Fungi as key elements in soil productivity, agriculture, and social wellness

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Received: 02/02/2021. **Revised:** 02/20/2021. **Accepted**: 03/25/2021

Abstract

The lack of knowledge and incorrect land management in certain agricultural practices represent a problem for organisms that contribute to soil health, such as fungi. The objective of this research is to demonstrate the importance of the use of fungi as key elements in soil productivity, agriculture, and social wellness to encourage their use, conservation, and protection. The study was carried out in a 1,5km transect at Finca Boquete-Sibü, Pérez Zeledón in Costa Rica, a Low Montane Rain Forest, where different species of fruiting bodies were observed for nine months during the dry and rainy season. During this period, information such as names, substratum, and altitude was recorded, and, through a review of literature, their functions for agriculture, soil and social wellness were examined. We observed 25 individuals of 17 species of mushrooms, which are the main decomposers of organic matter and recyclers of nutrients in the area. They create mycorrhizae, are nitrogen fixers and pest controllers, and are also used for bioremediation and as indicators of soil quality. Moreover, they can be used as food, medicine, art, or tourism. The responsible use of natural resources such as fungi will allow the conservation of the soil and the ecosystem in general, in addition to increasing food security and social wellness.

Key words: *mushrooms; soil; mycorrhizae; decomposition; bioremediation; social wellness.*

Introduction

The soil suffers serious damage by the intensive production systems due to the lack of knowledge of the characteristic of the edaphic resource, as well as not taking good care of it, third part of the surface is dedicated to agriculture, which exerts degradation and greater pressure in the land, contamination, erosion, loss of the characteristic of the resource and cultural aspects related (Burbano, 2016).

There are millions of forms that live in a small portion of land, which makes possible the functioning of the ecosystem, different biogeochemical cycles, and social wellness. Some of them are fungi, the decomposing organism of the lignin and cellulose (primary components of the wood) mainly, as well as nutrients recyclers since they transform the matter and degrade pollutants introduced to the soil (Moreira et al., 2012; Simeto, 2015).

Mushrooms are essential for the conservation of the land and roots of the plants, 90-95% of land plants create symbiotic relationships making mycorrhizae for the formation of hormones, chlorophyll, tolerance to abiotic and biotic stress, and the nutrients obtaining (occasionally, cause a faster growth of the roots to absorb nutrients like potassium or phosphorus), and that the fungus capture the carbon and nitrogen necessarily for the development, favoring the CO2 uptake the planet (Camargo et al., 2012; Corporación Colombiana de Investigación Agropecuaria, s.f.; Paillacho, 2014).

Also, they can be used in different cultural practices for their functions in medicine to combat diseases, some of them are edible, or in agriculture, since some mushrooms can fight other mushrooms o pathogens on the crops which affects the plants, land, or insects (called entomopathogens mushrooms), as well, they are important in art or tourism (Gómez et al., 2014).

The objective of the research is to demonstrate the importance of the observed mushrooms in Finca Boquete- Sibü in Costa Rica, on the agriculture production systems, soil conservation, and social wellness, promote responsible agriculture and human activities, as well as strengthen their use, protect crops and society.

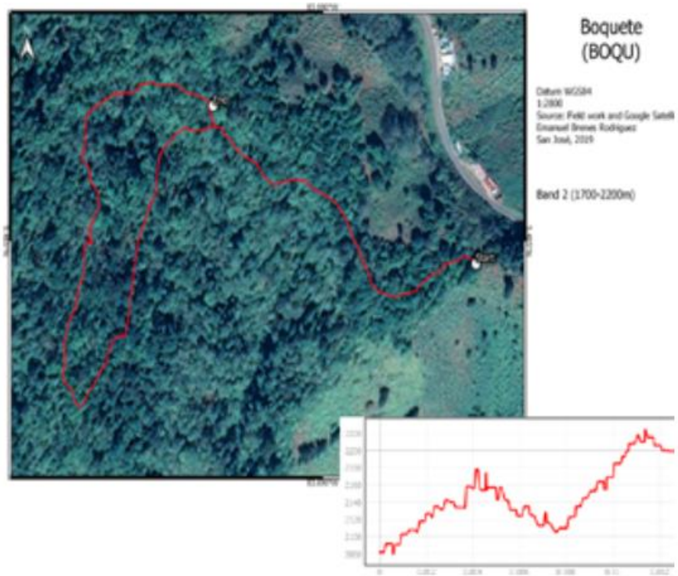

Figure 1. Finca Boquete-Sibü Trail

Note. Photography of Emanuel Brenes. Pérez Zeledón, 2019.

Methodology and materials

Research site

Finca Boquete-Sibü on "El Jardin", is a leafy forest with irregular topographic conditions located 28km north of the central park of Perez Zeledon, Costa Rica at the coordinates 9° 29' 41,9" N and 83° 41' 41,1" W (image 1), between 1500-2400 m.a.s.l. It's found in the lower montane rainforest life zone, with a humid premontane and very humid vegetation, surrounded by Berry plantation. The weather has two stations, the rainy season (mid-April to December) with high precipitations and the dry season (mid-December to mid-April). The average temperature is 13,7°C, with precipitation of 2455mm. The highest precipitation happens in October, with 385mm (Gamboa, 2013; Climate Data, 2021).

Data collection

A monthly visit was made in the camp from March to December 2020 on Finca Boquete-Sibu to document mushrooms fruiting bodies on the Trail of 1,5km. Found individuals were ubicated by a waypoint with a "Garmin Etrex 10" GPS. The gender or specie was noted, including the substratum, altitude, habit, color, or other ecological observations for the correct identification (Vasco et al., 2008).

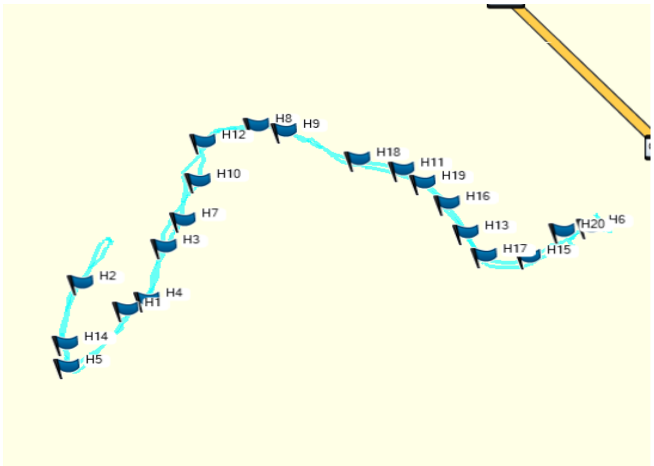

Figure 2. Location of the mushrooms observed on the trail according to your GPS point

Note. Finca Boquete-Sibü, Pérez Zeledón, 2020. Own elaboration.

Results and discussion

Data obtained

Through field visits, could be observed different species of macrofungal. Table 1 shows the most abundant mushrooms found on the trail, with a total of 25 individuals of 17 different species over 9 months. Figure 2 shows the GPS points and trail track where the mushrooms were observed. When marking the point, the identification, altitude, substratum, and others, are noted, besides taking photographs of the species.

Table 1. Mushrooms observed in the Trail on Boquete-Sibü, Pérez Zeledón, 2020

Date	GPS point	Scientific Name	Subtract	Altitude (m.a.s.l.)
15/03/2020	H1	*Chlorociboria aeruginascens*	Decomposing log *(Quercus sp)*	2080
15/03/2020	H1	*Russula sp*	Ground	2080
05/04/2020	H2	*Lentinus sp*	Decomposing log	2124

05/04/2020	H2	*Pleurotus sp*	Decomposing log	2124
07/05/2020	H3	*Ganoderma sp*	Decomposing log *(Quercus sp)*	2092
07/05/2020	H4	*Laetiphorus sulphureus*	Decomposing log	2114
06/06/2020	H5	*Trametes sp*	Decomposing log	2140
06/06/2020	H5	*Hericium sp*	Decomposing log	2140
06/06/2020	H6	*Hygrocybe sp*	Ground	2115
06/06/2020	H7	*Auricularia delicata*	Decomposing log	2191
06/06/2020	H8	*Ganoderma sp*	Decomposing log	2133
06/07/2020	H9	*Lactifluus indigo*	Roots of *Quercus sp*	2190
06/07/2020	H10	*Ramaria cyanocephala*	Roots of trees	2120
06/07/2020	H11	*Ramaria sp*	Decomposing log	2136
06/07/2020	H11	*Boletus sp*	Decomposing log	2136
06/07/2020	H12	*Trametes sp*	Decomposing log	2109
08/08/2020	H13	*Russula sp*	Ground and Litter	2141
08/08/2020	H14	*Lycoperdon sp*	Ground and Litter	2204
08/08/2020	H15	*Lactifluus indigo*	Ground	2195
17/09/2020	H16	*Auricularia delicata*	Decomposing log	2173
06/10/2020	H17	*Ligiella rodrigueziana*	Ground and Litter	2129
25/11/2020	H18	*Laetiphorus sulphureus*	Decomposing log	2166
25/11/2020	H19	*Xylaria sp*	Decomposing log	2201
25/11/2020	H19	*Ganoderma sp*	Decomposing log	2201
07/12/2020	H20	*Hygrocybe sp*	Ground	2153

Note: Elaborated by Krystal Zuniga based on the fungi observed in Finca Boquete-Sibu.

Soil degradation

There's a lot of diversity of fungi with different functions and relations with the environment, which allows the function of the ecosystems and healthy soil. Mycosphere is the area of the substratum where the mycelium develops and the mushroom grows (it conforms by filaments, mainly tubular called hyphae, vegetative units of the mushroom). It's the area where hyphae secretions are exposed and there's an exchange between the organisms that benefit the soil and plants (Kuhar et al., 2014).

Even so, substratum has been affected by unsustainable and intensive practices, like grazing, tillage, use of agrochemicals, contamination, deforestation, population growth, and the lack of knowledge of their characteristics, which affects the diversity, loss of fertility, erosion, the alkalization that damages worldwide food production and food safety. That's why, reducing grazing on agriculture practices can help the stability of soil conditions and ecosystems, protecting fungal networks (Rojas & Ibarra, 2003, FAO, 2015).

Function of fungi

Mycorrizhae:

This association is a symbiosis between a fungus and a plant, which carry out important actions in the natural development of ecosystems and agriculture. One of their functions is to colonize the bark and roots of different plants, increasing their volume, and allowing the individual to purchase nutrients, and minerals, tolerated changes in the soil, and highest water absorption in exchange for carbonated compounds that the guest synthesize on the photosynthetic process. At the same time, the fungi obtained organic nutrients and a protective niche (Yoda, 2009; Berdugo, 2009).

Interaction between plants and fungi are essential, majority of vascular plants get involved with other organisms, highly appreciate feature in the closest areas of the Talamanca Mountain Range of Costa Rica; especially, a forest where predominate Jaul (*Alnus acuminata*), and plants of the Ericaceae family, where is easy to see lots of mushrooms around this substratum (Vargas, 2015).

An important ecological characteristic tree of the trail is the Oak (*Quercus* sp) of the Fagaceae family, they have a big size, and have a strong crust with optimal conditions for symbiotic interactions with some mushrooms, also being the host of species like bromeliads, or orchids, which creates interactions with mushrooms in their early growth development to obtain nutrients and carbon, this mycorrhiza are called orchidoids endomycorrhizae (Marañón, 2011, Andrade, 2010). This tree creates interactions with some mushrooms found in the trail, like *Boletus sp, Russula sp* (figure 3a.), *Ramaria cyanocephala* "Coral mushroom" (figure 3 c.*), Lactifluus indigo* (figure 7a.), which collaborates with the ecosystem restauration of the ecosystem, and *Auricularia delicata* (figure 7.d), nutrients solubilizer mushroom of the plants (Velasco, 2019; Smith & Smith, 2007).

Some mycorrhizae create networks through the mycelium, which connects tree across the forest, share nutrients, warn of pest attacks and protect each other. Others gives mayor resistant to the plants and soil against hydric stress, pathogens, and give advantage in the absorption and transport of ions and essential elements for their development, especially phosphorus, zinc and cooper, which creates high affinity conveyors for these elements, giving additional energy to the plant. At the same time, they reduce the uptake of elements that can be toxic, like manganese (Azcón & Talón, 2008; Borie et al., 2000)

Figure 3. Mycorrhizal mushrooms.

Note. Selection: a- Russula sp., b- Hymenophore of Russula sp., c- Ramaria cyanocephala., d- Ramarioid-shaped basidioma detail of R. cyanocephala. Photography of Krystal Zuniga Castro. Finca Boquete-Sibu. Perez Zeledon, 2020.

Nitrogen fixes:

In agriculture, nitrogen is one of the principal components, if plants are deficient of this element, they can provoke chlorosis (yellow colorations, light green or white color in the foliage and low production or destruction of the leave chlorophyll, mostly for the lack of iron), weakening, and lack of developing, well, most plants can't metabolize nitrogen by their own. Some bacteria are capable to capture atmospheric nitrogen and dispose it for the microorganism and the plants, thus, some mushroom species create symbiotic relationships with other bacteria and at the same time with plants, and make easier the transportation of nitrogen, phosphorus and water. Various author shows that's substratum where the mushroom development happen are found in nitrogen values than oscillate between 0,1% y 1%, for this reason, they are considered that these could be capable of fixing atmospheric nitrogen (Sánchez, 2017).

Protection against phytopathogenic fungi and plant growth stimulators

Trichoderma genre mushroom can be found mostly in the soil, they are fast to grown, they have plant growth promoting enzymes through the production of auxins, gibberellins and organic acids. Its isolation and inoculation for agriculture can decrease the pH of the soil, improve phosphorus absorption, photosynthesis capacity, growth, increase tolerance to soil changes, pathogen control in crops, and others (Hernández et al., 2019)

Some of the cited mushrooms, as well of the genre *Gliocladium*, are used as bio controller against phytopathogens mushrooms, which provoke total or partial diseases of plants structure, alter their development, produce necrosis in their tissues, fruit disfigurement and subterranean products, rottenness, and when consumed can provoke health risks, besides, they are capable to produce mycotoxins that are distributed easily in the substratum (Carreras et al., 2013; Trigos et al., 2018).

Gliocladium roseum is used as a bio controller of *Botrytis cinerea*, parasite mushroom who affects plants fruit and flowers. When they are used, the use of chemicals is avoided and is more efficient than other product. Also, they compete for the substratum colonizing faster and avoids the action of the parasite mushroom *B. cinerea* (Chaves, 2004).

Controllers of nematodes and pathogens:

The soil has different organisms, among them nematodes, these individuals have a stylet in the mouth, which they use to pierce root cells of plants. Most of the cases, they attack the roots, however, they also can be found in the aerial parts of the plant, which facilitates the entry of pathogenic agents that cause damage to its interior (Piedra, 2008). As a measure to counteract this type of pest, it’s possible to implement hematophagous fungi use, which oversee control nematodes biologically.

One species of mushroom with this function are *Pleurotus sp*, one of the most studied species by the scientific. Is characterized by being a toxin producer that immobilize nematodes before getting them infected (López & Hans, 2001). One time the nematode is in touch with the toxin they immobilized, and the fungal hyphae grow through the mouth of the nematode (Piedra, 2015).

Some hematophagous mushrooms that live in soils with high concentrations of organic matter, are used to combat different types of phytoparasites nematodes, like the case of some mushrooms of the genre *Trichoderma*, that when used with metabolites of *Laetiporus sulphureus* (figure 8) allow to fight common phytoparasites nematode in lettuce cultivation, like the case of *Meloidogyne sp* and *Helicotylenchus sp* (Piedra & Vargas, 2016).

Gliocladium sp is one of the most common mushrooms used in the biocontrol of vegetable pathogens and share ecological niches similar as Trichoderma sp. With *Gliocladium*, scientific have created products that protects plants roots, and it is possible to reduce the use of chemical applications (Cano, 2011; Van, 2014).

Soil bioremediation:

Bioremediation mushrooms allow the degradation of polluting agents in the soil. An example can be the mushrooms genre of *Ganoderma* (figure 4) and *Pleurotus*, which have laccase enzymes and act in degradation of lignin waste (wall-reinforcing biopolymer cell that provides resistance to plants), allowing processes of enzymatic bioremediation in the soil (Valdés, 2018).

Pleurotus mushrooms is the main precursor for the reserve of organic material in the soil, can mineralize polluting agents of the land by introducing their enzymes, and regulates the carbon circle, being a requirement for the hydrolysis of plants biomass components, photosynthetic rate and phenological state (Coello, 2011; Ortiz, 2009; Cerón & Melgarejo, 2005).

Mushrooms like *Trametes* are important for the elimination of residuals and recycling of matter, its nutrition occurs through wood decomposition, being degraders of environmental pollutants like pesticides or explosives, and have a potential use in bioremediation, as well as *Trichoderma* since it grows on various substrates and degrades hydrocarbon, polysaccharides, and other (Estrada et al., 2016, Cano 2011).

Figure 4. Fungi for soil remediation

Note. Selection: a- Ganoderma sp., b- Details of Ganoderma sp. Photography of Krystal Zuniga Castro. Finca Boquete-Sibu. Perez Zeledon, 2020.

Figure 5. Organic matter decomposers and nutrient recycling

Note. Selection: a- Lycoperdon sp., b- Gasteroid morphology of Lycoperdon sp., c- Ligiella rodrigueziana., d- Hygrocybe sp. Photography of Krystal Zuniga Castro. Finca Boquete-Sibu. Perez Zeledon, 2020.

Organic matter decomposers and nutrient recycling:

Saprophytic mushrooms are individual that get their nutrition by organic matter residuals, helping with the decomposition. *Trichoderma* and *Lycoperdon* fungi are decomposers of woody and herbaceous matter. *Lycoperdon* (figure 5.a) has a gasteroid morphology (stomach shape), and one of the main functions is to degrade organic matter and the recycling of nutrients, making the soil more productive (Salinas & Gómez, s.f.).

Species like *Ligiella rodrigueziana* (figure 5.c) are indicators of a rich organic matter forest for their decomposition, also like *Hericium* and *Auricularia*, they contributed to the nutrients reuse (Sáenz & Nassar, 1981).

Hygrocybe genre (figure 5.d) are present in lands with gran amount of vegetal matter, they attack the remains of leaves with a network of hyphae, which provokes leaf mineralization. As well, indicates soil quality because they are in soil with little nitrogen and other nutrients, where the fructiferous bodies of the mushrooms are more dominant. Hygrophoraea family are used in North Europe and Greenland as a group with conservation purposes (Lodge et al., 2013). *Ganoderma, Pleurotus* and *Lentinus* (figure 6.a), are frequently used for the recycling of lignocellulosic waste and the transformation of pollutants like hydrocarbons, fertilizers, or pharmaceutical products. Their mycelium also exhibits rapid growth, reduce bacteria and have the capacity of growth in different substratum and environmental conditions (Sánchez & Royse, 2017; Gaia et al., 2015).

In the case of *Xylaria sp* "dead fingers" (figure 6.b), or *Trametes sp*, are important decomposers for its high production of enzymes, so they have been used for biotechnological applications in agriculture (Sandoval et al., 2017; Estrada et al., 2016).

Mushrooms like *Ganoderma* are one of the most abundant decomposers, they grow up in tropical environments and cause a "white death" on the roots and heartwood (central parts that provide resistance to branches or stems creating dead cells without conducting activity), until provoke their degradation. Some species of this genre have very important antioxidants properties (Hernández, s.f.; Islas et al., 2017).

Figure 6. Organic matter decomposers and nutrient recycling

Note. Selection: a- Lentinus sp., b- Xylaria sp. Photography of Krystal Zuniga Castro. Finca Boquete-Sibu. Perez Zeledon, 2020.

Edible, medicinal, artistic and tourist mushrooms:

Mushrooms can also be a great tourist attraction thanks to mycotourism, an activity focused on their appreciation, mycogastronomy and, on occasions, their collection. It is a cultural practice, due to the interest in knowing the places where mushrooms come from (mainly edible), their preparation and consumption ethics. For a sustainable myco-tourism, prior knowledge of fungi is needed, and a mycological information system through georeferencing methods and ethno-biological indicators, which will determine the fungi can be used and their availability (Thomé, 2014).

Some mushrooms can also be edible or medicinal, such as *Hericium sp* (Figure 9), one of the most important in medicine and gastronomy, which has a high fiber content, regenerates the intestinal mucosa, promotes brain development, is antitumor and it is used in neurodegenerative and digestive diseases (Hifas da Terra Mushroom Bioscience, 2020). Some, such as *Auricularia delicata* (Figure 7 c.), which is gelatinous and has the shape of an ear, despite being edible, due to its low nutritional content as it is 90.2% water, it is not very useful in gastronomy in Latin America (Melgarejo, 2014).

Figure 7. Edible and medicinal mushrooms.

Note. Selection: Hericium sp. Photography of Krystal Zuniga Castro. Finca Boquete-Sibü, Pérez Zeledón, 2020

Edible mushrooms such as *Lactifluus indigo*, abundant mainly in rainy seasons, form important mycorrhizae, and have a high nutritional value. Recent studies show that it also has pharmaceutical, anticancer and microbial properties (Cano & Romero, 2016). It is characterized by the presence of latex in the carpophores (fruiting body of the fungus made up of hyphae, with colors and shapes according to its species), which change color when cut (Ardiles et al., 2009). Latex contains different sesquiterpenes, including stearoildeterrol, this being the main one in the carporophos, and the one responsible for its blue color. Sesquiterpenes act as a chemical defense against predators since they present great microbial activity, for which their direct consumption, without prior cooking, could cause intoxication (Pomilio, 2019).

Figure 8. Edible mushrooms

Note. Selection: a-Lactifluus indigo, b-Hymenophore of L. indigo, c-Auricularia delicata, d- Details of A. delicata. Photography of Krystal Zúñiga Castro. Finca Boquete-Sibü, Pérez Zeledón, 2020.

Laetiporus sulphureus, popularly called "chicken of the woods", contains a large amount of protein, carbohydrates and a pleasant flavor that is very characteristic of its species, it has antimicrobial, antioxidant and antitumor properties. It should not be consumed in its immature state, and it is recommended not to mix it with alcohol (Rodríguez, 2019).

Figure 9. Edible mushrooms.

Note. Selection: a-Laetiporus sulphureus, b-Details L. sulphureus. Photography of Krystal Zúñiga Castro. Finca Boquete-Sibü, Pérez Zeledón, 2020

Chlorociboria aeruginascens fungi (figure 10 a.), which is found mainly in trees of the Fagaceae family (*Quercus sp*), has been used over time to create artworks, due to the color that the substrate takes on when it decomposes. Italian artists, more than 500 years ago, created an artistic method called Intarsia, in which wood is used with the presence of the blue-green pigment called xylindein released by the fungus (Robinson et al., 2012).

Figure 10. Mushrooms for artistic techniques.

Note. Selection: a- Chlorociboria aeruginascens, b- C. aeruginascens on Quercus sp, c- Xylindein pigment on Quercus sp, decomposition product of C.aeruginascens. Fotografías de Krystal Zúñiga Castro. Finca Boquete, Pérez Zeledón, 2020

Conclusions

The use of fungi in agriculture is one of the most important advances in the search for solutions and natural controllers to improve soil health and strengthen crops, since they can eliminate pathogens, control nematodes and diseases, which is why it is possible to reduce the number of agrochemicals and inhibitory drugs in the plants.

In addition, it is an efficient and ecological alternative that provides numerous benefits to the soil and plants, such as improving their nutritional level, obtaining nitrogen, water, favoring growth, development and communication through the networks formed by the mycelium.

Their protection can have a social and environmental impact due to their functions in the decomposition of matter and soil bioremediation, in addition to being used as food, medicine, in art and tourism. Mushrooms strengthen food security, development and environmental conservation.

References

Andrade, A. (2010). Micorrizas: antigua interacción entre planta y hongos. *Ciencia, vol 61 (4), 84-90.* https://www.revistaciencia.amc.edu.mx/images/revista/61_4/PDF/11_MICORRIZAS.pdf

Ardiles, V.; Osorio, F.; Barrera, E. (2009). *Gayana Botánica, 66 (1), 84-91*. https://scielo.conicyt.cl/scielo.php?script=sci_arttext&pid=S0717-66432009000100008

Azcón, J., Talón, M. (2008), *Fundamentos de fisiología vegetal.* Madrid, España. McGraw-Hill.http://exa.unne.edu.ar/biologia/fisiologia.vegetal/FundamentosdeFisiologiaVegetal2008Azcon..pdf

Berdugo, S. E. (2009). El uso de hongos micorrízicos arbusculares como una alternativa para la agricultura. *Biotecnología en el Sector Agropecuario y Agroindustrial, 7(1), 123-132.* https://revistas.unicauca.edu.co/index.php/biotecnologia/article/view/706

Borie, F.; Morales, R.; Castillo, C. (2000). Relación entre densidad de hifas de hongos micorrizógenos arbusculares y producción de glomalina con las características físicas y químicas de suelos bajo cero labranza. *Revista Chilena de Historia Natural, 73 (4), 749-756.* https://scielo.conicyt.cl/scielo.php?script=sci_arttext&pid=S0716-078X2000000400017

Burbano, H., (2016). El suelo y su relación con los servicios ecosistémicos y la seguridad alimentaria. *Revista de Ciencias Agrícolas, 33 (2), 117-124.* http://www.scielo.org.co/pdf/rcia/v33n2/v33n2a11.pdf

Camargo, S.; Montaño, M.; De la Rosa, C; Montaño, S. (2012). Micorrizas: una graqn unión debajo del suelo. *Revista Digital Universitaria, vol 13 (7), 4.* http://www.revista.unam.mx/vol.13/num7/art72/

Cano, A., Romero, L. (2016). Valor económico, nutricional y medicinal de hongos comestibles silvestres. *Revista Chilena de Nutrición, 43, (1), 75-80.* https://www.redalyc.org/pdf/469/46946023011.pdf

Cano, M. (2011). Interacción de microorganismos benéficos en plantas: micorrizas, *Trichoderma spp*. y *Pseudomonas spp.* Una revisión. *Revista UDCA Actualidad y Divulgación Científica, 14, (2), 15-31*. http://www.scielo.org.co/pdf/rudca/v14n2/v14n2a03.pdf

Carreras, N.; Hernández, E.; Sánchez, D. (2013). Conociendo a los hongos fitopatógenos. *Ciencia Hoy*. https://www.inecol.mx/inecol/index.php/es/2013-06-05-10-34-10/17-ciencia-hoy/1042-conociendo-a-los-hongos-fitopatogenos

Cerón, L.; Melgarejo, L. (2005), Enzimas Del Suelo: Indicadores de salud y calidad, *Acta Biológica Colombiana, 10 (1): 5-18.* https://www.redalyc.org/pdf/3190/319028576001.pdf

Chaves, N., Wang, A. (2004). Combate del moho gris *(Botrytis cinerea)* de la fresa *Gliocladium roseum*. *Agronomía Costarricense. 28(2): 73-85.* https://www.mag.go.cr/rev_agr/v28n02_073.pdf

Climate Data (2021). Jardín Clima, Costa Rica. *Climate-Data.org*. Consultado el 29 de enero de 2021. Recuperado de https://es.climate-data.org/america-del-norte/costa-rica/san-jose/jardin-719097/#weather

Coello, J. (2011). *Aplicación del Hongo Pleurotus ostreatus como alternativa para la biorremediación de suelos contaminados con metales pesados*. Tesis de Licenciatura. Guayaquil, Ecuador, Escuela Superior Politécnica del Litoral, Guayaquil. Ecuador. https://www.dspace.espol.edu.ec/bitstream/123456789/21150/1/D-92862.pdf

Corporación Colombiana de Investigación Agropecuaria. (s.f.). *Las Micorrizas: una opción sostenible de manejo de suelos y nutrición de las plantas.* Bogotá, Colombia: C*orpoica. 2 p.* https://books.google.co.cr/books?id=bTmd-_XYrPwC&pg=PA6&dq=micorrizas&hl=es&sa=X&ved=2ahUKEwj68LL68p3tAhXFQjABHfIKBfIQ6AEwAHoECAUQAg#v=onepage&q=micorrizas&f=false

FAO. (4 de diciembre 2015). Los suelos están en peligro, pero la degradación puede revertirse. *Organización de las Naciones Unidas para la Alimentación y la Agricultura*. http://www.fao.org/news/story/es/item/357165/icode/

Gamboa, F. (2013). *Promoción de herramientas organizativas, de planificación y fomento del capital social para el desarrollo comunal: el caso de la comunidad de El Jardín, Paramo, Pérez Zeledón (Marzo-Diciembre, 2013).* Trabajo final de graduación.

Universidad de Costa Rica. http://repositorio.sibdi.ucr.ac.cr:8080/jspui/bitstream/123456789/2553/1/38701.pdf

Gómez, H., Zapata, A., Torres, E., Tenorio, M., (2014). *Manual de producción y uso de hongos entomopatógenos.* Servicio Nacional de Sanidad Agraria de Perú. https://www.senasa.gob.pe/senasa/descargasarchivos/2017/09/Manual-de-Producci%C3%B3n-y-Uso-de-Hongos-Entomopat%C3%B3genos.pdf

Hernández, A. (s.f.). Albura y Duramen. *Ciencias en pocas palabras*, *232 (26)*, *415*. https://www.sabermas.umich.mx/archivo/la-ciencia-en-pocas-palabras/232-numero-26/415-albura-y-duramen.html

Hernández, D., Ferrera, R., Alarcón, A. (2019). Trichoderma: Importancia Agrícola, biotecnológica, y sistemas de fermentación para producir biomasa y enzimas de interés industrial. *Chil. j. agric. anim. Sci, 35, (1). 98-112.* https://scielo.conicyt.cl/scielo.php?script=sci_arttext&pid=S0719-38902019000100098#B67

Hifas da Terra Mushroom Bioscience., (2020). *Melena de León. Hifas da Terra* Mushroom Bioscience. (en línea). https://hifasdaterra.com/blog/hongos/melena-de-leon-hericium-erinaceus/

Islas, M., Castañeda, A., Álvarez, A., Valenzuela, R., Romero, L., Torres, J. (2017). Estudio preliminar de la actividad antioxidante de tres especies del género *Ganoderma* (Polyporaceae) nativas del estado de Hidalgo, México. *Revista Mexicana de Micología*, *Xalapa*, *46*, *37-45*. <http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-31802017000200037&lng=es&nrm=iso>

Lodge, D., Padamsee, M., Matheny, P., Aime, M., Cantrell, S., Boertmann, D.,_Kovalenko, A., Vizzini, A., Dentinger, B., Kirk, P., Ainsworth, M., Moncalvo, J., Vilgalys, R., Larsson, E., Lücking, R, Griffith, G., Smith, M., Norvell, L., Desjardin, D., Redhead, Scott., Ovrebo, C., Lickey, E., Ercole, E. Hughes, K., Courtecuisse, R., Young, A., Binder, M., Minnis, A. Lindner, D., Ortiz, S., Haight, J., Læssøe, T., Baroni, T., Geml, J., Hattori, T. (2014). Molecular phylogeny, morphology, pigment chemistry and ecology in Hygrophoraceae (Agaricales). *Fungal Diversity*, *64, (1). 1-99.* https://link.springer.com/article/10.1007/s13225-013-0259-0

Kuhar, F.; Castiglia, V.; Papinutti, L. (2013). Reino Fungi: Morfología y estructuras de los hongos. *Revista Boletín Biológica, 48 (7), 11-18.* https://core.ac.uk/download/pdf/52479411.pdf

Melgarejo, E. (2014). Dos hongos silvestres comestibles de la localidad de Incachaca, Cochabamba (Yungas de Bolivia). *Acta Nova, 6, (4), 384-394.* http://www.scielo.org.bo/pdf/ran/v6n4/v6n4_a04.pdf

Moreira, F., Huising, E., Bignell, D. (2012). *Manual de biología de suelos tropicales*. Instituto Nacional de Ecología, México. México. https://books.google.co.cr/books?id=m-QMZaBiP0YC&printsec=frontcover&hl=es&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Ortíz, M. (2009). Aproximaciones a la comprensión de la degradación de la lignina. *Orinoquia, 13 (2), 137-144.* https://www.redalyc.org/pdf/896/89613728007.pdf

Paillacho, F. (2014). *Evaluación de la efectividad de las micorrizas arbusculares nativas sobre el desarrollo y estado nutritivo del palmito (Bactris gasipaes hbk) en etapa de vivero, en santo domingo de los tsáchilas.* Tesis de maestría. Escuela Politécnica del Ejército, Ecuador. http://repositorio.espe.edu.ec/xmlui/bitstream/handle/21000/2892/T-ESPE-IASA%20II-002332.pdf?sequence=1&isAllowed=y

Piedra, R., Vargas, C. (2016). Hongos hematófagos en el combate de nematodos fitoparásitos asociados al cultivo de lechuga. *Alcances Tecnológicos, 11(1): 41- 48.* http://revista.inta.go.cr/index.php/alcances_tecnologicos/article/download/26/14/

Piedra, R. (2008). Manejo biológico de nematodos fitoparásitos con hongos y bacterias, *Tecnología en Marcha, 21(1): 123 – 132.* https://revistas.tec.ac.cr/index.php/tec_marcha/article/view/1345

Piedra, R. (2015). Guía de muestreo de nematodos fitoparásitos en cultivos agrícolas, *Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria San José, C.R., 22 p.* http://www.mag.go.cr/bibliotecavirtual/H10-10789.PDF

Pomilio, A., Maris, S., Alonso, A. (2019). Micetismos. Parte 3. Síndromes tempranos gastrointestinales. *Toxicología, 53, (2), 14-19.* https://www.redalyc.org/jatsRepo/535/53560335009/html/index.html

Robinson, S., Tudor, D., Snider, H., Cooper, P. (2012). Stimulating growth and xylindein production of Chlorociboria aeruginascens in agar-based systems. *AMB Express Journal, 2 (15), 1-7*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3350399/

Rodríguez, I. (2019). *El pollo del bosque no es un animal.* Revista de Biología Tropical (en línea). https://revistas.ucr.ac.cr/index.php/rbt/article/view/39416

Sáenz, J., Nassar, M. (1981). Hongos de Costa Rica: Familias Phallaceae y Clathraceae. *Revista de Biología Tropical. 30, (1), 41-52.* https://tropicalstudies.org/rbt/attachments/volumes/vol30-1/05-Saenz-Hongos.pdf

Salinas, M., Gómez, R. (s.f.). Los estómagos de los bosques, hongos gasteroides. *Saber Más, Revista de Divulgación de la Universidad Michoacana de San Nicolás de Hidalgo. 299, (52). 542.* https://www.sabermas.umich.mx/archivo/articulos/299-numero-35/542-los-estomagos-del-bosque-hongos-gasteroides.html

Sánchez, J., Royse, D. (2017). *La biología, el cultivo y las propiedades nutricionales y medicinales de las setas Pleurotus sp.* El Colegio de la Frontera Sur, San Cristóbal de las Casas, Chiapas, México. http://aleph.ecosur.mx:8991/exlibris/aleph/a22_1/apache_media/TVYDRJDU7JPAQEH4LF688NSKFF8S7Q.pdf

Sandoval, J.; Ochoa, F.; Torres, E. (2017). Evaluación de diferentes métodos de extracción de ARN a partir del hongo nativo *Xylaria sp*. *Revista Colombiana de Biotecnología, 19 (1), 42-54.* https://www.researchgate.net/publication/318006608_Evaluacion_de_diferentes_metodos_de_extraccion_de_ARN_a_partir_del_hongo_nativo_Xylaria_sp

Smith, T.; Smith, R. (2007). Ecología. Madrid, España: Pearson Educación.

Trigos, A.; Ramírez, K.; Salinas, A. (2018). Presencia de hongos fitopatógenos en frutas y hortalizas y su relación en la seguridad alimentaria. *Revista Mexicana de Micología, 28, 125-129.* http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-31802008000300015

Thomé, H. (2014). Turismo micológico, una nueva mirada al bosque. *Ciencia y Desarrollo, 25, 10-17.* https://www.cyd.conacyt.gob.mx/?p=articulo&id=25

Valdés, S. (2018). *Aislamiento y purificación parcial de enzimas microbianas de tipo Lacasa, para la degradación de desechos de piña, banano y caña, Universidad de Costa Rica.*

Tesis Lic. Heredia, CR. UNA. https://repositorio.una.ac.cr/bitstream/handle/11056/14365/Tesis%20Sandra%20Valdés%20Diaz.pdf?sequence=1

Van, A. (2014). *Encyclopedia of Agriculture and Food Systems.* ScienceDirect. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/gliocladium

Vargas, G. (2015). Botánica general: Desde los musgos hasta los árboles. San José, CR: EUNED.

Vasco, A.; Suaza, S.; Castaño, M.; Franco, A. (2008). Conocimiento etnoecológico de los hongos entre los indígenas Uitoto, Muinane y Andoke de la Amazonia de Colombia.

Velasco, M. (2019). *Hongos en rodales de pinos-encino en la comunidad de Miguel Hidalgo*. *Municipio de San Antonio Huitepec, Distrito de Zaachila, Oaxaca*. Tesis de Maestría. Universidad Autónoma de Chepingo, Oaxaca, México. http://dicifo.chapingo.mx/pdf/tesis