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REVIEW

Mycorrhizal science outreach: Scope of action and available resources in the face of global change

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Societal Impact Statement

Mycorrhizal associations are acknowledged as key components of global ecosystem functioning. This is especially relevant in the context of global change, since they contribute to the amelioration of adverse soil conditions and play crucial roles in agriculture. Generally speaking, the lay public is uninformed on the importance of mycorrhizal fungi and symbiosis to our planet. Therefore, mycorrhizal scientific outreach activities are of paramount importance in order to bridge the aforementioned gap. We think that informing people about the benefits of mycorrhizal fungi and symbiosis in the face of global change, will raise general awareness of relevant research and aid conservation efforts.

Summary

Science outreach has become a particularly important duty in shortening the knowledge gap between scientists and the public, in order to strengthen societal decision-making power in the global change crisis. Mycorrhizal fungi and mycorrhizal symbioses are key components of terrestrial ecosystems that contribute significantly to endure and reduce certain negative global change effects. Their importance has been gaining recognition in academic circles, but not among the general public. The aim of this article is to encourage as many mycorrhizal fungi researchers around the world as possible to build, through science outreach, a bridge between their scientific work and public interest. To this end, we conducted a review and discussed the relationship between global change and the mycorrhizal symbiosis. We highlight potential audiences, tools, resources, activities, outreach models, pros and cons, as well as the quantification potential for the outreach activities success. We extend an invitation to all mycorrhizologists around the world to contribute with mycorrhizal outreach material. Contributions will become available on the South American Mycorrhizal Research Network website for individuals or organizations interested in starting or innovating in mycorrhizal science outreach activities. Finally, the hashtag ***#mycorrhizalscienceoutreach*** is proposed to be used whenever a mycorrhizal fungi-related science outreach activity is shared in social media.

KEYWORDS

#mycorrhizalscienceoutreach, mycorrhizal fungi, public science, science communication, science outreach, social media

1 | INTRODUCTION

Global change is undoubtedly the main existential threat that humanity faces in the 21st century. Shortening the knowledge gap between scientists and the public, through science outreach, is essential to confront this threat. Peer-reviewed articles are mostly unintelligible for non-academics, unavoidably generating a communication gap between the public and academia (Bensaude-Vincent, 2001). For instance, currently a substantial proportion of the world's population (Bensaude-Vincent, 2001) and even policy decision makers (Bórquez, 2017) do not understand certain basic scientific concepts. Politics, religion, and culture, among other factors, have generated skepticism, and even hostility, towards science and technology (Dickson, 2005). Consequently, science outreach should no longer be considered a minor activity for scientists (Poliakoff & Webb, 2007) but rather a moral duty towards the public that funds most of the research scientists do. Science outreach enables the public to acknowledge and embrace the power of science in order to propose and demand evidence-based solutions to policy makers.

The aim of this article is to encourage as many mycorrhizal fungi researchers around the world as possible to build a bridge between their scientific work and public interest, as well as to transfer knowledge and act as translators of scientific jargon, in order to actively bridge the existing gap between society and scientists in a global change scenario. Here, we focus on global change and its relation with mycorrhizas and mycorrhizal science outreach, since this symbiosis is directly related to different environmental processes severely affected by this global phenomenon. Increasing public awareness of the relevance of this specific interaction between plants and fungi, presenting it as a key factor to mitigate global change and its effects on society, could be decisive towards appropriate actions and decision making in a changing world. Potential audiences, tools, resources, activities, outreach models, pros and cons, as well as quantification potential for outreach activity success are discussed. Final considerations, as well as a call for contributions to mycorrhizal science outreach, are also included.

2 | GLOBAL CHANGE AS A FACT

Even though change has been a constant to the global environment across the history of Earth, and would still be ongoing in the absence of humans, there is an overwhelming evidence that humans have vastly accelerated the pace of many, otherwise natural, changes (IPCC, 2013). Moreover, humans have also introduced several other changes, previously absent from Earth, such as the transformation of natural areas into agricultural and urban landscapes; species introductions, many of which become invasive, and extinctions; as well as changes in the frequency and severity of diseases and fires, among other disturbances. These different types of human-induced global changes act together to alter, impair, or eliminate many of the environmental services and amenities on which human societies are based (IPCC, 2013; National Research Council, 2000; Shah, 2014).

Several anthropogenic activities have an enormous impact on the global environment; for example, CO_2 levels and emissions of nitrogenous gases have increased disproportionately since the industrial revolution. Levels of CO_2 and N deposition are predicted to double by 2050 and 2100 (Collins et al., 2013), respectively, mainly as a consequence of fossil fuel combustion, an increasing number of industries, and agricultural intensification. Tropospheric levels of O_3 have also increased more than twofold in the last century and continue to rise (Cotton, 2018; IPCC, 2013). These atmospheric shifts have global consequences for ecosystems, both directly and indirectly. Increased CO_2 and N emissions have led to serious perturbations of the terrestrial C and N cycles. Furthermore, accumulated greenhouse gases have increased global temperatures 0.85°C between 1880 and 2012 and are likely to increase up to 0.3–4.8°C by the end of the 21st century (IPCC, 2013). Severe droughts and heavy rainfalls, among other subsequent changes in global weather patterns, are expected to reduce soil moisture during increasingly more intense and frequent extreme climate events (Carrenho & Krzyzanski, 2020; Cotton, 2018 and references within; IPCC, 2013; Shah, 2014).

3 | GLOBAL CHANGE AND MYCORRHIZAL SYMBIOSES

Plants, mycorrhizal fungi, and other soil organisms are not exempt from the consequences of global change. In fact, the role of mycorrhizal fungi and their symbioses as key components of ecosystems in the global change context is becoming increasingly recognized (Steidinger et al., 2019). This is because any variation in the functioning of this group of organisms will directly or indirectly alter plant responses to these disturbances. Consequently, they are expected to be important players in ecosystem responses to global change drivers or mitigation thereof.

Mycorrhizas are a symbiotic association that occurs between certain groups of soil fungi and the roots of most terrestrial plants (Smith & Read, 2008). Estimations indicate that these symbioses occur in 92% of terrestrial plants (Brundrett & Tedersoo, 2018). Four main mycorrhizal types are recognized, depending on the fungal and plant taxa involved, and the morphological structures formed: arbuscular mycorrhiza (AM), ectomycorrhiza (EcM), orchid mycorrhiza (OrM), and ericoid mycorrhiza (ErM) (Brundrett & Tedersoo, 2018; Kariman et al., 2018). This association has been described as having multiple functions and benefits for both symbionts. The most widely studied function corresponds to the exchange of nutrients between the plant and the fungus (Smith & Read, 2008), in which the mycobiont uptakes nutrients and water from soil and receives carbohydrates (Smith & Read, 2008)—, and also lipids in the case of AM (Jiang et al., 2017; Keymer et al., 2017; Luginbuehl et al., 2017)—in return. However, other significant functions include plant tolerance to biotic and abiotic stress provided by the fungus (Delavaux et al., 2017; Rasmann et al., 2017), and a plant-provided secure habitat for the mycorrhizal fungus that enables its survival and reproduction (Brundrett, 2002). These functions directly influence the biological fitness of both symbionts (Davison et al., 2016; Klironomos et al., 2011). Interestingly, the relevance of this symbiosis upscales to population, community, and ecosystem levels, as mycorrhizal associations play major roles in plant species recruitment, community diversity, and ecosystem productivity, modulating soil properties, and even driving C, N, and P cycling (van der Heijden et al., 2015; Tedersoo et al., 2020).

The study of global change effects on the mycorrhizal symbiosis presents major challenges. One of them is that global change factors are not usually independent of one another, but comprise a complex multifactorial scenario that must be considered in depth when designing a variety of approaches and in drawing conclusions (Carrenho & Krzyzanski, 2020; Rillig et al., 2002; Shah, 2014). In this sense, a fundamental distinction is required since a mycorrhizal symbiosis involves an interaction between two organisms with partially independent biology (Rillig et al., 2002), namely, the plant and the mycobionts. Some factors only directly affect the host plant (e.g., C fixation) and have indirect effects on mycobionts via altered C allocation from the host. Other factors include atmospheric changes (e.g., CO_2, UV-B radiation, and O_3) (Krupa & Kickert, 1989), against which soil largely acts as a buffer. On one hand, some other factors can directly affect not only the host plant but also the mycobionts (e.g., warming, altered precipitation, or droughts) (Figure 1). The direct effects of global change on mycobionts could also lead to an altered production of sporomes (EcM) or spores (AM) and could modify hyphal physiology (e.g., growth rate, nutrient uptake, or translocation ability). Any effect on the extraradical mycelium of mycorrhizal fungi can directly impact soil structure as well as biogeochemical cycling processes, including C sequestration (Rillig et al., 2002). On the other hand, such changes lead to asymmetrical effects on different mycorrhizal fungi, which may in turn result in significant shifts in fungal community composition or an altered mycobiont symbiotic efficiency and fungal dispersal, with a subsequent impact on plant communities (Bennett & Classen, 2020; Carrenho & Krzyzanski, 2020; Rillig et al., 2002).

In recent years, some reviews have compiled information on the effects of different factors associated to global change on different

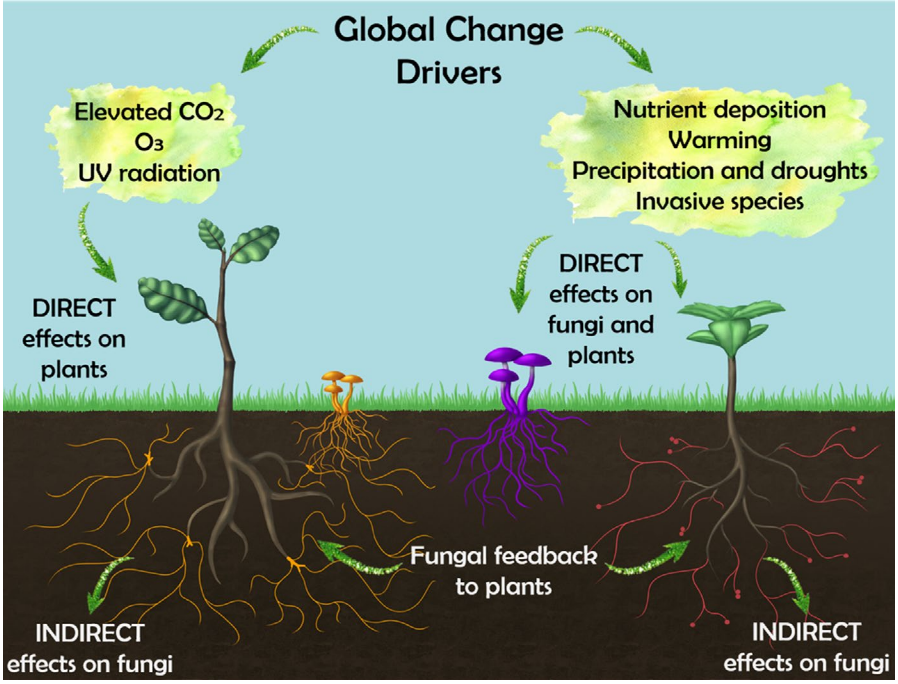

FIGURE 1 Effects of different global change factors on plant–fungi interactions. Some factors only affect plants directly and have indirect effects on mycobionts via altered carbon allocation from the plant to the fungus. Other global change factors directly affect both the plant and the fungus. At the same time, global factor-induced altered symbiotic functioning of mycobionts will result in different feedback effects on plants. The study of this intricate set of interactions poses an interesting challenge for mycorrhizologists

mycorrhizal associations (Bennett & Classen, 2020; Carrenho & Krzyzanski, 2020; Cotton, 2018; Johnson et al., 2013; Mohan et al., 2014). These studies reveal that a specific driving factor (e.g., elevated CO_2 or N deposition) might have positive, neutral, or negative impacts on the occurrence and activity of mycorrhizal fungi (Carrenho & Krzyzanski, 2020; Cotton, 2018; Mohan et al., 2014; Rillig et al., 2002; Shah, 2014). One of the reasons for such discrepancies is that the responses of mycorrhizal fungi to global change are often context specific; e.g., they vary widely depending on the plant and fungi taxa involved, their geographical location, and their physiological characteristics or intrinsic environmental features (Cotton, 2018; Mohan et al., 2014). Another reason is that there are several unfulfilled knowledge gaps. For example, most studies conducted to date have considered a single factor, despite overwhelming evidence suggesting that the drivers of global change are diverse and usually interact in complex ways to influence plant–mycorrhizal fungi feedbacks (Shah, 2014). Furthermore, most of the studies have only documented short-term and local-scale responses, neglecting the particular relevance of longer term and large-scale responses such as shifts in global distribution, or regional extinction, of plant communities and associated mycorrhizal types due to climate change. In addition, changes in a mycorrhizal fungal community, independent of changes in the plant community, may be some of the least understood, but potentially most important, mycorrhizal responses to global change (Bennett & Classen, 2020; Rillig et al., 2002).

Another well-documented limitation is that the vast majority of studies regarding mycorrhizal associations and global change were conducted in the northern hemisphere, thus leaving an extensive knowledge gap in areas of the world expected to be severely impacted by global phenomena. Furthermore, most of the studies have been conducted in AM and EcM, leaving ErM and OrM as the least studied groups (Bennett & Classen, 2020). This is astonishing, considering that orchids are one of the two largest families of flowering plants and occupy a wide range of habitats worldwide (Chase et al., 2015; Jacquemyn et al., 2017). Besides, they are all fully dependent on mycorrhizal fungi (mycoheterotrophic) during germination and early development stages. In fact, some orchids are fully mycoheterotrophic throughout their entire lives (Jacquemyn et al., 2017; McCormick et al., 2018). Consequently, any change that affects their mycobionts will definitely influence orchid communities, and determine whether they can colonize new habitats or become threatened in others (Carrenho & Krzyzanski, 2020; Jacquemyn et al., 2017). It is also important to keep in mind that mycorrhizal fungi cannot be viewed in isolation from the soil ecosystem; global change factors that influence other soil biota (e.g., fungal grazers, mycorrhization helper organisms, and/or other root-inhabiting microbes) or physical factors (e.g., soil structure) can have potentially large, indirect effects on mycorrhizal fungal diversity and functioning (Zhou et al., 2020).

What is the influence of all this in our daily lives and in society in general? Since the mycorrhizal symbiosis is essential to most plants, any factor influencing this symbiosis will have an impact on vegetation, in turn affecting the composition, distribution, and/or productivity of plant communities in our surroundings. Moreover, the mycelial networks that mycorrhizal fungi develop in soil have a significant binding action, improving soil structure and quality.

Consequently, any factor that reduces fungal biomass will negatively affect soil properties and increase the risk of soil erosion. This aspect is not to be underestimated, because soil is a nonrenewable resource on a human time scale and the impact of erosion is often cumulative and, in most instances, irreversible. In addition, mycorrhizal fungi might also promote plant growth and reduce the need for fertilizer inputs, which also contribute to global change. For example, under given field conditions, it has been estimated that a reduction of 80% of the recommended phosphate fertilizer could be supplemented by inoculation with AM fungi. It is evident that such reductions in phosphate application have important economic and environmental impacts. In the same sense, it is also known that mycorrhizal fungi increase plant tolerance against abiotic (mineral depletion, drought, salinity, heavy metals, extreme temperatures) and abiotic stresses (pathogens, competition), but also enhance plant quality for human health (e.g., increment Zn uptake by plants, stimulation of synthesis of secondary metabolites—such as antioxidants—and molecules with medicinal interest) (de Carvalho et al., 2010; Gianinazzi et al., 2010). One of the main challenges for agriculture today lies in the possibility to take advantage of the numerous economic benefits and ecosystem services as soil stabilization, biofertilization, bioprotection, and bioregulation offered by this natural resource (Gianinazzi et al., 2010).

The information above highlights the key role of mycorrhizal fungi and the mycorrhizal symbiosis in the context of global change. Understanding how global change affects this group of organisms will greatly facilitate nature- and evidence-based solutions to cope with such effects. However, the importance of these organisms is not widely taken into account by policy decision makers and the public, resulting in them being largely ignored in policy construction for global change mitigation.

4 | MYCORRHIZAL SCIENCE OUTREACH

In order to bridge the gap between the public and the knowledge that would allow them to gain awareness on the importance of mycorrhizas, not only to our environment and everyday life but also in the face of global change, it is imperative to develop and implement an array of outreach strategies including written, audiovisual, and interactive tools, to name a few. Within this context, in the following sections, we will focus on mycorrhizal science outreach, describing potential audiences, tools, available resources, and concerns about conducting science outreach in relation to mycorrhizas, using techniques ranging from mass media to social networks and on-site activities such as exhibits, community center demonstrations, and classroom activities or enhancement of school resources (Silva-Flores et al., 2019).

4.1 | Potential audience for mycorrhizal science outreach

In general, science outreach is directed towards all audiences outside academia. Thus, an important aspect in science outreach is to always consider the type of public addressed by a particular type of message or activity (Bush et al., 2018). Previous analyses on the topic proposed categories (e.g., Christensen, 2007; Marín, 2018), adapted herein to a mycorrhizal science outreach context as follows: general public, decision makers, scientists, and industry.

Some activities closely related with global change involve all four types of potential audiences, for example, agricultural systems. Several research teams are working on strategies to use mycorrhizal fungi to enhance sustainability and productivity in agro-ecosystems, since agricultural intensification has raised diverse environmental concerns, including poor nutrient-use efficiency, increased greenhouse gas emissions, groundwater eutrophication, soil quality degradation, and soil erosion (Banerjee et al., 2019; Foley et al., 2005). In a recent review, Wipf et al. (2019) proposed the development of a future "ecological engineering of AM fungi and their associated microorganisms" for integration into modern plant breeding, while preserving ecosystem services rendered by these valuable fungi (i.e., soil formation and quality, nutrient cycling, regulation of plant communities, plant growth promotion, and C sequestration, among many others). Likewise, French (2017) described how mycorrhizal engineering can be used to improve crop production and health. She also claims that, as the effects of global change and anthropogenic disturbance increase, global diversity of mycorrhizal fungi should be monitored and protected to ensure this important agricultural and biotechnological resource for the future. However, to achieve this, the ubiquity and importance of this symbiosis must first be acknowledged, and mycorrhizal science outreach is of vital importance to this end. Regarding the public involved in industrial activities, Vosátka et al. (2012) highlighted that there is a growing number of enterprises producing mycorrhizal fungi-based inocula, not only in the developed world but also increasingly in emerging markets. Collaboration between the private sector and the scientific community displays an upwards trend, as private sector developments can fuel further research (see Section 4.4 for examples of successful workshops towards the industry public).

4.2 | Potential tools for mycorrhizal science outreach

In the past years, researchers from across the scientific world have shown an increasing interest in science outreach, especially with the advent of social media. Nowadays, social media platforms, like Instagram, Facebook, and Twitter, are worldwide communication tools and their popularity has been leveraged to bring scientists closer to the general public using an easier language, a shorter format, and fewer technical terms. Besides, the widely used social media platforms, tools such as TED Talks, blogs, and websites are suitable alternatives for additional content, despite being less interactive. Table 1 presents some tools with outreach potential that have been used by scientists to communicate the importance and social relevance of scientific work to the general public, with potential for use in mycorrhizal science outreach.

TABLE 1 Tools with potential for use in mycorrhizal science outreach

Tool	Outreach functionality	References
Social media	Reach large and diverse public Dynamic and highly interactive Continued engagement of viewers/followers Image-based platforms combines information and images	Hines and Warring (2019) and Pavlov et al. (2018)
Community events	Include lectures, debates, festivals, forays Dynamic activities (e.g., workshops) Show and tell opportunities Interaction empowers participants to be more active	Illingworth (2017), Moscoe and Hanes (2019), and Silva-Flores et al. (2019)
Digital media	Include blogs, websites, podcasts, and videos Allows for longer narratives Requires equipment and technical know-how	Nisbet and Scheufele (2009)
Comics	Attractive and fun Combines science, learning and fun Requires a good script or story	Bouchard et al. (2019)
Science journalism	Disseminate scientific knowledge through newspaper, TV, magazines, and radio Integration of science and news	Lew and Rey (2016)

4.3 | Available resources for mycorrhizal science outreach

Today, people interested in learning more about mycorrhizase, citizen scientists or people interested in disseminating knowledge generated by mycorrhizal research, use the Internet as their primary source for material and information. The available resources are web pages, images, videos, online shops, and e-books. Searching the term "mycorrhiza outreach" returns 39,900 web pages results in Google Search in comparison to the 107,000 results of "mycorrhiza teaching" (May 21, 2020). However, access to diagrams or books is limited because images under the "labeled for reuse with modification" option, as well as recent scientific research books, carry restrictive copyright licenses. Here, we highlight the limited emphasis the mycorrhizal scientific community has placed on generating freely available and continuously updated outreach content conveying accurate knowledge, an issue that is especially prominent regarding information related to mycorrhizas and global change.

Videos and webpages are at the forefront of educational and more accessible outreach material, but no online manual for mycorrhizal science outreach is available to date. Informative material for generating demonstrative videos or workshop activities can be obtained from teaching material (Benny, 2008; Massicotte & Guinel, 2017; Siddiqui et al., 2008; Weber & Webster, 2001), but mycorrhizal science outreach requires some laboratory resources as well. Also, we point out that 3D mycorrhizal association models are not available at online shops, unlike ectomycorrhizal fungi sporocarps, which could be a source of revenue to fund other mycorrhizal science outreach projects. The most interactive resource available is an educational video game for Android which explores the ectomycorrhizal symbiosis, called "Shroomroot" (Maddison et al., 2018), which led to novel challenges to implement for outreach on AM fungi. The game is available at: https://apkpure.com/shroomroot/com.areadenialgames.shroomroot

Social networks are improving science communication as they provide information to users. A Twitter search for "mycorrhizal outreach" (https://twitter.com/search?q=mycorrhizal%20outreach&src=typed_query) returned seven entries on May 21, 2020, while "mycorrhizal teaching" (https://twitter.com/search?q=mycorrhizal%20teaching&src=typed_query&f=live) displayed more results. However, the term "mycorrhiza teaching" displays more academic than outreach content. Here, using the proper hashtag is essential to filter outreach material—including free diagrams, videos, or infographic material—for audiences less interested in academic topics. Mycorrhizal researchers should be required to release outreach material on Twitter, due to its faster dissemination rate over webpages or articles. Instagram and Facebook are the other social media platforms broadly used to communicate fungal science. Other than the platform of choice, the enthusiasm and creativity of posts are key to reach a target audience. Research centers and universities open to the community experiences in science and technology are quite popular as well; outside activities, like forays, tend to attract nature lovers in general. Community engagement in ectomycorrhizal fungi by means of mushroom cooking/tasting events in forays is an effective way to increase the number of attendees that ultimately enlist. During dry seasons, or during times of lockdown, platforms such as Mushroom Observer, iNaturalist, and even Facebook groups can be used to get people to share online and with experts their findings on the Funga in their surroundings, with potential identification of mycorrhizal fungi. Roy (2020) created the iNaturalist for Guyana, an app that interacts with users to gather information on the occurrence, locality, and growth time of all mushroom types, many of which are ectomycorrhizal. The "Cogumelos do Brasil" Facebook group has over 15,000 members posting photos from all over the country, contributing to the understanding of their distribution, type of environment, nearby plants, and how rare a species can be. Along the same line, "Micófilos ONG," "Hongos de Chile," and Fungi Foundation have more than 27,000 followers; these Facebook or Instagram groups gather users who share pictures and knowledge, mostly in Spanish but sometimes in English, regarding the Fungi Kingdom and, on occasion, about mycorrhizal fungi as well. A compendium of electronic resources can be found in Table 2.

TABLE 2 Electronic resources containing material for mycorrhizal science outreach

Provider	Description	Language	Type	Url	Last update
3dmdb—3D Model Database	3D model to render or print ectomycorrhizal models	English	Online shop[a]	https://3dmdb.com/en/3d-models/mycorrhiza/	2020
BBC News	A quick animation of the mycorrhizal network.	English	Youtube video	https://www.youtube.com/watch?v=yWOqeyPIVRo&feature=youtu.be	2018
British Mycological Society	Web page introducing the uses of mycorrhizal fungi in current agriculture.	English	Web page	https://www.ukfungusday.co.uk/blog/mycorrhizal-fungi-current-agriculture	2020
British Mycological Society	Web page describing the benefits of arbuscular mycorrhizae commercial inoculum application.	English	Web page	https://www.ukfungusday.co.uk/blog/mycorrhizal-fungi-and-your-garden	2019
British Mycological Society	Web page explaining the different types of mycorrhizal symbiosis.	English	Web page	https://www.ukfungusday.co.uk/blog/mycorrhizal-fungi-weird-and-wonderful-world-fungal-symbiosis	2020
British Mycological Society	Web page showing the importance of mycorrhizal fungi in strawberry cultivation.	English	Web page	https://www.ukfungusday.co.uk/blog/mycorrhizal-fungi-and-strawberries	2020
Clark University	A web page containing an explanation on the mycorrhizal partners of non-photosynthetic plants.	English	Web page	https://www2.clarku.edu/faculty/dhibbett/TFTOL/content/5folder/nonphotoplant.html	2005
Colombian Mycological Association	Videos of the Colombian Mycology Colloquium. Talks about diverse topics on Colombian Funga, including arbuscular and ectomycorrhizal diversity and uses.	Spanish	Youtube channel	https://www.youtube.com/watch?v=vjAjhZiBZn8 https://www.youtube.com/watch?v=qzn4rhrEhQE	2020
Cooperativa Simbiosis MX	Startup focused on mycological outreach and fair use; videos about arbuscular and ectomycorrhizae for outreach.	Spanish	Youtube channel	https://www.youtube.com/channel/UCCwgb_n5DyxsHTN_wrSduMQ/videos	2020
Cornell University	Jozsef Racsko's conference about the use of mycorrhizal fungi in horticulture.	English	Youtube video	https://www.youtube.com/watch?v=a4Y4A7TI5aE	2019
DEEMY Ludwig-Maximilians-Universität	An information system for characterization and determination of ectomycorrhizae.	English	Web page	http://www.deemy.de/	2020
Fantastic Fungi	A film about the mycelial network.	English	Film	https://fantasticfungi.com/watch/	2020
Farming Smarter	Presentation by Chantal Hamel, talking about mycorrhizae.	English	Youtube video	https://www.youtube.com/watch?v=Uux1HMBZiSY	2014
Fungi Foundation	Web page of an NGO working for the protection and promotion of fungi.	Spanish/English	Web page	https://ffungi.org	2020
FungiFest	Videos of the FungiFest: a mushroom festival centered on scientific and artistic themes.	Spanish	Youtube channel	https://www.youtube.com/channel/UCUitaU_tvqJHQI7KVoOzAnQ/videos	2020
German Centre for Integrative Biodiversity Research (iDiv)	An open experimental platform researching how dissimilar mycorrhiza communities, together with tree diversity, affect ecosystem functioning.	English	Web page	https://www.idiv.de/en/research/platforms-and-networks/mydiv.html	2020

(Continues)

TABLE 2 (Continued)

Provider	Description	Language	Type	Url	Last update
iBiology	Anne Pringle on video, introducing fungi and mycorrhizal symbiosis.	English	Youtube video	https://www.youtube.com/watch?v=ptFmDnsjlvQ	2017
International Mycorrhiza Society	IMS Quarterly e-Newsletter. Also, conferences, members, research and general news.	English	Newsletter	https://mycorrhizas.org/home/news/	2020
Kiss The Ground movie	A documentary on the global narrative around major environmental issues, focusing on the soil and its biodiversity.	English	Film	https://kissthegroundmovie.com	2020
Laboratório de Biologia de Micorrizas	Posts on arbuscular mycorrhizal fungi; general mycorrhizae news and updates.	English/ Portuguese	Facebook page	https://www.facebook.com/micorrizaslab/	2020
Lancaster University	Web page describing the main characteristics of mycorrhizal fungi and how they relate to the environment.	English	Web page	https://www.futurelearn.com/courses/soils/0/steps/9819	2020
Mark Brundrett	Web resource explaining the mycorrhizal association.	English	Web page	https://mycorrhizas.info/resource.html	2008
Michigan State University	A compilation of electronic resources from several mycorrhizal research groups.	English	Web page	https://s4.lite.msu.edu/res/msu/botonl/b_online/ppigb/mycolog2.htm	1997
Micofilos Chile	Web page of an NGO dedicated to research, teaching, conservation and outreach of the fungal kingdom.	Spanish	Web page	https://www.micofilos.cl	2020
Museo del Hongo	Museo del Hongo is a non-conventional museographic space dedicated to resignify the fungal kingdom.	English/Spanish	Art	https://museodelhongo.cl	2020
Mycorrhizal Applications	Manufacturer and supplier of mycorrhizal inoculant products and ingredients with information about the benefits of mycorrhizae.	English	Online shop[a]	https://mycorrhizae.com/	2020
National Geographic	An educational video describing the mycorrhizal symbiosis.	English	Youtube video	https://www.youtube.com/watch?v=7kHZ0a_6TxY&feature=youtu.be	2018
Natural Genetix	Video describing the relationship between mycorrhizae and the environment.	English	Facebook video	https://www.facebook.com/watch/?ref=search&v=784511638365492&external_log_id=7d050658489f0b9f542f6c6b1a102c7d&q=mycorrhiza%20teaching	2017
Naturalistas Chile	Group dedicated to promoting public outreach on biodiversity, hosting talks about mycorrhizal fungi.	Spanish	Youtube channel	https://www.youtube.com/channel/UCZVFo6X8Q6atiWHILDxU0TQ/videos	2020
No-Till Farmer	A podcast about the underground world of mycorrhizae.	English	Podcast	https://www.youtube.com/watch?v=9-ZMXhRuS6U	2019
North American Mycological Association	A brief explanation of mycorrhizae.	English	Web page	https://namyco.org/mycorrhizae_explained.php	2020
Ohio State University Extension Page	Web page describing the main characteristics of mycorrhizal fungi and how they relate to the environment.	English	Web page	ohioline.osu.edu/factsheet/plpath-tree-01	2016

(Continues)

TABLE 2 (Continued)

Provider	Description	Language	Type	Url	Last update
OYR Frugal & Sustainable Organic Gardening	A video about the use of mycorrhizal soil amendments.	English	Youtube video	https://www.youtube.com/watch?v=2tdo3wSHVhA&list=PLa2kCKQo0t79F-dph4_3OIQwjlzjn-iJt&index=76	2014
Plant Health Cure BV	A brief video about how to restore soil health.	English	Youtube video	https://www.youtube.com/watch?v=gJOiEbdFURE&list=PL-HegAUUc7FXhZX6w42ZBJq0o5khSNh54&index=33	2017
Restoration Ecology Lab	Web page of Colorado State University on arbuscular mycorrhizal fungi in sage steppe.	English	Web page	https://warnercnr.colostate.edu/frs/restoration-ecology-lab/arbuscular-mycorrhizal-fungi-sage-steppe/	2020
Rodale Institute	Quick guide of on-farm production of arbuscular mycorrhizal fungus inoculum.	English	Web page	https://rodaleinstitute.org/science/articles/quick-and-easy-guide-on-farm-production-of-arbuscular-mycorrhizal-fungus-inoculum/	2010
Shroomroot	Android game app where the objective is to grow into an underground root system.	English	Video game	https://apkpure.com/shroomroot/com.areadenialgames.shroomroot	2018
Sociedad Mexicana de Micología	Official website of the Mexican Mycological Society, containing news about conferences, talks and other events about fungi and mycorrhizae.	Spanish	Facebook page	https://www.facebook.com/SociedadMexicanadeMicologia/	2020
South American Mycorrhizal Research Network	Facebook page of a horizontal scientific community for mycorrhizal applications advancement.	English	Facebook page	https://www.facebook.com/southmycorrhizas/	2020
South American Mycorrhizal Research Network	Twitter channel of a horizontal scientific community for mycorrhizal applications advancement.	English	Twitter	https://twitter.com/southmycorrhiza	2020
South American Mycorrhizal Research Network	Blog discussing recent literature.	English	Web page	https://southmycorrhizas.org/reading/	2020
Ted Talk	A search page for the query "fungi," displaying several talks involving mushrooms and other fungi.	English	Ted Talks	https://www.ted.com/search?q=fungi	2020
Ted Talks	Suzanne Simard on video, explaining mycorrhizal networks.	English	Youtube video	https://www.youtube.com/watch?v=Un2yBgIAxYs	2016
TrophinOak	An experimental model comparing development, physiology and gene regulation involving mycorrhizae in Quercus robur.	English	Web page	https://www.ufz.de/trophinoak/index.php?de=19337	2018
Twitter search	An example of mycorrhiza science outreach to children.	English	Twitter photo	https://twitter.com/fmartin1954/status/642272448969371648/photo/1	2015
Twitter search	Twitter search pages listing threads about mycorrhizae and teaching.	English	Twitter search	https://twitter.com/search?q=mycorrhizal%20teaching&src=typed_query&f=live	2020
U.S. Forest Service	Document explaining the importance of mycorrhizae in forest tree nurseries.	English	Web page	https://www.fs.usda.gov/treesearch/pubs/41353	2012
University of California	Basic information about mycorrhiza written in non-technical language.	English	Web page	https://ucanr.edu/blogs/forestrymgmt/index.cfm?tagname=mycorrhizae	2012

(Continues)

TABLE 2 (Continued)

Provider	Description	Language	Type	Url	Last update
University of California	Information about common misconceptions on commercial mycorrhizal inoculants.	English	Web page	https://ucanr.edu/sites/news/all_uc_anr_blogs/?blogtag=mycorrhizae&blogasset=75643	2017
University of California	An introduction to mycorrhizae.	English	Web page	https://online.ucpress.edu/abt/article/53/1/13/14579/An-Introduction-to-Mycorrhizae	1991
Untamed Science	Group of scientists, educators, and filmmakers exploring the mycorrhizal symbiosis.	English	Web page	https://untamedscience.com/biology/ecology/mycorrhizae/	2016
West Virginia University	International culture collection of (vesicular) arbuscular mycorrhizal fungi.	English	Web page	https://invam.wvu.edu/	2020

Note: Links to websites were last accessed at April 30, 2021.

[a]Important note: Links and names of companies and institutions are provided herein as a compilation of current information; we do not endorse, recommend or make any comments, positive or negative, regarding their respective products.

4.4 | Workshops for industry and the public

Dynamic activities, such as workshops, are quite important and remarkable activities in the context of mycorrhizal associations and global change. Of particular importance are activities directed to the public sector and industry audience, comprising a public involved in agriculture, horticulture, and forestry that directly witness the important effect of soil and fungi on their crops. In particular, agriculture and forestry benefit from several mycorrhizal fungi-based products to improve their yields (Rillig et al., 2016). However, the methodologies used to inform producers about mycorrhizal fungi are not well documented in the scientific literature. Consequently, here we want to highlight two successful workshops aimed towards the industry audience.

4.4.1 | On-farm production of mycorrhizal inoculants: An alternative for organic coffee cultivation management

This outreach experience was carried out in an area traditionally planted with coffee, located in the north-central region of the Cordillera de la Costa (Coast Mountain Range) of Venezuela. In recent years, governmental coffee price regulations resulted in steady deforestation in the region, due to a shift to other crops that are perceived as more profitable. Forest loss increases the risk of land degradation and desertification, contributes to global climate change, and negatively impacts the habitat of many species. Thus, between 2018 and 2019 NGO Provita aimed to help coffee farmers produce higher quality, organic product at more attractive prices, allowing the recovery of shade-grown coffee plantations and enabling forest conservation and related ecosystem services. The proposed organic management included the use of arbuscular mycorrhizal fungi (AMF) inoculants, a critical factor considering coffee is a highly mycotrophic crop (Andrade et al., 2009).

Basic information about AMF and the advantages of using this symbiotic association in agriculture were provided through technical workshops. Coffee farmers were trained in the production of mycorrhizal inoculants on their farms in order to facilitate the incorporation of these fungi in their agricultural management practices. Outreach and training activities were carried out between Piedra de Cachimbo and La Florida, two rural communities located within the area of interest. Mycorrhizal inoculants were propagated from a mixture of commercial AMF strains (Micoven-IVIC) and from native AMF using soils obtained from neighboring forests and coffee plantations. These inoculants were maintained on-site at the farms, subjecting them to water stress, and cutting off the host on the dates scheduled in order to increase spore production. Finally, a demonstrative assay was carried out to evaluate the effectiveness of the inoculants on coffee seedlings. Native AMF from Piedra Cachimbo coffee plantations were more effective than commercial inoculants; thus, the use of this taxonomically diverse inoculum that is adapted to local conditions is highly recommended.

Additionally, the local production of native AMF inoculants has important economic and practical advantages, including reduced transportation costs for large volumes of inoculants required for agricultural activity (Singh et al., 2014).

The theoretical–practical approach to mycorrhizal outreach is highly valuable as it involves learning through experience. Coffee farmers were able to verify for themselves that the on-farm inoculant production process is simple and that the positive effects on seedling growth are noteworthy. Additionally, farmers were able to observe that not all the inoculants produce the same effect, hence the importance of previous assays to select the most effective inoculum. The learning experience was enriched by specialist advice to perform quality control of produced inoculants and the taxonomic identification of native AMF strains involved, an essential component towards a fruitful partnership between scientists and farmers. By the time of completion, 40 coffee growers had joined the project and 160 ha of coffee plantations obtained the Organic Certification under the USDA-NOP standard and the Organic Standard as per European Economic Community (EEC) regulations.

4.4.2 | Outreach on the benefits of AMF in an organic apple orchard

This experience was carried out in a medium-sized, export-oriented organic apple orchard, located next to the core zone of the La Campana-Peñuela Biosphere Reserve, in the central Mediterranean region of Chile. Unfortunately, biosphere reserves buffer zones are inadequately managed in Chile. Economic activities within buffer zones should be environmentally friendly in order to protect biological and cultural diversity, fostering biological connectivity towards the reserve's core zone. In this respect, organic or sustainable agriculture emerges as a feasible alternative that allows the development of such functions (Moreira-Muñoz & Salazar, 2014). Organic or sustainable agriculture enjoys increasing demand at the global level and is promoted via public policies at the local level. However, an important gap exists in between the knowledge and available technologies related to sustainable agricultural systems and advantages and how this translates into caring for the environment and public health (ODEPA, 2019).

The objective of this work was to demonstrate farmers the effect that the conservation of the native Mediterranean forest around organic apple orchards had on AMF diversity in the latter. The study comprised a 3-year period of systematic guidance, where an interdisciplinary research group developed a relationship with farmers, their workers, and agricultural advisors. A producer's guidance requirement is substantial when navigating and maintaining organic or sustainable management. The guidance therefore involves a social participation model, seeking different solutions in agricultural system management and practices, including technology strategies and innovation development.

Guidance was performed every 3 months per agricultural system, through semi-structured meetings and interviews, using a participatory approach. Researchers, through scientific disclosure of ecosystem and agricultural benefits of soil microorganisms, specifically AMF, raise a request to maximize the ecosystem functions of these microorganisms and their relationship with the management of the surrounding Mediterranean forest. To this end, mycorrhizal fungi diversity in the native forest was assessed, as well as the radial effect generated by diverse organic management practices, in order to improve their conditions and focused mainly on soil fertility and irrigation water retention. We found that the sites near the native forest had higher AMF diversity and displayed better soil quality and water retention. In consequence, a native inoculum was developed for the orchard, simultaneously enabling forest conservation to protect the biodiversity of the area while reaping the agricultural benefits microorganisms bring into the orchard. This work generated a value increase of the natural resources of the agricultural system, and a decrease in external inputs like commercial biostimulants, which are more expensive and can have an ecological impact on the ecosystem and on the native AMF communities (Hart et al., 2018).

As evidenced above, scientific dissemination of mycorrhizal fungi benefits, as well as the learning process by farmers in appreciation of their agronomic and ecological value, can lead to changes on a larger scale. In this case, the conservation policy of native forest surrounding the orchard, as well as the work culture of agricultural system workers, generate a greater understanding of the interrelation of organisms, the ecological benefits that microorganisms bring to the orchard, and the associated indirect benefits on human health. This experience suggests that outreach work must be participatory and prolonged over time, since a greater level of commitment and local knowledge is achieved over longer periods, also allowing for proper installation of transmitted technologies.

4.5 | Conceptual framework for mycorrhizal science outreach from a pedagogical approach

To succeed in improving both public engagement rates and the effectiveness of science outreach projects, outreach activities should be planned following the systematic framework of scientific thinking. Based on a review of the characteristics and diversity of outreach activities, we present a conceptual framework for designing a mycorrhizal outreach project from a pedagogical approach. This framework derives from a literature review, the study of mycorrhizal science outreach successful cases (Table 3), and personal experiences. However, the framework represents a transition into transdisciplinary science as it considers three dimensions—scientific, participant citizen scientist, and socio-ecological and economic dimensions—at each step of the project, providing a variety of guiding questions for monitoring and evaluation (Figure 2) for potential application across different outreach approaches.

At this point, we believe a three-step approach to creating an effective outreach project outline is necessary, as follows: planning, which involves identifying goals, objectives, audiences, and

TABLE 3 Available mycorrhizal classroom activities

Title	Type	Topic	Citation
Mysterious mycorrhizae? A field trip & classroom experiment to demystify the symbioses formed between plants & fungi	Field trip, experiment	Soil sample collection, plant mycorrhizal response experiment	Johnson, N. C., Chaudhary, V. B., Hoeksema, J. D., Moore, J. C., Pringle, A., Umbanhowar, J. A., & Wilson, G. W. (2009). Mysterious mycorrhizae? A field trip & classroom experiment to demystify the symbioses formed between plants & fungi. *The American Biology Teacher*, 71(7), 424–429.
A simple method for observing vesicular arbuscular mycorrhizae with suggestions for designing class activities	Laboratory	Methods to assist teachers in designing laboratory and field exercises	DeMars, B. G., & Boerner, R. E. (1995). A simple method for observing vesiculararbuscular mycorrhizae with suggestions for designing class activities. *Journal of Biological Education*, 29(3), 209–214. https://doi.org/10.1080/00219266.1995.9655447
Mycorrhizal associations: The web resource	Infographics	Methods	Brundrett, M.C. (2008). Mycorrhizal associations: The web resource: https://mycorrhizas.info/resource.html
Mycorrhizae: Mutualism or parasitism?	Simulation game, lesson plan	Definition of symbiosis, simulation of environmental effects on the symbiosis	http://kbsgk12project.kbs.msu.edu/blog/2013/08/29/mycorrhizae-mutualism-or-parasitism/

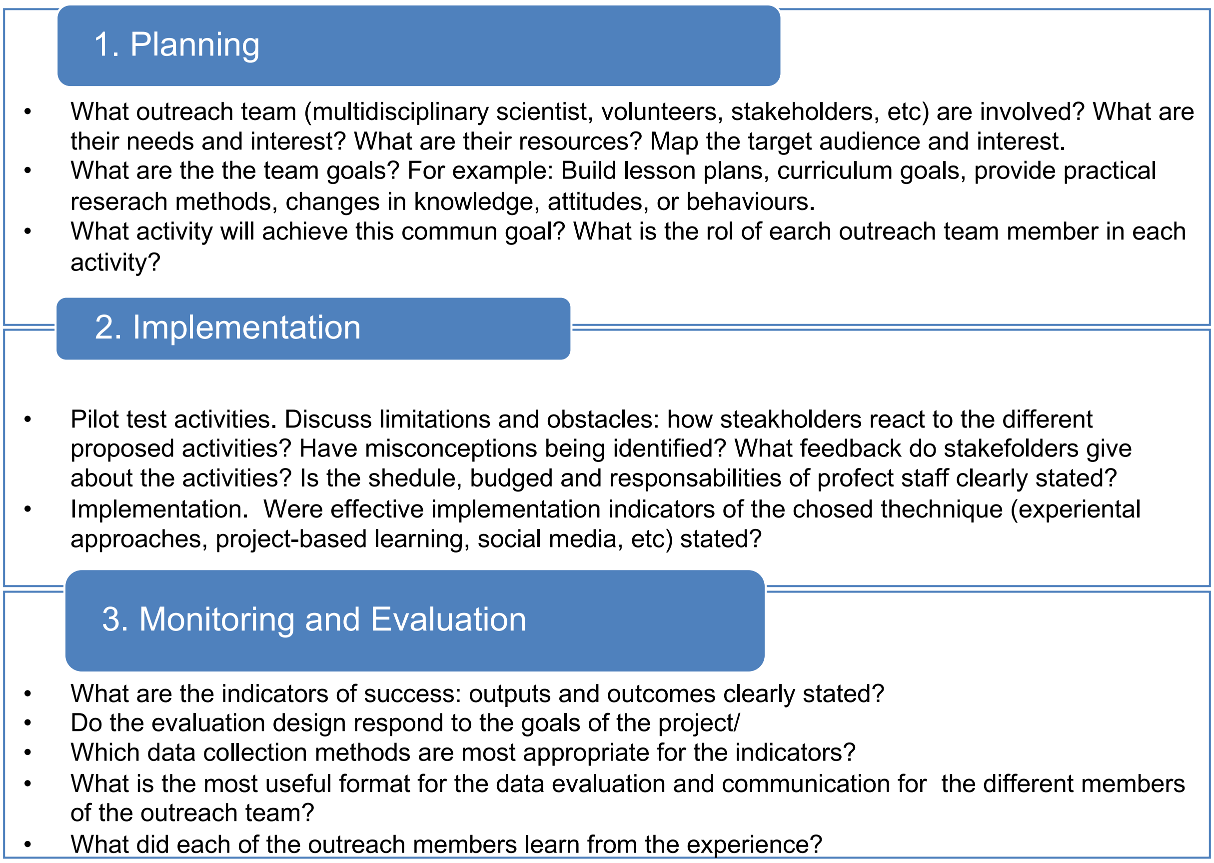

FIGURE 2 The outreach components model for education programs. Adapted from Jacobson et al. (2015) and Varner (2014)

educational strategies; implementation, concerned with the execution of activities; and monitoring and evaluation of results, to identify successful activities as well as components in need of improvement during and after project implementation. The supporting questions provided should be tailored to the specific outreach project, program goals, and target group needs (Skrip, 2015). For assessment methods, we have observed a mix of qualitative and quantitative methods: online surveys, usage statistics, interviews, focus groups, pre- and post-tests, among others (Kieslinger et al., 2017).

However, this current framework collectively acknowledges a range of limitations that occur across a number of outreach efforts. One of them is the need of establishing strong and reciprocal outreach partnerships (Knippenberg et al., 2020; Lopes et al., 2018); another one is the lack of scientific literature that document practitioner voices (Salmon & Roop, 2019). Finally, there is a great opportunity for integration and development of new approaches (e.g., McGaley & Paszkowski, 2021). We hope this paper provides a variety of tools and outreach mycorrhizal experiences that could be a seed for thought that motivates the development of specific outreach models.

4.6 | Pros and cons of mycorrhizal science outreach participation

A key factor in shaping science outreach and outcomes is what scientists themselves think about public engagement activities. Generally speaking, scientists consider public engagement in science important, in line with increasing requests from funding bodies to include outreach activities as an integral part of any research grant (Llorente et al., 2019). According to the level of confidence in the interest of the public or in their capacity to understand, the message scientists wish to convey may vary to some degree; moreover, the overall consensus among scientists is that improving public interest and enthusiasm for science is both a moral duty and a way to achieve greater public support for scientific research, ensuring its healthy future. Evidently, there are also obstacles, both cultural and practical, that limit the willingness of scientists to take an active role in outreach. Since no hint of this discussion exists in the specific field of mycorrhizal research yet, we will instead report on the broader confrontation currently ongoing regarding these issues, with a specific focus on the ideas of biologists, whenever possible.

While most of the literature on scientific outreach delves on the importance of this activity, on the public's perception of research outreach (Pham, 2016; Varner, 2014), and on how scientists could attain the best outcomes from their efforts in promoting public engagement, only a few systematic studies have focused on scientists' motivations to conduct outreach activities or not. For example, Ecklund et al. (2012) conducted surveys and interviews among US biologists and physicists, investigating their patterns of outreach engagement and "what they perceive as impediments to these activities." A 74% of respondents listed one or more significant barriers to their ability to do science outreach, with 31% perceiving that the academic system largely prioritizes research and publications, and does not provide any incentive or training for scientists to do outreach. As a consequence, scientists perceive their outreach work as not valued nor rewarded. "Outreach may be seen as outside of the responsibilities of the university scientist, an understanding tied in large part to institutional norms at top research universities that value research productivity over other types of contributions," (Ecklund et al., 2012). "Adherence to these norms limits the time and ability of scientists to take on other projects and even creates disincentives for participation in outreach–often in the form of disapproval by mentors or department heads" (Ecklund et al., 2012). The authors mention that this negative regard for outreach work may be tied to a "Sagan effect," a sort of stigma attached to outreach wherein a scientist's research is thought to be inversely proportional to the amount of outreach work he or she does.

A more recent study surveyed Singapore-based scientists about their personal motivations and barriers in doing outreach (Ho et al., 2020). Personal gratification, altruism, the importance of informing the public about health issues, accountability towards taxpayers, and the possibility of increasing personal and institutional recognition and attracting research funds were the most frequently mentioned motivations for conducting outreach activities. Moreover, the authors reported that "most participants stated that their institutes and superiors want them to prioritize 'research work' and 'publishing papers.' The participants also reported that their institutes regarded outreach as a 'higher-order thing' that scientists could pursue after fulfilling their research requirements" (Ho et al., 2020). It should be noted that sometimes personal barriers do add to institutional constraints. Some scientists, for example, prefer not to be involved as they are shy or feel they are not competent as science communicators with the implied conviction that science communication is better performed by communication specialists rather than researchers, or the belief that the public will not appreciate nor understand what they could say about their research (Figure 3). A further intriguing finding that emerged from several studies is that female scientists and younger researchers are the most likely to reach out and communicate their science to the public (Ecklund et al., 2012; Llorente et al., 2019; McCann et al., 2015), often using social media as a preferential channel, a very powerful science communication tool (Lesen, 2016; Rinaldi, 2014) as mentioned earlier.

But, are these worries justified? Does being involved in outreach activities have a negative impact on scientists' research output? The plain answer is: no. Analyzing data from a Swiss research center on sustainability science, Omar Kassab focused on the correlation between outreach and research performance, measured in terms of scientific publications and citations (Kassab, 2019). It was found that, overall, engaging in public outreach activities is positively correlated to both the number of publications and total citations. "This study concludes that there is no *per se* negative correlation between engaging in public outreach activities and the production of scientific publications" (Kassab, 2019), remarking that the "researcher's dilemma" on the necessity of science communication, and yet the presumed negative correlation between research performance and engagement in public outreach activities is actually an "urban legend" (Kassab, 2019).

4.7 | Quantifying success in science outreach

Evaluating effectiveness is a major concern in scientific outreach, especially as these activities are oftentimes funded by public resources.

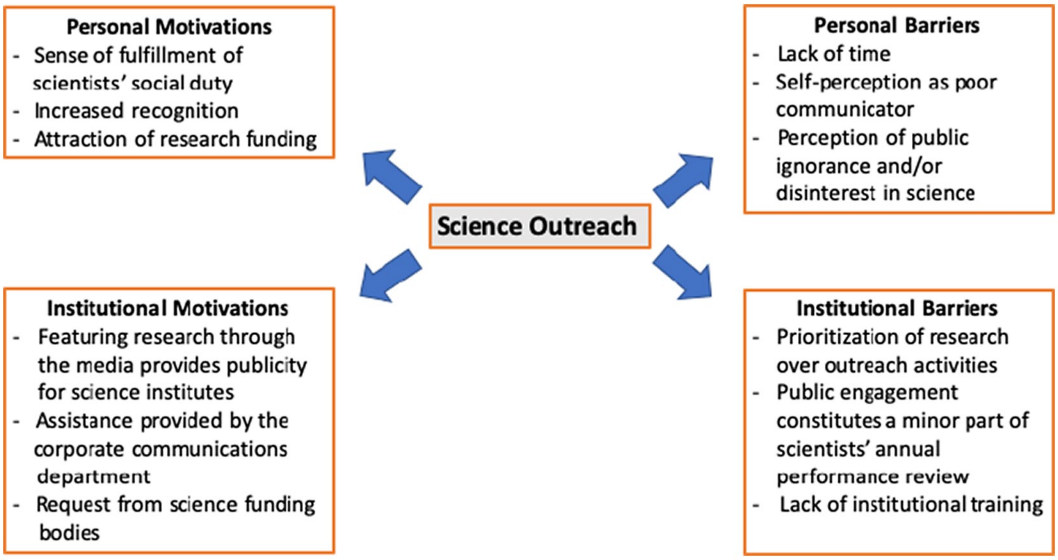

FIGURE 3 Main motivations and barriers researchers report for engaging in science outreach activities. Based on Ecklund et al. (2012) and Ho et al. (2020). See main text for further details

What can be defined as an 'effective' outreach activity? In the UK, effectiveness has been defined in terms of University recruitment in Science, Technology, Engineering, and Mathematics (STEM) programs (BIS [Department for Business, Innovation, & Skills], 2016, p. 54). We think this objective alone is far too simplistic; for example, it does not consider who is being recruited (i.e., if they come from underrepresented minority groups in STEM) and actually conflates outreach with recruitment, which is common in university policy (Harrison & Waller, 2017). Outreach should also change public perceptions on science, and overall should lead to scientific evidence-based public decision-making. Other outreach evaluation frameworks are less restrictive and focus not only on university recruitment, but also extend to exhibitions, mass media, community programs, and technology, among others (Allen et al., 2008). Most of these evaluations follow a "tracking" approach (Allen et al., 2008; Harrison & Waller, 2017), where individuals are followed and re-surveyed over time in regards to their involvement in the outreach activity, change in attitudes or opinions, and their decision to pursue a STEM program.

Science outreach programs face the potential issue of not reaching underrepresented communities (Merenlender et al., 2016). Several steps can be taken to address this issue: first, participant motivations must be known, ideally prior to the outreach activity (Merenlender et al., 2016); second, the motivations (or lack thereof) of underrepresented communities (both participant and non-participant) should be thoroughly evaluated; and third, focusing the outreach activity or program to meet the requirements of both the general public and underrepresented groups, as evidence has shown that a clear and directed objective largely influences whether someone participates in outreach activities or not (Chase & Levine, 2016).

Harrison and Waller (2017) propose a "small steps" approach for outreach evaluation, where evaluators need to be very clear on exactly what they expect to change on individual perceptions, as this is usually conceived in very vague terms in outreach activities. The multifactorial aspect of attitude change needs to be addressed, thus, to properly separate the effects of the outreach activity from other factors, which can be difficult, requiring at least the use of control groups. How to measure those changes also needs to be re-examined, as classical surveys sometimes do not capture them completely (Harrison & Waller, 2017). Finally, Harrison and Waller (2017) suggest establishing proper timelines—an aspect that sometimes creates conflict between funding agencies and a feasible evaluation—and a proper reaching to disadvantaged groups, who continue to be underreached in these initiatives.

5 | FINAL CONSIDERATIONS

Despite the importance of the Fungi Kingdom, and of mycorrhizal fungi in particular, across all ecosystems, only recently actions to reach the general public through social media have become more popular. Information regarding the role of mycorrhizal fungi in ecosystems exists but, for the most part, remains scattered on individuals or groups of mycology around the world. In South America, one channel dedicated to such research and outreach on mycorrhizal fungi is the South American Mycorrhizal Research Network (www.southmycorrhizas.org), which comprises over 250 researchers from 37 countries (Bueno et al., 2017). On the website, we are implementing a special section for mycorrhizal outreach, where the material mentioned here will be referred to and serve as a resource for those aiming to do mycorrhizal outreach (https://southmycorrhizas.org/outreach/). We hope that this article encourages more scientists, especially mycorrhizal researchers, to contribute with material being currently developed or unavailable during our searches for this article. Please send your information to the corresponding author, and it will be posted on the Network's website as well as on its social media platforms (all languages are welcome!). We also propose the use of the hashtag ***#mycorrhizalscienceoutreach*** whenever a mycorrhizal or related science outreach activity is posted on social media, in order to connect and be able to track a community of scientists committed to outreach, society and, ultimately, global change alleviation.

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AUTHOR CONTRIBUTIONS

PSF conceived the idea and sections of this article and communicated with each coauthor in order to assign tasks; each coauthor contributed with a specific topic in the article. PSF edited a first draft with all coauthors' contributions. All coauthors revised the first draft. PSF, AAM, NF, CM, and ACR provided significant corrections for the second draft. PSF edited and submitted the final version.

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