodule formation in soybean as revealed by the application of brassinolide and brassinazole. *Soil Sci Plant Nutr* 51(3):389–395

Tetlow, J. and **A. Wilson,** 1964. An absorptiometric method for determining ammonia in boiler feed-water. *Analyst* 89, 453-465.

Tukey, H. B. 1969. Implications of allelopathy in agricultural plant science. *The botanical review* 35, 1-16.

Upreti KK and GSR Murti, 2004. Effects of brassinosteroids on growth, nodulation, phytohormone content and nitrogenase activity in French bean under water stress. *Biol Planta* 48(3):407–411.

Wang, C., J. Liu and **J. Zhou,** 2017a. N deposition affects allelopathic potential of *Amaranthus retroflexus* with different distribution regions. *Anais da Academia Brasileira de Ciências* 89, 919-926.

Wang, C., J. Zhou, K. Jiang and **J. Liu,** 2017b. Differences in leaf functional traits and allelopathic effects on seed germination and growth of *Lactuca sativa* between red and green leaves of Rhus typhina. *South African Journal of Botany* 111, 17-22.

Wang, C., J. Liu, H. Xiao, J. Zho and **D. Du,** 2017c. Nitrogen deposition influences the allelopathic effect of an invasive plant on the reproduction of a native plant: *Solidago canadensis* versus Pterocypsela laciniata. *Polish Journal of Ecology* 65, 87-96.

Wang, C., K. Jiang, B. Wu, J. Zhou and **Y. Lv,** 2018. Silver nanoparticles with different particle sizes enhance the allelopathic effects of *Canada goldenrod* on the seed germination and seedling development of lettuce. *Ecotoxicology* .27:1116-25.

Wang, W., X. Wang, H. Ye, B. Hu, L. Zhou, S. Jabbar, X. Zeng and W. Shen, 2016. Optimization of extraction, characterization and antioxidant activity of polysaccharides from *Brassica rapa* L. *International Journal of Biological Macromolecules* 82, 979-988.

Warton B, JN Matthiessen and **MA Shackleton ,** 2001. Glucosinolate content and isothiocyanate evolution—two measures of the biofumigation potential of plants*. J Agric Food Chem* 49:5244–5250

Woo S.L., M. Ruocco, F. Vinale, M. Nigro, R. Marra, N. Lombardi , A. Pascale , S. Lanzuise,G. Manganiello and **M. Lorito ,** 2014. *Trichoderma*-based products and their widespread use in agriculture. *The Open Mycology Journal* 8 (1): 71–126.

Xiao, X., Z. Cheng, H. Meng, L. Liu, H. Li and **Y. Dong,**2013. Intercropping of Green Garlic (*Allium sativum* L.) Induces Nutrient Concentration Changes in the Soil and Plants in Continuously Cropped Cucumber (*Cucumis sativus* L.) in a Plastic Tunnel. *PLoS ONE*. 8, e62173.

Yu J and **DW Morishita,** 2014. Response of seven weed species to corn gluten meal and white mustard (*Sinapis alba*) seed meal rates. *Weed Technol*. 28:259–265

YE, X.-q., M. Wu, X.-x. SHAO and **L. Liang,** 2014. Effects of water extracts from *Solidago canadensis* on the growth of *maize* seedlings and the underlying photosynthetic mechanisms. *Acta Prataculturae Sinica* 23, 217.

Zhao, L., G. Wang, X. Liu, X. Chen, X. Shen, C. Yin and **Z. Mao,** 2022. Control of Apple Replant Disease Using Mixed Cropping with *Brassica juncea* or *Allium fistulosum*. *Agriculture*, 12(1), p.68.