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The role of fungi in enhancing plant productivity in grey-brown soils

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Abstract

The Republic of Azerbaijan is experiencing issues such as soil salinisation, pollution and declining productivity, which are particularly evident on the Absheron Peninsula. This peninsula is considered one of the driest regions in the Caucasus. It contains a significant amount of depleted soil. This highlights the importance of taking a more careful and sustainable approach to land use in the region, as well as increasing the productivity of crops grown on these soils. Soil samples were collected using standard methods from various types of soil (relatively clean, polluted, irrigated, etc.) across the Absheron Peninsula. The study isolated 79 fungal species from the soils of the Absheron Peninsula in the Republic of Azerbaijan, 28 of which were involved in forming epiphytic mycobiota. Evaluating these species' interactions with phytopathogenic fungi revealed that only those belonging to the *Trichoderma* genus demonstrated high antagonistic potential. Notably, strains *T. citrinoviride* AEF-2024 and *T. harzianum* AEF-2024 exhibited the greatest activity. An assessment of the effect of CF obtained from these two strains on plant growth and productivity revealed that seed germination in tomato, cucumber, wheat and pea increased by 4.7–6.7%. The most favourable results were achieved with a 50-fold dilution of CF under optimal conditions. In this case, seed germination increased by 1.4–1.5 times for *T. citrinoviride* and by 1.3–1.8 times for *T. harzianum*, compared with the untreated control. Furthermore, pre-sowing treatment of tomato seeds with CF improved plant morphometric characteristics and increased yield per plant. Specifically, CF from *T. citrinoviride* AEF-2024 increased yield per plant by 1.25 times compared to the control, while CF from *T. harzianum* AEF-2024 increased yield per plant by 1.20 times. The research clearly demonstrates that using fungi isolated from stressed agroecosystems is an effective way to increase crop productivity in such conditions.

Keywords: Soil, Fungal biota, *Trichoderma* genus, Antagonism, Plant, Productivity

1. Introduction

Absheron Peninsula is the part of the Republic of Azerbaijan with the most anthropogenic impact. Thus, 33 thousand ha of the total area of 2110 km^2 is polluted with oil and oil products. Furthermore, a significant proportion of the country's industrial potential is concentrated in this area (Aliyev *et al.*, 2023). More precisely, the Absheron Peninsula contains a significant amount of stressed soil. This requires a more careful and sustainable approach to land use in the region, and highlights the need to increase the productivity of crops cultivated in these soils. It is no coincidence that the Absheron Peninsula has relatively little flora and fauna compared to other regions of the country. Research findings indicate that plant species found in Absheron represent around a fifth of Azerbaijan's overall floral diversity (Ibadullayeva and Huseynova, 2021). These ecological limitations are exacerbated by global environmental challenges such as climate change, desertification, soil salinisation and biodiversity loss, further intensifying the already fragile situation. In light of this, the present study aims to explore the potential of utilising indigenous microorganisms, particularly fungi, from the Absheron Peninsula to enhance the productivity of stressed grey-brown soils and improve the yield of crops cultivated in this region.

It is known that plants, animals, bacteria, and fungi primarily contribute to the formation of soil biota and are all involved in soil processes—production, decomposition, regulation, and indication (Wang *et al.*, 2024). However, fungi have the unique ability to actively participate in all of these processes, making them an indispensable component of soil ecosystems (Matazimov *et al.*, 2025). Therefore, the research focuses exclusively on fungi included in the composition of soil biota involved in restoring the fertility of stressed soils on the Absheron Peninsula.

Despite lacking chlorophyll and being heterotrophic, fungi are considered ecological reducers. Although they cannot synthesise organic matter themselves, they can transform available organic materials into various compound classes (e.g. vitamins and organic acids), functioning as 'secondary processors' in the ecosystem. Compared to other organisms, fungi are characterised by their synthesis of secondary metabolites that exhibit a wide range of effects, compositions and applications (Abdel-Wareth, 2021). This biochemical diversity is a key factor in the growing interest in fungi, both quantitatively and qualitatively. Among fungi with high adaptive capacity, there are species that exhibit selective antagonism towards phytopathogenic organisms (Assylbek *et al.*, 2023). The use of such fungi has significantly enhanced the effectiveness of modern biological control strategies. Based on the above factors, true fungi (Mycota or Fungi) found in the gray-brown soils of the Absheron Peninsula were chosen as the primary study object in this study. This study also took into account the fact that local strains exhibit higher activity in the conditions from which they were isolated.

2. Materials and Methods

The study was conducted on the Absheron Peninsula of the Republic of Azerbaijan (40° 27' 49" N, 49° 57' 27" E), whose main soil type is gray-brown. Both relatively clean and contaminated (polluted, irrigated, etc.) soils were sampled. A total of 200 samples (50 clean, 150 contaminated) were collected during the experiments. The sampled soils differed from each other according to their physico-chemical indicators (Table 1).

Table 1. Some physico-chemical parameters of the sampled soils

№	Sampled location	Sampling depth(sm)	pH	Soil moisture (%)	Amount of humus (%)
1	Irrigated soil(40°29′32″ N. 50°08′20 E)	0-20	7,3±	21±	1,59±
2	Contaminated with oil and petroleum products soil(40°28′33″ N. 49°49′20″ E)	0-20	7,4±	19±	1,19±
3	Relatively clean soil(40°22′47″ N və 49°48′26″ E)	0-20	7,0±	20±	1,70±

Sampling was performed in accordance with standard methods widely accepted in microbiology and mycology (Maheshwari, 2016; Saba et al., 2024).

The isolation of microscopic fungi from the collected samples was prioritised. Standard nutrient media such as agarized malt extract (AME – 2-4°B), agarized Czapek-Dox medium (ACM) and Sabouraud agar (SA) were used for this purpose, as well as other standard culture media (SCM). Before transferring the soil samples onto the nutrient media, a 10% suspension was prepared. In some cases, this suspension was inoculated directly onto AME or SA using a sterile pipette; in other cases, it was diluted 10-, 50-, or 100-fold before inoculation. Cultivation was carried out in an incubator at 28 °C for 3–10 days. Once colonies began to form, visually identical colonies were transferred to fresh nutrient media and this process was repeated until homogeneous colonies were obtained. The purity of the colonies was monitored using a microscope (OMAX 40X-2500X LED Digital Lab Trinocular Compound Microscope with USB Camera). Identification of the purified fungal cultures was based on cultural, morphological and physiological characteristics, using established identification manuals (Kirk et al., 2008; Seifert, 2011) and atlases (Li et al., 2023).

The isolated and identified fungal species were screened for their antagonistic activity, specifically their interaction with phytopathogenic fungi. For this purpose, the following test cultures were used: *Alternaria alternata* (Fries) Keissler, *Bipolaris nodulosa* (Berk. & M.A. Curtis ex Sacc.) Shoemaker (= *Drechslera nodulosa* (Berk. & M.A. Curtis ex Sacc.) Subram. & B.L. Jain), *Botrytis cinerea* Pers., *Fusarium moniliforme* J. Sheld., and *F. oxysporum* Schltd. The evaluation of antagonistic activity was conducted based on a modified version of the Canson-Carlo scale, as improved by Alimova (2006). The assessment criteria were adapted from the original methodology as described below:

A = 1 point – Co-cultivation of the tested cultures is possible; no antagonistic interaction is observed.

B = 2 points – Both cultures grow until they come into contact, after which one culture begins to overgrow the other weakly over time.

C = 3 points – Upon contact, the growth of both fungal cultures is inhibited.

D = 4 points – After contact, one culture continues to grow and overgrows the other.

E = 5 points – One of the tested cultures completely inhibits the growth of the other and continues to grow over its colony surface.

To determine the optimal growth conditions for the selected fungal cultures, a liquid Czapek-Dox medium with the following composition was used: glucose (sucrose) – 30 g/L; yeast extract – 5 g/L; peptone – 5 g/L; KNO_3 – 2.5 g/L; KH_2PO_4 – 1 g/L; $MgSO_4 \cdot 7H_2O$ – 0.5 g/L; NaCl – 10 g/L; agar – 20 g/L. Sterilisation was performed at 0.5 atm for 30 minutes.

To assess the antibiotic activity of the biomass produced by the fungi in the nutrient medium, the resulting biomass was washed three times in phosphate buffer solution, then homogenised using a tissue grinder to disrupt the fungal cell structure (three repetitions, each

lasting three minutes). The resulting mixture was then centrifuged for 10 minutes at 5000 rpm, and the antibiotic activity was determined in the supernatant using the agar well diffusion method.

Phytotoxic activity has been determined by the germination capacity of the seeds of some plants. For this purpose, seeds of this or that plant were taken in 4 replicates, 100 each, and soaked in a fungal culture solution for 15 hours, then germinated at room temperature (20-22°C) in a Petri dish with filter paper inside, and the phytotoxic activity (%) was determined based on the number of seeds that do not germinate after 5 days.

Tomato cultivation was carried out in accordance with methodologies and approaches recommended for agricultural research (Litvinov, 2011). The experiments were conducted under field conditions at the experimental base of the Institute of Vegetable Growing of the Ministry of Agriculture of the Republic of Azerbaijan. 8 plots, each 2x5 m, were taken, 4 of which were used as controls and 4 for the experiment. Seeds soaked in a culture solution obtained from fungi selected as active producers were sown in the experimental field for 15 hours, and seeds soaked in Chapek medium used for mushroom cultivation were sown in the control variant.

During the research, experiments were repeated at least 4 times, and the results obtained were statistically processed (Welham *et al.*, 2014), and the results whose integrity was not in doubt (those that meet the formula $\sigma/X_o \leq 0{,}05$, σ-mean square deviation, X_o -average value of repetitions) were used.

3. Results

From the analyses of samples collected from various locations, 212 pure cultures of fungi belonging to 79 species were identified according to the classical mycological methods. Information on their taxonomic structure was provided in Table 2. It should be noted that the isolated fungi differed in their cultural-morphological, physiological, ecotrophic specialization, and other characteristics. Among them were species with characteristics typical of hemibionts, saprotrophs, necrotrophs, allergens, endophytes, toxigenics, thermotolerants, and others.

Table 2. Quantitative characteristics of the taxonomic structure of fungi recorded in the study

Kingdom	Phylum	Class	Order	Family	Genus	Species
1	3	7	17	21	34	79

Considering this diversity, it was deemed appropriate to conduct a screening of the fungal species recorded in the study, with the primary selection criterion being the possession of traits characteristic of endophytes. As a result, 28 species exhibiting such traits were selected, distributed among genera as follows: *Aspergillus* – 4 species, *Aureobasidium* – 1 species, *Cephalosporium* – 1 species, *Chaetomium* – 2 species, *Gliocladium* – 2 species, *Mucor* – 4 species, *Penicillium* – 5 species, *Trichoderma* – 6 species, *Rhizopus* – 1 species, and *Sordaria* – 2 species. The potential use of these fungi for qualitative improvement of grey-brown soils in Absheron—soils characterized by low fertility and productivity—was subsequently investigated. The remaining 51 fungal species were not utilized in the subsequent phases of the study, as literature data and our own research confirmed that they belong to toxigenic, phytopathogenic, and opportunistic (conditional pathogenic) groups (Bakshaliyeva et al., 2023; Bakshaliyeva, 2023).

The selected 28 fungal species were subsequently tested for their ability to exhibit antagonistic relationships with dangerous phytopathogenic fungi common in Azerbaijan and the Absheron region. This approach is consistent with recent global trends emphasizing the development of environmentally sustainable agriculture, which prioritizes the inherent biological potential of plants and minimizes the use of environmentally hazardous agrochemicals, such as mineral fertilizers, pesticides, and chemical stimulants. The results showed that selected fungi that are able to coexist in the same plant communities often exhibit antagonism towards each other. Quantitative assessment of this antagonism using established methods showed variability among fungi, with most demonstrating minimal antagonistic activity and scoring mainly between 1 and 2 on the evaluation scale (tab. 3).

Table 3. Evaluation of the Interaction Between Selected Fungal Strains and Phytopathogens (Based on a 5-Point Scale)

Tested Fungal Genera (Number of Strains)	Phytopathogenic Fungi				
	Alternaria alternata	*Biopolarius nodulosa*	*Botrys cinerea*	*Fusarium moniliforme*	*F.oxysporium*
Aspergillius (14)	1-2	1-2	1-2	1-2	1-2
Mucor (12)	1-2	1-2	1-2	1-2	1-2
Pencillium (15)	1	2	1	1	2
Trichoderma(19)	3-5	3-5	2-4	4-5	4-5
Cephalosporium (2)	3	2	2	3	3
Gliocladium(4)	3	3	3	3	3
Sordaria(4)	2-3	1-2	2	1-3	2
Aureobasidium(1)	2	1	2	1	1
Chaetomium (3)	1	2	2	1	1
Rhizopus(2)	1	1	1	1	1

These fungi are characteristic of strains belonging to the *Aspergillus, Aureobasidium, Chaetomium, Mucor* and *Rhizopus* genera. They can be described as weak antagonists. Those exhibiting moderate antagonistic activity primarily belonged to the Cephalosporium, Gliocladium and Sordaria genera, with antagonism levels ranging between 2 and 3. As expected, fungi with strong antagonistic properties were identified among strains of the genus *Trichoderma*, with quantitative antagonism scores ranging from 3 to 5. However, only strains belonging to the *Trichoderma* species, specifically *T. citrinoviride* and *T. harzianum*, exhibited maximal antagonistic activity against all tested phytopathogens. This justified their selection as active producers for the next stage of the research. The species composition of these fungi was initially determined using classical mycological methods and then refined using molecular genetic approaches based on the nucleotide sequences of the ITS genes and a comparison of the obtained GenBank results (Sharma S et al., 2019), resulting in their designation as *T. citrinoviride* AEF-2024 (KY764860.1 – 99,83%) and *T. harzianum* AEF-2024(MH865865.1 – 99,66%) (Muradov et al., 2025).

Subsequently, the cultivation conditions for the selected fungi were optimized based on the key culture medium parameters determined empirically during the primary screening. The results showed that the optimal cultivation temperature for T. citrinoviride AEF-2024 and T. harzianum AEF- is 28°C, and the optimal biomass

yield for these fungi is achieved by maintaining the initial pH of the Czapek-Doksa medium at 5.7 (Table 4). When studying the effect of inoculum preparation method and time on fungal growth efficiency in nutrient media, the results showed that biomass formation occurred in all variants, but the amount of biomass produced by the two fungi varied depending on the preparation method. The highest yield was observed using a spore suspension grown on wheat bran agar. Regarding the inoculum cultivation period, our study found five days to be optimal. This period corresponds to the logarithmic, or exponential, phase of biomass growth, which is associated with greater efficiency.

Table 4. Optimal Conditions Required for the Cultivation of T. citrinoviride AEF-2024 and T. harzianum AEF-2024

Producer Strain	Carbon Source (g/L)	Nitrogen Source (g/L)	Cultivation Temperature (°C)	pH	Inoculum
T. citrinoviride AEF-2024	Glucose (25.0)	NH_4NO_3 (1,8)	28°C	5,7	ASB, spore suspension
T. harzianum AEF-2024	Glucose (25.0)	NH_4NO_3 (1,7)	28°C	5,7	ASB, spore suspension

In the medium optimised for all parameters (Table 4), the maximum biomass yield during fungal cultivation was observed after 120 hours. This can be considered a good indicator compared to strains belonging to the genus *Trichoderma* used in similar studies. Specifically, the optimal time for maximum biomass production of promising fungi in this field is typically between 90 and 104 hours.

Several fungi, including those of the genus Trichoderma, have been the subject of optimisation studies (Rosales-López *et al.*, 2022). For different strains used for the same purpose, the optimal medium is characterised by varying quantitative indicators. In all cases, optimisation enables the achievement of significant results. Our research confirmed this too, as optimising the nutrient medium composition and cultivation conditions based on empirical formulations initially led to a 7–12% increase in biomass yield. This further indicates that the process of optimisation remains effective, justifying its continued use in such studies. More precisely, the principle of 'a specific approach for a specific producer' remains relevant today. During the study, *T. citrinoviride* AEF-2024 and *T. harzianum* AEF-2024 fungi were selected as active producers. As these fungi are anamorphic sac fungi that do not form mycelial clumps (i.e. vegetative biomass), both their vegetative biomass and their cultural filtrate are used as the target product. Accordingly, the next phase of the research evaluated both substances obtained from these fungi for antifungal activity. The test cultures included the following fungi: *Alternaria alternata, Bipolaris nodulosa, Botrytis cinerea, Fusarium moniliforme* and *Fusarium oxysporum*. These fungi were chosen for the following reasons: All of the selected strains have been unequivocally confirmed as phytopathogens in various scientific studies. Worldwide crop losses due to these fungi are significant each year (Chai et al., 2022; Niego et al., 2023) and are currently unacceptable. Some of these fungi cause some of the top 10 most dangerous fungal diseases (Dean *et al.*, 2012), such as *Botrytis cinerea* and *Fusarium oxysporum*. Furthermore, these fungi are widely distributed across the major geomorphological units of the Republic of Azerbaijan (Bakhshaliyeva, 2022; Muradov *et al.*, 2025), and in some biotopes they are dominant or frequently encountered species in the mycobi-

ota. The cultural filtrate and vegetative mycelium obtained from the optimised medium using the active producers exhibited antibiotic activity against the phytopathogenic fungi *Alternaria alternata, Bipolaris nodulosa, Botrytis cinerea, Fusarium moniliforme* and *Fusarium oxysporum*. However, the level of activity varied depending on the producer and the test culture (Table 4).

During the study, fungi selected as active producers and optimized for biomass yield were evaluated for antimicrobial activity. Both their vegetative biomass (VB) and culture filtrate (CF) were used. The culture filtrate and vegetative mycelium of both fungi exhibited antibiotic activity against *Alternaria alternata, Bipolaris nodulosa, Botrytis cinerea, Fusarium moniliforme,* and *Fusarium oxysporum*. However, the level of activity varied depending on the manufacturer and test culture (Table 5).

Table 5. Antibiotic Activity (mm) of VB and CF Obtained from *T. citrinoviride* AEF-2024 and *T. harzianum* AEF-2024 Against Phytopathogenic Fungi

Producer	Formulation	Phytopathogenic Fungi				
		Alternaria alternata	*Bipolaris nodulosa*	*Botrytis cinerea*	*Fusarium moniliforme*	*F.oxysporum*
T. citrinoviride ASF-2024	VB	31*	35	30	31	32
	CF	26	28	24	25	23
T. harzianum AEF-2024	VB	30	34	31	32	30
	CF	27	29	25	25	26

Note: The results were statistically processed, and in all cases, P ≤0,044

Given that CF demonstrated stronger antibiotic activity (i.e., inhibition zones greater than 29 mm) compared to VB in all cases, it was selected for further studies. Initially, the effect of VB on seed germination of the selected plants (tomato, cucumber, and wheat) was assessed (Table 6). As the results show, an increase in seed germination was observed for all three plants, ranging from 4.7% to 6.7%.

Table 6. Effect of CF Obtained from Fungi on Seed Germination Capacity of Plants

№	Plant Control		*T. citrinoviride* AEF-2024		*T. harzianum* AEF-2024	
			Number of Germinated Seeds (pcs)	Increase Compared to Control (%)	Number of Germinated Seeds (pcs)	Increase Compared to Control (%)
1	Tomato/control	250*	224/209	6,7	220/209	5,0
2	Cucumber/control		211/201	4,7	214/201	6,1
3	Wheat/control		230/215	6,5	228/215	5,7

Note: The results were statistically processed, and in all cases P ≤0,049

It should be noted that the concentration of secondary metabolites synthesised by fungi in the medium is one of the factors influencing their effect. This aspect was therefore also clarified during the course of the research. Results from related studies showed that, under deep cultivation conditions, using 50-fold diluted 5-day-old CF resulted in higher outcomes (Table 7). It was observed that diluting the obtained CF by a factor of 50 led to an increase in seed germination capacity of between 1.3 and 1.8 times compared to the initial, untreated control for the fungi *T. citrinoviride* AEF-2024 and *T. harzianum* AEF-2024.

Table 7. Effect of Different Concentrations of CF Obtained from Fungi on Seed Germination Capacity of Plants (Based on % increase compared to control)

№	Plants	*T. citrinoviride* AEF-2024				*T. harzianum* AEF-2024			
		Effect of diluted CF solution on seed germination capacity (expressed as percentage increase relative to control)							
		0	10	50	100	0	10	50	100
1	Tomato	6,7*	8,3	9,5	9,1	5,0	7,4	9,2	8,8
2	Cucumber	4,7	5,6	7,0	6,2	6,1	6,9	7,7	7,3
3	Wheat	6,5	8,6	9,4	8,6	5,7	6,7	8,9	8,5

Note: The results were statistically processed, and in all cases, $P \leq 0,05$

The increased capacity for seed germination is due to the presence of stimulatory metabolites in the CF of both fungi, which can also be classified as secondary metabolites. This enhanced germination increases the number of seedlings emerging from the treated seeds and shortens the time required for emergence by 1–2 days. This effect was confirmed in our experiments in a controlled environment using tomato plants as a model. The next phase of the research evaluated the impact of CF pre-treatment on the overall productivity of the plants. As a control, the commonly used pre-treatment method for seeds during crop cultivation was applied. These experiments were conducted using tomato plants as a model system. The results indicated that pre-treatment of tomato seeds with CF positively influenced the morphometric parameters and yield of individual plants (Table 8). As can be seen, the CF obtained from *T. citrinoviride* AEF-2024 increased yield per plant by 25%, compared to a 20% increase with *T. harzianum* AEF-2024.

Table 8. Effect of CF obtained from fungi on the morphometric parameters and overall yield of tomato plants.

№	Producer	Plant height (initial/final, cm)	Flowering duration (days)	Yield per plant (kg)
1	*T.citrinoviride* AEF-2024	12±0,56/95±2,7	31±1,3	2,5±0,08
2	*T. harzianum* AEF-2024	12±0,48/94±3,5,	32±1,2	2,4±0,02
3	Control	12±0,36/88±2,8	33±1,4	2,0±0,08

4. Discussion

As in many parts of the world, the soils of the Absheron Peninsula of the Republic of Azerbaijan are predominantly gray-brown and are largely in a state of stress (Aliyev *et al.*, 2023). For this reason, their productivity (fertility and yield of cultivated plants) is low. Addressing such problems positively is one of the current research trends everywhere, which is reflected in the research being carried out in various aspects of this field (Shahzad *et al.*, 2025). Enhancing plant viability, productivity and soil fertility through biologically derived activators is one of the most promising recent approaches in analogous studies. Analysis of studies in this field indicates that early-

stage research should focus on the microbial communities, including fungi, present in stressed soils and in the associated plants within agroecosystems. This should involve investigating species composition and subsequently exploring inter-microbial interactions. Studies of interactions among fungi, specifically antagonistic relationships, have revealed that fungi capable of coexisting in the same plant communities often exhibit antagonism towards each other. It should be noted that antagonism among microorganisms is increasingly recognised as a widely utilised form of interaction in biological control that is considered ecologically safe (van Lenteren *et al.*, 2018), with extensive ongoing research in this area (Fenta et al., 2023). Nevertheless, it is striking that the number of fungi showing promise in this regard is still very limited in current studies. Almost all fungi with serious potential in this field belong to the *Trichoderma* genus (Guzmán-Guzmán *et al.*, 2023), a finding that is also confirmed by our research. This underscores the fact that fungal interactions remain a largely unexplored field, highlighting the importance of further research in this area. Furthermore, considering that the fungi currently known to science represent only a small fraction of those existing in nature (approximately 150,000 described species compared to an estimated 2–11 million) (Phukhamsakda, 2022), there is no need for further justification of the critical importance of advancing research into fungal relationships.

The results obtained during the research (optimization of the environment for active strains, higher activity in the culture solution, increased germination and productivity of seeds, etc.) allow us to touch on one point, which is related to the better functioning of cultures isolated from different places under local conditions. Thus, increasing the fertility (in terms of productivity) of soils by using fungi isolated from the gray-brown soils of the Absheron Peninsula, which are under stress, and achieving an effect of up to 20-25%, allows us to note that the use of local strains is more promising. Besides, it highlights the potential of indigenous fungal strains as biocontrol agents and biofertilizers to mitigate the negative impacts of abiotic and biotic stressors on agroecosystems, as well as their role in the sustainable rehabilitation of degraded soils. The biotechnological potential of fungi occurring in Azerbaijan has also been demonstrated for other fungal groups, including xylotrophic macromycetes investigated as producers of biologically active compounds (Bakhshaliyeva *et al.*, 2026). More broadly, this approach demonstrates an ecologically clean and economically viable strategy for managing stressed agricultural soils by harnessing the adaptive capacity of local microbial communities.

5. Conclusion

Based on the results of the research, the use of fungi and their metabolites isolated from soils located in the same ecological conditions allows for the creation of an effective strategy for improving the productivity indicators of soils in similar conditions. This is particularly supported by studies involving bioproducts derived from Trichoderma species, primarily the *T. citrinoviride* AEF-2024 and *T. harzianum* AEF-2024 strains. The application of these fungal isolates and their bioproducts has been shown to significantly increase the yield of key crops, including tomatoes, cucumbers and beans. Furthermore, the use of these bioproducts offers great potential for improving the phytosanitary condition of stressed soils and restoring their fertility, as is the case in the Absheron region.

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Conflict of interests

The authors declare that they have no conflicts of interest that could have influenced the conduct, analysis, or presentation of the research.

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