Colegio de Postgraduados

Jalapeño pepper (*Capsicum annuum* L.): cultural importance and benefit of endomycorrhizal symbiosis in sustainable production

Gómez-García, Nayeli G.[1]; Aguirre-Cadena, Juan F.[1*]; Martínez-Solís, M.; Escobar-España, J. C.[1]; Niño-Domínguez, A.[1]

[1] Universidad Autónoma de Chiapas. Huehuetán, Chiapas, 30660, México.
* Correspondence: juan.cadena@unach.mx

ABSTRACT

Objective: This paper examines the background and current importance of the jalapeño pepper and the benefits to the plant and soil when bio-fertilized with endomycorrhizal fungi.

Design/methodology/approach: Literature related to the jalapeño pepper and the benefits of using endomycorrhizal fungi in its growth and production was reviewed. The importance of sustainable agriculture was also noted.

Results: Jalapeño peppers have been part of culture and traditions since pre-Hispanic times, and the importance of endomycorrhizal fungi in production has been established to reduce the need for synthetic fertilizers. Their morphological and physiological yield components have been improved, and their protein and capsaicin content has increased, reducing production costs.

Limitations on study/implications: The results found are encouraging but their response may vary depending on the bio-fertilized endomycorrhizal fungus.

Findings/conclusions: The jalapeño pepper continues to be a symbol of Mexico's culinary richness. The symbiosis between endomycorrhizal fungi and *Capsicum* spp. is effective and promotes growth and yield. It also helps the plant tolerate various biotic and abiotic stresses.

Mycorrhizal biofertilization is an alternative for cost-effectively and sustainably increasing *Capsicum annuum* L. production.

Keywords: Biofertilization; Sustainable Agriculture; Yield.

Citation: Gómez-García, N. G., Aguirre-Cadena. J. F., Martínez-Solís, M., Escobar-España, J., C., & Niño-Domínguez, A. (2025). Jalapeño pepper (Capsicum annuum L.): cultural importance and benefit of endomycorrhizal symbiosis in sustainable production. *Agro Productividad*. https://doi.org/10.32854/v2z4s208

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: January 14, 2025.
Accepted: April 13, 2025.
Published on-line: June XX, 2025.

Agro Productividad, 18(5). May. 2025. pp: 235-248.

INTRODUCTION

Capsicum annuum L. is a basic vegetable in the Mexican culture and gastronomy. It is used in the daily diet with contribution of vitamins, minerals and antioxidants. In addition, it has broad impact on the agricultural economy and is a strategic crop within the Mexican agricultural sector (Aguilar *et al.*, 2010; Aguirre *et al.*, 2017). *Per capita* consumption exceeds 15.0 kg, which reflects the deep-rooted tradition of using chili peppers in the Mexican diet (SIAP, 2023).

In the world production of chili, Mexico occupies a central role, it is the second largest producer after China (SIAP, 2018). According to the Ministry of Agriculture and Rural Development (SADER), in 2023 the national production of green chili exceeded the figures of previous years, it was 3.23 million tons. The states of Sinaloa, Chihuahua and Zacatecas contributed 59.7% of the national total (SADER, 2024).

This leading position in the production and consumption of jalapeño peppers is largely due to the wide genetic variability distributed in the country (Moreno-Pérez *et al.*, 2011). There is an extensive diversity of shapes and sizes of plants of the *Capsicum* genus, as well as a wide variety of flowers and fruits.

The five most cultivated species in Mexico are *C. annuum*, *C. chinense*, *C. pubescens*, *C. frutescens* and *C. baccatum* (Hernández-Verdugo *et al.*, 1999).

The jalapeño pepper is more than a culinary ingredient in the Mexican diet. Its presence transcends the gastronomic sphere and forms part of the country's cultural identity. Since pre-Hispanic times, chili has been a staple food in the cuisines of America and has been present in rituals, traditional medicine and social practices (Conaculta, 2021).

Despite its economic and cultural importance, jalapeño pepper production faces several challenges, such as climate change, expressed in terms of rainfall variability, temperature increase and soil degradation (SIAP, 2023). Besides, the intensive use of conventional fertilizers has generated environmental pollution problems with an increase in greenhouse gases (Bohlool *et al.*, 1992). Likewise, the NO_3 and NO_2 forms contaminate water sources by leaching (Martínez-Nieto *et al.* 2011) and soil microbiota are altered, as happened with *Rhizobium* spp. in beans (Caballero-Mellado and Martínez-Romero, 1999).

The future of jalapeño pepper production will depend on the adoption of innovative technologies and sustainable agricultural practices, with an agroecological approach to ensure the sustainability of the crop.

In addition to the above, the growing consumer demand for organic products and environmental awareness among consumers are driving the transition to more environmentally responsible production methods.

This paper examines the importance of jalapeño peppers and the benefits when bio-fertilized with endomycorrhizal fungi and highlights the sustainable approach.

Gastronomic and cultural importance of jalapeño peppers

The species *C. annuum* is the most representative within this diversity (FAO, 2022). The jalapeño pepper, like other chili varieties, is a profound symbol of Mexican identity. Its relevance goes beyond the merely culinary, as it is an element that has accompanied the history of the country since pre-Hispanic times, playing a fundamental role in food, culture and traditions (Spinoso, 2021).

Its versatility in the preparation of diverse dishes, according to the nutritional needs of the population, has allowed it to become an emblem of Mexican gastronomy, and the largest morpho-phenotypic variety is found in Mexico (Aguilar-Rincón *et al.*, 2010).

Some chilis are widely appreciated and used, such as jalapeño, ancho, guajillo, pasilla, serrano, manzano, habanero, de árbol and piquín (Kraft *et al.*, 2014; Santiago-Luna *et al.*, 2018).

Today, the jalapeño pepper continues to be a mainstay of Mexican gastronomy, and its versatility has made it an indispensable ingredient not only in a wide variety of dishes, but also in various beverages (Basulto *et al.*, 2021).

It is used in the preparation of sauces, moles and combined with other vegetables associated with beef, sheep or goat meat. It is also used in preserves and pickles, among others.

In addition, it has been incorporated into international cuisine, with wide acceptance in countries such as the United States, Spain and Japan, where its flavor and level of spiciness have been used in different culinary preparations (Dávila, 2023).

Its domestication and distribution have been widely documented by researchers who identify Mexico as its center of origin and development (FAO, 2022). The prevalence of jalapeño peppers has been confirmed in various studies that have analyzed production patterns in the country, highlighting its importance in the Mexican agricultural and gastronomic market (Cuarán *et al.*, 2022).

Since its origins, chili has been an essential ingredient in the diet of the indigenous peoples of Mesoamerica. Its domestication allowed the development of a wide diversity of genetic resources, adapted to different regions and climatic conditions (Aguirre-Mancilla *et al.*, 2017; Moreno-Pérez *et al.*, 2011).

It was first known and harvested in the wild, and little by little it was cultivated by indigenous women and men, who, over time, managed to generate a wide range of native variants (Larousse, 2020). This historical relationship with chili has cemented its presence in the gastronomy and daily life of Mexicans (Conaculta, 2021).

At a cultural level, chili is much more than an ingredient; it is a symbol of identity and belonging. Under that line, it can be mentioned that chili is one of the elements that offers the greatest sense of belonging to Mexicans, speaking from a culinary point of view (Guillaumin, 2020). It is present throughout the entire Mexican gastronomy.

Moreover, its importance has transcended to many other cultural manifestations (Saldaña-Arguello *et al.*, 2023). Thus, by appropriating resources such as chili, each town has created its ethnic identity, since, due to the indigenous cosmovision of nature, which is still preserved by many towns in Mexico, chili peppers are considered more than a food source (Dávila *et al.*, 2023).

Currently it is present in diverse aspects of the social and political life of the peoples of America. Chili peppers are not only consumed as food but were also used for other purposes in a wide variety of cultural manifestations, for example, pre-Hispanic peoples used it as a weapon of war, to pay tribute, and in education as a "disciplinary measure with children" (Quesada-Román, 2017). This food has transcended the frontiers of food and has proven to be a highly valued resource, both in economic and social terms (Saldaña-Arguello, 2023).

Additionally, the diversity of chilis in Mexico reflects the geographical and cultural richness of the country. Each region has developed its own recipes and procedures to make the most of the local varieties of this fruit.

The variety of chilis in Mexico is expressed from the Baja California peninsula to the Yucatan's, from the sandy desert of Sonora to the always humid Tabasco, or from the Pacific coast to the mountains of the Sierra Oriental (Katz & Meléndez, 2023). This diversity has allowed the chili pepper to adapt to multiple culinary styles and continues to be a symbol of Mexico's gastronomic richness.

Current challenges in the production of jalapeño peppers

Despite its economic and cultural importance, jalapeño pepper production faces the challenges of climate change and consumer preferences for organic products.

The future of jalapeño pepper production will depend on the adoption of innovative technologies and sustainable agricultural practices, with an agroecological approach to ensure the sustainability of the crop.

In addition to the above, there is a growing consumer demand for organic products and environmental awareness among consumers, driving the transition to more environmentally responsible production methods.

In this context, the use of various soil microorganisms, now known as microbial biofertilizers, has gained relevance as a sustainable strategy in the production of various annual and perennial crops (Aguirre-Medina, 2006).

In jalapeño pepper, the soil microorganisms that have demonstrated evident effects on chili production have been endomycorrhizal fungi (Aguirre-Medina and Espinosa-Moreno, 2016) and it has been confirmed in *Lycopersicon esculentum* L (Anzueto *et al.*, 2023), *Solanum Lycopersicon* L. (Bercian-Moguel *et al.*, 2025).

These fungi establish a symbiotic relationship with plant roots, facilitating the transport of essential nutrients such as phosphorus and nitrogen to the host plant and the host plant provides photosynthates to the fungus (Dabrowska, G. & Zdziechowska, 2015) which contributes to better crop development.

The effects of microbial symbiosis and the host plant are generally manifested by an increase in aerial and radical biomass production (Asrar *et al.*, 2012), flowering (Othman *et al.*, 2022) and yield.

In addition, their presence in the soil favors the stability of the microbiota and improves the structure of the substrate by storing carbon, binding the particles of the soil mineral fraction and providing stability to the aggregates (Vlček & Pohanka, 2019). These changes in the soil when endomycorrhizal fungi are present increase crop resilience to adverse conditions such as drought and salinity.

Recent studies have shown that the application of mycorrhizal fungi in the production of jalapeño peppers not only increases yields but also reduces the need to apply chemical fertilizers (Kaushal, & Wani, 2016). The implementation of these actions, combined with other sustainable agricultural practices, allows optimizing the productivity of jalapeño peppers without compromising soil quality or the biodiversity of the agricultural ecosystem (Das *et al.*, 2008).

Sustainable production: Background and importance

Sustainable production is an agricultural approach that seeks to balance productivity with environmental conservation, ensuring the viability of resources for future generations. In this context, the Sustainable Development Goals (SDGs) have become a fundamental guide to promote agricultural strategies that promote sustainability. These goals consist of 17 ambitious targets that are part of the 2030 Agenda, established by the United Nations World Organization (UN) on September 25, 2015, with the purpose of making the planet a fairer, safer and more sustainable place (SDGs, 2015). Although they cover a broad spectrum of issues, such as poverty eradication and the development of sustainable communities, they also include specific descriptors that enable the assessment of countries' progress in agricultural and environmental sustainability.

In recent years, the concept of sustainability has gained relevance, as evidenced by several studies that address its application in different contexts (Stolz and Bautista, 2015; Acuña-Moraga *et al.*, 2019; Pache-Durán and Nevado-Gil, 2020; Estrada Domínguez *et al.*, 2020).

The growing interest is closely related to the increase of the world population (Severo *et al.*, 2018), which demands more food and immediately increases the pressure on natural resources, leading to problems such as precariousness, degradation and destruction of the environment (Coy, 2018; Yin *et al.*, 2018).

Sustainability is based on the principle of intergenerational responsibility, which means that current human behavior must ensure that future generations enjoy living conditions equal to or better than the present.

In this sense, sustainable development seeks to maintain a balance between economic growth, social welfare, cultural preservation and environmental protection. The goal is to reach a state in which agricultural production is viable in the long term, allowing a harmonious interaction between humans and nature (Sarandón, 2019).

In this sense, sustainability and social responsibility are complementary. Both seek to contribute to the creation of scenarios that foster responsible and sustainable consumption (Antúnez da Luz *et al.*, 2016; Severino-González, 2017; Edinger-Schons *et al.*, 2018). To achieve this, it is essential to design theories, models and strategies to improve the quality of life without compromising the planet's resources.

One of the main benefits of sustainable production is the ability of small farms with biodiversity to generate more food, compared to large agro-industrial monocultures.

Agricultural diversity not only increases production but also represents an effective strategy to prevent problems such as drought, desertification and hunger in rural areas (FAO, 2020).

However, these sustainable local food production systems are threatened by the expansion of food production, which often privileges quantity over quality and environmental impact.

Sustainable agricultural practices offer multiple benefits, including soil conservation through the use of organic material as fertilizer. They also promote the efficient use of natural resources, promote biodiversity instead of destroying it, and contribute to improving human health by ensuring food sovereignty (Landini and Beramendi, 2020; Singh, 2021).

Nevertheless, conventional agricultural practices have had a negative impact on ecosystems. They have limited the capacity to provide food, maintain unpolluted freshwater sources, regulate climate and air quality, and even control diseases (Foley *et al.*, 2022). Faced with this global problem, it is essential to develop solutions that allow biodiversity to coexist with productive activities.

A key element in sustainable production is the implementation of agricultural techniques that improve soil fertility and resource use efficiency. Organic fertilizers and microbial biofertilizers represent a viable and economical alternative. They can be obtained locally and allow restoring soil structure, improving water retention and, over time, increasing agricultural yields due to their contribution of a wide variety of nutrients (Quezada, 2018).

In Mexico, agriculture has historically been a fundamental activity that has guaranteed the subsistence of peasant and indigenous communities throughout time. In the case of Mesoamerica, ancient civilizations developed diverse agroecosystems adapted to their environmental, social and economic conditions (González, 2021).

Currently, traditional agricultural systems persist in Mexico, such as chinampas, terraces, orchards, cacao fields, tlacolol, huamil and small irrigation systems, among others. Despite their resilience, these systems are not exempt from the impacts of modernity (Martínez and Gándara, 2017; Moreno *et al.*, 2023).

These traditional agricultural systems are characterized by a high level of biodiversity and efficient management of natural resources, including soil, water and flora. In addition, they play a crucial role in the conservation of native species, carbon sequestration, and a concomitant contribution to climate change mitigation.

They also reflect a close relationship with the cosmovision of the communities that practice them, incorporate ancestral knowledge, traditional agricultural technology and species domestication strategies. Their importance lies not only in the provision of food products for self-consumption, but also in their contribution to the local economy through commercialization in regional markets (Martínez and Gándara, 2017; Moreno *et al.*, 2023; Moctezuma *et al.*, 2018).

Sustainable production not only offers environmental and economic benefits but also represents a key strategy for food security and the well-being of rural communities. The implementation of sustainable agricultural practices is essential to guarantee a balance between productivity and environmental conservation, thus ensuring a future in which agriculture can continue to be a viable source of food and resources for generations to come.

Endomycorrhizae and their contribution to sustainable production

Endomycorrhizal fungi can associate with the roots of most terrestrial plant species and exchange soil nutrients for photosynthates (Coccina *et al.*, 2019) and facilitate the acquisition of mineral nutrients, such as P, N, Fe, Zn, Cu and Mo (Smith and Read, 2008), as well as increase host plant growth and yield.

Mycorrhizae colonize plant communities through spores present in the soil or added through various treatments.

Soil microorganisms, especially mycorrhizal fungi, play a fundamental role in the productivity and stability of ecosystems, since they facilitate nutrient absorption and contribute to soil structure (Van der Heijden *et al.*, 2008).

These fungi have shown a high incidence in the stability of ecosystems, especially in extreme edaphic conditions (Martínez and Pugnaire, 2009).

Most plant roots depend on the mycorrhizal system (Ortas, 2019), however, the availability of mycorrhizal spores over large agricultural areas may not be sufficient in high productivity systems (Klironomos, 2003). More consistent response has been achieved by bio-fertilizing various selected species of the genus *Glomus* spp, such as *G. mosseae* and *G. etunicatium* (Rafique and Ortas, 2018).

In general, the increase in demand for food without chemical fertilization has forced the agricultural sector to develop new technologies to increase both yield per unit area, and crop quality (Godfray *et al.* 2010). To achieve this, healthy and vigorous plants must be considered, which depends on the conditions of the substrate (Hamed *et al.*, 2019).

In this sense, the generation of technologies focused on improving seedling growth is a priority need (Hartmann *et al.*, 2002).

Soil is not only the physical support for plant growth but also plays a key role in the regulation of water flow, decomposition of organic matter and release of nutrients. In addition, it influences the emission of greenhouse gases (Stott and Taylor, 2016).

In this context, soil microorganisms play essential roles by actively participating in these ecological processes (Aislabie and Deslippe, 2013). Their highest concentration is found in the rhizosphere, where they interact with the organic exudates of plants, which influences the composition of microbial communities and their positive, neutral or negative impact on plant development (Massenssini *et al.*, 2014; Wolfe and Klironomos, 2005).

Given the need to reduce the use of chemical fertilizers and minimize their environmental impact, alternative strategies have been proposed to maintain efficient and sustainable production (Arias Mota *et al.*, 2019). Among these strategies, the use of mycorrhiza-forming fungi has proven to be a viable alternative to improve the biological balance of the soil and reduce dependence on inorganic fertilizers (Díaz Franco *et al.*, 2014). Biofertilization with these microorganisms allows greater efficiency in nutrient absorption, thus reducing the amount of fertilizers needed and reducing soil and water contamination (Cruz Hernández *et al.*, 2014).

In this sense, biofertilizers have gained relevance as a sustainable option to partially or totally replace conventional mineral fertilizers (Kennedy and Smith, 1995; Shah *et al.*, 2006). The growing understanding of the interactions between microorganisms, soil and plant is crucial for the sustainable development of agroecosystems, ensuring soil fertility and crop productivity (Johansson *et al.*, 2004; Maldonado *et al.*, 2010).

Arbuscular mycorrhizal fungi represent a biotechnological alternative that optimizes the use of agricultural resources, offering multiple benefits. Their functions include improved tolerance to abiotic stress factors (Porcel *et al.*, 2012), bioremediation capacity through the accumulation of heavy metals (Pérez *et al.*, 2019) and bio-protection against pathogens (Mohamed *et al.*, 2019). Their root system makes them key allies for the natural fertilization of crops (Durán *et al.*, 2013). In addition, they contribute to improve soil structure and aggregation (Barbosa *et al.*, 2019), increase plant growth and generate changes at morphological, physiological and nutritional levels (Muñoz, 2018).

The use of arbuscular mycorrhizal fungi not only represents an effective strategy to improve agricultural production in a sustainable manner but also has a positive impact on soil health and ecological stability. Their integration into agricultural systems could be key to meet the challenges of jalapeño pepper and other crop production in a context of climate change and increasing demand for food free of chemical fertilization.

Benefits of mycorrhizal symbiosis for jalapeño peppers

Among the benefits of the endomycorrhizal fungus host plant symbiosis, several crucial aspects stand out. Growth promotion and increased plant mineral nutrition are some of the most notable effects (Carpio *et al.*, 2005; Díaz *et al.*, 2013).

The endomycorrhizal fungi improve the absorption of essential nutrients, such as nitrogen (N) and phosphorus (P), which directly contributes to a better development of jalapeño peppers. In addition, this symbiosis also confers greater tolerance to soil pathogens, resulting in a decrease in the negative effects caused by diseases, significantly protecting plant health (Graham, 2001; Tahat *et al.*, 2010).

Another equally important aspect is that endomycorrhizal fungi enhance plant tolerance to adverse abiotic conditions, such as drought or salinity, which is especially relevant in an agricultural context marked by the effects of climate change (Davies *et al.*, 2002; Rabie, 2005).

In addition to these benefits, some of the endomycorrhizal fungi have been used as biofertilizers in agriculture, which has proven to be an effective strategy to increase agricultural productivity. This practice has had positive impacts on the production of various crops, including horticultural crops (Jeffries *et al.*, 2003).

In the case of jalapeño chili, mycorrhizal biofertilization has been a promising tool for improving yields and fruit quality. Endomycorrhizal fungi, when applied as biofertilizers, can be considered a key biotechnological component that contributes to increasing horticultural productivity and at the same time reducing dependence on synthetic fertilizers, promoting more sustainable agricultural practices (Azcón and Baera, 1997; Vosatka *et al.*, 1999; Ikiz *et al.*, 2009).

Therefore, mycorrhizal biofertilization represents a practice that should be incorporated into horticultural production systems, especially in those seeking ecological and efficient management of resources (Davies *et al.*, 2000; Carpio *et al.*, 2005; Oseni *et al.*, 2010).

Mycorrhizal fungi increase the root surface of plants through the growth of their hyphae, which explore the soil more efficiently than roots (Wang *et al.*, 2020).

Most agricultural crops respond to mycorrhizal symbiosis; however, the degree of response of plants to mycorrhizal colonization differs significantly between species (Ortas, 2019). The pepper plant is highly colonized in field conditions (Almaca *et al.*, 2021).

On the other hand, the interaction between plant growth promoting rhizobacteria and endomycorrhizal fungi also plays a key role in optimizing the growth and yield of various crops. This interaction, which can be selective and depends on the bacterial and fungal species involved, has shown positive results in improving the nutritional characteristics of the plant (Azcón, 2000). It has been observed that the combined bio-fertilization of *Rhizophagus intraradices* with bacteria such as *Azospirillum brasilense* have favored the growth of various crops, with significant increases in nitrogen (N) and phosphorus (P) levels in plant tissue (Aguirre Medina, 2006; Aguirre-Medina *et al.*, 2012). This not only improves vegetative development but also increases the nutritional quality of the fruit.

In addition to nutritional benefits, *Pseudomonas*, an important group of microorganisms in the rhizosphere, have the ability to promote plant growth and protect against pathogens. These bacteria, when interacting with endomycorrhizal fungi, could offer additional protection against various diseases affecting jalapeño chili, improving plant resistance and reducing the need for chemical treatments (Unno *et al.*, 2005).

In terms of production conditions, these can vary widely, from highly technical systems such as greenhouses to more economical systems such as shade mesh or bio spaces (Castellanos, 2004; Muñoz, 2004).

However, regardless of the technological level of the greenhouse, what is clear is that there are various factors related to agronomic practices of cultivation that impact both plant nutrition, and production quantity and quality (Muñoz, 2004). The joint implementation of management strategies that favor the plant's mycorrhizal nutrition can, consequently, improve the efficiency of the jalapeño chili cultivation.

The contemporary horticultural industry demands agricultural practices that reduce production costs, minimize the use of agrochemicals and optimize water use. In this sense, advances in the use of biological technologies, such as bio-fertilization with endomycorrhizal fungi and plant growth promoting rhizobacteria, are presented as a sustainable alternative that can help achieve these goals. According to Montero *et al.* (2010), it is essential to continue developing research that defines effective biological fertilization strategies that support sustainability and increase productivity in cropping systems.

CONCLUSIONS

Chili has been part of the culture and tradition in Mexico and there is a wide diversity adapted to various culinary styles and continues to be a symbol of the gastronomic richness of Mexico.

The symbiosis established between endomycorrhizal fungi and *Capsicum* spp. is effective and induces a positive impact on the photosynthetic activity of the plant and consequently on its growth and yield.

Radical colonization by the fungus increases its transport system of relatively motionless nutrients and water to the host plant, also favors tolerance to abiotic stress factors, soil remediation and protection against root pathogens.

Mycorrhizal biofertilization can be used in *Capsicum annuum* L. as an alternative to current practices to increase production in a cost-effective and sustainable manner.

REFERENCES

Acuña-Moraga O, Severino-González P, Cires-Gómez A (2019) Responsabilidad social empresa rial y ventaja competitiva. El estudio de pequeñas empresas mineras de Chile. *Encuentros* 17: 178-186.

Aguilar-Rincón, V. H., Corona-Torres, T., López-López, P., Latournerie-Moreno, L., Ramírez-Meraz, M., Villalón-Mendoza, H., & Aguilar-Castillo, J. A. (2010). Los chiles de México y su distribución (1ª ed.). SINAREFI.

Aguirre-Mancilla, CL., Iturriaga-De la Fuente G., Ramírez-Pimentel J.G., Covarrubias-Prieto J., Chablé-Moreno F., & Raya-Pérez J.C. (2017). El chile (*C. annuum* L.), cultivo y producción de semilla. *Ciencia y Tecnología Agropecuaria,5*(1), 19-31.

Aguirre-Medina, J.F. y Espinosa-Moreno, J.A. (2016). Crecimiento y rendimiento de *Capsicum annuum* L. inoculado con endomicorriza y rizobacterias. *Revista Mexicana de Ciencias Agrícolas, 7*(7):1539-1550. DOI: https://doi.org/10.29312/remexca.v7i7.148

Aguirre, M. J. F. 2006. Biofertilizantes microbianos: Experiencias agronómicas del programa nacional del INIFAP en México. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Centro de Investigaciones Regionales Pacífico Sur. Campo Experimental Rosario Izapa. Libro técnico Núm. 2. 201 p.

Aguirre, M. J. F.; Aguirre, C. J. F.; Cadena, I. J. y Avendaño, A. C. H. 2012. Biofertilización en plantas de la selva húmeda tropical. Colegio de Postgraduados. Montecillo, Estado de México. 99 p.

Aislabie, J. and Deslippe, J. R. 2013. Soil microbes and their contribution to soil services. In: Dymond, J. R. (Ed.). Ecosystem services in New Zealand - conditions and trends. Lincoln, New Zealand, Manaaki Whenua Press. 112-161 pp.

Almaca, A., Almaca, N. D. and Senbayram, M. (2021). Interactive effect of arbuscular mycorrhizal fungi inoculation and phosphorus fertilizer applicatoin on yield and nutrient content of red pepper (*Capsicum annuum* L.) in a semi-arid region. *Applied Ecology and Environmental Research, 19*(4):2779-2792. DOI: 10.15666/aeer/1904_27792792

Antunes da Luz A, de Francisco AC, Miranda Santos SFM, Mesquita Soares A, Kovaleski JL (2016) Sustainable development and conscious consumption: A per ception of undergraduate interns in the region of Campos Gerais, Parana, Brazil. *Interciencia* 41: 312-318.

Anzueto-Herón, Z. C., Aguirre-Medina, J. F., Aguirre-Cadena, J. F., & Pedro, C. I. (2023). Growth of Four Varieties of *Coffea arabica* L. Biofertilized with *Rhizophagus intraradices* and *Azospirillum brasilense* in Nursery. *American Journal of Plant Sciences, 14*(5), 552-568.

Arias Mota, R. M., Romero Fernandez, A. J., Bañuelos Trejo, J., y Cruz Elizondo, Y. (2019). Inoculación de hongos solubilizadores de fósforo y micorrizas arbusculares en plantas de jitomate. *Revista Mexicana de Ciencias Agrícolas, 10*(8), 1747-1757. https://doi.org/10.29312/remexca.v10i8.1558

Asrar, A.A., Abdel-Fattah, G.M. & Elhindi, K.M. (2012). Improving Growth, Flower Yield, and Water Relations of Snapdragon (*Antirhinum majus* L.) Plants Grown under Well-Watered and Water-Stress Conditions Using Arbuscular Mycorrhizal Fungi. *Photosynthetica*, 50, 305-316.

Azcón, A. C. and Baera, J. M. 1997. Applying mycorrhiza biotechnology to horticulture significance and potentials. *Sic. Hort*. 68:1-24.

Azcón, R. 2000. Papel de la simbiosis micorrizica y su interacción con otros Microorganismos rizosfericos en el crecimiento vegetal y sostenibilidad agrícola. In. Alarcón A. y Ferrera-Cerrato, R. (Eds.). Ecología, fisiología y biotecnología de la micorriza arbuscular. Mundi Prensa México. 251 p.

Barbosa, M. V., Pedroso, D. D. F., Curi, N., & Carneiro, M. A. C. (2019). Do different arbuscular mycorrhizal fungi affect the formation and stability of soil aggregates? *Ciência e Agrotecnologia*, 43. Doi: 10.1590/1413-7054201943003519

Basulto, F. S., Meraz, M. R., Pérez, R. D. G., Sandoval, J. Á. G., & Chalé, J. A. T. (2021). Variedades comerciales para el incremento del rendimiento y calidad de fruto del sistema productivo de chile jalapeño en Quintana Roo, México. *Brazilian Journal of Animal and Environmental Research, 4*(4), 6340-6351

Bercián-Moguel, M. B., Aguirre-Medina, J. F., de Lourdes Zaragoza-Martínez, M., & Raj-Aryal, D. (2025). Growth and Production of *Solanum lycopersicum* L. Bio Fertilized with *Rhizophagus intraradices*, *Azospirillum brasilense* and Foliar Application of Homobrassinolide in Nursery. *Asian Journal of Microbiology and Biotechnology, 10*(1), 46-57.

Bohlool, B., J. Ladha, D. Garrity and T. George. (1992). Biological nitrogen fixation for sustainable agriculture. *Plant and Soil*, 141:1-11. https://doi.org/10.1007/BF00011307

Caballero-Mellado, J. and E. Martínez-Romero. (1999). Soil fertilization limits the genetic diversity of *Rhizobium* in bean nodules. *Symbiosis*, 26: 111-121. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0032955239&partnerID=40&md5=b3a61e8299abc40b36ef9c99a871ed8a

Carpio, A. L.; Davies, F. T. and Arnold, M. A. 2005. Arbuscular mycorrhizal fungi, organic and inorganic controlled-release fertilizers: effect on growth and leachate of container-grown bush morning glory (*Ipomoea carnea* ssp. fistulosa) under high production temperatures. *J. Amer. Soc. Hort. Sci*. 130:131-139.

Castellanos, Z. J. 2004. La industria de la horticultura protegida en México. In: Castellanos, Z. J. (ed.). Manual de producción hortícola en invernadero. 2ª. Ed. Intagri. México. 18-34 pp.

CONACULTA, 2021. El Cocinero Mexicano, Colección de Recetarios Antiguos, México.

Coy, M (2018) Los estudios del ries go y de la vuelnerabilidad desde la geografía humana. Su relevancia para América Latina. *Poblac. Sociedad* 17: 9-28.

Cruz Hernández, Y., García Rubido, M., León González, Y., y Acosta Aguiar, Y. (2014). Influencia de la aplicación de micorrizas arbusculares y la reducción del fertilizante mineral en plántulas de tabaco. *Cultivos Tropicales, 35*(1), 21-24. http://scielo.sld.cu/pdf/ctr/v35n1/ctr03114.pdf.

Cuarán-Cuarán, D. A. del P., Jiménez-Cardona, J. R., Rojas-Pantoja, R. D., Vélez-Lozano, J. A., Vallejo-Cabrera, F. A., & Caetano, C. M. (2022). Caracterización morfológica y proximal de introducciones de

Capsicum chinense Jaqc. (Solanaceae) para uso en programas de mejoramiento genético. *Magna Scientia UCEVA, 2*(1), 121-132. https://doi. org/10.54502/msuceva.v2n1a12

Dabrowska, G. & Zdziechowska, E. (2015). The Role of Rhizobacteria in the Stimulation of the Growth and Development Processes and Protection of Plants against Environmental Factors. *Progress Plant Protection*, 55, 498-506. DOI: 10.14199/ppp-2015-083

Das, K., Dang, R. and Shivananda, T.N. (2008). Influence of Bio-Fertilizers on the Availability of Nutrients (N, P and K) in Soil in Relation to Growth and Yield of *Stevia rebaudiana* Grown in South India. *International Journal of Applied Research in Natural Products*, 1, 20-24. https://www.oalib.com/paper/2589102

Davies, F. T.; Saraiva, G. J. A.; Carpio, L. and Estrada, L. A. A. 2000. Colonization and growth effects of the mycorrhizal fungus *Glomus intraradices* in a commercial nursery container production system. *J. Environ. Hort*. 18:247-251.

Dávila, M. A. V., Meléndez, A. A., Katz, E., & Medina, G. I. M. (Eds.). (2023). Chiles en México: historias, culturas y ambientes. IRD Éditions. doi.org/10.1590/s0102-053620180319

Díaz F. A.; Alvarado, C. M.; Ortiz C. F. y Grageda, C. O. 2013. Nutrición de la planta y calidad de fruto de pimiento asociado con micorriza arbuscular en invernadero. *Rev. Mex. Cienc. Agric*. 4:315-321.

Díaz Franco, A., Salinas García, J. R., Espinosa Sandoval, F., Peña del Río, M. D. L. Á., de la Garza Requena, F. R., y Grageda Cabrera, O. A. (2014). Características de planta, suelo y productividad entre sorgo fertilizado e inoculado con micorriza arbuscular. *Revista Mexicana de Ciencias Agrícolas, 5*(3), 379-390. http://ref.scielo.org/7mfkyc.

Durán, P., Acuña, J. J., Jorquera, M. A., Azcón, R., Borie, F., Cornejo, P., & Mora, M. L. (2013). Enhanced selenium content in wheat grain by co-inoculation of selenobacteria and arbuscular mycorrhizal fungi: A preliminary study as a potential Se biofortification strategy. *Journal of Cereal Science, 57*(3), 275-280. Doi: 10.1016/J.JCS.2012.11.012

Edinger-Schon LM, Sipilä J, Sen S, Mende G, Wieseke J (2018) Are two reasons better than one? The role of appeal type in consumer responses to sustainable products. *J. Cons. Psychol*. 28: 644-664.

Estrada-Domínguez JE, Cantú-Mata JL, Torres-Castillo F, Barajas Ávila E (2020). Factores que influyen en el consumidor para la adquisición de producto sustentables. *Interciencia* 45: 36-41.

FAO (2020). "Food Ou tlook" #3, junio, 2020. World Wacth. Lester Brown.

FAO. (2012). Panorama de la seguridad alimentaria y nutricional en México 2012. México: La Organización de las Naciones Unidas de la Alimentación y la Agricultura.

FAOSTAT (2022). Food and Agriculture Organization of the United Nations. https://www.fao.org/ faostat/es/#data/QCL.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Godfray J, Beddington J, Crute I, Haddad L, Lawrence D, Muir, Pretty J, Robinson S, Thomas S, Toulmin C (2010) Food security: The challenge of feeding 9 billion people. *Science* 327: 812-818.

González Jácome, A. (2021), Historias varias. Un viaje en el tiempo con los agricultores mexicanos, Universidad Iberoamericana, México, 531 pp.

Graham, J. H. 2001. What do root pathogens see in mycorrhizas? *New Phytol*. 149:357-359.

Guillaumin-Martha. 2020. "Historia de los Pesos y medidas en México. Historia de la cocina y la gastronomía", Consultado el 19 de marzo del 2025 en: https://www.historiacocina.com/es/pesos-y-medidas-mexicanos.

Hamed, M., Kalita, D., Bartolo, M.E., Jayanty, S.S. (2019). Capsaicinoids, polyphenols and antioxidant activities of *Capsicum annuum*: Comparative study of the effect of ripening stage and cooking methods. *Antioxidants. 8*(9):364-71. https://doi.org/10.3390/antiox8090364

Hartmann, H. T., Kester, D. E., Davies Jr, F. T., & Geneve, R. L. (2002). The Feasibility of Utilizing Tobacco Greenhouses as Propagation Facilities for Ornamental Plants©. In Combined Proceedings International Plant Propagators' Society (Vol. 52, p. 440).

Hernández-Verdugo, S., Dávila-Aranda, P., & Oyama, K. (1999). Síntesis del conocimiento taxonómico, origen y domesticación del género *Capsicum*. *Boletín de la Sociedad Botánica de México*, 64, 65-84. https://doi.org/10.1007/s11099-012-0024-8

Ikiz, O. K.; Abak, H. D.; Desgan, Y. H. and Ortas, I. 2009. Effects of mycorrhizal inoculation in soilless culture on pepper plant growth. *Acta Hort*. 807:533-540.

Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K., & Barea, J. M. (2003). The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology and fertility of soils,* 37, 1-16.

Johansson, J. F., Paul, L. R., y Finlay, R. D. (2004). Microbial interactions in the mycorrhizosphere and their significance for sustainable agriculture. *FEMS Microbiology Ecology, 48*(1), 1-13.

Katz, E., & Meléndez, A. A. (2023). Chile: el sabor característico de la cocina mexicana. *Enfoque Rural, 1*(1), 1-4.

Kaushal, M. & Wani, S.P. (2016) Plant-Growth-Promoting Rhizobacteria: Drought Stress Alleviators to Ameliorate Crop Production in Drylands. *Annals of Microbiology*, 66, 35-42. https://doi.org/10.1007/s13213-015-1112-3

Kennedy, A. C. and Smith, K. L. 1995. Soil microbial diversity and the sustainability of agricultural soils. *Plant Soil*. 170:75-86 pp.

Klironomos, J. N. (2003). Variation in plant response to native and exotic arbuscular mycorrhizal fungi. *Ecology 84*(9): 2292-2301. https://doi.org/10.1890/02-0413

Kraft, K. H., Brown, C. H., Nabhan, G. P., Luedeling, E., Luna-Ruiz, J. L., D'Eeckenbrugge, G. C., Hijmans, R. J., & Gepts, P. (2014). Multiple lines of evidence for the origin of domesticated chili pepper, *Capsicum annuum*, in Mexico.

Landini, F., Beramendi, M. R. 2020. Agroecology or modern conventional agriculture? Positionings of Argentine rural extension workers. *RIA, Revista de Investigaciones Agropecuarias*. v, 46. n, 3. p, 352-361.

Maldonado-Chávez, E., Rivera-Cruz, M. C., Izquierdo-Reyes, F., & Palma-López, D. J. (2010). Effects of rizosphere, microorganisms and fertilization on bioremediation and phytoremediation of soils with new and weathered crude oil. *Universidad y ciencia, 26*(2), 121-136.

Martínez Saldaña, T., y L. Gándara Mendoza (2017), "La agricultura sustentable: una opción de desarrollo para una dimensión social de la agricultura", en A. González, S. del Amo y F. Gurri (coords.), Los nuevos caminos de la agricultura: procesos de conversión y perspectivas, Universidad Ibe roamericana/Plaza y Valdés, México, pp. 147-160.

Martínez-Nieto, P., D. García-González, P.S. Silva-Bonilla, G. Vargas-Chaparro y F. Valderrama Escallón. (2011). Manejo de residuos generados directa o indirectamente por el cultivo de cebolla en Aquitania (Boyacá-Colombia). *Revista AIDIS de Ingeniería y Ciencias Ambientales: Investigación, Desarrollo y Práctica, 4*(2): 23- 34. https://revistas.unam.mx/index.php/aidis/article/view/3

Martínez, L. B., & Pugnaire, F. I. (2009). Interacciones entre las comunidades de hongos formadores de micorrizas arbusculares y de plantas. Algunos ejemplos en los ecosistemas semiáridos. *Ecosistemas, 18*(2).

Massenssini, A. M.; Bonduki, V. H. A.; Melo, C. A. D.; Tótola, M. R.; Ferreira, F. A. and Costa, M. D. 2014. Soil microorganisms and their role in the interactions between weeds and crops. *Planta Daninha, Viçosa-MG. 32*(4):873-884.

Moctezuma Pérez, S. (2018), "Aportes alimenticios de los agroecosistemas tradicionales en el México rural", en Silvia Padilla Loredo (coord.), La crisis alimentaria y la salud en México, Castellanos Editores/uaem, Toluca, pp. 83100

Montero, L.; Duarte, C.; Cun, R.; Cabrera, J. A. y González, P. J. 2010. Efectividad de biofertilizantes micorrízicos en el rendimiento del pimiento (*Capsicum annuum* L.) cultivado en diferentes condiciones de humedad del sustrato. *Cultivos Trop*. 31:11-14.

Moreno Calles, A. I., V. M. Toledo y A. Casas (2023), "Los sistemas agroforestales tradicionales de México: una aproximación biocultural", *Botanical Science* 91: 375398.

Moreno-Pérez., E. del C., Avendaño-Arrazate, C.H., Mora-Aguilar, R., Cadena-Iñiguez, J., Aguilar-Rincón, V.H., Aguirre-Medina, J.F. (2011). Diversidad morfológica en colectas de Chile guajillo (*Capsicum annuum* L.) del centro-norte de México. *Revista Chapingo Serie Horticultura 17*(1): 23-30. https://revistas.chapingo.mx/horticultura/?section=articles&subsec=issues&numero=106&articulo=1140

Muñoz Carrillo, M. G. (2018). Análisis de expresión de genes de respuesta al estrés hídrico en plantas de *Sorghum bicolor* (L) Moench en presencia y ausencia de asociaciones con hongos micorrízicos (Doctoral dissertation, Universidad Autónoma de Aguascalientes).

Muñoz, R. J. J. 2004b. Manejo del cultivo de pimiento en invernadero. In: Castellanos, Z. J. (ed.). Manual de producción hortícola en invernadero. 2ª. (Ed.) Intagri. México. 257-281 pp.

ODS (2015). Objetivos de Desarrollo Sostenible de la Organización de Naciones Unidas. https://www.un.org/sustainabledevelopment/es/

Ortas, I. (2019). Under field conditions, mycorrhizal inoculum effectiveness depend on plant species and phosphorus nutrition. *Journal of Plant Nutrition 42*(18): 2349-2362. https://doi.org/10.1080/01904167.2019.1659336

Oseni, T. O.; Shongwe, N. S. and Masarirambi, M. T. 2010. Effect of arbuscular mycorrhiza (AM) inoculation on the performance of tomato nursery seedlings in vermiculite. *Int. J. Agr. Biol.* 12:789-792.

Othman, Y.A., Tahat, M., Alananbeh, K.M. and Al-Ajlouni, M. (2022). Arbuscular Mycorrhizal Fungi Inoculation Improves Flower Yield and Postharvest Quality Component of Gerbera Grown under Different Salinity Levels. *Agriculture*, 12, Article 978. https://doi.org/10.3390/agriculture12070978

Pache-Durán M, Nevado-Gil MT (2020) Compromiso de las em presas españolas del Dow Jones Sustainability World Index 2018 con la divulgación de información responsable. *Rev. Esp. Docum. Cient. 43*(1): e255.
Pérez Moncada, U. A., Gómez, M. R., Serralde Ordoñez, D. P., Peñaranda Rolón, A. M., Wilches Ortiz, W. A., Ramírez, L., & Rengifo Estrada, G. A. (2019). Hongos formadores de micorrizas arbusculares (HFMA) como estrategia para reducir la absorción de cadmio en plantas de cacao (*Theobroma cacao*). *Terra Latinoamericana, 37*(2), 121-130. Doi: 10.28940/TERRA.V37I2.479
Porcel, R., Aroca, R., & Ruiz-Lozano, J. M. (2012). Salinity stress alleviation using arbuscular mycorrhizal fungi. A review. *Agronomy for Sustainable Development, 32*(1), 181-200. Doi: 10.1007/S13593-011-0029-X
Quesada-Román, A. (2017). Geomorfología Fluvial e Inundaciones en la Cuenca Alta del Río General, Costa Rica. *Anuário do Instituto de Geociências, 40*(2).
Quezada UQ. 2018. Producción orgánica sostenible y su demanda en el mundo al 2030. *Kuntur, 6*(06), 11. Recuperado en 2020, de http://revistas.udaff.edu.pe/index.php/kuntur/article/view/40
Rabie, G. H. 2005. Influence of arbuscular mycorrhizal fungi and kinetin on the response of mungbean plants to irrigation with seawater. *Mycorrhiza* 15:225-230.
Rafique, M., Ortas, I. (2018): Nutrient uptake-modification of different plant species in Mediterranean climate by arbuscular mycorrhizal fungi. *European Journal of Horticultural Science 83*(2): 65-71. DOI: 10.17660/eJHS.2018/83.2.1
Saldaña Argüello, J, A., Náñez Velázquez, A., G. Álvarez Rateike, L. 2023. Chiles de Chiapas, entre gastronomía, cultura e historia. Universidad de Ciencias y Artes de Chiapas, UNICACH. Primera edición. ISBN: 978-607-543-194-9
Santiago-Luna, E. G., Carrillo-Rodríguez, J. C., Chávez-Servía, J. L., Perales-Segovia, C., & Heredia-García, E. (2018).
Santos, M.S., Nogueira, M.A. and Hungria, M., 2019. Microbial inoculants: reviewing the past, discussing the present and previewing an outstanding future for the use of beneficial bacteria in agriculture. *AMB Express, 9*(1),
Sarandon S. 2019. Evaluación de la sustentabilidad en Agroecosistema: Una propuesta metodológica. *Agroecología* 4. Obtenido de https://revistas.um.es/agroecologia/article/view/117131
Secretaria de Agricultura y Desarrollo Rural. (20 de julio de 2020). Reconoce gobierno de México la importancia del chile en identidad cultural y gastronómica del país.
Severino-González P (2017) Responsabilidad social empresa rial y conductores de valor: análi sis de empresas chilenas que publican informes de sustentabilidad. Multidiscip. *Bus. Rev*. 10: 20-34.
Severo EA, de Guimarães JCF, Dorion ECH (2018) Cleaner production, social responsibility and eco-innovation: Generations' perception for a sustainable future. *J. Cleaner Prod*. 186: 91-103.
Shah, S. K.; Shah, R. P.; Xu, H. L. and Aryal, U. K. 2006. Biofertilizers: an alternative source of nutrients for sustainable production of tree crops. *J. Sust. Agric*. 29:85-95.
SIAP, 2018. Servicio de información agroalimentaria y pesquera, producción anual por estado cierre agrícola 2018.
SIAP, 2023. Servicio de información agroalimentaria y pesquera, producción anual por estado cierre agrícola 2023.
Singh, M. 2021. Organic farming for sustainable agriculture. *Indian Journal of Organic Farming*. v, 1. n, 1. p. 1 - 8.
Smith, S. E. and Read, D. J. 2008. Mycorrhizal Symbiosis. 3th. (Ed.). Academic Press. London.
Spinoso Arcocha, R. M. . (2021). Jalapeños: una historia cultural "picante". *Temas Americanistas,* (45), 319-342. https://doi.org/10.12795/Temas-Americanistas.2020.i45.16
Stolz J, Bautista R (2015) Corporate sustainability: perception and response by older consumers. *Int. J. Cons. Stud*. 39: 343-351.
Stott, M. B. and Taylor, M. W. 2016. Microbial ecology research in New Zealand. *New Zealand J. Ecol. 40*(1):12-28.
Tahat, M. M.; Sijam, K. and Othman, R. 2010. Mycorrhizal fungi as a biocontrol agent. *Plant Pathology J.* 9:198-207.
Unno, Y.; Okubo, K.; Wasaki, J.; Shinano, T. and Osaki, M. 2005. Plant growth promotion abilities and microscale bacterial dynamics in the rhizosphere of Lupin analysed by phytate utilization ability. Environ. *Microbiol. 7*(3):396-404
Van Der Heijden, M. G., Bardgett, R. D., & Van Straalen, N. M. (2008). The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecology letters, 11*(3), 296-310.
Vlček V., Pohanka M. (2019). Glomalin – an interesting protein part of the soil organic matter. *Res. Soil and Water Research*, 14. https://doi.org/10.17221/29/2019-SWR
Vosatka, M.; Jansa, J.; Regvar, M.; Sramek, F. and Malcoma, R. 1999. Inoculation with mycorrhizal fungi a feasible biotechnology for horticulture. *Ann. Rev. Bot*. 39:219-224.

Wang, X., Werf, W., Yu, Y., Hoffland, E., Feng, G., Kuyper, T. (2020). Field performance of different maize varieties in growth cores at natural and reduced mycorrhizal colonization: yield gains and possible fertilizer savings in relation to phosphorus application. *Plant Soil 450*(1-2): 613-624. https://doi.org/10.1007/s11104-020-04524-1

Wolfe, B. E. and Klironomos, J. N. 2005. Breaking new ground: soil communities and exotic plant invasion. *BioSci. 55*(6):477-487.

Yin J, Qian L, Singhapakdi A (2018) Sharing sustainability: How va lues and ethics matter in consumers' adoption of public bi cycle-sharing scheme. *J. Bus. Ethics* 149: 313-332.