

Horticulturists perceive that arbuscular mycorrhizal fungi improve the nutrition of chili plants

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ABSTRACT

Objective: To classify 19 horticulturists based on their perception concerning knowledge (human capital, HC) about the use of arbuscular mycorrhizal fungi (AMFs) and their effects on chili production plots along the agricultural strip region in the state of Zacatecas.

Design/methodology/approach: A questionnaire with 16 statements on technical-productive issues and on the use of AMFs belonging to the HC was designed and applied to 19 chili producers within the Calera, Morelos, Villa de Cos, and Zacatecas municipalities. The data were subjected to a principal components analysis (PCA). A multivariate cluster analysis (CA) was also performed to classify the horticulturists involved through standardized variables and to ratify the groups evidenced by the PCA.

Results: PC1 and PC2 explain 54% and 12.8% of total variance, respectively. The orthogonal plane defined by these PCs identified three groups of horticulturists. The CA allowed visualization of the same three groups as appreciated by the PCA.

Limitations on study/implications: The sample is relatively small because in fact there are still few horticulturists that use AMFs.

Findings/conclusions: The group integrated by the four most productive horticulturists perceives that AMF use (*Trichoderma harzianum* and *Bacillus subtilis*) allows improving chili plant nutrition, soil aeration, and phosphorus plant absorption.

Keywords: Human capital, Principal Components Analysis, Multivariate Cluster Analysis, Likert scale.

Citation: Enríquez-Hernández, G., Blanco-Macías, F., Gallegos-Vázquez, C., Márquez-Madrid, M., & Valdez-Cepeda, R. D. (2025). Horticulturists perceive that arbuscular mycorrhizal fungi improve the nutrition of chili plants. *Agro Productividad*. <https://doi.org/10.32854/qdwc661>

Academic Editor: Jorge Cadena Iñiguez

Associate Editor: Dra. Lucero del Mar Ruiz Posadas

Guest Editor: Daniel Alejandro Cadena Zamudio

Received: November 9, 2024.

Accepted: August 17, 2025.

Published on-line: October XX, 2025.

Agro Productividad, 18(9). September, 2025. pp: 63-69.

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INTRODUCTION

The use of agrochemical products in agricultural production systems contributes to the emission of carbon dioxide (CO₂) (Vermeulen *et al.*, 2012), which affects biodiversity, and the environment (Steffen *et al.*, 2015). The interest in minimizing the use of these products leads to substituting them with microbial inoculants. In general, many microorganisms catalogued as beneficial have the capacity to increase food production when they are used adequately (Singh *et al.*, 2020).

In this sense, the soil microbiota lead between 80% and 90% of edaphic biotic processes (Bajsa *et al.*, 2013). Specifically, arbuscular mycorrhizal fungi (AMFs) form symbiotic associations with plant roots and exchange nutrients such as phosphorus, and nitrogen (Scott, Kiers and West, 2025). Sadhana (2014), Jamiolkowska *et al.* (2018), and Parihar *et al.* (2020) have documented that AMFs improve some soil properties such as water retention, nutrient availability, and carbon, nitrogen and phosphorus cycles. In addition, AMFs induce stress tolerance and resistance to attacks from disease (Klironomos, 2003; Chen *et al.*, 2018). Recently, Scott, Kiers, and West (2025) described that, when a plant is attacked by an herbivore, it can send a signal to other plants connected to the same mycorrhiza network that regulates its defense mechanisms; this translates into the hypothesis that attacked plants produce an alert signal to other plants to prevent damage.

In the case of sweet chili pepper (*Capsicum annum* L.) cultivation, the inoculation with AMFs during seedling production can cause an increase in the concentration of phosphorus in the soil solution and its fast absorption through a larger absorbent surface of the root system due to the mycelium hyphae, which at the same time has positive effects on the yield and quality of the fruits (Franczuk *et al.*, 2023). For example, sweet chili pepper plants inoculated with AMFs presented more fruits, had fruits with thicker pericarp and more mass, leaves with more chlorophyll, stem with greater diameter, root system with more mass, and aerial part with more mass than that corresponding to plants without inoculum (Franczuk *et al.*, 2023). In addition, inoculation with AMFs increases nearly 4 times the production of capsaicin and dihydrocapsaicin in *C. annum* compared to the control (without inoculation) (Canpolat and İşlek, 2023).

In general, the multiple benefits evidenced with a scientific basis are translated into important ecological services (Chen *et al.*, 2018). Consequently, the selection of the best inoculum of AMFs should be carried out for each crop (Rouphael *et al.*, 2015). However, the decision that the farmer makes is a function of the products (AMF complexes) available on the market and of the knowledge that the grower has in that regard. Nevertheless, information about the knowledge, experience and disposition that growers have to adopt the practice of using AMFs in chili production is absent from the literature. Without a doubt, this type of information could be useful to classify the horticulturists, to design strategies for the development of their skills, and to transfer effective technology and innovations. Therefore, the aim was to classify 19 horticulturists based on their perception regarding knowledge (human capital, HC) on the use of arbuscular mycorrhizal fungi (AMFs), and their effects on the chili pepper (*Capsicum annum* L.) production units along the agricultural strip region in the state of Zacatecas, Mexico.

MATERIALS AND METHODS

A questionnaire with 16 statements (appreciated in Table 2) about technical-productive aspects that belong to human capital (HC) was designed and applied to 19 chili pepper growers from the municipalities of Calera, Morelos, Villa de Cos, and Zacatecas. The statements were designed based on the Likert scale and five levels of perception (Likert, 1932). The levels were the following: Totally disagree; Partially disagree; Neither disagree nor agree; Partially agree; Totally agree. The scale allowed us to evaluate the perception

of horticulturists on the use of AMFs in chili production reliably. The level of reliability of the information generated was estimated through the Cronbach's Alpha. A principal components analysis (PCA) was conducted to determine the statements that explained most of the variance of the data matrix. The principal components (PCs) facilitated the identification of the variables (statements) that explained the structure of each component to perform the ordination of the involved growers. A multivariate cluster analysis (CA) was carried out to group the involved horticulturists through standardized variables and to ratify the groups evidenced through the PCAs. The analyses were carried out with the Minitab[®] 16 software.

RESULTS AND DISCUSSION

The first two PCs explain 66.8% of the total variation of the data matrix (Table 1). The PC1 explains 54% of the total variance and the PC2 12.8%. The PC1 is a compound variable defined by statements CH3, CH4, CH5, CH6, CH7, CH8, CH9, CH10, CH11, CH12, and CH14 (Table 2); this suggests that horticulturists know that AMFs induce root development, homogeneous plant growth, product quality, reduction in the amount of used chemical fertilizers, enrichment of the soil with microorganisms, improvement of soil aeration, improvement of plant nutrition, promotion of tolerance to hydric and nutritional stress, resistance to diseases, reduction of soil contamination caused by chemical fertilizers, and incorporation of nutrients to the soil solution and its faster absorption. The PC2 is dominated by statements CH1, CH2, CH13, CH15 and CH16; this means that some horticulturists perceive that the application of AMFs is a simple task, germination improves with their use, more soil aggregates formed, decreases of loss of phosphorus in the soil through lixiviation, and the application of nitrogen, sulfur, copper and zinc is reduced.

In the orthogonal plane defined by PC2 and PC1, three groups of horticulturists are identified (Figure 1). The first group is made up of survey respondents 10, 12, 14, 18, and 20, who disagree with the statement that the use of AMFs allows for the reduction of used chemical fertilizer; they use complexes of *Glomus intraradices* and *Trichoderma harzianum*. The second group is made up of survey respondents 1, 4, 5, 7, 8, 9, 11, 16, 17, and 19; this group is characterized by the perception that the application of AMFs is a simple task, and the soil is enriched with microorganisms when AMFs are used; these horticulturists disagree with the idea that soil aggregation is improved; the complexes that they use involve *Glomus intraradices*, *Trichoderma harzianum*, and *Bacillus subtilis*. For their part, the

Table 1. Eigenvalues, proportion of variance explained, and accumulated variance explained of the first two Principal Components (PCs) corresponding to 16 statements of human capital about the use of arbuscular mycorrhizal fungi according to the perception of 19 horticulturists.

	PC1	PC2
Eigenvalue	8.642	2.042
Proportion of Variance Explained	0.540	0.128
Accumulated Variance Explained	0.540	0.668

Table 2. Coefficients of correlation (loadings) between the first two Principal Components (PCs) and the 16 statements or variables of human capital on the use of arbuscular mycorrhizal fungi (AMF) according to the perception of 19 horticulturists.

Variable		Principal Component	
		CP1	CP2
HC1	I am convinced AMF application is simple.	0.194	0.377
HC2	I know that use of AMF improves germination.	0.002	-0.537
HC3	I know the effect of AMF on roots.	0.307	0.034
HC4	I know plants grow in an homogeneous form when using AMF.	0.258	-0.081
HC5	I perceive plant products improves their quality when using AMF.	0.318	-0.025
HC6	I know use of AMF allows diminishing chemical fertilizers needs.	0.251	0.235
HC7	I know use of AMF enriches soil microbiota.	0.296	0.051
HC8	I know use of AMF improves soil aeration.	0.248	0.037
HC9	I know use of AMF improves plant nutrition.	0.290	0.119
HC10	I know use of AMF promotes plant hydric and nutrient stress tolerances.	0.295	-0.103
HC11	I have observed use of AMF provides plant disease resistance.	0.281	-0.032
HC12	I know use of AMF reduces soil contamination by chemical fertilization effect.	0.231	-0.147
HC13	I know use of AMF increases soil aggregation formation.	-0.172	0.404
HC14	I perceive use of AMF improves nutrients soil incorporation and plant absorption.	0.298	0.125
HC15	I perceive use of AMF reduces soil phosphorus losses.	0.196	-0.331
HC16	I know use of AMF reduces nitrogen, sulfur, copper and zinc fertilization needs.	0.166	0.407

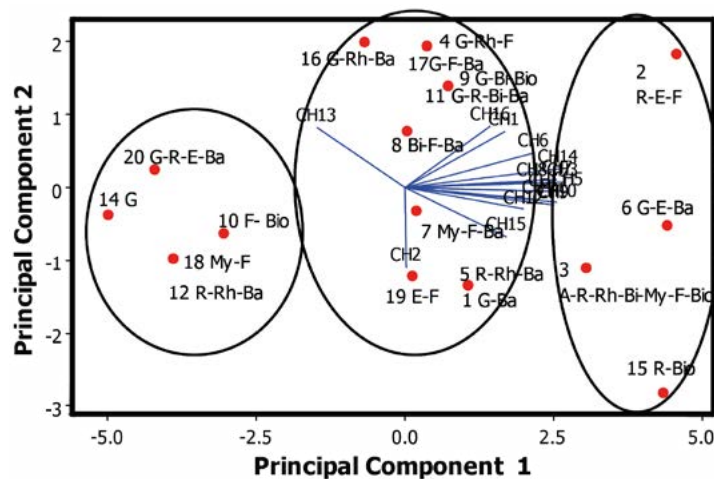


Figure 1. Position of the 19 horticulturists and the 16 statements of human capital (CH) on the use of arbuscular mycorrhizal fungi in the orthogonal plane defined by the first two extracted Principal Components.

third group is integrated by the rest of the horticulturists (2, 3, 6, and 15), who perceive that plant nutrition improves with the use of AMFs; they use complexes of *Trichoderma harzianum*, and *Bacillus subtilis*.

The CA through the Ward's method and the Manhattan distance at a similarity = -47.99 allowed us to ratify the three groups (Figure 2), previously evidenced through the PCAs. The first group of 5 horticulturists disagrees with the statement that the use of AMFs allows the reduction of used chemical fertilizer. This result differs from what was pointed out by Chen *et al.* (2018), who noted that the application of AMFs contributes to decreasing the amount of fertilizers incorporated into the soil without affecting the yield; this could be attributed to the fact that AMFs release phosphatases to hydrolyze the phosphate of the organophosphorus compounds (Marschner, 2011); if this process takes place, the productivity of the crops can improve (Smith *et al.*, 2011). Likewise, the AMFs are important to increase the absorption of ammonium and micronutrients that have scarce mobility in the soil, such as copper and zinc (Smith and Read, 2008).

The second group is made up of 10 growers and characterized because they perceive that the application of AMFs is a simple task and that with their use, the soil is enriched with microorganisms. This result agrees with what is described by Larkin (2008), and Vestberg *et al.* (2011), who describe that the density and diversity of AMFs tend to increase; this could be attributed to the rotation of crops have a significant impact on the populations and activities of the AMFs (Rouphael *et al.*, 2015).

The third group is made up of 4 horticulturists; they perceive that with the use of AMFs the plants' nutrition improves. This result agrees with that described by Chen *et al.* (2018), who pointed out that AMFs contribute to the nutrition of plants regarding the absorption and translocation of mineral nutrients; this could be attributed to the fact that AMFs interfere with the phytohormonal balance of host plants and influence the development of plants (bioregulators) (Rouphael *et al.*, 2015).

In general, the perception of the involved horticulturists, segmented into three groups, confirms that the application of AMFs is a simple task, and that with their use the soil is enriched with microorganisms. They use complexes that involve at least two of the species *Glomus intraradices*, *Trichoderma harzianum*, and *Bacillus subtilis*, which has allowed them to understand that they can reduce the use of chemical fertilizers, and improve the nutritional

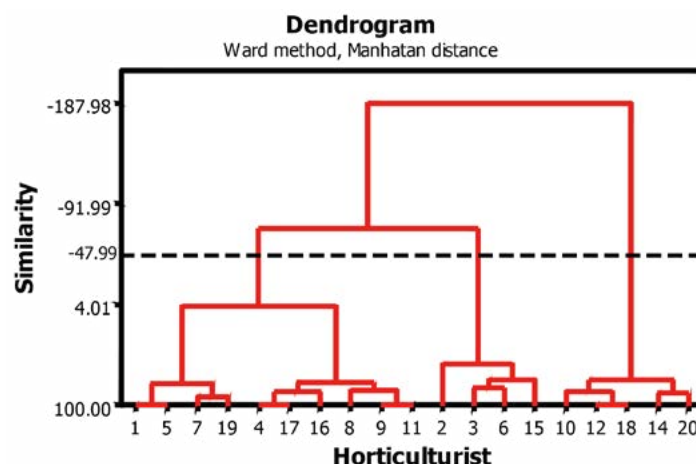


Figure 2. Dendrogram of the 19 horticulturists when considering their perception on human capital regarding the use of arbuscular mycorrhizal fungi based on 16 statements.

condition of plants with the intention of increasing their chili pepper (*C. annum*) yield and quality. In other words, chili pepper growers from the agricultural strip region in Zacatecas have knowledge in accordance with the scientific knowledge generated regarding the use of AMFs as inoculum, particularly what was described by Klironomos (2003); Smith and Read (2008); Sadhana (2014); Chen *et al.* (2018); Jamiolkowska *et al.* (2018); Parihar *et al.* (2020); Franczuk *et al.* (2023) and Scott, Kiers and West (2025), among others.

CONCLUSIONS

The four most productive horticulturists (2, 3, 6, and 15) perceive that the use of AMFs (*Trichoderma harzianum*, and *Bacillus subtilis*) improves the nutrition of the chili pepper plants, the aeration of the soil, and the absorption of phosphorus. In addition, they also perceive that, with the use of AMFs, production costs decrease from minimizing the use of inorganic fertilizers as sources of nitrogen, phosphorus, sulfur, copper, and zinc. Therefore, joint work among horticulturists, technical advisors, public servants, and input suppliers on the use of AMFs in chili production is advisable; this can contribute to the improvement of soil conservation programs with an integral approach to develop capacities regarding the use of AMFs.

ACKNOWLEDGEMENTS

Germán Enríquez-Hernández wishes to thank the Consejo Nacional de Humanidades, Ciencias y Tecnología for the scholarship granted during his Master in Sciences studies. All the authors thank the Universidad Autónoma Chapingo for the support granted through the Master in Sciences Program on Regional Rural Development.

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