International Mycorrhiza Society

ISSN 2563-1497

VOL. 4 ISSUE 3, DECEMBER 2023

International Mycorrhiza Society
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IMS Newsletter

The International Mycorrhiza Society quarterly e-newsletter

"Here comes the weekend!"
By: Heiko Sievers
Mushroom of the Day, Berlin
Click to artist' website

CONTENT:

Editorial: four years of the International Mycorrhiza Society Newsletter

César Marín[1, 2*] and Marcel G.A. van der Heijden[3, 4]

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Time sometimes happens too fast! Its been four years since we started this quarterly e-Newsletter of the International Mycorrhiza Society, and the energy and response from the mycorrhizal scientific community has been very encouraging. In the XXI century is impossible to only communicate our research results, opinions, and questions only through Web of Science-indexed scientific articles – often behind a paywall. It is also impossible to keep up with the huge amount of mycorrhizal literature produced everyday: the search we do for our Top 10 mycorrhizal articles, is based on between 400-600 mycorrhizal articles every year, but probably more is being produced. There is also a need to communicate research spread knowledge as much as possible – such as in this Newsletter, hopefully generating cordial, productive debate that advance our field (Marín 2022). Thankfully, and spreading outside the bubble of our scientific community, there are dedicated science outreach tools for mycorrhizas (Silva-Flores *et al.* 2021)!

ICOM12 News – Registration is Open:

The 12th International Conference on Mycorrhiza (ICOM12) will take place in Manchester, United Kingdom, 4-9 August 2024. Please visit the ICOM12 website: **https://icom12.org/**

Marcel G.A. van der Heijden (left) and César Marín (right) in the Amazon River, August 2023.

ICOM12 is being organized by Prof. David Johnson and his team. Workshop proposal submission is open until 15 January 2024 at: https://icom12.org/workshop-submission/

Workshop length is of 90 minutes and between 4 to 6 speakers should fill this time slot.

As ICOM returns to an in-person format, it is important to remind our **Diversity and Inclusivity Statement** (page 12).

Please also find the list of speakers by theme, including plenary talks, keynote speakers, and rising stars:

ICOM12 (Manchester, UK, 2024) Speakers by theme

Type of talk/ Topic	Mycorrhizas as drivers of Interaction Networks	Managing mycorrhizas for Sustainability and food security
Plenary Talks	Bala Chaudhary	Giles Oldroyd
Keynote Speakers	Gu Feng Lena Mueller* Brian Steidinger	Elisa Pellegrino Carlos Urcelay Anders Dahlberg Nina Wurzburger
Rising Stars	Camille Truong	Adam Frew

*To be confirmed

	Regulation and transport in Mycorrhizal networks	Functional consequences of Mycorrhizal diversity
Plenary Talks	Uta Paszkowski	Lingli Liu
Keynote Speakers	Jonathan Plett Zhilin Yuan Lotus Lofgren Silvia Perotto	Serita Frey Adriana Corrales Minxia Liang Peter Kennedy
Rising Stars	Hiromu Kameoka	Mark Anthony

Call for award nominations to be given during ICOM12

The International Mycorrhiza Society offers four prestigious awards at the next meeting in Manchester, United Kingdom. These are the: 1) **Student Award**, 2) the **Early Career Award for Excellence in Mycorrhiza Research**, 3) the **Mid-Career Mycorrhiza Research Excellence Award** and 4) the **Eminent Mycorrhiza Researcher Award**. If you know a person which you feel deserves an award or if you like to nominate yourself because you feel you made a ground breaking discover, please check out the terms of reference here:
https://mycorrhizas.org/icom/icom-12/

In addition, there is the UMAHARI (Ultimate Mycorrhiza Application for Harnessing Agriculture Resources Integration) award constituted and enacted by Dr. Alok Adholeya in fond memories of his Father and Mother for best oral and poster presentations, given by Umahari LLC St Louis USA. Participants below 30 years are encouraged to nominate/register themselves for this award via email (Alok@umahari.com) at the time of acceptance of their abstract in ICOM12 and after confirming in-person participation. Through this award the best poster and the best oral presenter will be selected by an independent jury. Young researchers who have worked in applied research of mycorrhizas towards products or inoculants will be considered for these two awards. The award includes a cash prize of USD$100 each, besides a certificate and citation.

IMS News

→ **Two board positions to be filled:** After ICOM12, Justine Karst will become the new President of the International Mycorrhiza Society and Marcel van der Heijden will act as Past President. After four years, Ian Dickie will leave the Board of Directors – we are very thankful to Ian for his great contributions to our Society. As such, at ICOM12 two positions need to be filled:
- New Vice President of the IMS (it can be someone from the current Board or from outside).
- New member of the Board of Directors.

If you are interested in filling any of these positions, please send your application to Justine Karst (karst@ualberta.ca), until 30 June of 2024.

→ **IMS Seminars:** Starting on 2024, we will organize online regular seminars from an eminent researcher and from a rising star in mycorrhizal research. More information soon!

→ **IMS Archive:** as part of our effort to archive the history of the IMS, we are currently rescuing different sources of information regarding past ICOMs, Boards of Directors, awardees, and so on. Among these, we are documenting past IMS activities and are looking for copies of the IMS Newsletter (with different name) prior to 2015. On file we have: Volume 4 October 2009, Volume 4 March 2010, Volume 6 February 2012, Volume 7 July 2012, Volume 8 April 2013. If you have any old newsletters not on this list, can you please email them to Justine Karst?: karst@ualberta.ca

→ **Call for ICOM14 proposals in 2028:** If you are interested in organizing ICOM14 in 2028, please write to Katarina Zachariasova (zachariasova@associationhouse.cz) and/or to Justine Karst (karst@ualberta.ca), so your proposal can be presented during ICOM12 in Manchester, United Kingdom. Please do so until 30 June of 2024.

IMS Newsletter news

→ **Articles/interviews welcomed:** If you want to highlight your recent mycorrhizal research/publications formally or informally, to give your expert opinion on any mycorrhizal topic of interest, or to present the 'behind-the-scenes' stories often not shown in publications, please reach out to us.

There are two ways you can do this. First, you can write a short article (800-1200 words), which our Editorial Team will review (check all the articles over the last four years here: https://southmycorrhizas.org/ims-newsletter/).

Second, we can program a YouTube interview through the South American Mycorrhizal Research Network channel (see our interviews here: https://southmycorrhizas.org/reading/). Please get in touch with IMS Newsletter Editor-in-Chief César Marín (cmarind@santotomas.cl) if interested!

→ **Managing Editor position:** We are looking for a Managing Editor of the IMS Newsletter who helps the Editor-in-Chief and Topic Editors produce the Newsletter every four months. Your tasks would include helping with the format design and graphic layout of the Newsletter, updating a list of events and job opportunities, checking reference formats of the articles, and spreading the Newsletter through social media. PhD students, postdocs, early career, and established mycorrhizal researchers are welcome to apply. Previous similar expertise helps your application, as well as a demonstration of editing, graphic, web design, and social media skills. Please contact IMS Newsletter Editor-in-Chief César Marín (cmarind@santotomas.cl) before 30 April 2024 if you are interested!

In this issue...

The Top 10 mycorrhizal research papers of the last four months (papers published between May and August 2023) include a *Curr Biol* article by Heidi-Jayne Hawkins and co-authors (Rank 1). With an impressive analysis of almost 200 datasets, they found that 13.12 Gt of CO2e fixed by land plants is -at least temporarily- allocated to mycorrhizal mycelium each year, corresponding to approximately ~36% of current yearly CO2 emissions from fossil fuels. The time to include mycorrhizal fungi in global carbon balance estimations and, more importantly, to protect them is now! The second-best paper was by Nils Henriksson and co-authors (*New Phytol*), who re-examined the evidence for the mother-tree hypothesis in ectomycorrhizal systems. They analyzed three sources: ectomycorrhizal carbon

metabolism, patterns of ectomycorrhizal forest regeneration, and isotopic methods studies. They found evidence for carbon movement between trees but no conclusive evidence that ectomycorrhizal common mycorrhizal networks have a role in this, nor on plant growth. Patterns of forest regeneration are not congruent with the patterns a common network would give (Henriksson *et al.* 2023). Also, we do not know of any physiological mechanism for carbon transfer between ectomycorrhizal fungi and the plant-fungal interface. The third rank was also a *New Phytol* paper by Johanna R. Jantzen and co-authors, where the leaf spectra evolution of 92 arbuscular and ectomycorrhizal plants is modeled through phylogenetic comparative methods. They found that the leaf spectra of both mycorrhizal types do not differ after accounting for phylogeny.

This 12th IMS Newsletter issue includes a short article, a written interview, and two meeting reports. A short article by Laura M. Bogar describes source-sink dynamics in ectomycorrhizal associations – please also find a YouTube interview with Laura on related issues by Camille Truong from the Royal Botanic Gardens Victoria, Australia. The interview with Francis Martin (past president of the IMS and awardee as an eminent mycorrhizal researcher) by Jonathan Plett explores his career, his definition of success in science, advice to young researchers, and how he sees the future of fungal research – which he helped build quite significantly. Clara Peña-Venegas and co-authors report on the III International Symposium of the Mycorrhizal Symbiosis in South America (https://southmycorrhizas.org/events/), celebrated in the Colombian Amazon in August 2023, while James N. Prout and co-authors report on the 6th international Molecular Mycorrhiza Meeting, which took place in Cambridge, United Kingdom, in September 2023. Ariadne N.M. Furtado was interviewed on YouTube about her and co-authors' discovery of Guapirioid ectomycorrhiza, a novel fungus-plant subtype in the Brazilian restinga. Also in YouTube, please find an interview with Yiming Meng (by César Marín), PhD student at the University of Tartu, about her global-scale analyses to assess the effects of plant phylogeny and environment (soil, climate) on two crucial plant mycorrhizal traits: type and status. As always, please find our Tools and Events sections at the end of our Newsletter.

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Top 10 papers on mycorrhizal research*

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2. Henriksson N, Marshall J, Högberg MN, *et al*. 2023. Re-examining the evidence for the mother tree hypothesis–resource sharing among trees via ectomycorrhizal networks. *New Phytol* 239:19-28. https://doi.org/10.1111/nph.18935

3. Jantzen JR, Laliberté E, Carteron A, *et al*. 2023. Evolutionary history explains foliar spectral differences between arbuscular and ectomycorrhizal plant species. *New Phytol*, 238:2651-2667. https://doi.org/10.1111/nph.18902

4. Yu H, Bai F, Ji C, *et al*. 2023. Plant lysin motif extracellular proteins are required for arbuscular mycorrhizal symbiosis. *Proc Natl Acad Sci USA* 120:e2301884120. https://doi.org/10.1073/pnas.2301884120

5. Berrios L, Yeam J, Holm L, *et al*. 2023. Positive interactions between mycorrhizal fungi and bacteria are widespread and benefit plant growth. *Curr Biol* 33:2878-2887.e4. https://doi.org/10.1016/j.cub.2023.06.010

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9. Wang G, Jin Z, George TS, Feng G, Zhang L. 2023. Arbuscular mycorrhizal fungi enhance plant phosphorus uptake through stimulating hyphosphere soil microbiome functional profiles for phosphorus turnover. *New Phytol* 238:2578-2593. https://doi.org/10.1111/nph.18772

10. Romero F, Argüello A, de Bruin S, van der Heijden MG. 2023. The plant–mycorrhizal fungi collaboration gradient depends on plant functional group. *Funct Ecol* 37:2386-2398. https://doi.org/10.1111/1365-2435.14395

*Selected from 168 Web of Science articles published between *May – August*, 2023 by: Bala Chaudhary, Pedro M. Antunes, Francis M. Martin, Joseph Birch, Justine Karst, Junling Zhang, Jan Jansa, Annegret Kohler, Judith Lundberg-Felten, Jason Hoeksema, and César Marín.

Research commentaries

Can plants choose their fungi? Source-sink dynamics provide a simple frame for a complex issue

Laura M. Bogar[1]*

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What structures communities of mycorrhizal fungi? It seems likely this has intrigued people since long before mycology officially existed – the specificity of certain mushrooms for particular tree hosts is hard to overlook, and the diversity and shifting phenologies of forest mushroom communities is as mysterious as it is compelling to anyone who spends time in the woods. Certainly, the physics and chemistry of the soil environment and the interactions among fungi and other organisms have large roles to play, but for the mycorrhizal fungi specifically, the plant host must have some role in structuring the community of fungi on its roots. Determining the extent to which mycorrhizal host plants can select among fungal partners, however, has proven difficult.

One popular model is to conceptualize the plant-fungal relationship as a trading interaction, with the plant exchanging excess carbon resources for fungal nutrients such as nitrogen and phosphorus. This is an appealing framework on many levels: if carbon allocation is directly linked to nutrient provisioning, then the evolution and maintenance of cooperation in these symbioses would be nearly guaranteed; "cheater" fungi (and plants) that failed to provide resources should not get a foothold (with occasional mycoheterotrophic exceptions; Frederickson 2013; Perez-Lamarque *et al.* 2020). And the data we have on fungal benefit to plant hosts is consistent with this sort of regime: mycorrhizal fungi generally improve host biomass, at least on nutrient-limited soils (Hoeksema *et al.* 2010).

However, available data on trading *per se*, where plant carbon provisioning is compared directly to fungal provisioning of soil resources, paints a much different picture. In ectomycorrhizas, carbon rewards for nitrogen rarely occur (Hortal *et al.* 2017, Plett *et al.* 2020, Stuart *et al.* 2023; but see Bogar *et al.* 2022), and appear to be possible for phosphorus (Horning *et al.* 2023), but has yet to be quantified for any other potentially-traded resources (such as potassium, magnesium, or even water). In arbuscular mycorrhizas, the evidence for trade is much stronger (Bever *et al.* 2009; Kiers *et al.* 2011), but appears to be complicated by fungal redistribution of resources and other phenomena that disrupt simple trading expectations (Whiteside *et al.* 2019; van't Padje *et al.* 2020, 2021). In a recent Tansley Insight for *New Phytologist* (Bogar 2023), I propose that a simpler paradigm might be useful to understand these phenomena: source-sink dynamics. This framework has been put to good use by many previous scholars (Nelson 1964; Bidartondo *et al.* 2001; Wu *et al.* 2002; Cairney 2012), but I will add my voice to the chorus. I believe this can

apply to carbon, nitrogen, phosphorus, and potentially other resources, but carbon is the simplest scenario to envision. Let's begin there.

For carbon movement, the implications of source-sink dynamics are clear, largely consistent with available data, and could potentially free us from the challenging task of identifying plant and fungal trading strategies to explain carbon allocation, except in unusual circumstances. As a fungus grows and respires, it becomes a powerful carbon sink; this could passively direct carbon resources towards its activities. Because ectomycorrhizal fungi are known to proliferate in resource-rich patches, this could, at times, create straightforward trade-like interactions: by investing carbon in the mycelium that is exploiting a rich resource, the plant could expect to receive significant access to the resource via the fungi, without specifically sensing or responding to fungal resource provisioning *per se*. The appeal of this hypothesis is that it requires no direct monitoring by the plant (beyond what it might apply to its own root system): if fungal partner quality is determined by soil volume access, the plant could benefit automatically by regulating carbon through simple source-sink approaches, similar to how it might allocate carbon to its own roots (Farrar and Jones 2000). Plant rewards for cooperation could be nothing fancy.

However, it is easy to imagine this going awry: if a fungus represents a significant carbon sink for reasons other than resource mobilization, such as competing with other fungi, or if it regulates its nutritional contribution to the plant in a way that decouples plant C from fungal resource allocation, the plant would be left with no recourse. This scenario has not been extensively explored – how often does this happen? – but is plausible enough to be worth serious consideration. To what extent can plants monitor fungal performance and respond in real time? And is that response a trade-type response, restricting carbon directly, or an immune response, ramping down symbiosis with that partner (or all partners) to control symbiotic losses? In ectomycorrhizas, this is a wide-open set of questions; plants are known to be subject to exploitation by fungal "hoarding" of nitrogen (Näsholm *et al.* 2013; Franklin *et al.* 2014), suggesting perhaps limited control of carbon. It remains true, however, that experiments show improved growth with these fungi generally (Hoeksema *et al.* 2010), suggesting that uncooperative behaviors are context-dependent. In arbuscular mycorrhizas, fungal resource "hoarding" may also occur in some contexts (Whiteside *et al.* 2019; van't Padje *et al.* 2020), although it has not been implicated in ecosystem-wide nutrient limitation like for ectomycorrhizal fungi.

In the end, I hope that my Tansley Insight (Bogar 2023) (and this IMS Newsletter piece) prompts other mycorrhiza researchers to consider the immense diversity of potential mechanisms that could move resources among mycorrhizal organisms, and prioritize the simplest explanations when possible. I think that source-sink dynamics are a useful null hypothesis to explain resource movement in mycorrhizal symbioses: in many situations, they may be sufficient to describe and predict the resource movement, while in others, deviations from simple source-sink expectations will point to new immunological and ecological mechanisms that can regulate resource flow between plants and fungi. Importantly, combining source-sink dynamics with plant immunological control of symbiosis could produce simple rewards for cooperation, without necessarily requiring that the plant maintain a strict ratio of traded resources with each fungal partner. I expect the next few years to reveal many details of resource

movement in these symbioses, and look forward to a better understanding of how the balance of power between plant and fungal control of symbiosis is regulated.

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Francis M. Martin interview: fungal *omics*, science writing, and catalyzing collaboration

By: Jonathan M. Plett[1]*

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Trying to quantify the impact that the research headed by Francis M. Martin has had on the field of mycorrhizal research, and fungal research more broadly, is very difficult. One can turn to his many achievements including becoming INRA's youngest Research Director and then Senior Research Director, or consider his receipt of many awards including the INRA Laurel Wreath for Excellence, the prestigious "Angiola Gili e Cataldo Agostinelli" International Prize, or his recognition as a Highly Cited Researcher since 2015. But I like to think that his biggest contribution to our field is the people he has mentored and encouraged across his career. I am one of those people, and I am so thankful for having had the opportunity to work with Francis for over 14 years. I still remember receiving notification early one morning that I had been hired as a postdoctoral researcher in his laboratory, and to be honest I am not sure what he saw in me – I had only one co-authored publication accepted (not published) to my name and had yet to submit the final revisions to my PhD thesis. But took a chance on me he did, and it has profoundly impacted my career. I remember meeting him in person for the first time in a train station in Paris on our way to a planning meeting on an international project seeking to understand the mechanisms inherent to mycorrhizal fungi that enabled symbiosis. I was unbelievably nervous

and tried to be on my best behaviour – that was until I took the first bite of my lunch which I had unwisely dosed with too much real Dijon mustard! My mouth was burning so badly, and I valiantly tried so hard not to cry while maintaining a professional appearance before this highly decorated researcher. Through my struggling not to choke, Francis was the consummate gentleman (though with quite the twinkle of mirth in his eye!) and I realized then that this was not someone who used position to distance himself from junior lab members, but someone who could truly be a colleague.

Francis fosters a spirit and culture of collaboration with those that he works with, he encourages discussion, and promotes risk taking. His passion for understanding nature is infectious and he is able to bring joy to the process of science discovery. I remember spending hours in his office just talking through ideas and hypotheses as to where our data was directing us, and it led us to some very profound and exciting discoveries. It's been a decade since I was in Francis' lab group, and I still count myself blessed to be a mentee, collaborator, and friend. Interviewing him for this article also reminded me again that, while a life in research can sometimes be a drudgery with the light at the end of the tunnel being very far away, there is so much fun that can be had in searching for the answers to our burning questions, and so much joy that can be had working together both nationally and internationally with others toward a common goal. I hope that you enjoy and are encouraged by Francis' insights as much as I was.

What made you first interested in mycorrhizal fungal research?

I was raised in Lorraine, northeastern France, where rolling hills and farmlands are carpeted by large beech and oak forests. It was not difficult to let my mind wander during the long holiday summer camps in the countryside. As a child, I remember walking in misty woods hunting for golden chanterelles with my father and uncles. There were many other botanically interesting plants in these forests, but it was the large, majestic oaks and their tiny mushroom associates that attracted my attention and whetted my appetite for studying mycorrhizal associations.

Who was your most influential mentor?

Good mentorship is essential, and I have been fortunate enough to benefit from the guidance of two exceptional mentors, Prof. Pierre Gadal and Dr. François Le Tacon. Pierre supervised my introduction to experimental plant biology with his legendary thoroughness and good humour during a summer bachelor internship and then during my PhD project in his newly established Department of Plant Physiology at the University of Nancy. In Nancy, Pierre mentored a group of remarkable students and postdocs, who have now become respected professors and department heads. This was an exhilarating period, where we had the freedom to pursue research driven by curiosity, exploring the intricacies of carbon and nitrogen metabolism in plants. Pierre's mentorship set a personal benchmark for me throughout my career.

Towards the end of my master's project, Pierre Gadal and François Le Tacon from the INRA Forestry Center in Nancy collaborated on a project aimed at understanding the role of ectomycorrhizal fungi in nitrate assimilation in pine roots. They invited me to delve into this novel and unexplored field of research. Upon completing my PhD project, I joined François newly established Laboratory of Forest Microbiology, where I had the freedom to develop a lifelong project on the physiology of ectomycorrhizal symbiosis. As the first physiologist at the Forestry Center, I enjoyed an incredible level of autonomy. I am indebted to these two individuals, who guided me in the right direction at the right time. They both advised me to embrace the idea of seeking and highlighting the unexpected, rather than attempting to predict and plan too specifically for a particular scientific direction.

What was your favorite conference and why?

Arguably, my favorite conference is the International Conference on Mycorrhiza, along

with its previous iterations as the North American Conference on Mycorrhizae and European Symposium on Mycorrhiza. The memories of attending the 6th North American Conference on Mycorrhizae in Bend, Oregon in June 1984, and the 1st European Symposium on Mycorrhizae in Dijon, France in 1985, are still vivid in my mind. What sets these gatherings of mycorrhiza aficionados apart is the remarkable opportunity they provide to learn, explore, and engage with topics that extend beyond one's usual domain. As a plant physiologist, I have gained invaluable insights by connecting with fellow ecologists and consistently participating in these conferences over the years.

How do you define 'success' in science?

Success in science can be seen as a noble pursuit, with its definition varying according to the context and aspirations of individual scientists. However, they encompass a wide range of compelling elements that resonate within the scientific community.

- *Advancement of knowledge*: To me, at the core of scientific success lies the desire to unlock the secrets of the universe, unravel its mysteries, and push the boundaries of understanding. We strive to forge new insights, discover uncharted phenomena, and shape novel theories that expand our understanding of the natural world, such as the establishment of mycorrhizal symbiosis. The quest to make noteworthy and profound contributions to the scientific body of knowledge is a hallmark of success.
- *Publication and dissemination*: We aim to communicate our findings through various channels, research papers, conferences, scholarly books, and scicoms. Success is often measured by the publication of our studies in distinguished journals, such as Nature or Science, or by the privilege of presenting our research as invited speakers at esteemed conferences, such as ICOM. Nevertheless, it is essential to bear in mind that our scientific endeavors should be motivated by the desire to disseminate discoveries, foster additional inquiry, and build credibility within our scientific community. This should take precedence over a mere aspiration for publication in prestigious, high-tier journals.
- *Peer recognition and impact*: Gaining recognition and acknowledgment from fellow scholars and the wider scientific community is highly esteemed. Many individuals strive for recognition through awards, grants, prestigious fellowships, and conference invitations. Moreover, the impact of one's work, evaluated by the citations received from fellow researchers or the

practical application of scientific discoveries, is evidence of the significance of one's scientific pursuits.

- *Collaborations and teamwork*: Success in science thrives through the collaborative efforts and teamwork of researchers. I have always done my best to act as a catalyst for collaboration, bringing together diverse expertise and perspectives to address complex scientific questions. I am deeply convinced that the formation of productive collaborations and seamless interplay of interdisciplinary research are key indicators of achievement.
- *Personal and professional growth*: Success in science is closely related to personal and professional development. We embark on a long winding journey of continuous self-improvement, dedicated to refining our skills, broadening our knowledge, and nurturing our expertise. This ongoing process of learning, experimentation, and adaptability enables us to overcome challenges, learn from setbacks and experimental frustration, and pursue scientific aspirations through determination. The ability to embrace difficulties, learn from failures, and pursue scientific objectives persistently represents an important aspect of accomplishment.

This being said, remember that "success" bears an inherently multifaceted nature. Each scientist brings forth a unique perspective, and the definition of success is an intimate reflection of aspirations and dreams.

What is the achievement you are most proud of in your career?

Producing hundreds of mycorrhizal fungal genomes for our scientific community is undoubtedly a remarkable achievement. As a techie, my passion for exploring novel, high-tech equipment and developing innovative approaches has been a driving force behind my choice of a research career. My generation of scientists has witnessed remarkable advancements in scientific technology, such as *in vivo* nuclear magnetic resonance, desktop computers, PCR machines, genetic engineering, genome sequencing, next-generation sequencing technologies and now AI. I truly enjoyed transitioning to new techniques or approaches every five years, akin to playing with intriguing toys. I vividly recall the immense excitement I felt when new laboratory equipment, like our first PCR machine, NMR spectrometer, or DNA sequencing machine was delivered and unpacked, or when I first accessed the genome browser for the first sequenced ectomycorrhizal fungus, *Laccaria bicolor*. This was truly exhilarating.

What has been your biggest challenge in your career?

Uncovering the function of the mycorrhiza-induced small secreted protein of 7 kDa (MiSSP7) from the ectomycorrhizal basidiomycete *Laccaria bicolor* has been a lengthy and challenging journey. It was a formidable task indeed! In early 2007, we made the discovery that the fungal gene exhibiting the highest upregulation in Poplar-*Laccaria* ectomycorrhizal tips encoded a small secreted protein of 7 kDa. Through subsequent investigations using indirect immunofluorescence and confocal microscopy, we successfully localized this fungal protein within the Hartig net and host cell nuclei. We discovered the first potential symbiotic effector. In 2010, during your postdoctoral tenure in my laboratory, you demonstrated that MiSSP7 is an essential effector protein for mutualistic establishment. It was revealed that MiSSP7 targets the plant nucleus and influences the transcriptome of the host cell. Building upon this finding, in 2012, you showed that MiSSP7 interacts with the host protein

PtJAZ6, a negative regulator of jasmonic acid (JA)-induced gene regulation in poplar. A significant conclusion drawn from this research was the revelation that *L. bicolor* promotes mutualism by inhibiting JA action, thereby preventing the host defense reaction, through the interaction of MiSSP7 with PtJAZ6. Over the subsequent years, the collaborative efforts of two brillant PhD students, Yohann Daguerre and Veronica Basso, demonstrated that MiSSP7 enhances the symbiotic interaction by modulating the dynamics of a protein-protein interaction network associated with JA signaling. This alteration maintains the repression of PtMYC2.1-regulated genes. Recently, thanks to the dedicated work of José Marqués-Gálvez, we made the breakthrough discovery that the MiSSP7/JAZ6/MYC2 complex regulates terpene synthases and the synthesis of monoterpenes, which impact mycelial growth. Consequently, it took more than 16 years to decipher the MiSSP7 signaling pathway. Considering that *L. bicolor* releases over 50 MiSSPs during mycorrhiza development, there is ample work ahead for a new generation of committed young scientists.

On a more personal level, striking the right balance between my professional and family life has consistently posed a challenge.

What advice would you give to young researchers?

Mentoring young scientists and collaborating with my 'dream team' has been a highly rewarding experience. Developing genuine and lasting friendships is not merely a myth within the realm of large-scale international scientific endeavors. Building a career in science can be likened to the construction of monumental cathedrals during the Middle Ages. It requires unwavering faith and serves as a conduit for the creative energy of

highly motivated people. While scientific pursuits may often be driven by personal egos, they undeniably rely on collective efforts. Profound enthusiasm, ambition, and commitment to excellence are necessary in the quest to explore uncharted territories. However, it is crucial for young scientists to recognize that science requires a willingness to be part of a process that transcends individual contributions.

As an Editor, what is the key piece of advice for writers?

As an Editor of *New Phytologist* for over 30 years, I have found that the key piece of advice for authors is prioritizing clarity and coherence in their writing. It is crucial to convey ideas and information effectively in a concise and understandable manner. The following are some specific tips I have gathered from my experience:

- *Clearly articulate your main points*: Make sure that your main ideas and arguments are expressed clearly and consistently throughout your writing. This helps readers to understand the central message of your work.
- *Use plain language*: avoid unnecessary jargon or overly complex terminology. Strive for simplicity and clarity, making your writing accessible to a broader audience. Recall that the goal is effective communication.
- *Structure your writing effectively*: Organize your content logically using headings, subheadings, and paragraphs to guide readers through your work. Incorporate transitions to smoothly connect ideas and create coherent narrative flow.
- *Proofread and edit meticulously*: Pay close attention to grammar, spelling, punctuation, and quality of figures and tables to maintain a professional standard. Take the time to review your work multiple times, seek feedback from peers, or utilize proofreading tools to eliminate errors and improve the overall clarity.
- *Revise and refine*: Writing is an iterative process. Dedicate time to revise and refine your work, seek opportunities to clarify ambiguous statements, strengthen arguments, and enhance overall coherence. The idea is that improvements can always be achieved. I often produce around ten versions of my articles before I am satisfied.

One important aspect to consider is carefully selecting the journal to publish your best results.

What development in the field of mycology is you most looking forward to in the next decade?

One promising area of development in mycology is exploration of the mycobiome, which refers to the collective fungal communities present in various ecosystems. Although the study of the bacterial microbiome has gained significant attention in recent years, the mycobiome has received comparatively less attention. Understanding the diversity, functions, and interactions of fungal communities in different environments holds great potential for advancing our knowledge of ecological processes, plant-fungal interactions, and the impact of fungi on ecosystem sustainability.

Advancements in high-throughput sequencing technologies, bioinformatics, and computational analysis have revolutionized our ability to study the cryptic, soil fungal communities in greater detail. These technologies enable the characterization of the mycobiome, including mycorrhizal fungi, across various scales, from individual organisms to entire ecosystems. With the growing availability of reference fungal and tree genomes, as well as the advancements in RNA extraction from soils and mycorrhizal tips obtained from mature trees, metatranscriptomics has now become a powerful tool for assessing gene expression *in situ*. By harnessing environmental genomics, we can now establish connections between genes and ecological traits. It enables us to investigate the function of genes in just one gram of soil sample, opening up new possibilities for understanding the intricate relationships between genetic traits and ecological characteristics.

In the next decade, I anticipate that further investigations of the mycobiome will lead to significant discoveries and insights. These may include identifying novel fungal species, elucidating their ecological roles, uncovering their potential biotechnological applications, and understanding the impact of environmental changes on fungal communities. The integration of environmental genomics with the exploration of mycorrhizal diversity through global surveys, facilitated by initiatives like the Society for the

Protection of Underground Networks (SPUN), is offering exciting new perspectives.

How did you learn to communicate your research effectively to the public?

I am fully convinced that the effective communication of our research to the public is an essential skill in bridging the gap between scientific activities and the broader community. Through my career, I learned valuable lessons on how to effectively communicate my research to the public. Here are some rules of thumb that have guided me.

- *Know your audience*: Having a thorough understanding of the audience's background, interests, and level of knowledge is essential. By adjusting your language, terminology, and examples, you can make your research accessible and relatable... the audience of high school students and forest managers is quite distinct.
- *Simplifying complex concepts*: It is crucial to strike a balance when breaking down complex scientific concepts. While it is important to make ideas more accessible, oversimplification can lead to inaccuracies or the loss of scientific substance. Analogies, metaphors, and real-life examples can help explain abstract ideas, but it is important to exercise caution and ensure that they accurately represent underlying scientific principles. For example, although the Wood-Wide-Web concept of mycorrhizal networks was initially captivating, its scientific validity has been questioned. It is essential to critically evaluate concepts and to avoid perpetuating myths or unsupported claims when communicating complex ideas to the public.
- *Embracing storytelling*: Framing your research within a captivating narrative can engage the audience and attract their attention. By highlighting the motivations, challenges, and potential impacts of your work, you can create a compelling story about your research.
- Using everyday language and avoiding excessive jargon and technical terms is crucial when communicating with a non-expert audience.
- Highlighting the "*So what?*" It is clear that communicating the significance and relevance of your research is crucial. By explaining how your work addresses real-world problems, such as the impact of climate change on forests, contributes to scientific knowledge, or has practical implications, you can emphasize the potential impact of your research.
- Actively encouraging interactions and questions from your audience fosters engagement. By listening attentively, responding thoughtfully, and creating a two-way conversation, one can build a connection with the audience.
- *Exploring different media*: It is important to explore different communication media to reach a wider audience. Writing articles for science communication magazines, giving public talks, visiting high schools, creating videos, engaging on social media platforms, such as Twitter, and collaborating with science communicators can expand our reach.
- *Continuous improvement*: Hone your communication skills through practice and seek feedback from diverse sources.

How has the public's perception and interest in fungi changed over your career?

Over the past 40 years, there has been a notable shift in public perception and interest in fungi. While fungi have long been important in various aspects of human life, as you know too well, French people cannot enjoy life without a glass of wine and a crusty baguette. Their understanding and appreciation has evolved in several ways.

- *Awareness of ecological importance*: There is now greater recognition of the ecological importance of fungi. People have come to

understand that fungi play crucial roles in nutrient cycling, decomposition, symbiotic relationships with plants, and maintaining overall ecosystem health.

- *Medical and biotechnological applications*: The public has become increasingly aware of the medical and biotechnological applications of fungi. The discovery and development of antifungal drugs, such as those used to treat fungal infections, and cholesterol-lowering drugs, such as statins, have highlighted the importance of understanding fungal biology. Additionally, the use of fungi in various biotechnological processes such as the production of enzymes, biofuels, and pharmaceuticals has garnered attention and generated interest in fungal research.
- *Culinary and cultural significance*: There has been growing appreciation for the culinary and cultural significance of fungi in Western countries. Mushrooms have become increasingly popular in various cuisines worldwide and people have become more adventurous in exploring different mushroom varieties and flavours This culinary interest has contributed to the recognition of fungi not only as functional organisms but also as a source of enjoyment and gastronomic exploration.
- The establishment of mycological societies and the rise of citizen science initiatives have helped engage the public in fungi-related activities. These organizations provide platforms for enthusiasts to share knowledge, participate in forays, and contribute to fungal data collection. In France and many European countries, mushroom picking is a familial tradition.
- With growing concern for environmental issues, the public has become more conscious of the impact of human activities on fungal habitats and biodiversity. Efforts to conserve and protect fungal species and their habitats have gained attention, emphasizing the interconnectedness of fungi and broader conservation efforts

What led you to write popular science books (e.g., *Sous la Forêt*)?

Popular science books play a crucial role in the sharing of scientific knowledge, sparking curiosity, and engaging the public. By demystifying science and facilitating discussions on the ethical and societal impacts of scientific advancements, these books contribute to the development of a scientifically literate and involved society. The primary objective of my books is to inspire people to explore the wonders of forests by encouraging them to walk in the woods, appreciate the beauty of trees, and discover the enigmatic world of subterranean mushrooms. I believe that love and appreciation for nature go hand-in-hand with respect to and care for it.

Given the urgency of challenges, such as climate change, it is essential to foster a deeper understanding and appreciation of the natural world, including forests and mushrooms. Popular science books and public lectures serve as powerful tools to raise awareness of environmental issues and promote sustainable practices. Hopefully, they have the potential to shape public opinion, motivate individuals to take action, and advocate positive change. Humbly, I must acknowledge that the reading of my books inspired several students to embark on PhD projects focused on fungal or tree biology or forest ecology. It is gratifying to see how these books have played a role in sparking enthusiasm and igniting the curiosity of young students. The fact that my books have had a tangible impact on the career paths of aspiring researchers filled me with a sense of pride and accomplishment.

As mycologist, what does a forest look like you?

For mycologists, a forest is not merely a collection of trees, but a rich and intricate ecosystem teeming with life, including an incredible diversity of fungi. When we enter a forest, we see beyond the surface and delve into the hidden world beneath their feet. A forest to a mycologist is a vast network of interconnections, where fungi play a crucial role as decomposers, symbionts, and agents of nutrient cycling. We observe the forest floor, scanning for signs of mycelium weaving through the soil, decomposing organic matter, and forming intricate mycorrhizal associations with the roots of trees. These mycorrhizal networks facilitate the exchange of nutrients between fungi and plants, contributing to the health and vitality of the entire ecosystem.

As mycologists, we notice the variety of fruiting bodies emerging from the forest floor, ranging from delicate mushrooms to sturdy brackets and brightly coloured lichens. We observe the diverse forms, colours, and textures of these fungal structures, appreciating their beauty and marvelling at their intricate adaptations for reproduction and dispersal. To me, a forest is a place of wonder, curiosity, and endless exploration.

What do you like to do in your spare time, which is not related to fungi?

I thoroughly enjoy spending early summer days hiking along the alpine trails of the most secluded valleys in the French Alps, foraging for mushrooms in the forests of the nearby Vosges mountains, and capturing countless nature photographs.

Meeting reports

Mycorrhizal joy in the Amazon: a Meeting Report of the III International Symposium on Mycorrhizal Symbiosis in South America

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The South American Mycorrhizal Research Network (Fig. 1; https://southmycorrhizas.org/) was created in Valdivia, Chile, in March 2017 and currently boasts 406 members from 50 countries. The South American Mycorrhizal Research Network is a horizontal scientific community directed towards the progress of mycorrhizal applications, research, and public outreach in South America. Since its creation, the Network has organized three international symposia (Valdivia, Chile in 2017; Bariloche, Argentina in 2019; and the one we are reporting here, Leticia, Colombia, 2023) (Bueno *et al.* 2017; Godoy et al. 2017; Mujica *et al.* 2019; Marín 2021), an online workshop, and three symposia within the Latin American Congress of Mycology (in Perú, Chile, and Panamá). In addition, it has published five scientific articles, two Springer books edited by Mónica A. Lugo and Marcela C. Pagano, and a special issue in the journal *Diversity* (https://southmycorrhizas.org/about/publications/). We have a dedicated team (South American Mycorrhizal Traits Database) leading the vast and important task of generating a database on mycorrhizal traits for South America (J. Duchicela, C.G. Bueno, P. Silva-Flores, and M.I.

Figure 1. Logo of the South American Mycorrhizal Research Network. Designed by Heiko Sievers.

Mujica – all co-authors of this report). In addition, we regularly release interviews on YouTube featuring mycorrhizologists at all career stages (https://southmycorrhizas.org/reading/), provide outreach tools (Silva-Flores *et al.* 2021; https://southmycorrhizas.org/outreach/), and collaborate with various other networks and Latin American and global scientific societies (e.g. FAO, Soil-BON, Latin American Mycology Association, SPUN) and scientific journals. Notably, we collaborate strongly with the IMS Newsletter (https://southmycorrhizas.org/ims-newsletter/). Interested people can join our Network here: https://southmycorrhizas.org/join/

Since the creation of the Network, it became clear that despite South America's vast size, biodiversity, and an increasing number of mycologists and ecologists specializing in mycorrhizae, mycorrhizal research on the continent needs to be substantially expanded (Marín and Bueno 2019). We identified three main reasons for the regional shortfall in mycorrhizal research (Mujica *et al.* 2019): insufficient funding across South American nations with the absence of a unified mechanism for conducting continental-scale research (as seen in the European Union or the United States), a demand for more robust training in sampling, statistical, molecular, and bioinformatic methods, especially among young researchers and students, and a lack of comprehensive information on plant mycorrhizal traits across several biomes and countries. In turn, we have observed research biases about certain mycorrhizal types (with orchid and ericoid mycorrhizas generally overlooked compared to arbuscular or ectomycorrhizas), ecosystem functions (with a predominant focus on plant growth), and concentration of research in specific countries (with Brazil, Argentina, and Chile accounting for 80% of regional mycorrhizal research) (Marín *et al.* 2022). Our Network knows such biases and works directly and powerfully to combat them. Recently, Cazolla Gatti *et al.* (2022) estimated that more than 9,200 tree species worldwide are yet to be discovered, 40% of them in South America! This underscores the imperative for foundational, methodical research within our continent, beginning with the systematic collection of mycorrhizal-type information as a baseline.

In this context, we present our Meeting Report of the III International Symposium of the Mycorrhizal Symbiosis in South America (Fig. 2), held from August 24th to 31st, 2023, in the beautiful city of Leticia, Amazonas, Colombia. This symposium saw participation from approximately 75 attendees on-site and over 30

Figure 2. Logo of the event and sponsors.

individuals virtually (Fig. 3). The organization was headed by Clara Peña-Venegas and César Marín, with substantial contributions from all co-authors of this report. It was a great joy to have such a varied group discussing mycorrhizas in the Amazon! The event was supported and hosted by the Instituto Amazónico de Investigaciones Científicas – SINCHI and the Universidad Nacional de Colombia and also had financial support from the New Phytologist Foundation, the Society for the Protection of Underground Networks (SPUN), and MycoNativa ©. This event included two pre-symposium courses focused on Amazonian mycorrhizas (arbuscular mycorrhizas, AM, and ectomycorrhizas, ECM) and bioinformatics, as well as a post-symposium workshop to start building a South American mycorrhizal traits database. Here we summarize six significant themes discussed during the symposium and highlight selected presentations within each theme.

Mycorrhizas in Amazonia and other natural environments

Since the Amazon was the location of our symposium and given its status as such a diverse yet unexplored ecosystem in terms of mycorrhizal research, our initial focus was naturally on this region, where we had to start. Clara Peña-Venegas shared the latest research advances in

arbuscular mycorrhizal fungi (AMF) in the Colombian Amazon, showing fascinating evidence of a biogeographic gradient in the distribution of AMF in Colombia. Also, Aida M. Vasco-Palacios summarized about ten years of her career in the Colombian Amazon. Her work highlighted the discovery of new species of ECM fungi, specifically delving into the exploration of less studied underground environments like the Amazonian white sands and terra-firme forests, particularly emphasizing the association with the dipterocarp tree, *Pseudomonotes tropenbosii* (Vasco-Palacios *et al.* 2018, 2019; Vasco-Palacios and Boekhout 2022). Continuing with ectomycorrhizas, Maria Alice Neves introduced new Amazonian taxa of ectomycorrhizal fungi from the Atlantic Forest. Despite claims that they are only found in temperate and boreal ecosystems, these findings shed light on their morphology with detailed insights. Maria Alice Neves, Ariadne N.M. Furtado and their coauthors introduced a novel type of mycorrhiza (Furtado *et al.* 2023): guapiroid mycorrhizas. As the existence of guapirioid mycorrhizas may be unfamiliar to some, people can learn more about this topic in an interview with Ariadne, available online: https://youtu.be/npXtj05eX60?si=sOYIwYek-If1uFHk

At the same session, Tomas Figura showed how similar the seedling development is between orchids and the Pyrola genus (Ericaceae). Both plant groups have tiny seeds that require mycorrhizal fungi to germinate; this process is known as "symbiotic germination". Overall, this session spanned other countries such as Panamá, Colombia, and Brazil, as well as relationships with other soil organisms (like *Rhizobium*), among other topics. One open question that emerged during this session was whether the endemic ECM host tree *Pseudomonotes tropenbosii* (Dipterocarpaceae) forms dual relationships with AMF as well, an example of how much remains to be studied in the tropics with open minds.

Mycorrhizas and climate change

Understanding the environmental drivers of mycorrhizal fungal distribution is essential to predict their responses to global changes, including climate change. In addition, trait information might help to assess how different species will respond. Three contrasting talks tackled these issues. Through the study of the genus Tuber, Tine Grebenc presented compelling evidence that geographical distance is a determining factor in genome distribution. On her part, Bala Chaudhary captivated the audience, discussing the ecological traits of AMF and how these can provide insights into processes such as their dispersal, persistence, and relationships with plant carbon. Bala presented an AMF spore trait database, which includes information from 315 species and will be released soon. Through a large-scale phylogenetic study (using a comparative method), Marco Cosme detected correlated evolution between mycorrhizal types and plant drought adaptation. For example, plant taxa associated with ericoid mycorrhizas or ECM had higher transition rates between tolerance and intolerance to drought than those groups without mycorrhizal associations. Marco's work (Cosme 2023) was voted Top 1 in our last IMS Newsletter issue (Vol. 4, Issue 2). Other topics raised during this session included agronomic aspects (in tomatoes, grapevines, and legumes) and mycorrhizas in temperate and Mediterranean Chilean ecosystems.

Mycorrhizas in agriculture

This session boasted the highest number of talks and posters during our Symposium, reflecting the state of mycorrhizal research in our continent (Marín and Bueno 2019). Miroslav Vosátka showed significant advances in applying base knowledge of microorganisms (plant growth-

Figure 3. Upper part: group photo of the event. **Lower part:** countries of the participants.

promoting bacteria, AMF, among others), which helps improve sustainable agriculture. He and his team have experimented and put into practice mass inoculation techniques highlighting the importance of using native AMF in the field, which has increased agricultural yield in Middle-East deserts (by creating vertical gardens) and promoted a circular economy in Africa. In turn, Ian Sanders spoke about the immense potential of various AMF strains in improving Cassava production in Latin America and Africa. Cassava is a significant food source for millions of people in the world's poorest and most hungry countries. The increase in its production and sustainable production can contribute to the circular economy of different Global South countries. Nevertheless, the considerable intra and interspecific variation in AMF is still a stumbling block in predicting their application as inoculants (Terry *et al.* 2023), representing a challenge for mycorrhizal scientists. Also in Cassava systems, Diego Camilo Peña made visible the significant contribution of AMF in the retention of carbon (C), avoiding its incorporation into the atmosphere with its dire consequences on global climate change. This is relevant given the geographical range and agroeconomic importance of this crop. He also showed the differences in the productivity of

Cassava depending on the genetics of the inoculated AMF and soil aggregation, as well as the possible larger-scale effects being studied directly in the field in Colombian Cassava crops.

Fabiana Pezzani presented a platform for the efficient use and transfer of bio inputs in Latin America, whose mission is to disseminate basic knowledge and the broad benefits of bio inputs to agricultural and livestock producers in South America. Maria del Rocío Vega examined the above and belowground traits of chili peppers (*Capiscum annuum*). More than 60 varieties of *C. annuum* widely used in México, Bolivia, and Perú differ in the morphology and allometry of their leaves, stems, and roots, depending on their degree of domestication. One of the challenges in studying the allometric redistribution of resources in relation to associations with AMF and its relationship with domestication was to find wild forms of *C. annuum*. Eureka! Wild *C. annuum* only grows in very restricted pristine areas of the Mexican subdeciduous tropical forest. Comparative studies between wild, semi-wild, and domesticated plants inoculated with AMF show different morphological and functional leaves and root traits.

Erica McGale presented her research on using inoculants for different species of edible plants (corn, Cassava, and coffee), investigating different genetic variants of AMF and host allometry. AMF contributed to changing the 1:1 shoot: root tissue partition occurring in non-colonized plants, redistributing resources, and increasing the proportion of roots: aerial part of the host. This differential allometries produced by AMF could also be differentiated between structural and reproductive tissues and the competitive capacity of the host. Erica cautioned about the uninformative nature of evaluating host allometric traits only at the end of the inoculation trial, as allometry changes with plant phenology. María Margarita Ramírez presented an econometric analysis of AMF inoculants in cape gooseberry, "uchuva" (*Physalis peruviana*), in Colombia. The production of this native plant is carried out primarily by small local producers in high-altitude areas, which are dangerously ascending towards the Páramo, the great water reservoir of the country. After testing mixed inoculants with growth-promoting bacteria and AMF, she and her group tested them in field plots with promising results for their application. Although the estimated economic benefits were positive, they have once again encountered the unpredictability of applying inoculants in crops to mass produce cape gooseberry. It is necessary to continue investigating in order to apply this outstanding knowledge!

Distribution of mycorrhizal symbiosis, co-invasions, and restoration

Jéssica Duchicela showed that in the Ecuadorian jungle associated with *Inga* sp., mycorrhizal fungi were predominantly Ascomycota, while Glomeromycota were scarce, contradicting the paradigm of AMF associations being predominant in the Tropics. Furthermore, in the Galápagos, she studied not only native hosts but also invasive ones, finding little colonization in native plants and high colonization in invasive and naturalized ones. These results were also confirmed in field trials, where the invasive hosts were more successful than the native ones when grown in the islands' soils. Everything indicates that invasive plants and the expansion of the agricultural frontiers threaten the islands' endemic plants. It is imperative to apply conservation and management practices to avoid losing the rich endemic flora of the Galápagos!

The revelation that certain tropical tree species can host ECM fungi or even a new related

association called guapiriod, as showcased by Jessica Duchicela, Aida M. Vasco-Palacios, and Ariadne N.M. Furtado, in this conference, challenges the prevailing global assumptions regarding tropical forests. This underscores the imperative for a broader collection of empirical data on mycorrhizal associations and a more inclusive scientific stance toward diverse perspectives (as addressed in Albornoz *et al.* 2021, Bueno *et al.* 2021, among others). Part of the disparity between empirical evidence and expectations arises from unfounded assertions concerning the phylogenetic conservatism of mycorrhizal associations within plant orders, families, and genera. A significant stride in this direction was presented by C. Guillermo Bueno, where Tartu University researchers conducted pioneering measurements of the phylogenetic signal of various mycorrhizal associations. They also assessed the relative contributions of phylogeny and environment in elucidating the global distribution of mycorrhizal symbiosis (Meng *et al.* 2023). Utilizing the most recent plant mycorrhizal dataset, their study indicates that extrapolations of mycorrhizal types within plant taxa often neglect crucial environmental factors influencing these associations. Taxonomic extrapolations should be exercised cautiously, primarily when mycorrhizal information is limited, treating their outcomes as hypotheses. During this conference, Daniela León highlighted this cautious approach by presenting her research findings on the distribution of mycorrhizal symbiosis in the Colombian Páramo. Her study utilized genus extrapolations, emphasizing the need to consider outcomes as hypotheses (León *et al.* 2024).

Nahuel Policelli discussed the role of non-native invasive ectomycorrhizal fungi in partially explaining the invasiveness of their plant partners (Policelli *et al.* 2023). He highlighted the importance of critical non-native invasive fungi, such as suilloid fungi, which can act as global drivers of Pinaceae invasions. Policelli's research in temperate Patagonian forests demonstrated how the community of ECM fungi changes from non-native pine plantations to the pine invasion fronts, where suilloid fungi are dominant. In turn, the evidence presented demonstrates how native ECM *Nothofagus* trees and non-native pine trees can find suitable mycorrhizal partners in each other's dominated areas. While it is typically assumed that non-native invasive mammals, including wild boars and deer, play a significant role in the dispersal of invasive ECM fungi within Patagonia forests, Policelli's discovery of these non-native fungi on lake islands raises new questions regarding the potential for bird or human-mediated dispersal, as well as wind dispersal (Policelli *et al.* 2022). Finally, he introduced some new hypotheses on dryland systems in Patagonia dominated by willows (*Salix* spp.), where he is studying whether native trees can facilitate the invasion of non-native congeners mediated through ECM fungi.

Mycorrhizas: ecology, diversity, and evolution

This session commenced with a captivating presentation by Martin Bidartondo, revealing the extensive presence and multifaceted roles of Mucoromycotina fungi across various ecosystems, surpassing prior conceptions (Hoysted *et al.* 2023). Jason Hoeksema delivered an illuminating talk debunking misconceptions surrounding Common Mycorrhizal Networks (CMN) (Karst *et al.* 2023; with an interview on our YouTube channel: https://youtu.be/7IGhb36AyPM?si=gb6-GgkpSqikx9Wb). By a detailed analysis of cumulative misinterpretations of current evidence, Jason showed how we need much more evidence to understand and claim how widespread they are, the potential effects of CMN on plants' growth, and whether trees 'can talk' or not with each

other through a CMN. Adriana Corrales focused on characterizing the ECM fungal communities associated with the endangered and monodominant host tree *Trigonobalanus excelsa* (black oak) in the Colombian Andean region. She highlighted the high number of new species of ECM fungi and high beta diversity associated with different populations of this host plant. Adriana placed particular emphasis on conserving these forest systems to preserve tropical ECM fungi, highlighting the importance of continuous monitoring of permanent plots and developing strong collaborations with local communities.

Among several other topics, this session included discussions on the roles of plant mycorrhizal and seed dispersal interactions as drivers of ecosystem structure and function (Marta Correia), the mycorrhizal associations of the Eastern pasque flower (*Pulsatilla patens*) across its native range (Savannah Draud), and, when analyzing South American *Nothofagus* ECM associations, evidence suggesting that ECM fungi have a restricted habitat volume (Felipe Figueroa). From Czechia, Zuzana Kolaříková introduced the *GlobalAMFungi* database (Větrovský *et al.* 2023), and her understanding of community assembly in AMF, while Martina Janoušková showed compelling evidence of AMF from arable fields being equally efficient in providing P but more demanding for C and N compared to grassland AMF.

Mycorrhizal fungi and their interactions with other organisms

Peter Kennedy started this session by discussing how dead mycorrhizal fungal mycelium is linked to global carbon cycling, examining its decomposition's abiotic and biotic (other microorganisms) drivers. Fungal necromass constitutes a significant source of soil C and nitrogen, and its decomposition is highly dependent on both abiotic and biotic factors, including a diverse mix of bacteria and fungi with a consistent assemblage structure across ecosystems. Marcel G.A. van der Heijden, IMS President, talked about the past, present, and future of AMF-based agronomic practices, among other things, showing that a vast majority of AMF biofertilizers do not work (Salomon *et al.* 2022a), but also proposing a quality management framework for them (Salomon *et al.* 2022b). His approach was cautionary but optimistic, showing excellent results from trials across Switzerland and Spain.

Awards

We recognized the life and career of two eminent mycorrhizologists who have greatly impacted South American mycorrhizal research. First, Prof. Ewald Sieverding from Germany was recognized for his pioneer mycorrhizal contributions across several countries of the continent, such as Colombia and Chile. In a very emotive presentation, Prof. Gisela Cuenca from Venezuela was given the Second South American Eminent Mycorrhizologist Award for her outstanding contributions to AMF ecology and applications, new species descriptions, forming dozens of students across South America and building the first slides collections of AMF species in South America. In addition, we gave three awards for best oral presentations to (in order) Natalie Ferro Lozano (Wageningen University), João Paulo Ernzen (Universidade Federal de Santa Catarina), and Savannah Draud (University of Mississippi). The best poster award was given to Ezequiel A. Cruz-Campuzano (Universidad Nacional Autónoma de México), with Sofía Crescio (Universidad de Buenos Aires) in the second place. The best online poster award was given to Pablo García Parisi (Universidad de Buenos Aires), while a special mention award – poster with social impact, was given to Yessica Lorena Perdomo (Fundación Universitaria del Área

Andina). More details on the awards here: https://southmycorrhizas.org/events/awards/

Concluding remarks and acknowledgments

Over the past 6.5 years, more than 100 individuals have contributed voluntarily to our Network in various capacities, excluding the authors of our published works. This includes but is not limited to organizing events, conducting interviews on our YouTube channel, writing blog posts, arranging online workshops and working groups, and providing financial and outreach support. The organization of this Symposium involved many individuals, as noted below. In today's climate, it is essential to reject helicopter science (Haelewaters *et al.* 2021) and acknowledge the prevalence of discrimination, particularly racial discrimination, in academia (Hofstra *et al.* 2020). Additionally, incorporating non-English scientific literature can enhance global understanding of ecological matters (Zenni *et al.* 2023). Therefore, our Network and scientific methodology appear well-suited for this current landscape. It is impressive that despite being from the Global South and lacking a legal constitution and a traditional scientific society structure with formality and annual fees, we have achieved so much in such a short time. The attention received from numerous individuals, organizations, and journals is impressive, reinforcing our personalized and horizontally collaborative approach to science and scientific engagement.

Our III Symposium would have been impossible without the support of the Instituto Amazónico de Investigaciones Científicas – SINCHI. We thank its General Director Luz Marina Mantilla, Clara Peña-Venegas, Sandra Mora, Daniela León, Ana Paola Aponte, Andrés Barona, and Diana Mora. This Symposium also took place and was supported by the Universidad Nacional de Colombia sede Amazonas, with the crucial help of its Director and co-organizer Eliana Jiménez, and also from Angela Hooz Chaparro, Patricia Marín, Laura Vargas, Camila Orca, and Mónica Andrea Ríos. Thanks for the support of the Colombian Mycology Association, ASCOLMIC. From New Phytologist, we thank its Editor-in-Chief Alistair M. Hetherington, Maarja Öpik, and Sarah Lennon. From the Society for the Protection of Underground Networks (SPUN), we thank its Executive Director, Toby Kiers, Adriana Corrales, and Bethan F. Manley for organizing a fantastic bioinformatics course! Similarly, many thanks to Clara Peña-Venegas, Aída M. Vasco-Palacios, Maria Alice Neves, and several other co-authors in this piece and people above-mentioned in this paragraph, for organizing an excellent course on Amazonian mycorrhizas which involved an intense, well-deserved, and even better-planned fieldwork. On that note, special thanks to Angel Pijachi and Miguel Angel Arcangel of the Bora and Uitoto-N+pode indigenous communities, whose guidance and expertise were crucial for an unforgettable and successful fieldwork. Thanks to the South American Mycorrhizal Traits Database leading team and all the post-symposium workshop attendees for starting to build our database. C.G.B was supported by the Spanish Ministry of Science and Innovation through a Ramón y Cajal fellowship (RYC2021-032533-I).

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Meeting Report of the 6th international Molecular Mycorrhiza Meeting

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The 6th international Molecular Mycorrhiza Meeting (iMMM) made a stellar return to the in-person format this year when the Sainsbury Laboratory in Cambridge welcomed delegates from the 25th to the 27th of September 2023. Lead local organiser Sebastian Schornack opened the meeting by welcoming Benoit Lefebvre to give a keynote address where he explored the diversity and functionality of the Lysin Motif Receptor-Like Kinase (LysM-RLK) family. There are three major phylogenetic groups of LysM-RLKs, these being LYRIA, LYRIB, and LYRIIIA, and investigations using YFP-fusion tagged versions of these proteins and radiolabelled (or crosslinked radiolabelled) lipochitooligosaccharides and chitoioligosaccharides, have determined their binding affinities to these fungal symbiosis elicitors. LYRIA, LYRIB, and LYRIIIA display affinity for binding LCO, while in LYRIB the high affinity for LCO is superseded by a higher affinity for short chain COs, and remarkably, affinity can be changed by altering the length of the protein which is expressed. The expression of these receptors was also shown to affect root architecture and LYRIA has a function in regulating plant defence.

This was followed by a session on fungal signalling, chaired by Hiromu Kameoka who discussed induced responses in AM fungi. William Ledford, of the Luisa Lanfranco group in Italy, shared exciting evidence for a new model of cross-kingdom RNA interference within his study system of *Rhizophagus irregularis* and *Medicago truncatula*. Ledford explained that there are three main classes of fungal small RNAs with distinct functions within *R. irregularis:* Dicer-like, which are cleaves double-stranded or hair-pin constructs, Argonaute-like, which are involved in gene silencing, and RNA-dependent RNA polymerases, which are involved in amplification. Ledford *et al.* demonstrated that the fungal sRNA *Rir-2216* is upregulated in the intraradicle hyphae where it was identified as having the potential to target the transcription factor *MtWRKY69*. Ledford presented that *Rir-2216* can silence *WRKY69* when these proteins are co-expressed in *Nicotiana benthamiana* and that 5' RLM TACE degradome sequencing could retrieve a cleaved *WRKY69* fragment. The new model suggests that *Rir-2216* is transported to the roots where it interacts with AGO1 to silence *WRKY69* and increase *R. irregularis* colonisation. Uta Paszkowski then chaired a session covering molecular aspects of the chemical signalling from plants to fungi with fascinating insights into the role of D14L (Raphaella Hull), the evolution and functional significance of receptor kinases (Chai Hao Chiu), LYSM protein regulation of architecture and mycorrhizal symbiosis in rice (Luisa Lanfranco), and finally, the role of proanthocyanidins in ectomycorrhizal roots (Judith Lunberg-Felten).

Nicolas Corradi chaired a session on the genomics and evolution of mycorrhizal symbioses, which he began by sharing his latest insights on the genetics and genome biology of arbuscular mycorrhizal (AM) fungi. Corradi explained that

there are two distinct karyotypes within the six strains of *R. irregularis* studied to date, homokaryons, where all nuclei present one genotype, or dikaryons, where all nuclei originate from two parental strains and co-exist within the coenocytic mycelium. The frequency of alleles can vary between and within these two karyotypes, and was shown to be changeable in response to a change in the host plant. The 30+ chromosomes in *R. irregularis* vary in gene content, size, and their epigenetics, with each compartment functioning differently where these differences correlate to the methylation status of transposable elements. Corradi highlighted that one of these compartments, compartment B, is responsible for the expression of effector genes and secreted proteins, and that shifts in allele frequencies within this compartment in response to a change in plant host species is an indication of a changeable molecular dialogue of symbiosis. This was followed by an exciting set of talks ranging from evolution of mycorrhizas (Pierre-Marc Delaux), mycorrhizal rice translatomes (Garo Akmakjian), and tolerance of heavy metals in ectomycorrhizas (Joske Ruytinx).

The second day of the conference kicked off with cellular and molecular aspects of mycorrhizal symbioses, ranging from regulation via kinases (Li Xue, Sergey Ivanov) to LysM receptors, immunity (Feng Feng), and pathogen effectors (Albin Teulet). During this session we were treated to a fantastic presentation by Jennifer McGaley on the temporal dynamics of nutrient exchange at the arbuscule. To conduct this work, McGaley had devised a novel *in-planta* slide device, where an intact plant is able to develop its roots along a compartment lined with glass so that transformed roots can be visualised for fluorescence by confocal microscopy. McGaley explained that arbuscules are dynamic, turning over their life cycle in a matter of days, and that the expression

and localisation of nutrient transporters varies across this period. For example, PT11 is expressed in young arbuscules but its expression is at a maximum in mature stages while an ammonia transporter is present from young arbuscules through to collapsed arbuscules, suggesting that the uptake of ammonia and phosphate may have different dynamics. Even more strikingly, McGaley showed that STR1/2 is present as early as the trunk stage of arbuscule development through to the mature stage, suggesting that the plant may first feed the fungus with carbon before it begins to uptake nutrients at the arbuscule. McGaley made the astute point that there appears to be a diversity of arbuscules, with variable trends in size development and time before collapse.

We were then treated to talks concerning interactions between mycorrhizas and the environment at the molecular scale, including a talk from Giles Oldroyd (chair) about environmental regulation of mycorrhizal colonisation focusing on barley as part of an exciting programme aiming to improve sustainable production of this cereal, Ertao Wang on perception of symbiotic signals in *Medicago,* and Armando Bravo on the regulatory controls in AM symbioses. Sebastian Schornack and Alan Wanke started the afternoon with an exciting presentation introducing the newly-sequenced genome of a Mucoromycotina 'fine root enodphyte' fungal isolate, previously shown to be nutritionally mutualistic with clover (Hoysted *et al.* 2023). This was followed with a look back in time with Christine Strullu-Derrien who presented some of her research on ancient symbiotic fungal associations in early land plants with evidence taken from Rhynie Chert fossils. The session finished with an interesting, genetic look at endosymbioses in Dryas by Martin Parniske.

The final session of the day was chaired by Jean-Michel Ane who took us on a detective hunt for the true identity of glomalin (*or is it glomalose?*), before Katie Field presented the latest insights into the functional significance of the 'other' mycorrhizas with Mucoromycotina 'fine root endophytes'. Sabine Zimmermann followed discussing the ectomycorrhizal transportome before Toon Leroy presented more applied aspects of AM symbioses, and how carbon status of tomato might be modulated to improve outcomes. Silvia Perotto finished the session with a fascinating insight into orchid metabolism in orchid mycorrhizas using multi-pronged genetic, laser microdissection, and stable isotope labelling approaches.

A fantastic couple of days of research presentations and discussions was finished with a wonderful gala dinner at Newnham College where discussions went on late into the night…

Day three of the conference opened with a session focussing on the interaction of mycorrhizal fungi with atypical plant hosts. The host of the session, Juliana Almario, opened with their work to functionally characterise the interaction and nutrient exchange between mycorrhizal-like fungi with non-mycorrhizal plants. For example, *Arabis alpina*, a plant inhabiting phosphorus-starved alpine soils, have lost their ability to establish symbiosis with AM fungi. Instead, they are found to associate with a range of fungal endophytes. Almario studied the root-associated fungal microbiome which was abundant with Heliotales, a taxon rich in ericoid mycorrhizas. Through functional nutrient exchange experiments, they confirmed that Heliotales played an important role in supplying *A. alpina* with desperately needed phosphorus. Almario's work highlights a niche role that mycorrhizal fungi can play in extreme environments and poses interesting

questions on the unknown diversity of fungal species and the ecological roles they serve. Unfortunately, Chris Bell was unable to attend the meeting, so co-author Katie Field stepped in to present their work on mycorrhizal carbon for nutrient exchange dynamics in the presence of plant parasites. They showed that despite the addition of nematodes as a carbon sink, there was no additional loss of carbon to the plant. Metabolic and gene expression analyses suggested that in response to the nematode feeding, the host plant was able to partition its supply of carbon to AM fungi, and minimise loss of carbon to the parasitic worm. They identified that this was mediated by down-regulating hexose sugar transporters whilst maintaining expression of fatty acids transporters. Bell's work reinforces the idea that regulation of mycorrhizal nutrient exchange is context-dependent and dynamic, and gave a valuable new insight into how a beneficial symbiosis might be maintained when parasites and other symbionts co-colonise. This was followed by a fascinating look at the twin roles of two AP2/ERF transcription factors (Yueyang Ge).

We were then treated to a talk on the biodiversity-environmental feedbacks of AM fungi by Cynthia Albracht. Using a long-term site in Jena (The Jena Experiment), she showed that the assembly of AM fungal communities were driven by soil legacy rather than plant history, with these communities converging under monocultures and not diverging or converging in more diverse grasslands. Albracht offered exciting insights into the factors dictating the species found in plant communities and ways to manage soils for improved mycorrhizal diversity. Following this, Thais Guillen Otero presented really interesting insights into facultative mycorrhization in ferns and how this was influenced by the soil environment and light incidence.

Maria Harrison chaired the final session on cellular aspects of the AM symbiosis. Harrison shared their impressive work identifying key genes in *Medicago* involved in the reorganization of root cells to maintain AM symbiosis. Harrison revealed an exciting technique to sequence individual cells during colonization, while offering fantastic resolution of spatial expression profiles. This innovation paves the way to untangling differential gene expression at the cellular level. Erik Limpens discussed the role of DELLA proteins, followed by Ronelle Roth discussion of the role(s) of extracellular vesicles in communication between AM fungi and host plants. Caroline Gutjahr closed the conference with a timely plenary summarizing her group's most recent and exciting work on the regulation of AM symbioses in model plants.

The 6th iMMM in Cambridge was a fantastic meeting (big thank you to everyone who made it possible, especially the local organizing team), which emphasized progress whilst defining the outstanding questions in the molecular mycorrhizal research field. We're excited to hear about more progress in these areas at the upcoming ICOM12 in Manchester this summer (4 – 9 August, 2024) - can't wait to see you all there!

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YouTube interviews*

- **Ariadne N.M. Furtado on Guapirioid ectomycorrhizas in the restinga**

Ana Bermudez Contreras (PhD student, University of Alberta, Canada) interviews Ariadne N. M. Furtado (Postdoc at the Federal University of Paraíba, Brazil), about a new sub-type of ectomycorrhizal association, the Guapirioid ectomycorrhizas.

Interview: https://southmycorrhizas.org/reading/october-2023/
Study: Furtado AN, Leonardi M, Comandini O, et al. 2023. Guapirioid ectomycorrhiza: a novel fungus-plant subtype is described associated to *Guapira opposita* (Nyctaginaceae) in the Brazilian restinga. *For Syst* 32:e009-e009.
https://doi.org/10.5424/fs/2023322-19998

- **Laura M. Bogar on source–sink dynamics in ectomycorrhizal symbiosis**

Camille Truong (Royal Botanic Gardens Victoria, Australia), interviews Laura M. Bogar (University of California – Davis) on how a relatively simple framework (source-sink dynamics) can inform a very complex issue: determine if plants choose their fungi.

Interview: https://southmycorrhizas.org/reading/november-2023/
Study: Bogar LM. 2023. Modified source–sink dynamics govern resource exchange in ectomycorrhizal symbiosis. *New Phytol*. Early View. https://doi.org/10.1111/nph.19259

- **Yiming Meng on how plant phylogeny & environment affect mycorrhizal type & status**

César Marín (Universidad Santo Tomás, Chile) interviews Yiming Meng (Ph.D. student at the University of Tartu, Estonia) about her global-scale analyses to assess the effects of plant phylogeny and environment on plant mycorrhizal type and status.
Interview: https://southmycorrhizas.org/reading/december-2024/
Study: Meng Y, Davison J, Clarke JT, *et al*. 2023. Environmental modulation of plant mycorrhizal traits in the global flora. *Ecol Lett* 26:1862-1876.
https://doi.org/10.1111/ele.14309

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Tools

→ *GlobalAMFungi:* global metabarcoding database for arbuscular mycorrhizal fungi (AMF)

Větrovský *et al.* (2023) present GlobalAMFungi, a sister database of GlobalFungi. This curated database contains metabarcoding data from the markers ITS2, LSU, and SSU. It currently contains the data of 8464 samples coming from 100 studies. Access the database here: https://globalamfungi.com/

Study: Větrovský T, Kolařík ová Z, Lepinay C, *et al.* 2023. GlobalAMFungi: a global database of arbuscular mycorrhizal fungal occurrences from high-throughput sequencing metabarcoding studies. *New Phytol* 240:2151-2163. https://doi.org/10.1111/nph.19283

→ Keep rarefying your metabarcoding data!

Over the last decade, some researchers have questioned the validity of a common practice many of us use to normalize the data coming from metabarcoding sequencing: rarefying. In particular, in 2014, a couple of authors made some simulations and concluded that rarefying is "inadmissible". That article has been cited more than 2,600 times! Schloss (2023) revisited that article, run the numbers and simulations, and to make a long story short, concluded that you should keep rarefying your data!

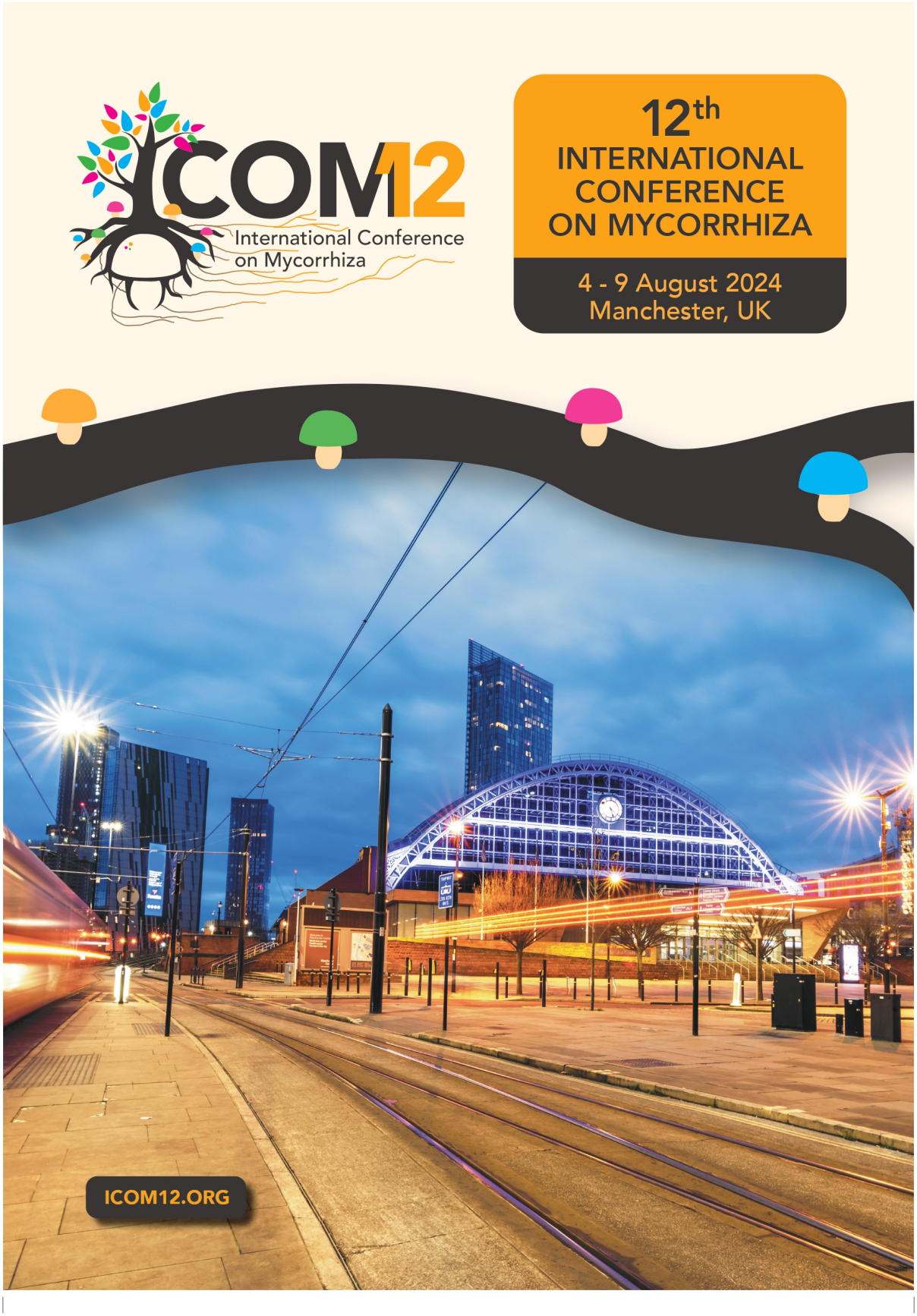
Study: Schloss PD. 2023. Waste not, want not: Revisiting the analysis that called into question the practice of rarefaction. *mSphere*. Early View. https://doi.org/10.1128/msphere.00355-23

→ Camille Truong's Lab protocols

Camille Truong, Research Scientist at the Royal Botanic Gardens Victoria, Australia, has on her website, freely available protocols regarding mycorrhizal roots and spore mats sampling, CTAB and rapid DNA extraction, and Illumina metabarcoding analyses protocols. Access (and cite) these great resources here: https://camillethuyentruong.github.io/protocols/

Click for previous Tools: Vol1_I1 (p. 11), Vol1_I2 (p. 15), Vol1_I3 (p. 16), Vol2_I1 (p. 19), Vol2_I2 (p. 15), Vol2_I3 (p. 15), Vol3_I1 (p. 16), Vol3_I2 (p. 17), Vol3_I3 (p. 26), Vol4_I1 (p. 19), and Vol4_I2 (p. 23).

MYCORRHIZAL EVENTS:



Events

- The 12th International Conference on Mycorrhiza (ICOM12) will take place in Manchester, United Kingdom, 4 – 9 August, 2024.
Further information in Twitter: @ICOM_12

- The 13th International Conference on Mycorrhiza (ICOM13), will take place in Cairns, Australia, in 2026. Stay tuned for further information.

→ **Call for ICOM14 proposals in 2028:** If you are interested in organizing ICOM14 in 2028, please write to Katarina Zachariasova (zachariasova@associationhouse.cz) and/or to Justine Karst (karst@ualberta.ca), so your proposal can be presented during ICOM12 in Manchester, United Kingdom. Please do so until 30 June of 2024.

11th International Workshop of Edible Mycorrhizal Mushroom

Website

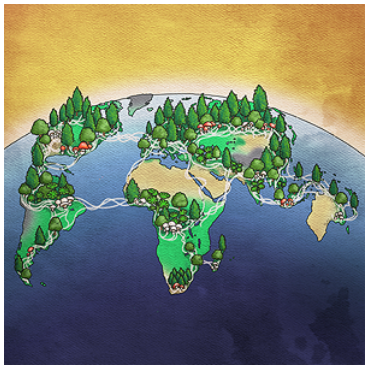
CIEFAP, Esquel, Argentina

22 – 26 April, 2024

Organizers: CIEFAP.

MYCOLOGICAL EVENTS:

45th *New Phytologist* Symposium: Ecological and evolutionary consequences of plant–fungal invasions



Website

University of Campinas, Campinas, Brazil

26 – 29 June, 2024

Organizers: New Phytologist Foundation.

12th International Mycological Congress

Website

MECC, Maastricht, the Netherlands

11 – 15 August, 2024

Organizers: Local & International organizers and International Mycological Association.

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ICOM12 will be organised in the summer of 2024 in Manchester, United Kingdom, by Prof. Dr. David Johnson (University of Manchester) and colleagues.