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The Effect of *Trichoderma* spp. on the Growth and Development of *Alhagi maurorum* and Evaluation of Its Potential for Biological Control

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Abstract. *Alhagi maurorum is characterized as a rapidly spreading weed outside its natural distribution range, with a high capacity to adapt to various soil and climatic conditions, and is particularly considered an undesirable plant in pasture and forage areas. In addition, the richness of this plant in biologically active compounds and its interactions with phytopathogenic microorganisms make it a relevant subject for investigation in the field of biological control. In modern agriculture, the investigation of alternatives to chemical control agents and the study of plant–microorganism interactions are of great importance for the development of biological control strategies. The aim of this study was to evaluate the interaction between Alhagi maurorum and Trichoderma spp. and to determine the effects of Trichoderma strains on plant development and biological resistance to phytopathogens. During the study, soil and plant samples were collected from different areas, fungal isolation was performed on Czapek medium, solidified malt extract medium, the obtained Trichoderma isolates were evaluated based on their morphological characteristics, and culture solutions were prepared. The results obtained demonstrated that the application of Trichoderma spp. could positively affect the growth parameters of Alhagi maurorum and indicated that the plant–microorganism interaction has considerable biological potential. Furthermore, the Trichoderma isolates were found to have potential as biological control agents capable of suppressing the development of phytopathogenic fungi. The findings of this study demonstrate that the interaction between Alhagi maurorum and Trichoderma spp. has significant scientific and practical potential for maintaining plant health, developing biological control agents, and promoting environmentally sustainable agricultural technologies.*

Keywords: *Alhagi maurorum, Trichoderma spp., microorganisms, biological control, biologically active compounds*

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Introduction

Plants that occur in the wild as well as those cultivated under agricultural conditions are widely used in medicine, the confectionery industry, perfumery, phytotherapy, and various other fields. As the practical and industrial importance of these plants increases, their areas of application also continue to expand almost every year. More than 35,000 plant species worldwide are used for medicinal purposes. According to data from previous and contemporary researchers, phenols, polyphenols, and flavonoids are considered natural antioxidant compounds of plants and are present at varying concentrations, particularly in medicinal plants (Tarawneh et al., 2010; Parthasarathy et al., 2009; Borchardt et al., 2009; Kiselova et al., 2006). In this regard, natural products possess interesting and beneficial biological properties and also perform various functions (Biswas et al., 2010). In general, in recent years, researchers have increasingly focused on natural products with the aim of developing more effective medicinal agents against cancer as well as viral and microbial infections (Revathi & Parimelazhghan, 2010). Among plants possessing the aforementioned properties, *Alhagi maurorum* is of particular interest. The number of studies conducted on this species in the aforementioned areas is limited, both internationally and in Azerbaijan. Nevertheless, *A. maurorum* is considered one of the plants with a wide distribution range and sufficiently abundant natural resources worldwide (Safarova, 2018), as well as throughout the territory of Azerbaijan. The limited number of scientific studies available indicates that environmental conditions may also play an important role in determining the biological effects of the components present in the plant. *Alhagi maurorum* is mainly distributed in areas with hot and arid climates and is characterized by its tolerance to saline soils. This plant usually grows and flowers actively during the spring and summer months. It can adapt well to unfavorable environmental conditions such as drought and salinity. Due to its thorny nature, it may hinder grazing by animals in pastures (Mandaville, 2011; Sharma, 2013). The ability of this species to adapt to saline and arid soils increases its economic and ecological importance (Jones & Brown, 2015). In particular, its occurrence in agricultural areas, meadows, and pastures may contribute to ecosystem services such as soil stabilization and the prevention of erosion (Brown & Green, 2016).

The plant is also considered an important resource from both agricultural and industrial perspectives (Almenova, 2021). It can be used as animal feed and may also be evaluated as a biomass source for bioethanol production. Alongside all these characteristics, it should also be emphasized that several factors affect the growth and productivity of *Alhagi maurorum*. One of these factors is diseases caused by phytopathogenic microorganisms. Examples of phytopathogenic microorganisms that cause diseases in *Alhagi maurorum* include *A. alternata, A. cucumerina, A. awamori, A. fumigatus, A. niger, A. repens, C. herbarum, E. alhagi, F. moniliforme, F. oxysporum, M. mucedo, P. cyclopium, P. chrysogenum,* and *P. restrictum*, among others.

Currently, fungal diseases constitute one of the important areas of integrated disease management in agriculture. Integrated disease management encompasses multiple strategies and a comprehensive approach based on knowledge of pathogens, plants, agronomic practices, and the interactions among them. Fungal diseases are strongly influenced by environmental conditions, pathogen virulence, and plant–pathogen interactions. In addition to affecting disease development, factors such as pesticide application, soil cultivation, the amount of primary inoculum, climatic conditions, and other environmental factors may also influence the biological control potential of microorganisms belonging to the genus *Trichoderma* against disease-causing pathogens in *Alhagi maurorum*. Several studies have demonstrated that the application of *Trichoderma* species has promising biological potential not only for reducing the effects of disease-causing pathogens but also for improving plant growth and development parameters (Shirinova et al., 2025).

Materials and Methods

Samples were collected from different regions of Azerbaijan for the study. Soil samples were collected from the rhizosphere zones where *A. maurorum* plants were growing in order to obtain *Trichoderma* spp. strains. The collected soil samples were placed in sterile bags, labeled, and transferred to the laboratory for microbiological analyses. The samples were stored at 5 °C until analysis. During the study, the effects of *Trichoderma* strains on the vegetative growth parameters of *A. maurorum*, particularly plant height, were evaluated. Czapek medium (CS) and agarized malt extract (AME) were used as nutrient media for the isolation of *Trichoderma* spp. strains from the soil samples.

Before cultivation on the nutrient media, the investigated samples were initially prepared as suspensions under sterile conditions. Serial dilutions were prepared from the resulting suspension, and the obtained solutions were inoculated onto the surfaces of the respective nutrient media using sterile pipettes. In addition, some samples were directly placed onto the nutrient media without prior dilution. The inoculated samples were incubated at 28 °C under thermostat conditions for 3–6 days. During this period, the morphological characteristics of the developing fungal colonies, including colony color, growth characteristics, and sporulation features, were observed. The morphological characteristics of the resulting fungal colonies were evaluated by microscopic examination, and the purity of the cultures was monitored. To obtain pure cultures, portions taken from selected colonies were inoculated onto the surface of fresh medium under sterile conditions and incubated again. The culture suspension of the obtained *Trichoderma* spp. strains was applied to the root zone of *A. maurorum* plants. Care was taken to ensure that the same application method was used for each *A. maurorum* plant.

Results and Discussion

In this study, changes in some biological characteristics of *A. maurorum*, a species that is important as a medicinal raw material and is also one of the plants that can be colonized by toxigenic, allergenic, and opportunistic pathogenic fungi, were investigated in relation to environmental conditions. The study revealed that camelthorn (*A. maurorum*) samples growing in different geographical regions differed from one another in terms of their morphometric characteristics, particularly plant height, as well as moisture content. It is assumed that the ecological characteristics of the environment in which the plant develops play an important role in the formation of these differences. The identified differences in morphometric and moisture parameters can be considered an expression of the adaptive characteristics of *A. maurorum* to different environmental conditions. At the same time, it is possible that temperature, soil moisture, nutrient availability, and other abiotic factors of the environment in which the plant develops affect its vegetative growth. These changes in environmental conditions are presumed to influence the moisture balance of the plant's tissues and organs, as well as its physiological status. On the other hand, the differences observed in the morphological characteristics of the plant may also be associated with the growth dynamics of microorganisms inhabiting its surface and tissues, including microscopic fungi. In this regard, the assessment of the morphometric and moisture parameters of *A. maurorum* samples together with their mycobiological characteristics is of considerable importance for determining plant–microorganism interactions.

Figure 1
Alhagi maurorum

As a result of the mycological studies conducted, various fungal species were identified in the mycobiota of the camelthorn plant (*Alhagi maurorum*) collected as a sample. A significant proportion of the detected taxa were isolated into pure cultures and identified based on their morphological and cultural characteristics, while the remaining taxa were identified on the basis of disease symptoms observed on the plant and the morphological characteristics of spore structures formed during the vegetation period. In assessing the taxonomic status of the identified fungal species, their systematic position according to modern classification systems and their accepted nomenclature were taken into consideration. Particular attention was also given to the presence of phytopathogenic fungal species that may cause various diseases in the plant. Considering the potential effects of these pathogens on the growth and phytosanitary condition of *A. maurorum*, the prospects of using antagonistic fungi belonging to the genus *Trichoderma* for their biological control were also considered one of the important directions of the study (Muradov et al., 2019).

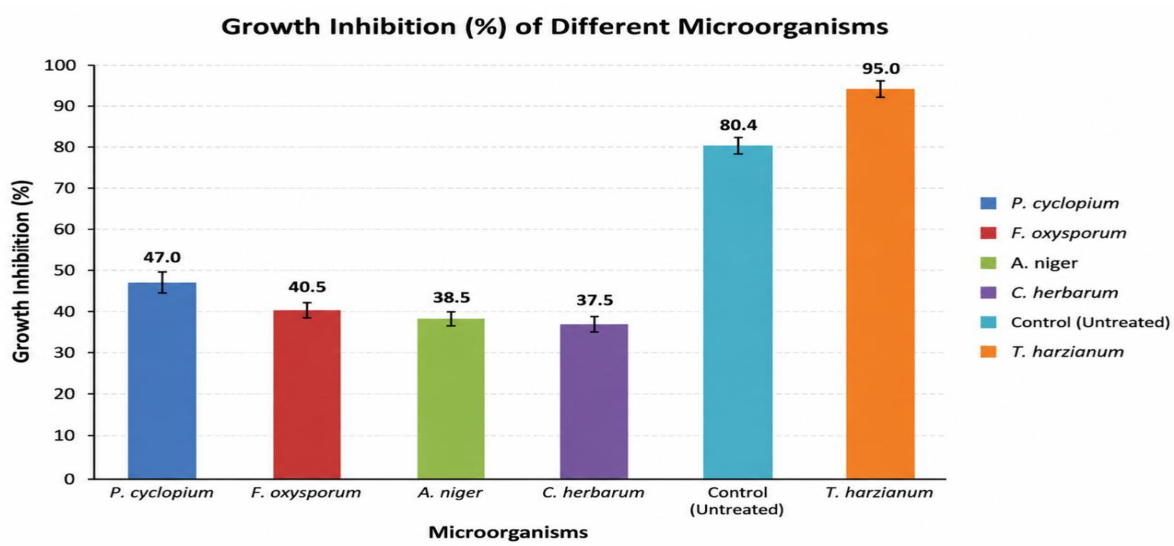

Figure 2
Effect of Trichoderma harzianum on the inhibition of the growth of various phytopathogenic microorganisms

The application of *Trichoderma* preparations as biocontrol agents is largely influenced by their stress tolerance (e.g., high temperature, desiccation, ultraviolet radiation, etc.) and storage stability (for more than one year under normal temperature conditions) (Alfiky & Weisskopf, 2021). Although *Trichoderma* plays an important role in promoting the growth and increasing the productivity of many plants, several challenges associated with the application of this genus in biological control still need to be addressed (Caruso et al., 2020; Boamah et al., 2021). For this purpose, it is necessary to develop effective *Trichoderma* preparations suitable for use through various application methods, enhance their biological control efficacy, and improve the preparation and processing technologies of *Trichoderma* formulations in order to extend the shelf life of biological control agents.

Table 1

Trichoderma species under different environmental conditions

Economic region	Experimental treatment	Stem height (cm)	Number of leaves (per plant)	Number of flowers (per plant)	Effect on plant growth
Kura–Araz Lowland	Control	38,5	42	8	Control
	Trichoderma CS	48,6	55	12	Stimulating
Greater Caucasus	Control	36,9	40	7	Control
	Trichoderma CS	46,2	52	11	Stimulating
Absheron	Control	40,2	44	9	Control
	Trichoderma CS	51,4	60	14	Effective
Talysh zone	Control	34,6	38	6	Control
	Trichoderma CS	43,5	49	10	Effective

In *A. maurorum* plants treated with *Trichoderma* culture suspension, higher values were observed for stem height, leaf production, and flower formation compared with the control treatment. The most pronounced positive changes were recorded in the Absheron samples, followed by those from the Kura–Araz Lowland and Greater Caucasus. In the Talysh zone, the application of *Trichoderma* culture suspension also had a positive effect on the vegetative and generative development of the plant.

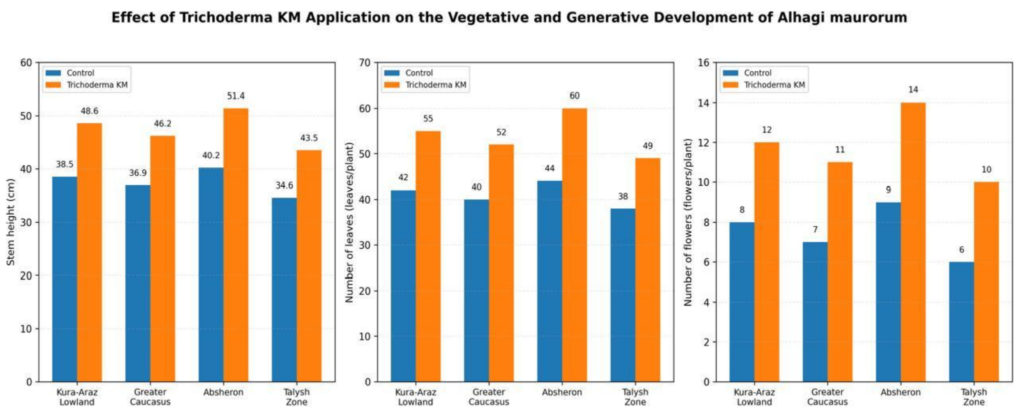

Figure 3

Effect of Trichoderma culture suspension application on the growth parameters of Alhagi maurorum plants in different ecological zones

The application of *Trichoderma* culture suspension significantly stimulated both the vegetative and generative development of *Alhagi maurorum* plants in all economic regions. Stem height increased in all regions. The highest value was recorded in Absheron, where stem height increased from 40.2 cm to 51.4 cm, corresponding to an increase of approximately 27.9%. The number of leaves also increased in all treatments, with the greatest increase again observed in Absheron (36.4%). The effect of *Trichoderma* culture suspension on the number of flowers was even more pronounced. In Absheron, the number of flowers increased from 9 to 14, while in the Talysh zone it increased from 6 to 10. The highest relative increase in flower number was observed in the Talysh zone (66.7%), followed by the Greater Caucasus (57.1%).

Table 2
Biological control indicators of Trichoderma application in Alhagi maurorum

Economic region	Optical density (656 nm)	AE	Expected biological control effect after *Trichoderma* application (%)	Effect on plant growth
Kura–Araz Lowland	0,715	1,250	75–85	high
Greater Caucasus	0,696	1,200	70–80	high
Absheron	0,734	1,268	78–88	high
Talysh zone	0,567	1,196	60–70	Moderate to high

The correlation of the biological control indicators of *Alhagi maurorum* across different economic regions with the application of microorganisms belonging to the genus *Trichoderma* indicates that, in areas with higher optical density values, the potential for *Trichoderma* preparations to colonize the rhizosphere of the plant and restrict the development of pathogenic microorganisms may be comparatively greater.

Conclusion

The obtained results indicate that the combined use of *A. maurorum* extracts and *Trichoderma* spp. represents a promising approach in terms of plant–microorganism interactions. In particular, the relatively high values observed in samples obtained from Absheron and the Kura–Araz Lowland indicate that these samples may have greater potential for integrated biological control with *Trichoderma* and for promoting plant growth. The results of the experimental studies conducted indicate that the interaction between *Trichoderma* spp. and *Alhagi maurorum* may be of potential importance for adaptation to arid and unfavorable environmental conditions. Colonization of the rhizosphere by *Trichoderma* isolates may stimulate the development of the plant root system, improve the uptake of water and mineral nutrients, and thereby support the growth capacity of *A. maurorum* under stress conditions. At the same time, the antagonistic activity of these fungi against phytopathogenic microorganisms may contribute to maintaining plant health and establishing a microbiological balance in the rhizosphere. At the same time, the results obtained showed that the application of *Trichoderma* culture suspension significantly stimulated the vegetative and generative growth parameters of *Alhagi maurorum* plants in all study zones. The highest growth parameters were recorded in the Absheron zone. In this area, significant increases in stem height, number of leaves, and number of flowers were observed following the application of *Trichoderma* culture suspension.

Declaration of Competing Interests

The authors declare that they have no conflict of interest.

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