Shahid Bahonar University of Kerman
Agricultural Biotechnology Journal
Print ISSN: 2228-6705 Online ISSN: 2228-6500
Iranian Biotechnology Society

Contributing to reducing the damage caused by *Fusarium solani* that causes rot of wheat seeds and roots using *Trichoderma harzianum* and gibberellic acid

Mohammed Naithel Radhi
Department of Field Crops, College of Agriculture and Marshes, University of Thi-Qar, Thi-Qar, 64001, Iraq. E-mail: muhamed-n@utq.edu.iq and mradhi84@yahoo.com

Abstract

Objective

This study evaluated the efficacy of *Trichoderma harzianum* and gibberellic acid (GA_3) in mitigating the adverse effects of *Fusarium solani* on growth and yield attributes of wheat (*Triticum aestivum* L.). The research also examined whether integrating biological control with GA_3 could improve wheat performance under pathogen stress.

Materials and methods

The experiment was carried out in the winter season and the treatments were arranged in a factorial experiment as the presence or absence of *T. harzianum* and *F. solani* and four concentrations of gibberellic acid (0, 100, 200, and 300 mg L^{-1}). Parameters related to growth and yield were measured. This included plant height, length of roots, area of leaves, length of spikes, number of tillers per plant, number of grains per spike, and weight of 1000 grains. All data were analyzed statistically using the ANOVA technique. Mean comparisons were made at the 0.05 probability level.

Results

Data for most of the traits studied differed significantly ($P \leq 0.05$) among treatments. The combined treatment with *T. harzianum* and gibberellic acid significantly enhanced all the parameters of wheat growth and productivity compared to the untreated plants. Integrated application significantly improved growth and yield traits compared with pathogen-inoculated plants. On the other hand, most of the parameters of growth and yield were significantly reduced when plants were grown in soil infested with *F. solani* as compared with plants grown in pathogen-free soil, which confirms the deleterious effect of this pathogen. Besides, the *T. harzianum* treatments ameliorated the adverse effects of pathogen infection and enhanced plant vigor and productivity. The improvement observed reveals an effective interaction between biological control and plant growth regulation in alleviating disease-induced stress.

Conclusion

The results prove that the application of *T. harzianum* with gibberellic acid is effective in reducing the adverse effects of F. *solani* on wheat. In fact, this treatment improved growth, yield components, and overall plant performance. Therefore, use of T. *harzianum* in combination with gibberellic acid may be considered a sustainable and environmentally friendly approach to increase wheat productivity under pathogen stress.

Keywords: *Fusarium solani, gibberellic acid, T. harzianum,* wheat

Paper Type: Research Paper.

Citation: Radhi, M. N. (2026). Contributing to reducing the damage caused by *Fusarium solani* that causes rot of wheat seeds and roots using *Trichoderma harzianum* and gibberellic acid. *Agricultural Biotechnology Journal,* 18(4), 511-524.

Agricultural Biotechnology Journal, 18(4), 511-524. DOI: 10.22103/jab.2026.27134.1890

Received: May 08, 2026. Received in revised form: July 15, 2026.

Accepted: July 16, 2026. Published online: August 30, 2026.

Publisher: Shahid Bahonar University of Kerman & Iranian Biotechnology Society.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most essential cereal crops on a global scale and represents a staple in Iraq due to its nutritional value and economic importance. According to the recent report (Qader et al., 2018), Iraq produced 4.23 million tons of wheat grain and 10.46 million tons of straw. Wheat grains are valued as a source of carbohydrates, proteins, and lipids, with vitamins and minerals and essential amino acids for human nutrition, as highlighted by Wieser et al. (2020). Biotic stresses are many and various on wheat, but perhaps the most destructive is root rot disease. The most common agent of the disease is soil-borne fungi, particularly *Fusarium solani*. These fungi result in severe rotting of the roots, limited uptake of nutrients and water, stunted growth, and poor establishment of the stand with very great losses in yield. In fields heavily infested with the pathogen, the disease may cause great mortality of seedlings and lead to significant economic injury thus threatening wheat production and food security. Biological control using beneficial microorganisms has come up as a frontline approach among sustainable disease management strategies. Among beneficial microorganisms, *Trichoderma harzianum* stands out as one of the biocontrol agents most widely used against soil-borne pathogens. Antagonism by this organism comes through mechanisms that include competition for nutrients and space, mycoparasitism, and production of antifungal metabolites and hydrolytic enzymes. The most recent addition to these mechanisms is systemic resistance and induction of systemic resistance. *Trichoderma harzianum* also enhances root development and nutrient acquisition by the plant, enabling it to outcompete the pathogen for available nutrients while promoting the growth and vigor of the host plant. Plant growth regulators also improve the resistance of plants to biotic and abiotic stress. Gibberellic acid is one of the naturally occurring plant hormones. Its functions are listed as follows: breaking seed dormancy, cell elongation, stem growth, activating enzymes, and regulating other physiological processes. Some reports also stated that it increases photosynthetic efficiency, improves nutrient utilization, and develops roots. It also reduces the inhibitory effect of stress on growth. All these factors enhance crop performance under adverse conditions (Castro-Camba et al., 2022). Because *Trichoderma* improves root health whereas GA_3 enhances plant physiological performance. Thus, the present study was undertaken to investigate the efficacy of *T. harzianum* in the control of *F. solani* and to assess the role of gibberellic acid, applied alone and in conjunction with *T. harzianum*, in enhancing the growth and yield of wheat under field conditions.

Materials and methods

Experimental site and design: The study was carried out at the College of Agriculture and Marshes, University of Thi Qar, during the growing season 2023-2024 at Thi Qar Province, Iraq. The experiment started on 11 October 2023 with the objective to evaluate the efficacy of *Trichoderma harzianum* and gibberellic acid (GA_3) on reducing the adverse effects of *Fusarium solani*, which is the causative agent of rot disease in seeds and roots of wheat. A pot experiment was conducted using wheat (*Triticum aestivum* L.) cv. Bohuth 22. Forty-eight plastic pots were used, each containing 10 kg of soil, with a diameter of 30 cm and a height of 28 cm. Set up the experiment in a Randomized Complete Block Design (RCBD) with three replicates. Test sixteen treatments that include *T. harzianum, F. solani*, gibberellic acid at various concentrations, and their combinations. In total, there were 48 experimental units, with each treatment replicated three times. Soil samples were collected and analyzed for some selected physical and chemical properties: texture, pH, electrical conductivity (EC), organic matter content, and available nitrogen, phosphorus, and potassium. The characteristics of the experimental soil are presented in Table 1.

Table 1. Selected physical and chemical properties of the experimental soil

Attribute	Value	Measurements' unit
Soil reaction rate (pH)	7.36	
Electrical conductivity (Eco)	9.32	Desi Siemens. m^{-1}

Seed germination test: Seed viability was tested in a standard Petri dish germination test before sowing. The wheat seeds of cv. Bohuth 22 showed a germination percentage of 95%. Ten seeds were sown in each pot on 11 October 2023 (Figure 1).

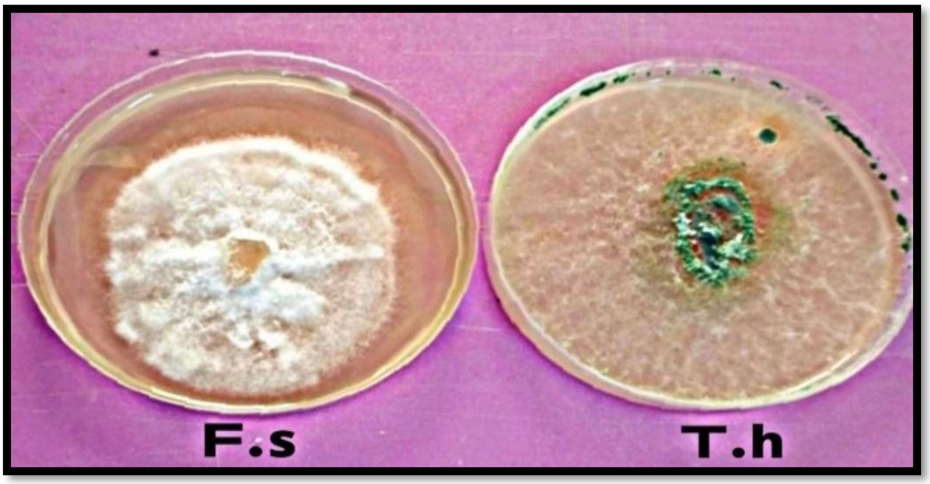

Figure 1. Colony morphology of *Trichoderma harzianum* and *Fusarium solani* cultured on PDA medium

Treatments used in the experiment: Sixteen treatments were included in the experiment as shown in Table 2.

Table 2. Experimental treatments

T1	*T.harzianum* (T.h) only	T9	G300 + *T.h*
T2	*F.solani* (F.s) only	T10	G100+ F.s
T3	*T.h + F.s*	T11	G200+ F.s
T4	Gibberellic acid concentration 100 (G100)	T12	G300+ F.s
T5	Gibberellic acid concentration 200 (G200)	T13	Control treatment
T6	Gibberellic acid concentration 300 (G300)	T14	*T.h* + G100 + F.s
T7	G100+ *T.h*	T15	*T.h* + G200 + F.s
T8	G200 + *T.h*	T16	*T.h* + G300 +F.s

Isolation and identification of fungal isolates: The isolates of *Trichoderma harzianum* and *Fusarium solani* were isolated and maintained on potato dextrose agar (PDA) medium. Identification was based on the criteria of colony morphology and microscopic characteristics as per the standard taxonomic keys. *F. solani* was identified based on the criteria of the appearance of colonies, pigmentation, and the morphology of *macroconidia, microconidia*, and *chlamydospores*. *T. harzianum* was identified based on the criteria of the characteristics of colonies, morphology of conidia, and pattern of branching of conidiophores.

Preparation of *Trichoderma harzianum* inoculum: The inoculum of *T. harzianum* was prepared as per Zhang et al. (2018). A mixture of wheat bran, sand, and distilled water was prepared in a ratio of 2:1:1 (w/w/v). This was distributed into 250 mL glass flasks and sterilized in an autoclave at 121°C and 15 psi for 60 min. After cooling, each flask was inoculated with a 0.5 cm agar disc that was taken from a four-day-old culture of *T. harzianum* grown on PDA medium. The flasks were incubated at 30°C and shake them every three days until the substrate is fully colonized.

Crop management: All pots were uniformly irrigated throughout the growing season to fulfill the water needs of the crop so as to achieve and maintain optimum soil moisture. Humic acid and chemical fertilizers were applied to all treatments following recommended agronomic practices for wheat production. Standard crop management practices were followed during the entire experimental period.

Germination and seedling mortality assessment: Germination percentage was recorded seven days after sowing. Seedling mortality percentage was determined three weeks after sowing. Germination percentage was calculated according to the following equation:

$$\% \text{ germination} = \frac{\text{Numbers of germinated seeds}}{\text{Numbers of total seeds}} \times 100$$

The ratio seedling death calculated after three weeks of germination according to the following equation:

$$\% \text{ death} = \frac{\text{Numbers of dead seedlings}}{\text{Number of germinating seedlings}} \times 100$$

Preparation of *Fusarium solani* inoculum: The inoculum of *F. solani* was prepared as described by Abawi and Pastor-Corrales (1989) with slight modifications. Wheat seeds were soaked in distilled water for 6 h, then air-dried and transferred to 250 mL flasks containing 100 g seeds. The flasks were moistened with distilled water and then sterilized at 121°C and 15 psi. After cooling, each flask was then inoculated with 0.5 cm PDA discs colonized by *F. solani*, and then they were incubated at 30°C. They were shaken every three days until complete fungal colonization was achieved.

Application of *Trichoderma harzianum:* The inoculum of *T. harzianum* was applied to the soil of the designated treatments at a rate of 1% (w/w) two days before sowing; it was mixed very well with the soil before planting.

Application of *Fusarium solani:* The inoculum of *F. solani* was added to the soil of these treatments at the rate of 1% (w/w) five days prior to sowing, after which the soil was mixed thoroughly and regular irrigation practiced until the time of planting to help in the establishment of the fungus.

Application of gibberellic Acid: Gibberellic acid (GA_3) was applied as a foliar spray at 100, 200, and 300 mg L^{-1}. The required concentrations were prepared by dissolving the appropriate amount of GA_3 in distilled water. Spraying was done by hand until complete wetting of the foliage. The control treatment was sprayed with only distilled water. All spraying treatments were applied during the vegetative growth stage under suitable weather conditions to ensure uniform coverage of the plant canopy.

Studied characteristics

Spike length (cm): Measurement of spike length at the end of flowering was done between the base and tip of the spike with five randomly selected spikes in each experimental unit.

Leaf area (cm²): Leaf area was estimated after flowering by taking five or more random leaves per unit of experiment by the below formula (Rouet et al., 2021):

$$\text{Leaf length} \times \text{maximum leaf width} \times 0.95 = \text{leaf area}$$

Plant height (cm): A five randomly selected plants per experimental unit were used to measure the plant height at the end of flowering between the surface of the soil to the end of the spike.

Weight of 1000 grains (g): Each of the experimental units was weighed using sensitive electronic balance with a weight of 1000 grains.

Number of grains per spike: The average quantity of grains in five random spikes was established as the mean of the number of spikes in an experimental unit.

Root system length (cm): Root length was determined at full maturity and the average length of roots of five randomly selected plants in an experimental unit.

Root system weight (g): When at full maturity the average weight of roots of five randomly selected plants per experimental unit was used as the root weight.

Number of shoots: The shoots count was counted as the mean number of plants that were selected randomly in each experimental unit after flowering.

Statistical analysis: The data obtained from this experiment were analyzed using GenStat statistical software to perform analysis of variance (ANOVA). The data were checked for the assumptions of analysis of variance before analysis. In cases where significant differences among treatment means were found, comparisons of means were made using the Least Significant Difference (LSD) test at p = 0.05. All values in the tables are means of the treatments.

Results and discussion

Germination percentage and mortality of seedling: Table 3 shows that there are considerable differences between treatments. The pathogenic fungus *F.solani* in soil recorded the lowest percentage of germination and maximum death of seedlings (80% and 25% respectively) than the control treatment in which the percent germination was 90 and the percent seedling death was 5.3. It can be assumed that such inhibition of germination and mortality can be explained by the possibility of pathogenic fungi to block the process of water and nutrient transportation and release cell-wall breaking enzymes. These processes cause infection of seeds and roots which eventually result in the death of seedlings.

Influence on height of plants, size of the leaves, length of the spikes: Findings in Table 4 have shown significant variation between treatments. Gibberellic acid in combination with *T.harzianum* at 300 mg L $^{-1}$ gave the best mean values of plant height, leaf area and spike length (57.63 cm, 30.15 cm 2 and 16.46 cm, respectively). Plants grown in soil infested with *F. solani*, conversely, had the lowest values of plant height and spike length (42.3 cm and 12.58 cm, respectively) and the lowest leaf area (21.6 cm^2) was recorded in the control treatment. The effectiveness of treatments with gibberellic acid is superior and this may be explained by its effect to promote cell division and elongation, promote higher photosynthetic efficiency and translocation of nutrients. Gibberellic acid enhances internode development, foliage growth and general vegetation development leading to longer spikes and higher plants. The results are in line with those of Poutanen et al. (2022), who found that there were significant increments in plant height after the application of gibberellic acid. The *T.harzianum* also played a beneficial role through the provision of nutrients to the soil, increased biomass formation, and biological growth promoter. The positive impacts are linked to the synthesis of growth regulators in plants, nutrient uptake, and the competition with pathogenic fungi by competition, enzyme degradation, and mycoparasitism (Geng et al., 2025).

Table 3. Percent germination and deaths of seedlings

T	Treatments	Germination %	Seedling mortality %
T1	*T.h.*	92.30	2.60
T2	G100	92.00	4.70
T3	G200	92.60	3.50
T4	G300	93.30	2.80
T5	*F.s*	80.00	25.0
T6	*T.h* + G100	91.50	2.00
T7	*T.h* + G200	93.50	1.30
T8	*T.h* + G300	95.70	0.50
T9	*T.h* + G100 + *F.s*	90.80	4.00
T10	*T.h* + G200 + *F.s*	92.60	3.20
T11	*T.h* + G300 + *F.s*	93.70	1.60
T12	*F.s* + G100	90.40	3.40
T13	*F.s* + G200	93.20	3.00
T14	*F.s* + G300	94.00	2.20
T15	*T.h* + *F.s*	92.30	3.80
T16	Control	90,00	5.30
	L.S.D 0.05	3.100	2.60

Table 4. impact of gibberellic acid, *T.harzianum*, and *F.solani* on the height, leaf area and length of spike of plants

T	Treatments	**Plant height in Flowering Stage (cm)**	**Leaf area (cm^2)**	**Spike length (cm)**
T1	*T.h.*	53.63	25.96	14.39
T2	G100	51.52	25.25	14.46
T3	G200	53.75	26.30	15.04
T4	G300	56.87	29.90	16.31
T5	*F.s*	42.30	21.78	12.58
T6	*T.h* + G100	52.13	25.14	14.18
T7	*T.h* + G200	53.15	26.10	15.00
T8	*T.h* + G300	57.63	30.15	16.46
T9	*T.h* + G100 + *F.s*	51.37	22.93	14.39
T10	*T.h* + G200 + *F.s*	51.61	22.74	15.46
T11	*T.h* + G300 + *F.s*	52.58	22.44	15.07
T12	*F.s* + G100	48.20	21.75	13.66
T13	*F.s* + G200	49.52	21.94	14.40
T14	*F.s* + G300	51.73	23.42	13.82
T15	*T.h* + *F.s*	51.33	22.47	14.25
T16	Control	50.12	21.60	14.32
	L.S.D 0.05	3.1	4.979	3.891

Height of Plants, Length of the root, and Grains per Spike: Treatments had significant impacts on the plant height, root length and the number of grains per spike (Table 5). When the seed was soaked in gibberellic acid at 300 mg L $^{-1}$, the highest mean was achieved with respect to plant height (72.12 cm), root length (38.87 cm), and the number of grains per spike (40.96). Conversely, the *F.solani* treatment had the lowest values of these traits (60.36 cm, 24.37 cm, and 28.74, respectively) in comparison to the control one. The improvement that is achieved with gibberellic acid is presumably. This improvement may be attributed its interaction with auxins which facilitates cell elongation by suppressing enzymes that break down indole-3-acetic acid (IAA). This action is synergistic, which results in augmented cell expansion, gene expression, and protein and RNA synthesis, subsequently resulting in a greater growth of the vegetative and reproductive growth (Anwar et al., 2024; Hamoda et al., 2025). Gibberellins also promote plasticity of the cell wall due to the action of acidification, which promotes the uptake of water and the subsequent cell expansion based on turgor (Gao et al., 2024; Cosgrove, 2024).

Table 5. Gibberellic acid, *T.harzianum* and *F.solani* Effect on plant height, root length and number of grains per spike

T	Treatments	**Plant height in Physiological Maturity Stage (cm)**	**Root length (cm)**	**number of grains per spike**
T1	*T.h.*	66.82	38.83	36.15
T2	G100	60.76	36.67	34.89
T3	G200	67.90	36.53	35.60
T4	G300	72.12	38.87	40.96
T5	*F.s*	60.37	24.37	28.74
T6	*T.h* + G100	65.88	31.27	34.78
T7	*T.h* + G200	69.07	36.03	38.29
T8	*T.h* + G300	71.10	34.90	40.79
T9	*T.h* + G100 + *F.s*	65.59	33.93	36.15
T10	*T.h* + G200 + *F.s*	66.72	34.77	37.22
T11	*T.h* + G300 + *F.s*	66.89	35.20	38.16
T12	*F.s* + G100	65.72	31.83	32.82
T13	*F.s* + G200	65.92	32.23	38.62
T14	*F.s* + G300	65.39	35.77	38.30
T15	*T.h* + *F.s*	65.97	35.78	35.78
T16	Control	60.41	35.20	33.27
	L.S.D 0.05	3.1	4.386	5.695

Branch count, root weight and 1000 grain weight: Table 6 indicates significant differences between treatments. The combined treatment with 300 mg L $^{-1}$ gibberellic acid and *T.harzianum* gave the highest mean of tillers (5.39) and the *F.solani* gave the lowest mean of tillers (3.4), against the control (3.49). Such an enhancement can be explained by the fact that gibberellic acid has a stimulatory effect on lateral buds' development and vascular development, and it also increases nutrient and water uptake enabled by *Trichoderma* (Cabral-Miramontes et al., 2022; Deng et al., 2024). In terms of root weight, *T.harzianum* treatment had the highest mean result (3.13 g) and the combination of *F.solani* and 100 mg L -1 gibberellic acid had lowest root weight

(1.76 g) compared to the control (2.5 g). This beneficial effect of *T. harzianum* can be explained by the enhanced root growth and nutrient uptake because of a symbiotic relationship between the plant roots and the symbiont (mycorrhizal), which is also observed (Reid & Gifford, 2024; Bahadur, 2022). Seeds that were soaked in gibberellic acid (39.6 g) yielded the highest level of the 1000-grain weight and *F.solani* treatment gave the lowest value (19.27 g) compared to the control (20.97 g). The increase in weight of grain recorded in plants treated with gibberellic acid may be due to the effect of GA_3 in stimulating cell elongation, efficiency in photosynthesis, and translocation of assimilates toward developing grains. It is well documented that gibberellins improve source-sink relationships which lead to better grain filling and heavier grains (Miceli et al., 2019; Tripathi et al., 2025).

Table 6. Response of gibberellic acid, *T.harzianum*, and *F.solani* on the number of tillers, **root weight, and 1000-grain weight**

T	Treatments	**Number of tillers**	**Root weight (g)**	**Weight of 1000 seeds (g)**
T1	*T.h.*	3.95	3.13	37.30
T2	G100	3.54	2.66	35.33
T3	G200	4.81	2.73	35.43
T4	G300	3.77	2.63	39.60
T5	*F.s*	3.40	1.86	19.27
T6	*T.h* + G100	3.81	2.33	36.37
T7	*T.h* + G200	4.49	2.70	30.39
T8	*T.h* + G300	5.39	3.03	34.97
T9	*T.h* + G100 + *F.s*	3.79	2.13	19.57
T10	*T.h* + G200 + *F.s*	4.05	1.96	28.03
T11	*T.h* + G300 + *F.s*	4.23	2.00	29.27
T12	*F.s* + G100	3.75	1.76	31.30
T13	*F.s* + G200	3.73	2.46	27.33
T14	*F.s* + G300	3.73	2.36	28.50
T15	*T.h* + *F.s*	3.08	2.60	28.43
T16	Control	3.49	2.50	20.97
	L.S.D 0.05	0.31	0.8988	0.7746

These results are quite similar to those of many other researchers who found significant improvements in wheat yield components through the application of GA_3 under normal as well as stress conditions. In contrast, plants inoculated with *Fusarium solani* showed reduced growth and yield parameters. This reduction can be ascribed to the damage in the root tissues of the plants which creates an infection with the fungus and therefore affects water and nutrient uptake as well as lowering photosynthetic activity and disrupting normal physiological processes. The deterioration of tissues and reduced vigor of the plant is also enhanced by cell wall-degrading enzymes and toxic metabolites by Fusarium species. The positive effect of *T. harzianum* may be due to its known antagonistic activity against soil-borne pathogens. It competes with Fusarium for nutrients and infection sites, acts as a mycoparasite, produces antifungal metabolites, and secretes hydrolytic enzymes like chitinases and glucanases. It also stimulates the growth of roots and the acquisition of nutrients, resulting in enhancement of plant development and stress tolerance. The better performance of the combined treatment *T. harzianum* with gibberellic acid simply shows a synergistic interaction between biological control and growth hormones. While *T. harzianum* reduced pathogen pressure and improved health gibberellic acid. In contrast, boosted physiological processes related to plant growth and the formation of a yield. These two treatments gave better protection against disease and the overall performance of the plant than the individual applications (Yan et al., 2018).

Conclusion: The results obtained from this study confirmed that gibberellic acid (GA_3) increased some growth and yield-related traits of wheat, more specifically at higher concentrations. These positive effects could be related to the function of GA_3 in stimulating cell elongation, growth, and translocation of assimilates. The inoculation of *Trichoderma harzianum* improved the growth and yield performance of plants under the conditions of this study. Generally, the combined application of *T. harzianum* and gibberellic acid gave better values for most of the measured traits as compared to the individual treatments. The results suggest that the combined application of *T. harzianum* and GA_3 represents a promising integrated strategy for improving wheat tolerance to *F. solani* by simultaneously enhancing plant growth and mitigating pathogen-induced damage. More research is suggested to assess field disease incidence, disease severity, and pathogen suppression to gain a better understanding of how this integrated approach can help manage wheat root rot caused by *Fusarium solani.*

Author contribution

Not applicable.

Acknowledgments

The author would like to express their sincere gratitude to the Department of Field Crops, College of Agriculture and Marshes, University of Thi-Qar, Thi-Qar, Iraq for support.

Ethical considerations

Not applicable. This study focused on wheat and did not involve human subjects or animal experiments that require ethical approval.

Funding

This research received no external funding.

Conflict of interests

The author declares no conflict of interest.

References

Abawi, G. S., & Pastor-Corrales, M. A. (1989). Charcoal rot screening procedure and virulence of *Macrophomina phaseolina* isolates on dry edible beans. *Turrialba*, *39*, 200–207. https://hdl.handle.net/20.500.14330/PER01000093993

Anwar, T., Qureshi, H., Siddiqi, E. H., Ullah, N., Naseem, M. T., & Soufan, W. (2024). Synergistic effects of gibberellic acid, biochar, and rhizobacteria on wheat growth under heavy metal and drought stress. *BMC Plant Biology*, *24*, Article 1168. https://doi.org/10.1186/s12870-024-05833-8

Bahadur, A. (2022). *Trichoderma*: A unique bio-control agent boost up plants immunity. *Advances*, *3*(3), 42–48. https://doi.org/10.11648/j.advances.20220303.11

Cabral-Miramontes, J. P., Olmedo-Monfil, V., Lara-Banda, M., Zúñiga-Romo, E. R., & Aréchiga-Carvajal, E. T. (2022). Promotion of plant growth in arid zones by selected *Trichoderma* spp. strains with adaptation plasticity to alkaline pH. *Biology*, *11*(8), Article 1206. https://doi.org/10.3390/biology11081206

Castro-Camba, R., Sánchez, C., Vidal, N., & Vielba, J. M. (2022). Plant development and crop yield: The role of gibberellins. *Plants*, *11*(19), Article 2650. https://doi.org/10.3390/plants11192650

Cosgrove, D. J. (2024). Plant cell wall loosening by expansins. *Annual Review of Cell and Developmental Biology*, *40*, 329–352. https://doi.org/10.1146/annurev-cellbio-111822-115334

Deng, J., Deng, X., Yao, H., Ji, S., & Dong, L. (2024). Gibberellins play an essential role in the bud growth of *Petunia hybrida*. *Current Issues in Molecular Biology*, *46*(9), 9906–9915. https://doi.org/10.3390/cimb46090590

Gao, J., Zhuang, S., & Zhang, W. (2024). Advances in plant auxin biology: Synthesis, metabolism, signaling, interaction with other hormones, and roles under abiotic stress. *Plants*, *13*(17), Article 2523. https://doi.org/10.3390/plants13172523

Geng, Y., Chen, S., Lv, P., Li, Y., Li, J., Jiang, F., Wu, Z., Shen, Q., & Zhou, R. (2025). Positive role of *T. harzianum* in increasing plant tolerance to abiotic stresses: A review. *Antioxidants*, *14*(7), Article 807. https://doi.org/10.3390/antiox14070807

Hamoda, A., Khojah, E. Y., & Radhi, K. S. (2025). Synergistic effects of herbicides and gibberellic acid on wheat yield and quality. *Scientific Reports*, *15*, Article 7496. https://doi.org/10.1038/s41598-025-90217-7

Miceli, A., Moncada, A., Sabatino, L., & Vetrano, F. (2019). Effect of gibberellic acid on growth, yield, and quality of leaf lettuce and rocket grown in a floating system. *Agronomy*, *9*(7), Article 382. https://doi.org/10.3390/agronomy9070382

Poutanen, K. S., Kårlund, A. O., Gómez-Gallego, C., Johansson, D. P., Scheers, N. M., Marklinder, I. M., Eriksen, A. K., Silventoinen, P. C., Nordlund, E., Sozer, N., Hanhineva, K. J., Kolehmainen, M., & Landberg, R. (2022). Grains – a major source of sustainable protein for health. *Nutrition Reviews*, *80*(6), 1648–1663. https://doi.org/10.1093/nutrit/nuab084

Qader, S. H., Dash, J., & Atkinson, P. M. (2018). Forecasting wheat and barley crop production in arid and semi-arid regions using remotely sensed primary productivity and crop phenology: A case study in Iraq. *Science of the Total Environment*, *613–614*, 250–262. https://doi.org/10.1016/j.scitotenv.2017.09.057

Reid, T. E., & Gifford, M. L. (2024). *Trichoderma* gets by with a little help from *Streptomyces*: Fungal–bacterial symbiosis in plant growth promotion. *Journal of Experimental Botany*, *75*(22), 6893–6897. https://doi.org/10.1093/jxb/erae439

Rouet, S., Barillot, R., Leclercq, D., Bernicot, M. H., Combes, D., Escobar-Gutiérrez, A., & Durand, J. L. (2021). Interactions between environment and genetic diversity in perennial grass phenology: A review of processes at plant scale and modeling. *Frontiers in Plant Science*, *12*, Article 672156. https://doi.org/10.3389/fpls.2021.672156

Tripathi, J. M., Khan, B. R., Gaur, R., Yadav, D., Verma, K. K., & Gupta, R. (2025). Gibberellic acid improves photosynthetic electron transport and stomatal function in crops that are adversely affected by salinity exposure. *Plants*, *14*(21), Article 3388. https://doi.org/10.3390/plants14213388

Wieser, H., Koehler, P., & Scherf, K. A. (2020). The two faces of wheat. *Frontiers in Nutrition*, *7*, Article 517313. https://doi.org/10.3389/fnut.2020.517313

Yan, K., Han, G., Ren, C., Zhao, S., Wu, X., & Bian, T. (2018). *F. solani* infection depressed photosystem performance by inducing foliage wilting in apple seedlings. *Frontiers in Plant Science*, *9*, Article 479. https://doi.org/10.3389/fpls.2018.00479

Zhang, F., Huo, Y., Cobb, A. B., Luo, G., Zhou, J., Yang, G., Wilson, G. W. T., & Zhang, Y. (2018). *Trichoderma* biofertilizer links to altered soil chemistry, altered microbial communities, and improved grassland biomass. *Frontiers in Microbiology*, *9*, Article 848. https://doi.org/10.3389/fmicb.2018.00848

مجله بیوتکنولوژی کشاورزی
دانشگاه شهید باهنر کرمان
انجمن بیوتکنولوژی ایران
شاپا چاپی: ۶۷۰۵-۲۲۲۸ شاپا الکترونیکی: ۶۵۰۰-۲۲۲۸

کمک به کاهش خسارت ناشی از *Fusarium solani* که باعث پوسیدگی بذر و ریشه گندم می‌شود با استفاده از *Trichoderma harzianum* و اسید جیبرلیک

محمد نائل راضی

گروه زراعت، دانشکده کشاورزی و تالاب‌ها، دانشگاه ذی‌قار، ذی‌قار، ۶۴۰۰۱، عراق. ایمیل: muhamed-n@utq.edu.iq و mradhi84@yahoo.com

تاریخ دریافت: ۱۴۰۵/۰۲/۱۸ تاریخ دریافت فایل اصلاح شده نهایی: ۱۴۰۵/۰۴/۲۳ تاریخ پذیرش: ۱۴۰۵/۰۴/۲۴

چکیده

هدف: این پژوهش با هدف ارزیابی کارایی قارچ *Trichoderma harzianum* و اسید جیبرلیک (GA_3) در کاهش اثرات زیان‌بار *Fusarium solani* بر شاخص‌های رشد و عملکرد گندم (Triticum aestivum L.) انجام شد. همچنین، بررسی شد که آیا تلفیق کنترل زیستی با اسید جیبرلیک می‌تواند عملکرد گندم را در شرایط تنش ناشی از این عامل بیماری‌زا بهبود بخشد یا خیر.

مواد و روش‌ها: این آزمایش در فصل زراعی زمستان اجرا شد و تیمارها به‌صورت یک آزمایش فاکتوریل شامل حضور یا عدم حضور *Trichoderma harzianum* و *Fusarium solani* و چهار غلظت اسید جیبرلیک (۰، ۱۰۰، ۲۰۰ و ۳۰۰ میلی‌گرم در لیتر) طراحی گردید. صفات مرتبط با رشد و عملکرد شامل ارتفاع گیاه، طول ریشه، سطح برگ، طول سنبله، تعداد پنجه در هر بوته، تعداد دانه در هر سنبله و وزن هزار دانه اندازه‌گیری شدند. تمامی داده‌ها با استفاده از روش تجزیه و تحلیل واریانس بررسی شدند و مقایسه میانگین‌ها در سطح احتمال ۰/۰۵ انجام گرفت.

نتایج: نتایج نشان داد که بیشتر صفات مورد بررسی بین تیمارهای مختلف دارای اختلاف معنی‌دار بودند ($P \leq 0.05$). کاربرد همزمان *Trichoderma harzianum* و اسید جیبرلیک، در مقایسه با گیاهان شاهد، موجب بهبود معنی‌دار تمامی شاخص‌های رشد و عملکرد گندم شد. همچنین، این تیمار تلفیقی در مقایسه با گیاهان آلوده به عامل بیماری‌زا، رشد و اجزای عملکرد را به‌طور قابل توجهی افزایش داد. در مقابل، کشت گیاهان در خاک آلوده به *Fusarium solani* باعث کاهش معنی‌دار بیشتر صفات رشد و عملکرد نسبت به گیاهان رشد یافته در خاک عاری از پاتوژن شد که اثرات زیان‌بار این قارچ را تأیید می‌کند. با این حال، تیمارهای حاوی *Trichoderma harzianum* توانستند اثرات منفی آلودگی را تا حد زیادی کاهش داده و موجب افزایش رشد، شادابی و بهره‌وری گیاه شوند. بهبود مشاهده‌شده بیانگر وجود یک اثر متقابل مؤثر میان کنترل زیستی و تنظیم‌کننده رشد گیاهی در کاهش تنش ناشی از بیماری است.

نتیجه‌گیری: نتایج این مطالعه نشان داد که کاربرد همزمان *Trichoderma harzianum* و اسید جیبرلیک در کاهش اثرات زیان‌بار *Fusarium solani* بر گیاه گندم مؤثر است. این تیمار موجب بهبود رشد، اجزای عملکرد و عملکرد کلی گیاه شد. بنابراین، استفاده تلفیقی از *Trichoderma harzianum* و اسید جیبرلیک می‌تواند به‌عنوان یک راهکار پایدار و سازگار با محیط زیست برای افزایش تولید گندم در شرایط تنش ناشی از عوامل بیماری‌زا مورد استفاده قرار گیرد.

کلمات کلیدی: اسید جیبرلیک، گندم، *Fusarium solani*، *Trichoderma harzianum*

نوع مقاله: پژوهشی

استناد: محمد نائل راضی (۱۴۰۵). کمک به کاهش خسارت ناشی از *Fusarium solani* که باعث پوسیدگی بذر و ریشه گندم می‌شود با استفاده از *Trichoderma harzianum* و اسید جیبرلیک. *مجله بیوتکنولوژی کشاورزی*، ۱۸(۴)، ۵۱۱-۵۲۴.

Publisher: Shahid Bahonar University of Kerman & Iranian Biotechnology Society.