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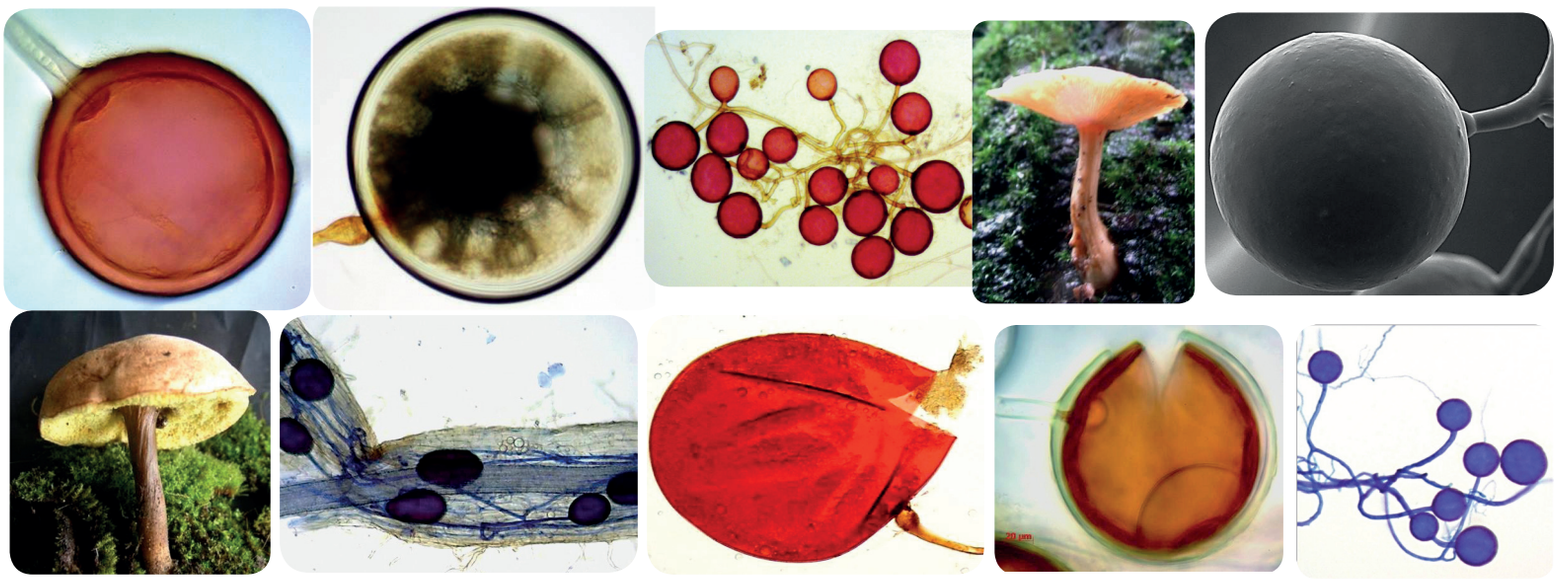

About **TERI**

The Energy and Resources Institute (TERI) is a dynamic and flexible organization with a global vision and a local focus. TERI's focus is on research in the fields of energy, environment, and sustainable development, and on documentation and information dissemination. The genesis of these activities lies in TERI's firm belief that the efficient utilization of energy, sustainable use of natural resources, large-scale adoption of renewable energy technologies, and reduction of all forms of waste would move the process of development towards the goal of sustainability.

TERI's **Mycorrhiza Network**

TERI's Mycorrhiza Network is primarily responsible for establishing the Mycorrhiza Information Centre (MIC), the Centre for Mycorrhiza Culture Collection (CMCC), and publishing *Mycorrhiza News*. The Network helps scientists carry out research in mycorrhiza and promotes communication among mycorrhiza scientists.

Mycorrhiza News

The *Mycorrhiza News* provides a forum for the dissemination of scientific information on mycorrhiza research and activities; publishes state-of-the-art papers from eminent scientists; notes on important breakthroughs; brief accounts of new approaches and techniques; publishes papers complied from its RIZA database; provides information on forthcoming events on mycorrhiza and related subjects; lists important research references published during the quarter; and highlights the activities of the CMCC.

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Research finding papers

Mutualism Breakdown Between Host and Arbuscular Mycorrhizal Fungi

Akshaya S[*] and Manoharachary C[*]

Plant–fungal partnership or mycorrhiza is one of the world's most ancient and widespread symbioses (Werner and Kiers 2015). Despite reciprocal benefits and non-persistence of mutualisms, conflicts among partners can arise. Two potential trajectories towards evolutionary breakdown of their co-operation are: (i) symbiont switching and (ii) mutualism abandonment. Plants stop interacting with the arbuscular mycorrhizal fungi (AM Fungi) when they find other mutualists or develop alternative strategies to extract nutrients from the environment. Instances of the former include mutualisms with ectomycorrhizal fungi, orchidaceous mycorrhizae or plant growth-promoting rhizobacteria (PGPR) while those of the latter include plants opting to carnivory, parasitism, or developing adaptations such as root hair/cluster roots. The loss of key functional genes (in due course of evolution) that are involved in encoding root mutualism effectors has been found to make noteworthy contributions. The breakdown could also be favoured by a range of factors such as environmental changes, habitat shifts, migration, invasion, or partner abundance. Dual symbiosis, although evolutionarily unstable, has been found to be a transitory state on the path towards a complete switch and breakdown of the original mutualism. Another potential reason is when low-quality partners or parasites arise in one of the lineages. Thus, this can drive the interaction from mutualism to parasitism and cause the other partner to abandon the interaction. It has also been found that some plants abandon the mutualism completely because of at least one of the aforementioned reasons while some others re-establish the mutualism either in time (that is, the same generation that gave up the partnership reverts back to the old lifestyle with the same fungus or a new partner), or several generations later. The fact that cooperation among plants and AM fungi has persisted in a highly stable state for more than 350 million years illustrates the importance of the mutualistic services provided by AM fungi to most host plant species (Werner, Cornelissen, Cornwell, *et al.* 2018). However, even ancient and versatile mutualists like AM fungi can be completely and permanently lost under certain circumstances and need to be studied in depth.

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Physiological Studies on *Cantharellus* sp., an Ectomycorrhizal Mushroom from Central India

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Introduction

A single-root system of an individual ectomycorrhizal (ECM)-dependent plant is simultaneously associated with many different ECM fungal species and different individuals of the same species (Guidot, Verner, Debaud, *et al.* 2005). Furthermore, although a host plant is permanently associated with ECM fungi, its properties such as composition, species richness, and diversity of associated ECM fungal community undergo change during the course of forest ageing as well as in response to various disturbances associated with ecosystem such as N deposition (Smith, Molina, Huso, *et al.* 2002; Peter, Ayer, Egli 2001; Lilleskov, Fahey, Horton, *et al.* 2000; Avis, McLaughlin, Dentinger, *et al.* 2003). Functional diversity needs to be evaluated to understand the functioning of ECM symbiosis under field conditions. Different ecological and physiological factors affect growth of ECM fungi and also the process of mycorrhiza formation (Bowen 1994). Physical characteristics and nutrients of soils, especially C and N sources, greatly influence the establishment and growth of ECM fungi in field and also in controlled conditions in laboratory (Lilleskov, Fahey, Horton, *et al.* 2000). Influence of N, C, P, pH, temperature, and water stress on growth of ECM fungi has been analysed by many authors (Rangel-Castro, Danell, Taylor 2002; Sawyer, Chambers, Cairney 2003b,c; Sarjala 1999; Sawyer, Chambers, Cairney 2003a; Sanchez, Honrubia, Torres 2001).

An important function that ECM fungi perform is to explore soil to find new sources of N and subsequently use them. ECM fungi differ in their physiological capacities to acquire and transfer N to a range of plant hosts. The ability of ECM fungi to access organic sources of N is of practical interest, as in absence of ECM fungi these N sources would not be available to plant hosts. Quantitative differences in utilization of inorganic and organic N sources have been documented both between ECM fungal species and also between strains belonging to same species (Anderson, Chambers, and Cairmey 1999; Rangel-Castro, Danell, Taylor 2002; Sawyer NA, Chambers, and Cairney 2003a,b,c).

It has been well established that symbiosis between fungi and trees is essential for fulfilling P nutrition of the trees, especially on soils low in P concentration. Phosphatase activity in mycorrhizal fungi varies with species. Although rate of excretion depends largely on composition of growing medium, variation may also occur with fungal species. Wallander, Johansson, and Pallon (2002) carried out particle-induced X-ray emission (PIXE) analysis of element contents and concluded that ECM *Rhizopogon* species has the ability to mobilize P and K to host trees. Study of availability of P (inorganic versus organic), after response of host plants to ECM was carried out by Baxter and Deighton (2001). A large fraction of the P in most temperate forest soils occurs in organic forms, such as inositol phosphates, nucleic acids, and phospholipids. Host's access to organic P sources depends on its association with a range of ECM fungi that produce extracellular enzymes, capable of acquiring P in organic forms.

Enhancement in nutrient uptake is beneficial for host's and symbiont's growth, however, in high concentrations, both essential and non-essential elements may be toxic. In fact, in some cases, excessive uptake could be deleterious. Moreover, accumulation of heavy metals in soil adversely affects formation and development of ECM of tree species. The isolation of metal-tolerant ECM fungi from polluted sites has been well-documented (Colpaert and Ticheler 1996). Axenic screening provides a rapid evaluation of metal tolerance in ECM fungi and demonstrated differential tolerances to metals (Hartley, Cairney, Meharg, *et al.* 1997a,b). It has been found that, tolerance to zinc and cadmium (Colpaert and van Assche 1992a,b) or aluminum (Egerton–Warburton and Griffin 1995) is higher in ECM isolates from metal-contaminated soils in comparison to non-contaminated soils. Responses of ECM fungi to toxic metals are important parameters

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for developing strategies of reclamation of polluted sites, besides they influence plant growth and productivity. Hence, in this work, we studied the effect of different C and N sources, pH, temperature, minerals and heavy metals, growth regulators and vitamins to study growth of ECM fungi in pure culture of *Cantharellus*.

Materials and Method

Modified Melin-Norkrans (MNM) and Malt Extract Agar (MEA) media were used for inocula preparation on agar plates. These were adjusted to pH 5.6±0.02 with 1N HCl or 0.5 and 4M NaOH and sterilized before plating. The pH value was measured with a glass electrode pH meter (India, Systronics 320). The culture for inoculum preparation was raised on MNM and MEA media in Petri dish after incubation at 26±2°C for 14 days. The mycelium was grown in Petri dish for 14 days and 9 mm disc was used as inocula by inoculating the 150 mL flask containing 50 mL of sterilized liquid medium. Vegetative growth of mycelium on liquid medium was observed by measuring the dry fungal biomass of the colony. Mycelial dry weight was measured by oven drying at 80±2°C for 48 h (Rangel–Castro 2002; Yamanaka 2003). The pH value of the medium also was measured at the end of the experiment. Three replicates and one control were taken for each set of observation. Differences in dry weight production, final pH of the remaining culture solution were analysed on the basis of calculated mean and standard deviation. To test whether different factors considered in the present study affected *Cantharellus* sp. response on mycelial growth in terms of dry weight production, one-way analysis of variance (ANOVA) was used to analyse experimental data. Significant differences between treatments were determined by least significant difference (LSD) test. The statistical analysis was confirmed using Statview software.

Evaluation of Basal Medium

The culture of *Cantharellus* sp. was grown on 20 different liquid media to evaluate the best medium for mycelial growth. Inoculated flasks were incubated for 15 days and dry fungal biomass was measured. The final pH of the liquid media was recorded immediately after harvesting and executing other investigations on best-suited medium before conducting cultivation experiments (Sharma 2008).

Effect of Physical Factors

The inoculated flasks were incubated at 5–45 ± 2°C for 15 days in an incubator and dry fungal biomass was measured. The effect of pH on vegetative mycelial growth was studied by adjusting best-suited liquid medium at different pH levels (±0.02), ranging in 1–12. The pH was adjusted with 1N HCl or 0.1M and 4M NaOH. The selected liquid medium was inoculated with mushroom culture and was given continuous light, dark, and intermittent (that is, 12:12 h light and dark) treatment at optimum temperature and pH.

Effect of Carbon and Nitrogen

Carbon (C) and nitrogen (N) requirements were studied by replacing D-glucose and ammonium chloride from FDA liquid medium by substituting with different carbon and nitrogen sources. The selected medium (FDA medium) was to be supplemented separately with desired C compounds including 7 monosaccharides, 3 disaccharides, 1 trisaccharide, 3 polysaccharides, 5 organic acids, and 2 alcohols. The quantities were determined on the basis of their molecular formulae so as to furnish an equal amount of carbon as was present in 0.5 g of D-glucose FDA broth. The polysaccharides were added at 0.5 g L^{-1}. Similarly, the quantities of N compounds were evaluated on the basis of N present in 0.5 g of ammonium chloride. The selected medium (FDA Medium) was supplemented separately with different N compounds (23 N sources including 10 inorganic, 10 amino acids, and 3 organic acids). One control flask each with no carbon and nitrogen source was also maintained.

Effect of Mineral and Trace Elements

Studies were also carried out to investigate the effect of magnesium (Mg), Phosphorus (P), Potassium (K), and Sulphur (S) on the mycelial growth of mushroom culture. This was done by growing the mushroom culture in a complete mineral medium and in various mineral deficient media. One control flask each with no mineral and trace element was also maintained.

Effect of Different Vitamin Sources

Five vitamins with four different concentrations were studied to find out their effect on mycelial growth. The best-selected liquid medium was supplemented with five vitamin sources at four concentrations (5, 10, 15, 20 µg/L). The stock solutions of all vitamins except biotin were prepared in double-glass distilled water and stored at 5±2°C in refrigerator. The stock solution of biotin was prepared in 5 mL of 50% ethanol and volume made up with double-glass distilled water. Five millilitres of each of these concentrations were used in the best-selected liquid basal medium to study their effect.

Effect of Different Growth Regulators

Four growth regulators at four different concentrations were used to assess their effect on mycelial growth of *Cantharellus*. The stock solutions of growth regulators except gibberellic acid were prepared in double-distilled water and stored at 5±2°C in refrigerator. Gibberellic acid was first dissolved in 5 mL HCl and then the required concentrations were prepared (10 µg/L). Five millilitre of each of these concentrations was used in the best-selected liquid basal medium to study their effect.

Results

Evaluation of Basal Media

As there was no previous data on *in vitro* growth of *Cantharellus* sp., starting point in present study was to select the best-suited medium for the growth of this fungus. Figure 1 shows 21 different ECM broth tested for the growth of *Cantharellus* sp. The best growth of *Cantharellus* sp. isolate in terms of dry mycelial weight was significantly high (P<0.05) on Ferry Das (FD medium), followed by Chanterelle medium and Nutrient solution**.** However, no significant difference was observed between Hagem's, GYP, PACH, and Yeast peptone glucose media. Therefore, FD medium was selected as best-suited medium for further studies.

Effect of Physical Factors

Cantharellus sp. generally grows in different soil texture with slightly acidic pH, close to 5–6.5±0.02. The results in Figure 2 indicate that 5.5±0.02 was the optimum pH for the growth of *Cantharellus* sp. Within 5.5 and 6.0, there was no significant difference (P<0.05) in mycelial growth. However, it showed moderate to rapid growth over a pH range of 2–12±0.02. Temperature studies indicated that growth, estimated as dry weight, was better at 30±2°C (significantly high at P<0.05) and 25±2°C than at 20±2°C for *Cantharellus* sp. (Figure 3). In the present study, the results obtained (Figure 4) revealed that mycelial growth of *Cantharellus* sp. differed with

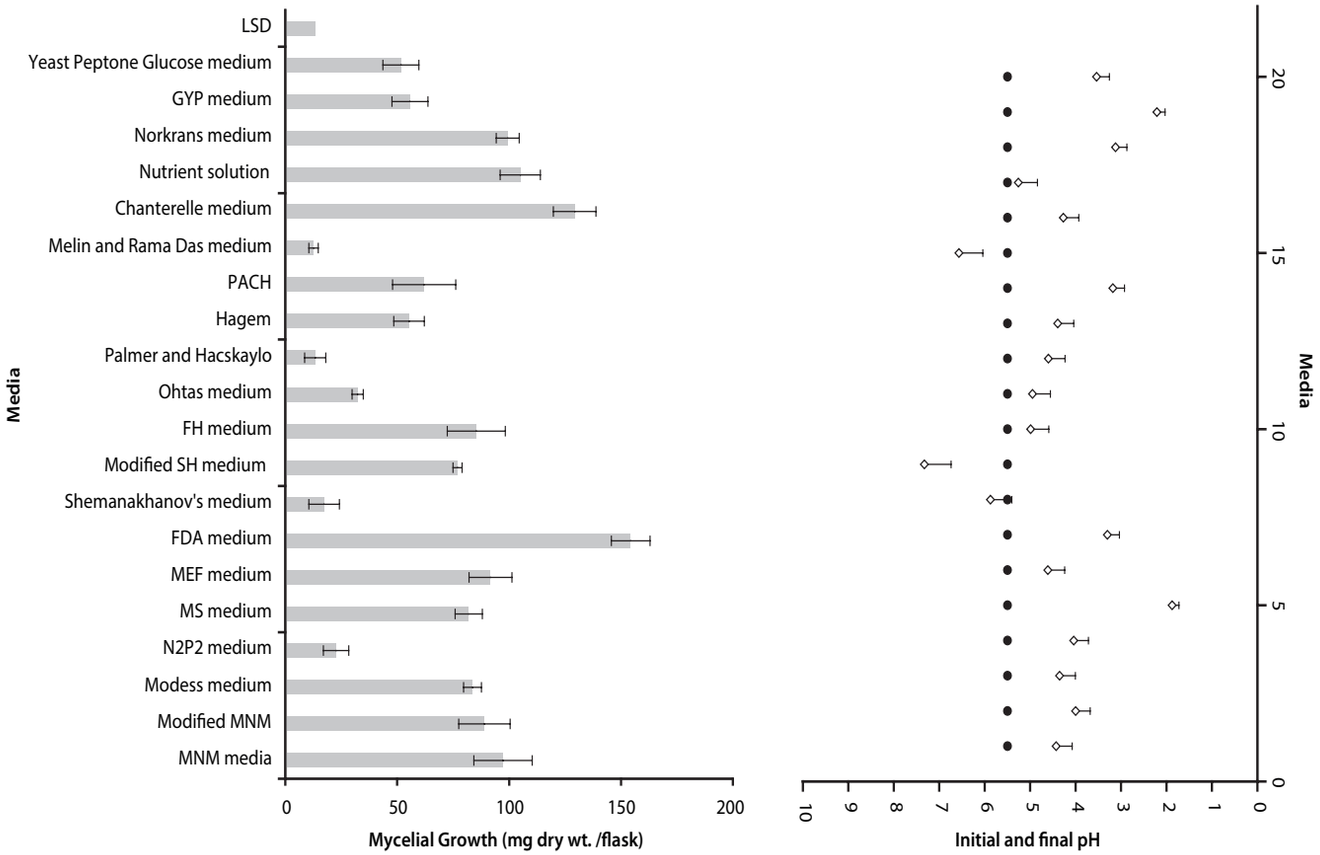

Figure 1 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different media

Note Bars indicate standard deviations. LSD is significant at P<0.05.

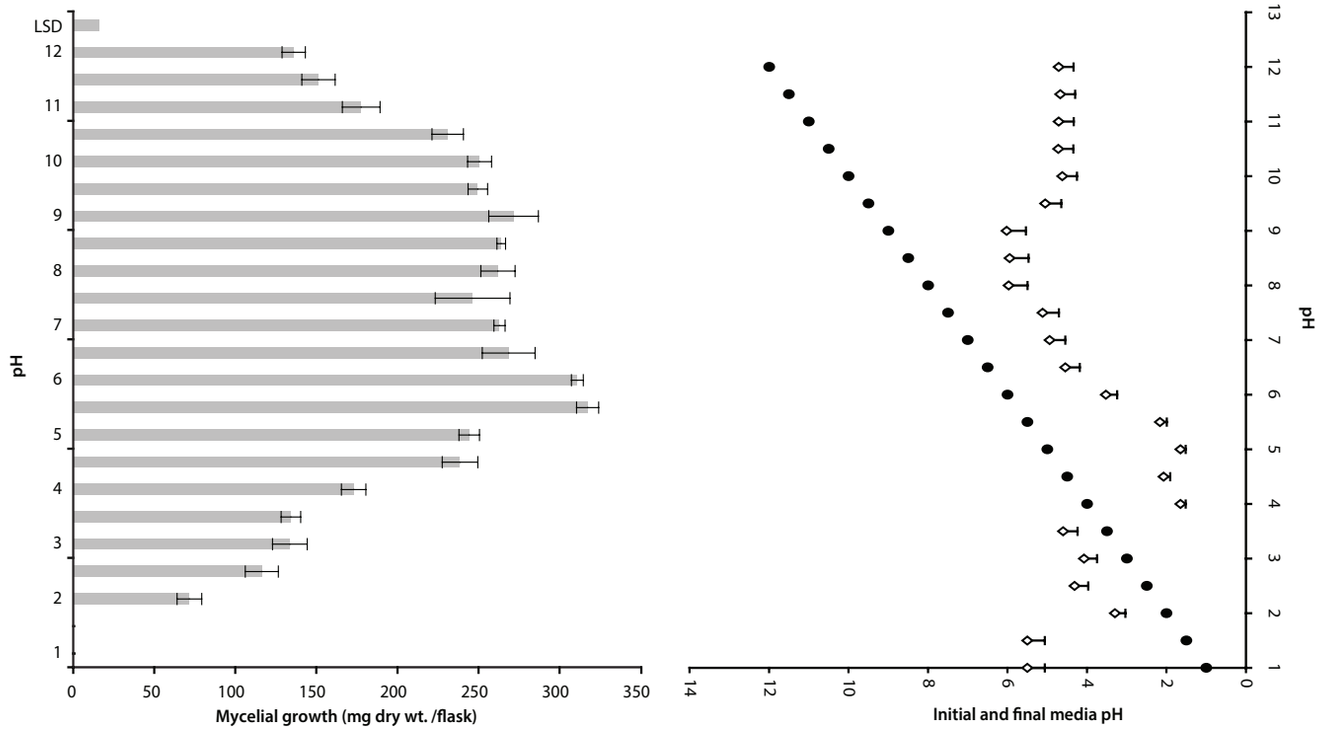

Figure 2 Mycelial growth of *Cantharellus* sp. after 15 d, and final pH values with different initial pH

Note Bars indicate standard deviations. LSD is significant at P<0.05.

exposure to different light conditions, as indicated by the significant high mycelial dry weight on exposure to intermittent period of 12 h light and dark.

Effect of Carbon and Nitrogen Sources

All tested C sources except oxalic acid, methanol, and ethanol had a stimulatory effect on fungal growth.

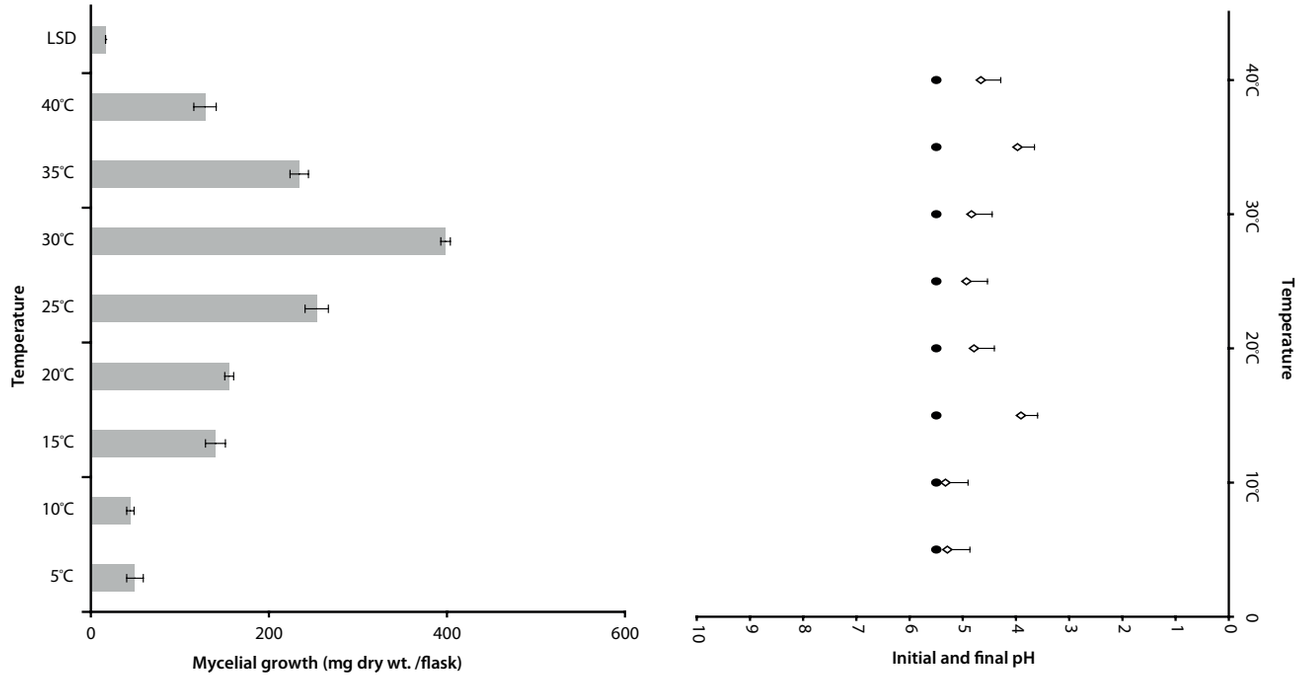

Figure 3 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values at different temperatures

Note Bars indicate standard deviations. LSD is significant at P<0.05.

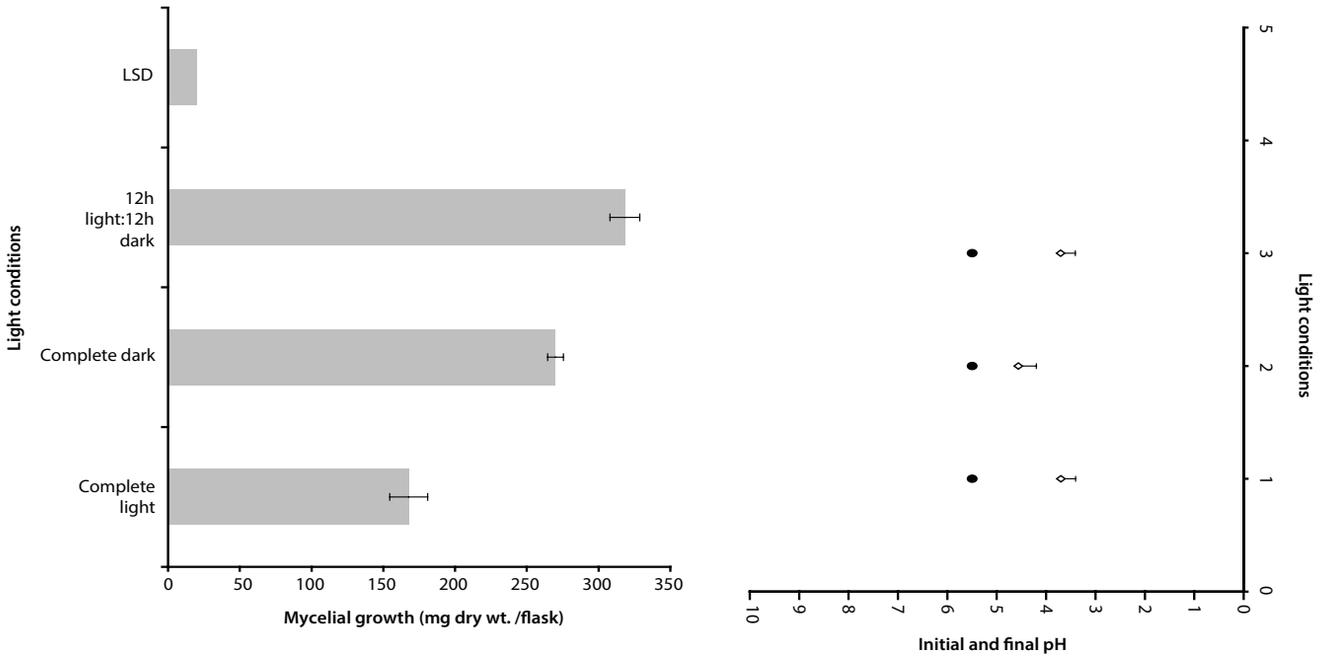

Figure 4 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different light conditions

Note Bars indicate standard deviations. LSD is significant at P<0.05.

When oxalic acid was used as the sole C source in medium, *Cantharellus* sp. isolate completely failed to grow. CMC, d-xylose, and ascorbic acid (significantly different at $P<0.05$) were the optimal C source for the mycelial growth and minimum mycelial growth was recorded in two alcohols tested (not significantly different at $P<0.05$) (Figure 5).

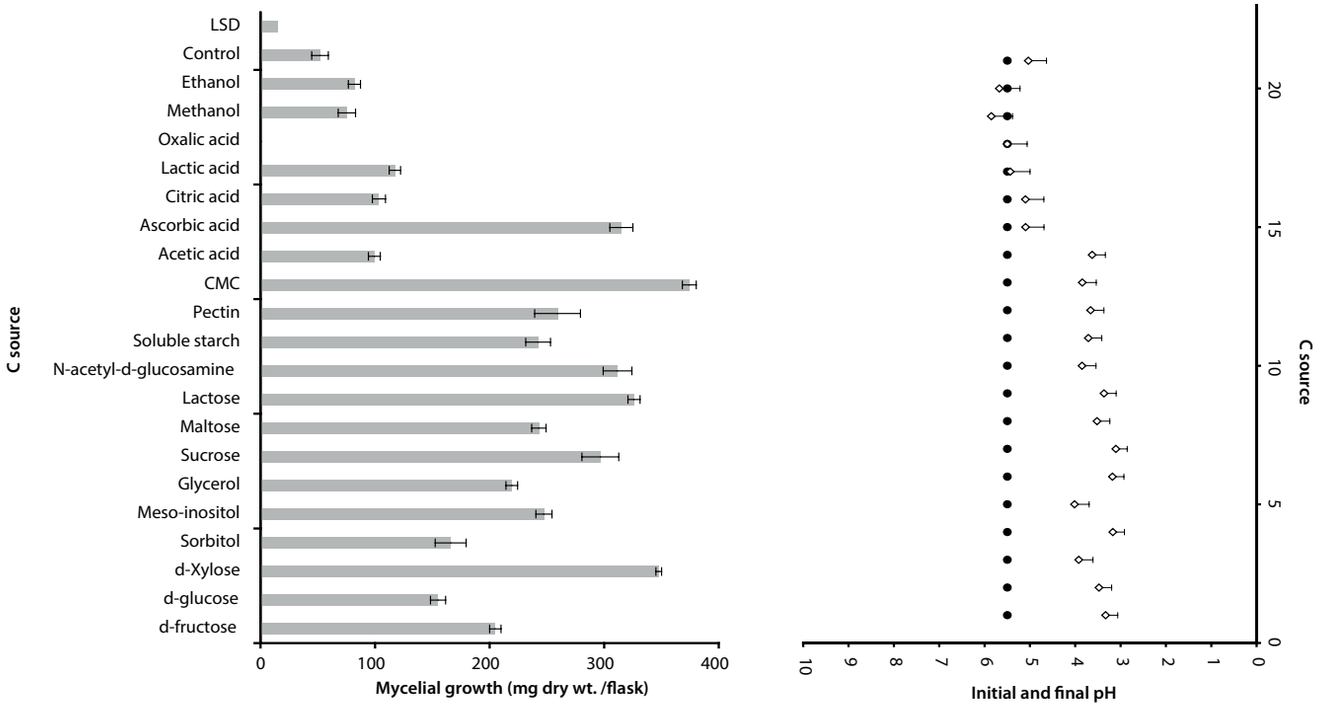

Figure 5 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different C sources

Note Bars indicate standard deviations. LSD is significant at P<0.05.

The *Cantharellus* sp. isolate showed appreciable but different patterns of growth and N utilization on all N sources provided. *Cantharellus* sp. grew well on medium containing ammonium in various forms supplied singly. The changes in pH of culture medium reflected very closely the uptake of the different N sources. Although, biomass was quite high on the nitrate treatment, there was no increase in the pH of the culture solution, which suggests limited assimilation of nitrate. The results in Figure 6 show that *Cantharellus* sp. had a preference for ammonium. It utilized the ammonium compounds, ammonium phosphate, ammonium citrate, ammonium nitrate, ammonium oxalate, ammonium tartrate, and ammonium sulphate. No significant difference in fungal dry weight was observed when grown with yeast extract, malt extract, ammonium chloride, l-asparagines, dl-valine, dl-phenylalanine, dl-asparatic acid and dl-glutamic acid.

Differences in fungal biomass were observed in all substituted phosphorus sources. However, di-ammonium hydrogen phosphate produced significantly higher (P<0.05) fungal biomass (Figure 7). Amongst the heavy/trace elements, best results were obtained with manganese sulphate and magnesium sulphate, followed by copper sulphate and ferric chloride, as shown in Figure 8. However, the control flask which did not had any heavy metal produced significantly higher (P<0.05) dry mycelial biomass. Observations on the effect of vitamins are depicted in Figures 9–11. The significantly high mycelial growth in three concentrations was recorded with thiamine HCl (5 µg/L) and carnitine chloride (10 µg/L, 15 µg/L). Results on the effect of growth regulators on *C. tropicalis* growth are shown in Figures 12–14. Highest mycelial growth was recorded in gibberellic acid (10 µg/L, 20 µg/L, 30 µg/L), which was significantly higher (P<0.05) than the others, followed by kinetin.

Discussion

Amongst the mycorrhiza-forming fungi, only ECM and ericoid mycorrhizal fungi can be grown in pure culture (Jakobsen 1996). Study of the physical and physiological factors of these fungi could be a key for analysing the mechanism of their symbiosis with host plants. These studies might reveal features of their survival and colonization in soil. ECM fungi vary widely in their ability to gain access and utilize C compounds. A wide variety of C sources including carbohydrates, organic acids, amino acids along with their derivatives and some polycyclic compounds are used by fungi (Shukla, Rahi, Rajak, *et al.* 2005).

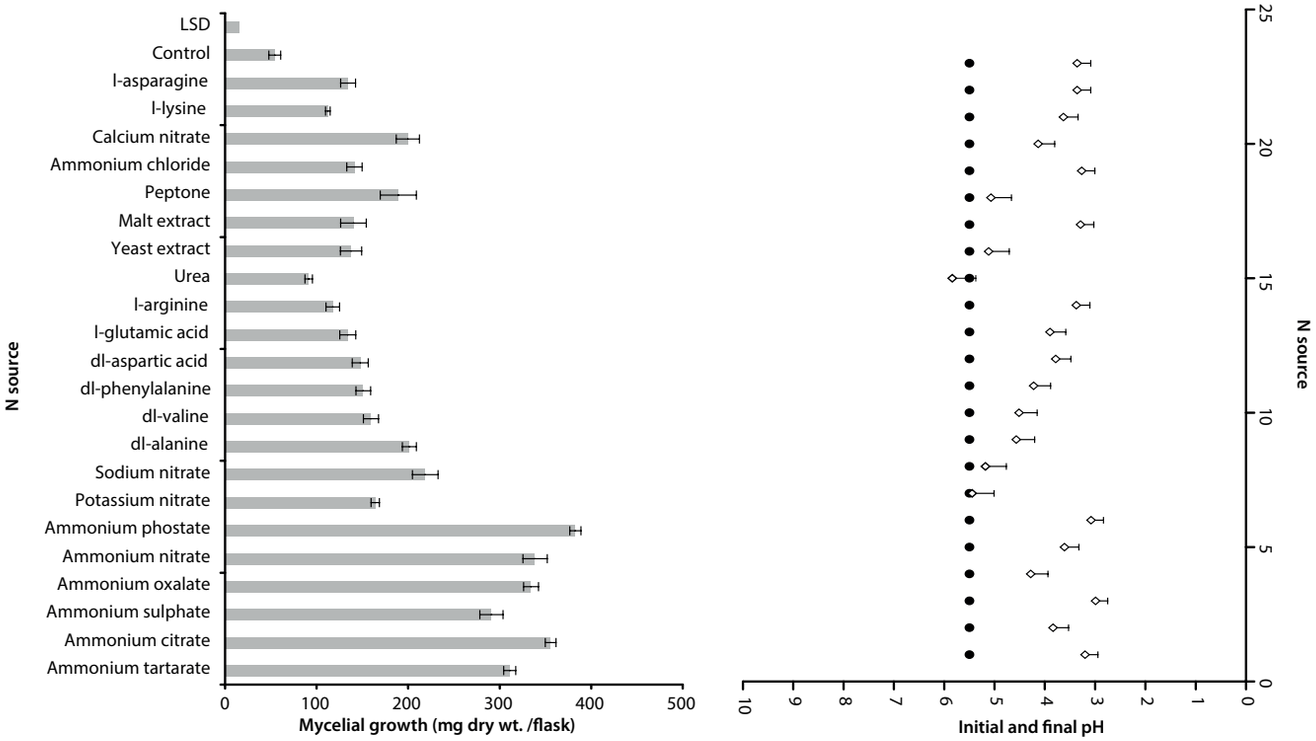

Figure 6 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different N sources

Note Bars indicate standard deviations. LSD is significant at P<0.05.

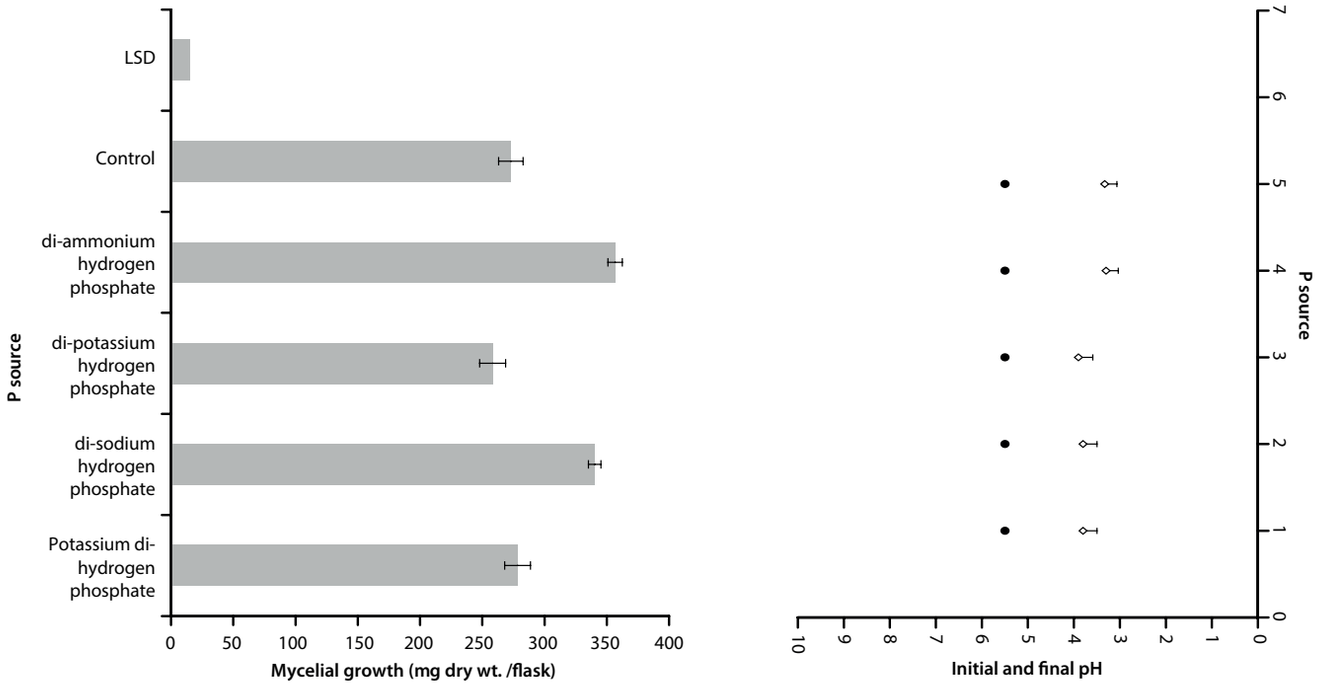

Figure 7 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different P sources

Note Bars indicate standard deviations. LSD is significant at P<0.05.

In the present investigation, *Cantharellus* sp. utilized CMC, *d*-xylose, and ascorbic acid (significantly different at P<0.05) for maximum mycelial biomass and two alcohols tested produced minimum mycelial biomass (Figure 5). Most of the workers have reported mannitol as the most generally utilizable C source. According to Taber and Taber (1987), three isolates of *Pisolithus tinctorius* grew poorly on selected C sources than non-mycorrhizal fungi. The C utilization pattern did not change significantly with changes in composition of basal medium or inoculum preparation, however, the pattern changed with culture medium pH and addition of small amounts of glucose. In another study by Berredjem, Garnier, Prima Putra, *et al.* (1998), glucose and maltose in mixture (20:5) were found to be the most effective carbohydrates for promoting growth of *Lactarius bicolor*, followed by starch, dextrins, maltose, glucose, and sorbitol. However, it did not grow when the medium contained sucrose or galactose as C source. Daza, Manjón, Camacho, *et al.* (2006) also studied the effect of C on *in vitro* growth of several isolates of *Amanita caesarea*.

Nitrogen eutrophication of forest ecosystems via atmospheric N deposition is an important factor in the decline of ECM sporocarp production and species richness (Treseder and Allen 2000; Taylor, Martin, Read 2000; Rangel–Castro, Danell, Taylor 2002). In the present study, *Cantharellus* sp. utilized ammonium compounds (significantly different at P<0.05). Although, biomass was also quite high when medium was supplemented with nitrate as N source whereas no significant difference in fungal dry weight was observed with other N sources (Figure 6). The findings agreed broadly with the results reported for other ECM fungi (Guidot, Verner, Debaud, et al. 2005). Ammonium is generally recognized as the most readily utilizable source of N for most ECM fungi (Smith and Read 1997) and results from present study with *Cantharellus* sp. support this assertion. The results also confirm the work of Straatsma and van Griensven (1986) who reported that ammonium is a suitable source of N for ECM mushrooms. Utilization of ammonium by *Pisolithus involutus* have been shown in several in vitro studies (Finlay, Forestgård, Sonnerfeldt 1992; Kieliszewska-Rokicka 1992). Utilization of ammonium by Cantharellus sp. indicates that these species are tolerant to high concentrations of inorganic N (nitro tolerant) which is in accordance with field observations of Baar and Kuyper (1993) and Daza, Manjón, Camacho, et al. (2006). Other ECM fungi were reported to grow on nitrates (Smith and Read 1997). Daza, Manjón, Camacho, et al. (2006) have reported utilization of albumin bovine and nitrate utilization as N source by *Amanita caesarea* (Scop.:Fr.) Pers. associated with *Quercus suber* Linn. and Castanea sativa. Some ECM fungi can readily utilize a wide range of amino acids (Finlay, Forestgård, Sonnerfeldt 1992; Keller 1996; Dickie,

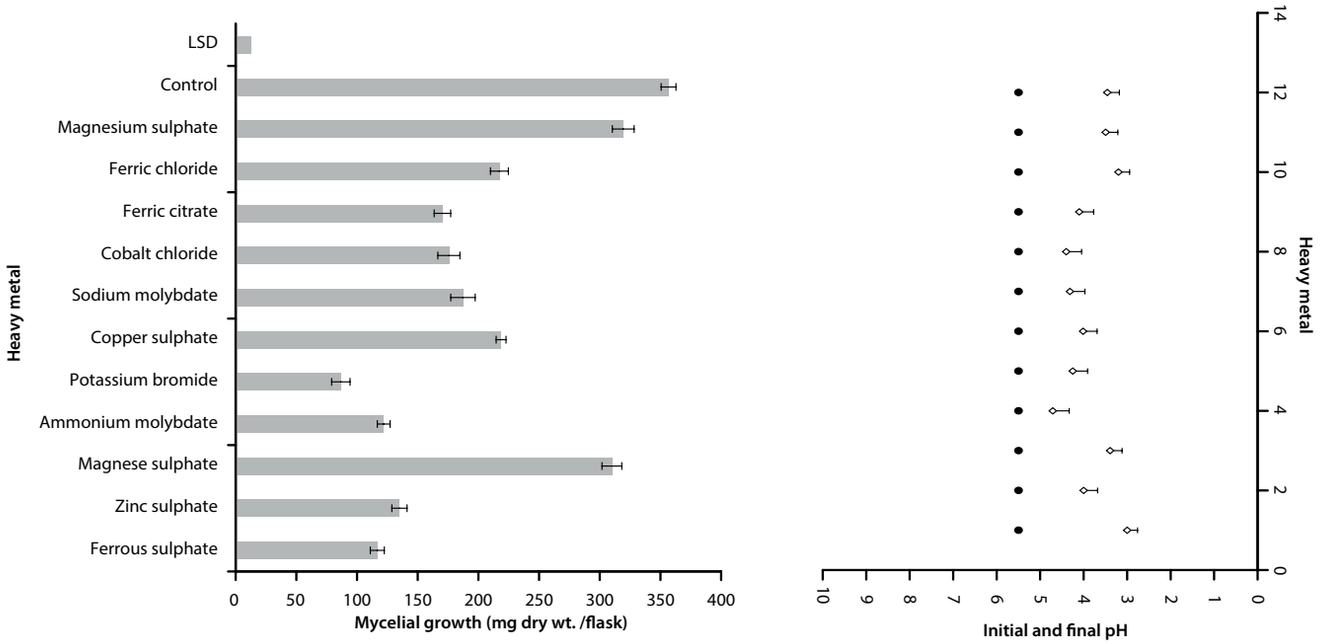

Figure 8 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different heavy metals.

Note Bars indicate standard deviations. LSD is significant at P<0.05.

Koide, Steven 1998) while some have the capability to grow on more complex organic N sources, including proteins (Finlay, Forestgård, Sonnerfeldt, et al. 1992; Keller 1996; Anderson, Chambers, Cairmey 1999; and chitin (Leake and Read 1990). Many investigations have analysed the influence of N on the growth of ECM fungi (Baar, Comini, Elferink, Kuyper, *et al.* 1997; Chalot and Brun 1998; Dickie, Koide, Steven, *et al.* 1998; Rangel-Castro, Danell, Taylor 2002, Sarjala 1999).

Vitamins are not only known to perform catalytic functions, they significantly influence mushrooms' growth as well (Shukla, Rahi, Rajak, *et al.* 2005. Observations recorded on the effect of vitamins show significantly high mycelial growth in three concentrations, that is, thiamine HCl (5 µg/L) and

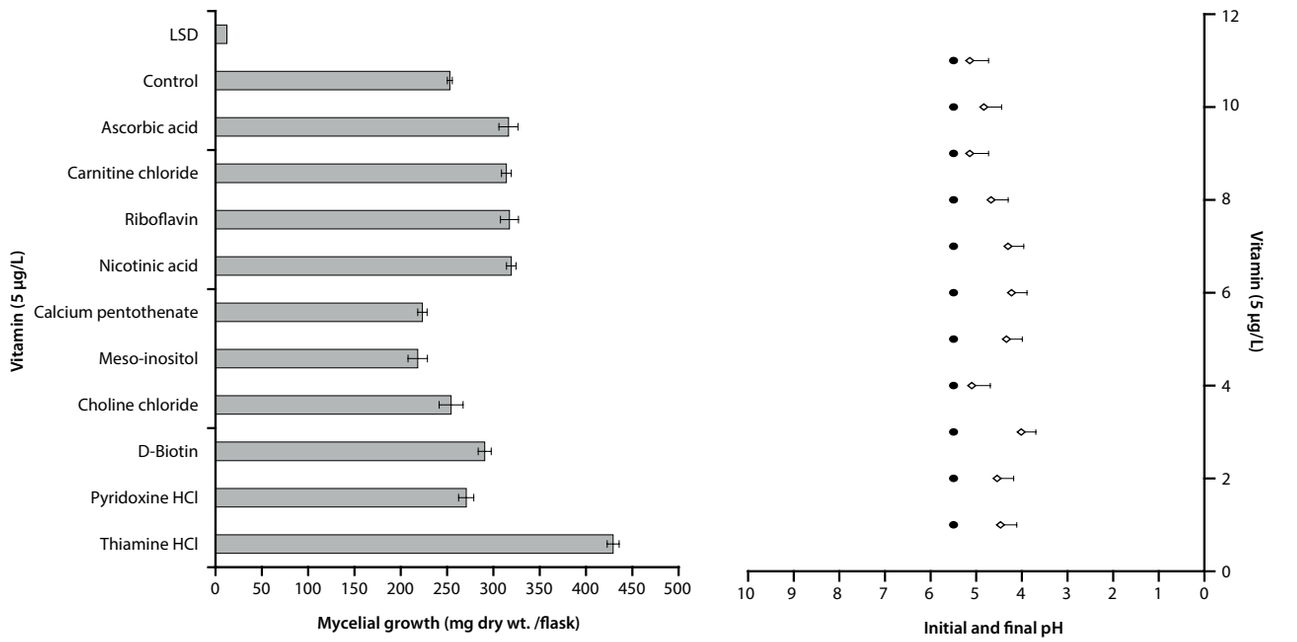

Figure 9 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different vitamins (5 µg/L)

Note Bars indicate standard deviations. LSD is significant at P<0.05.

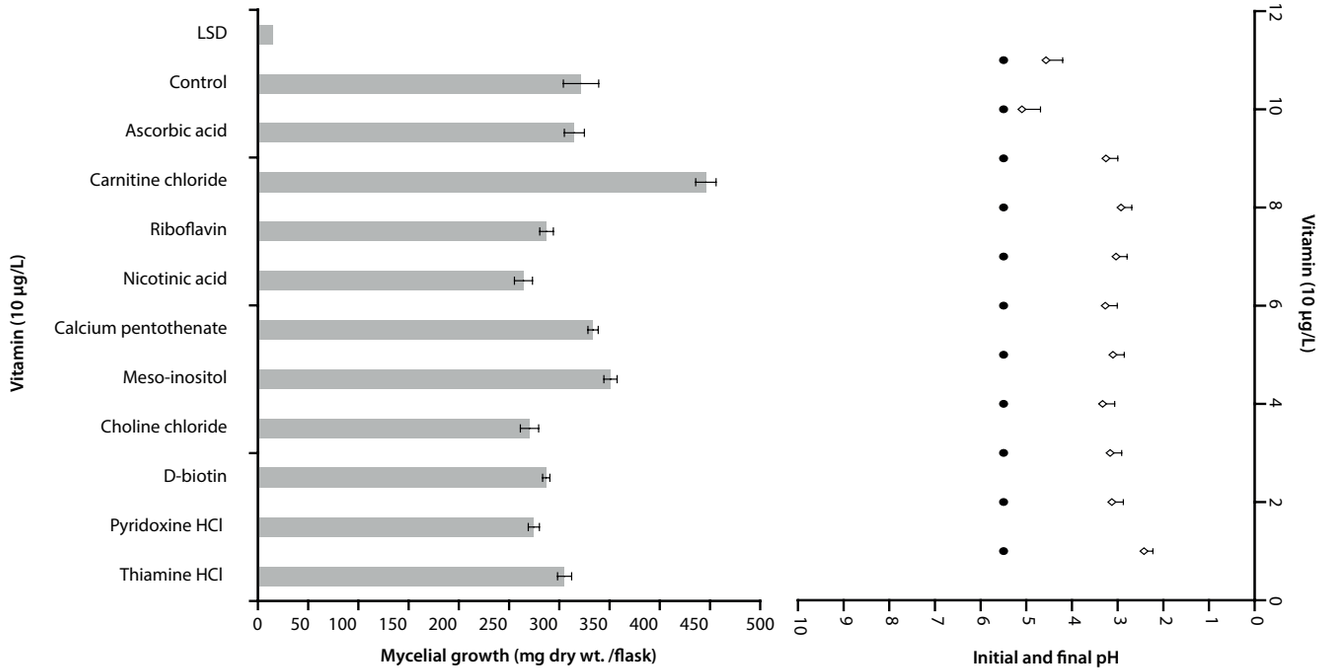

Figure 10 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different vitamins (10 µg/L)

Note Bars indicate standard deviations. LSD is significant at P<0.05.

carnitine chloride (10 µg/L, 15µg/L) (Figure 9). According to Ishikawa (1967) thiamine was found to be stimulating for mycelial growth of *Lentinus edodes* (Berk.) Sing. (non-ECM mushroom).

The effect of any growth factor depends on its concentration of application and type of ECM fungal species. Results presented in Figure 10 recorded gibberellic acid (10 µg/L, 20 µg/L,30 µg/L) as the best utilized growth regulator (significantly high at P<0.05). Several growth factors have also been reported to exert stimulatory effect on fungal growth and activities (Kaur and Lakhanpal 1995). Similarly,

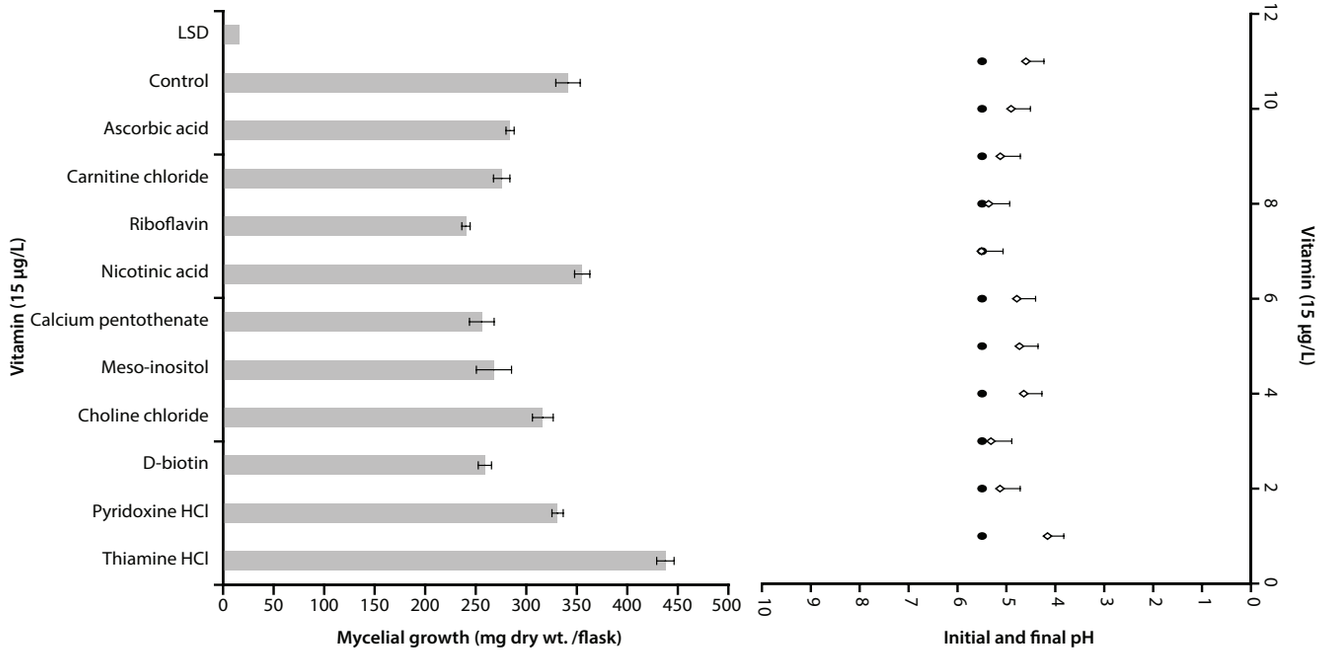

Figure 11 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values with different vitamins (15 µg/L)

Note Bars indicate standard deviations. LSD is significant at P<0.05.

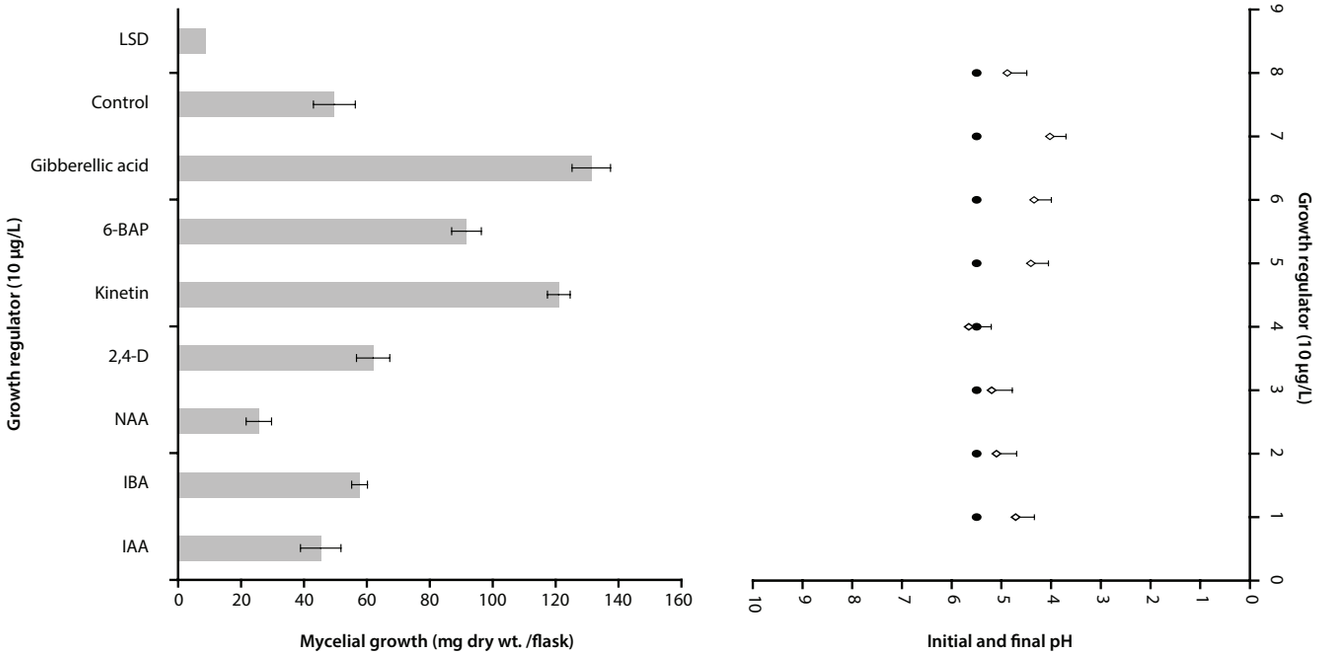

Figure 12 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values of media with different growth regulator (10 µg/L)

Note Bars indicate standard deviations. LSD is significant at P<0.05.

Nakamura, Kawanabe, Takiyama, *et al.* (1978) too reported that indole acetic acid (IAA) and gibberellic acid produce stimulatory effect on vegetative growth of mycelium of *Lentinus tigrinus* (Bull.) (non-ECM mushroom).

Interspecific variations have been demonstrated in a number of studies of axenically cultured ECM fungi. In the present study, best mycelial growth was observed in medium substituted with magnesium sulphate and manganese sulphate as shown in

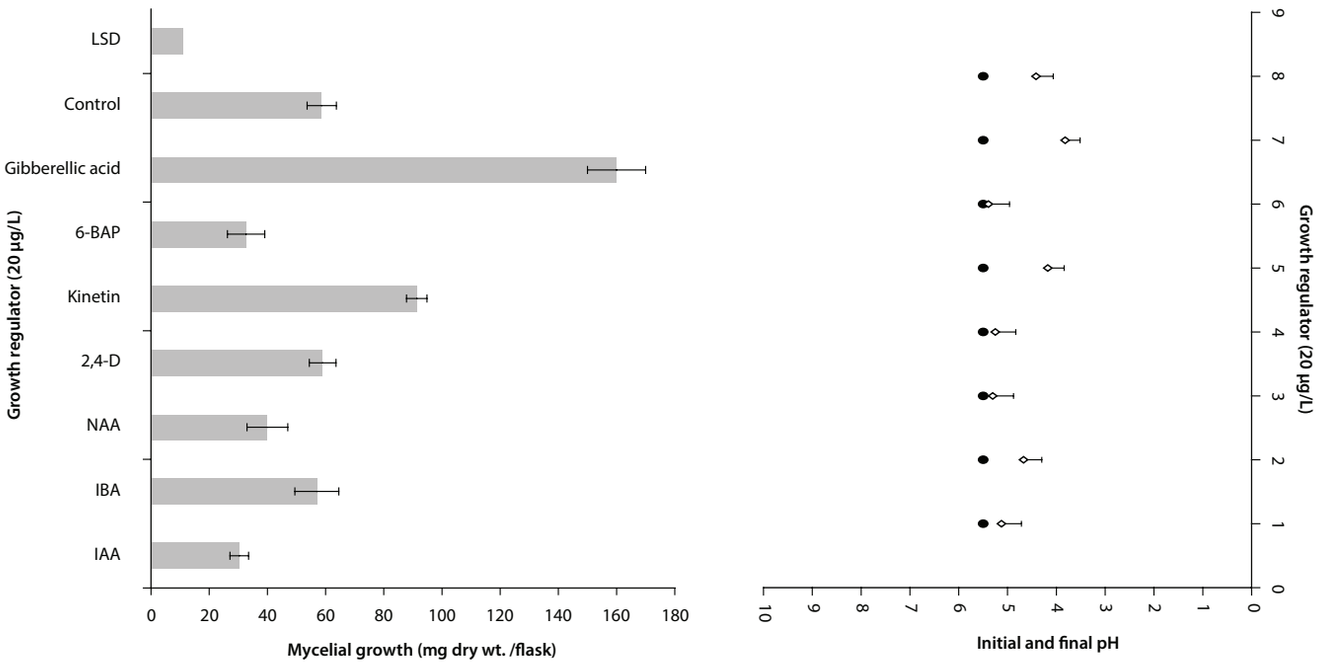

Figure 13 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values of media with different growth regulator (20 µg/L)

Note Bars indicate standard deviations. LSD is significant at P<0.05.

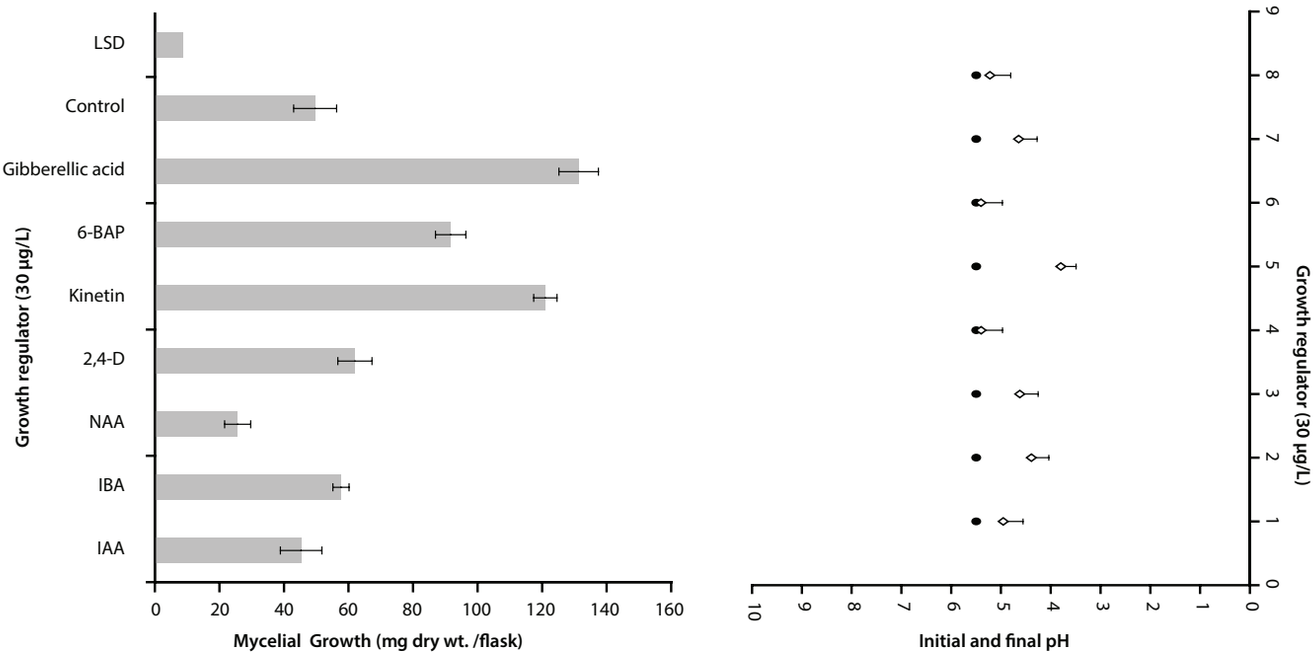

Figure 14 Mycelial growth of *Cantharellus* sp. after 15 d, and initial and final pH values of media with different growth regulator (30 µg/L)

Note Bars indicate standard deviations. LSD is significant at P<0.05.

Figure 8. In one study, all isolates of *Pisolithus involutus* were found to be less tolerant to Zn than any of those of *Amanita muscaria*. *Scleroderma citrinum* was less tolerant to Cu than *Pisolithus involutus* and *Laccaria laccata* (Howe, Evans, Ketteridge, *et al.* 1997). *Laccaria proxima* (Boud.) Pat. appeared to be less sensitive to Ni than *Scleroderma flavidum* (Jones and Hutchinson 1986). Growth stimulations of ECM isolates by Cu and Ni have already been demonstrated by Jones and Hutchinson (1988) and McCreight and Schroeder (1982). Possible mechanisms for passive binding, or metabolic detoxification which can lead to metal tolerance in ECM fungi are discussed by several workers (Hartley, Cairney, and Meharg 1997a; Tilstone, Macnair, and Smith 1997).

Tolerant behaviour of mycobiont may be an important factor in conferring plant tolerance (Colpaert and van Assche 1987; Blaudez, Jacob, Turnau, *et al.* 2000). The higher metal concentrations which inhibit growth of non-mycorrhizal tree species are, however, generally far lower than those which inhibit growth of ECM fungi in pure culture, and consequently this axenic screening could in some cases predict which fungi will increase host tolerance. Moreover, there has not been any study of heavy metal interactions in ECM fungi in symbiosis with host plants (Hartley-Whitaker, Cairney, and Meharg 2000), and this research is needed to further clarify the role of ECM fungi in metal sensitivity of plants.

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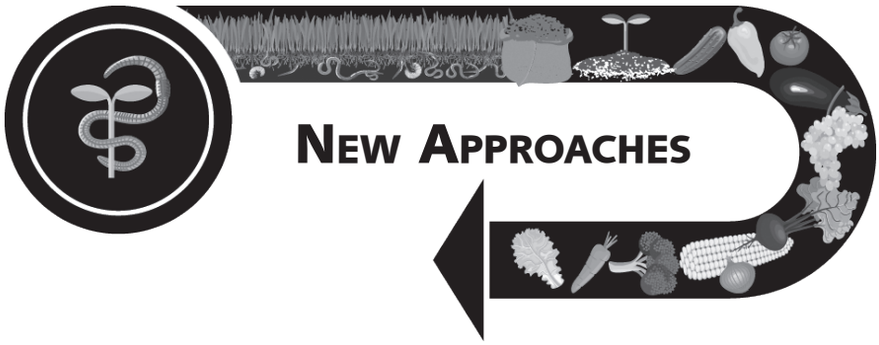

New Approaches and Techniques

1. Proteomics to identify the interactions among mycorrhiza
   (French K. 2017. Engineering Mycorrhizal Symbioses to Alter Plant Metabolism and Improve Crop Health. *Frontiers In Microbiology*, *8*. doi: 10.3389/fmicb.2017.01403)

Proteomics is an emerging field which can enable the identification of specific proteome in associated cellular processes. It can also help to locate specific protein modifications, often leading to assessment of protein abundance or their expression during different processes in living systems. To identify the symbiotic associations amongst fungal and plant counterparts and involvement of specific protein groups in the process, proteomics can be utilized. It could be one of the key techniques which can unravel the key incidents and associations during a mycorrhizal symbiosis.

2. Computational biology for enhanced symbiosis
   (Chiapello M, Perotto S, and Balestrini, R. 2015. Symbiotic Proteomics — State-of-the-Art in Plant–Mycorrhizal Fungi Interactions. *Recent Advances in Proteomics Research*. doi: 10.5772/61331)

The symbiotic association between fungus and plant is one of the key aspects of mycorrhiza. Computational biology is an efficient tool which can be globally used for enhancing the sustainability of the agricultural systems. By employing computational studies, specific locations of the genomes indicating genes which are specifically involved in the symbiosis process can be identified. These locations can further be modified to enhance symbiosis. It is an effective option which can assist in promising research to boost agricultural productivity.

Recent references

The latest additions to the network's database on mycorrhiza are published here for the members' information. The list consists of papers from the following journals:

- *Agricultural Water Management*
- *Chemosphere*
- *Ecological Engineering*
- *Ecotoxicology and Environmental Safety*
- *Environmental and Experimental Botany*
- *European Journal of Agronomy*
- *European Journal of Soil Biology*
- *Field Crops Research*
- *Fungal Biology*
- *Fungal Ecology*
- *Industrial Crops and Products*
- *Journal of Environmental Management*
- *Journal of Integrative Agriculture*
- *Journal of Plant Physiology*
- *Mycorrhiza*
- *Pedobiologia*
- *Plant Physiology and Biochemistry*
- *Rhizosphere*
- *Science of The Total Environment*
- *Scientia Horticulturae*
- *Soil Biology and Biochemistry*

Name of the author(s) and year of publication	**Title of the article, name of the journal, volume number, issue number, page numbers (address of the first author or of the corresponding author, marked with an asterisk)**
Adam B Cobb*, Gail W T Wilson. 2018	**Influence of smallholder farm practices on the abundance of arbuscular mycorrhizal fungi in rural Zambia** *Pedobiologia* **69**: 11–16 [*Oklahoma State University, 008C AGH, Stillwater, OK, 74078, USA]
Aída M Vasco-Palacios*, Johnathan Hernandez, María Cristina Peñuela-Mora, Ana E Franco-Molano, TeunBoekhout. 2018	**Ectomycorrhizal fungi diversity in a white sand forest in western Amazonia** *Fungal Ecology* **31**: 9–18 [*Fundación Biodiversa Colombia, Carrera 22 # 41–80 Apto. 004, 111311, Bogotá DC, Colombia]
Alireza Pirzad*, Sevil Mohammadzadeh. 2018	**Water use efficiency of three mycorrhizal Lamiaceae species (*Lavandula officinalis*, *Rosmarinus officinalis and Thymus vulgaris*)** *Agricultural Water Management* **204**: 1–10 [*Department of Agronomy, Faculty of Agriculture, Urmia University, Urmia, Iran]
Babacar Thioye*, Hervé Sanguin, Aboubacry Kane, Sergio Maniade Faria, DioumacorFall, YvesPrin, DiaminatouSanogo, Cheikh Ndiaye, Robin Duponnois, Samba NdaoSylla, Amadou MustaphaBâ. 2019	**Impact of mycorrhiza-based inoculation strategies on *Ziziphus mauritiana* Lam. and its native mycorrhizal communities on the route of the Great Green Wall (Senegal)** *Ecological Engineering* **128**: 66–76 [*Laboratoire Commun de Microbiologie IRD/ISRA/UCAD, BP 1386 Dakar, Senegal]
Cheng-Gang Ren*, Cun-Cui Kong, Shuo-Xiang Wang, Zhi-Hong Xie. 2019	**Enhanced phytoremediation of uranium-contaminated soils by arbuscular mycorrhiza and rhizobium** *Chemosphere* **217**: 773–779 [*Key Laboratory of Biology and Utilization of Biological Resources of Coastal Zone, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, 264003, PR China]
ClaudiaRuta*, Anna Tagarelli, Angela Campanelli, Giuseppe De Mastro. 2018	**Field performance of micropropagated and mycorrhizal early globe artichoke plants** *European Journal of Agronomy* **99**: 13–20 [*Department of Agricultural and Environmental Science, University of Bari "A. Moro", Bari- via Amendola, 165/A - 70126, Italy]

Name of the author(s) and year of publication	Title of the article, name of the journal, volume number, issue number, page numbers (address of the first author or of the corresponding author, marked with an asterisk)
Ella Thoen*, Anders B Aas, Unni Vik, Anne K Brysting, Inger Skrede, Tor Carlsen, Håvard Kauserud. 2019	**A single ectomycorrhizal plant root system includes a diverse and spatially structured fungal community** *Mycorrhiza* **29** (3): 167–180 [*Section for Genetics and Evolutionary Biology (EVOGENE), Department of Biosciences, University of Oslo, Norway]
Fabian Carriconde*, Monique Gardes, Jean-Michel Bellanger, Kelly Letellier, Sarah Gigante, Véronique Gourmelon, ThomasI banez, Stéphane McCoy, Julie Goxe, Jennifer Read, Laurent Maggia. 2019	**Host effects in high ectomycorrhizal diversity tropical rainforests on ultramafic soils in New Caledonia** *Fungal Ecology* **39**: 201–212 [*Institut Agronomique néo-Calédonien (IAC), « Equipe Sol & Végétation » (SolVeg), BP 18239, 98800, Nouméa, New Caledonia]
Franklin M Scrase*, Fergus L Sinclair, John F Farrar, Paulo S Pavinato, Davey L Jones. 2019	**Mycorrhizas improve the absorption of non-available phosphorus by the green manure *Tithonia diversifolia* in poor soils** Rhizosphere **9**: 27–33 [*Environment Center Wales, Bangor University, Bangor, Gwynedd LL57 2UW, UK]
Giulia Conversa*, Corrado Lazzizera, Antonio Eugenio Chiaravalle, Oto Miedico, Anna Bonasia, Paolo La Rotonda, Antonio Elia. 2019	**Selenium fern application and arbuscular mycorrhizal fungi soil inoculation enhance Se content and antioxidant properties of green asparagus (*Asparagus officinalis L.*) spears** *Scientia Horticulturae* **252**: 176–191 [*Department of the Science of Agriculture, Food and Environment (SAFE), University of Foggia, via Napoli 25, 71100 Foggia, Italy]
Guangjuan Cui*, Shaoying Ai, Kang Chen, Xiurong Wang. 2019	**Arbuscular mycorrhiza augments cadmium tolerance in soybean by altering accumulation and partitioning of nutrient elements, and related gene expression** *Ecotoxicology and Environmental Safety* **171**: 231–239 [*State Key Laboratory for Conservation and Utilization of Subtropical Agro-bioresources, Root Biology Center, South China Agricultural University, Guangzhou 510642, China]
Hamed Aalipour*, Ali Nikbakht, Nematollah Etemadi. 2019	**Co-inoculation of Arizona cypress with arbuscular mycorrhiza fungi and *Pseudomonas fluorescens* under fuel pollution** *Mycorrhiza* **29**(3): 1–13 [*Department of Horticulture, College of AgricultureIsfahan University of Technology, Isfahan, Iran]
Hector Urbina*, Martin F Breed, Weizhou Zhao, Kanaka Lakshmi Gurrala, Siv G E Andersson, Jon Ågren, Sandra Baldauf, Anna Rosling. 2018	**Specificity in *Arabidopsis thaliana* recruitment of root fungal communities from soil and rhizosphere** *Fungal Biology* **122**(4): 231–240 [*Department of Ecology and Genetics, Uppsala University, Norbyvägen 18D, SE-75236, Uppsala, Sweden]
Klara Andrés Rask*, Jesper Liengaard Johansen, Rasmus Kjøller, Flemming Ekelund. 2019	**Differences in arbuscular mycorrhizal colonisation influence cadmium uptake in plants** *Environmental and Experimental Botany* **162**: 223–229 [*Terrestrial Ecology Section, Department of Biology, University of Copenhagen, Universitetsparken 15, 2100, Copenhagen Ø, Denmark]
Katarzyna Rożek*, Kaja Rola, Janusz, Błasz kowski, Szymon Zubek. 2019	**Associations of root-inhabiting fungi with herbaceous plant species of temperate forests in relation to soil chemical properties** *Science of The Total Environment* **649**: 1573–1579 [*Institute of Botany, Faculty of Biology, Jagiellonian University, Gronostajowa 3, 30–387 Kraków, Poland]

Name of the author(s) and year of publication	Title of the article, name of the journal, volume number, issue number, page numbers (address of the first author or of the corresponding author, marked with an asterisk)
Letizia Bernardo*, Paolo Carletti, Franz W Badeck, Fulvia Rizza, Caterina Morcia, Roberta Ghizzoni, Youssef Rouphael, Giuseppe Colla, Valeria Terzi, Luigi Lucini. 2019	**Metabolomic responses triggered by arbuscular mycorrhiza enhance tolerance to water stress in wheat cultivars** *Plant Physiology and Biochemistry* **137**: 203–212 [*Council for Agricultural Research and Economics, Research Centre for Genomics and Bioinformatics (CREA-GB), via San Protaso 302, 29017, Fiorenzuola d'Arda, PC, Italy]
Li CUI*, Feng GUO, Jia-lei Zhang, Sha Yang, Jing-jing Meng, Yun Geng, Quan Wang, Xin-guo Li, Shu-bo Wan. 2019	**Arbuscular mycorrhizal fungi combined with exogenous calcium improves the growth of peanut (*Arachis hypogaea* L.) seedlings under continuous cropping** *Journal of Integrative Agriculture* **18**(2): 407–416 [*Biotechnology Research Center, Shandong Academy of Agricultural Sciences/ Key Laboratory of Crop Genetic Improvement and Ecological Physiology of Shandong Province, Jinan 250100, P.R.China]
Marianna Papp*, Szilvia Fóti, Zoltán Nagy, Krisztina Pintér, Katalin Posta, Sándor Fekete, Zsolt Csintalan, János Balogh. 2018	**Rhizospheric, mycorrhizal and heterotrophic respiration in dry grasslands** *European Journal of Soil Biology* **85**: 43–52 [*MTA-SZIE Plant Ecology Research Group, Szent István University, 2100 Gödöllő, Páter K. u,]
Nuria Molinero-Rosales*, José Ángel Martín-Rodríguez, TaniaHo-Plágaro, José Manuel García-Garrido. 2019	**Identification and expression analysis of the arbuscular mycorrhiza-inducible Rieske non-heme oxygenase Ptc52 gene from tomato** *Journal of Plant Physiology* **237**: 95–103 [*Department of Soil Microbiology and Symbiotic Systems, Estación Experimental del Zaidín (EEZ) CSIC, Calle Profesor Albareda nº1, 18008, Granada, Spain]
Saeedeh Rahimzadeh*, Alireza Pirzad. 2019	**Pseudomonas and mycorrhizal fungi co-inoculation alter seed quality of flax under various water supply conditions** *Industrial Crops and Products* **129**: 518–524 [*Urmia University, Urmia, Iran]
Setareh Amanifar*, Maryam Khodabandeloo, Ehsan Mohseni Fard, Mohammad Sadegh Askari, Mohsen Ashrafi. 2019	**Alleviation of salt stress and changes in glycyrrhizin accumulation by arbuscular mycorrhiza in liquorice (Glycyrrhiza glabra) grown under salinity stress** *Environmental and Experimental Botany* **160***: 25–34* [*Department of Soil Science, Faculty of Agriculture, University of Zanjan, Zanjan, Iran]
Shijie Zhang*, Lu-Min Vaario, Yan Xia, Norihisa Matsushita, Qifang Geng, Momi Tsuruta, Hiroyuki Kurokochi, Chunlan Lian. 2019	**The effects of co-colonising ectomycorrhizal fungi on mycorrhizal colonisation and sporocarp formation in Laccaria japonica colonising seedlings of *Pinus densiflora*** *Mycorrhiza* **29**(3): 207–218 [*Asian Natural Environmental Science CenterThe University of Tokyo, Japan]
Simon T Okiobe*, Jürgen Augustin, India Mansour, Stavros D Veresoglou. 2019	**Disentangling direct and indirect effects of mycorrhiza on nitrous oxide activity and denitrification** *Soil Biology and Biochemistry* **134**: 142–151 [*Berlin-Brandenburg Institute of Advanced Biodiversity Research (BBIB), D-14195, Berlin, Germany]
Wenxuan Mai*, Xiangrong Xue, Gu Feng, Rong Yang, Changyan Tian. 2018	**Can optimization of phosphorus input lead to high productivity and high phosphorus use efficiency of cotton through maximization of root/mycorrhizal efficiency in phosphorus acquisition?** *Field Crops Research* **216**: 100–108 [*Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China]

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Xin-Xin Wang*, Ellis Hoffland, Liesje Mommer, Gu Feng, Thomas W Kuyper	**Maize varieties can strengthen positive plant-soil feedback through beneficial arbuscular mycorrhizal fungal mutualists** *Mycorrhiza* **29**(3): 251–261 [*College of Resources and Environmental Sciences and Centre for Resources, Environment and Food Security China Agricultural University, Beijing, People's Republic of China]
Xun Wen Chen*, James Tsz Fung Wong, Zhan Ting Chen, Anna Oi WahLeung, Charles Wang WaiNg, Ming Hung Wong. 2018	**Arbuscular mycorrhizal fungal community in the topsoil of a subtropical landfill restored after 18 years** *Journal of Environmental Management* **225**: 17–24 [*Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China]
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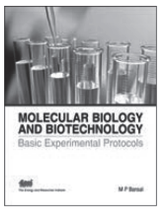

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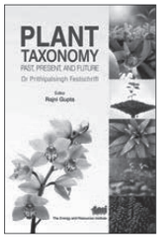

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Osaka, **Japan** July 15–16, 2019	**Mycology Congress: 4th World Mycology & Mushroom Congress** *Email:* mycologycongress@insightsummits.com *Website:* https://www.asianmeetings.net/conferences/mycology
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Tsu, **Japan** October 1–4, 2019	**Asian Mycological Congress 2019** *Email:* amc2019officer@mycology-jp.org *Website:* http://amcfungi2019.com
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