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SEASONAL FLUCTUATIONS IN ARBUSCULAR MYCORRHIZAL FUNGAL COMMUNITIES: A REVIEW

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ABSTRACT: Arbuscular mycorrhizal fungi (AMF) enjoy being the cynosure in most agro-ecosystems. These fungi benefit the plant in multiple ways. They improve plant growth by enhancing nutrient uptake and protecting the plant from various plant pathogens, thereby promoting plant diversity. These fungi improve plant tolerance to various abiotic stresses, such as salinity, drought, extreme temperatures, and heavy metals. They also provide aid in improving soil aggregation and soil stabilization, resultantly leaving a positive impact on ecosystem structure. The diversity of AMF varies among different habitats of the globe. The study of dynamics in the variety of these fungi in other host species in accordance with seasonal changes in a particular agro-climatic zone is significant to evaluate the natural status of these fungi in a specific region. It also becomes necessary to explore these fungal communities in different habitats for efficient utilization and conservation. The exploration of predominant AMF is also helpful in forming inoculums and its utilization for the production of better seedlings and their survival in adverse conditions.

INTRODUCTION: Among different microbial inoculants being used as biofertilizers, the most promising one is vesicular-arbuscular mycorrhiza (VAM), now famously known as arbuscular mycorrhizal (AM) fungi. Extensive research was carried out on the use of VAM fungi as biofertilizer to supplement nitrogen and phosphorus and observed considerable improvement in the growth of several crop plants [1, 2]. The use of VAM fungi as potential biofertilizers has received increased attention at commercial level [3-5].

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The AMF contributes predominantly to soil organic matter by creating a sink demand for plant C and distributing it to below-ground hyphal biomass [6]. Plant colonized by AMF will use more of the adaptation mechanisms compared to a plant without mycorrhizae [7].

Seasonal Dynamics of Am Fungi: To more fully understand the basic ecology of arbuscular mycorrhizal fungi and their role in natural ecosystems, it is necessary to document seasonal changes of various aspects of the life history of these fungi. Despite the importance of these soil fungi in various ecosystems, few studies exist that examine the seasonality of different variables of AM fungi which are directly related to ecosystem functions. Arbuscular mycorrhizal fungi have been observed to be associated with medicinal and aromatic plants [8, 9].

AM fungi play a pivotal role in plant growth enhancement in natural and managed ecosystems [10, 11]. The improved plant growth is mainly due to the extension of root hair and uptake of water and mineral nutrients from the soil [12]. The significance of these soil fungi suggests that the AM fungi might be able to substitute for reduced fertilizers and biocide inputs in organic farming systems. The distribution, diversity, abundance, and functioning of AM fungi are primarily based upon the extent of root colonization and spore count. Root colonization, growth, and sporulation of AM fungi depend upon many environmental factors [13].

It was thought that the production of AM spores increased after a period of extensive root growth or as the host matured. Apart from this, edaphic factors can also affect spore germination, root colonization, and the ability of the AM fungi to influence the growth and physiology of the host plant. In addition to the sensitivity of soil type, some other factors that affect behaviour of AM fungi are host plant, crop rotations, soil pH, moisture content of the soil, soil temperature, nutrient levels, and interaction with another soil biota. The abundance of AM fungi in agricultural soil varies with the season of the year. Also, it depends on factors such as inherent plant growth, edaphic factors, seasonal patterns in weather, and seasonally applied management practices *e.g.*, fertilization, manuring, and tillage practices [14].

The relative contribution of environmental factors showed that factors such as elevation, relative air humidity, soil pH, and soil available P, K, and Mg determine the shaping of AMF communities in the native forest of Azores [15]. The availability of phosphorus in the soil has a strong effect on the community of AM fungi in different ecosystem [16, 17]. As, VAM colonization is the result of interaction between soil, host, and mycorrhizal fungi, the rate of germination and efficiency of these fungi depends upon the composition of AM species which change with the season [18-20]. Seasonal dynamics in pH, moisture, temperature, and soil nutrient show a drastic effect on AM spore population, root colonization, and distribution [21-23]. The effect of soil pH, soil temperature, and soil moisture on wheat was analyzed, and found that the optimum range is the most favourable for the growth of VAM fungi [24]. Dispersal is a key process driving local-scale community assembly and global-scale biogeography of plant symbiotic AM fungal communities. Large numbers of AM fungal spores were also present in the air over one year course of investigation [25].

The development and seasonal fluctuations in AM fungi have been investigated in different plant species and in several countries like Great Britain, Israel, India, and Magnolia [26-29]. An earlier study showed that the spore count and root colonization in different plant species in Madras were more in summer than in the rainy season. The infection of the root and development of arbuscular started in the rainy season, and as the soil dried, the number of vesicles increased while arbuscules number decreased [30]. The work on seasonal variation of AM fungal communities was done in commonly cultivated crops of Dharwad district in Karnataka, and a higher spore count in summer and low in rainy season was detected [31]. A greater increase in AM spore diversity was recorded in rabi season than kharif in weedy plants of degraded land of Naldurg, Maharashtra [32]. The winter and monsoon seasons favour the growth of AMF, while summer is suitable for glomalin production [33]. The number of VAM spores was found to be higher at a temperature above 25 ºC in Brazillian rubber plantations [34].

The increase in root length due to AM fungi at higher temperature in seedlings of *Populus angustifolia* was also proved [35]. The seasonal dynamics of AM fungi in plants of *Theobroma grandiflorum* and *Paullinia cupana* showed the highest spore count and percent root colonization in rainy season [36]. Smilauer evaluated the seasonal dynamics of a community of endomycorrhizal fungal morphotypes in the roots of three grassland species (*Achillea milliefolium*, *Poa angustifolia*, *Plantago lanceolata*) and reported the comparable pattern of richness of AM morphotypes with change in season [37]. A higher rate of AM colonization in the spring season than autumn season has been observed in the roots of *Alnus acuminate* [38]. Significantly higher values on the total mycorrhizal colonization in Ilex paraguariensis crops were observed in winter, and organic matter and nitrogen were the soil factors that showed a significant correlation with the percentage of colonization [39]. The total infection rate of AMF and the infection rates of arbuscules and vesicles in Caragana korshinskii roots as well as the spore density of AMF in soil, varied significantly among seasons [40]. The significant effect of seasons on AM spore population and root colonization in Tectona grandis and *Dendrocalamus strictus* was also examined [41]. The remarkable variation in the extent of root colonization in the different season was reported in *Desmodium trifolium* in *Zoysia tenuifoliai* lawn [42]. Seasonal fluctuations in arbuscular mycorrhizal fungi in Vineyard soil planted with the legume crops, semi-natural grassland, salt marsh grass, Mojave desert, wetland habitats has also been well documented [43-47]. The habitat type also affects the species diversity and composition of soil AMF communities [48]. According to Li *et al.*, spore density was found to be highest in the dry season and lowest in the wet season, with intermediate values in autumn and spring [49]. The previous work also revealed a decreased occurrence of AM fungi related to the increasing level of soil minerals and between June and September in two plant species [50].

A presumable correlation between monthly precipitation and the degree of arbuscules formation was noted in *Mentha piperita* [51]. Temporal variation in AM hyphae, arbuscules, vesicles, spores, and even in glomalin, a glycoprotein produced by AM fungi, was also observed [52]. Regardless of the broad range of seasonality and temperal dynamics, several studies have reported the same pattern of AM seasonality among different habitats. Spore abundance of three *Glomus* species (*G. mosseae, G. monosporum*, and *G. fasciculatum*) was investigated in sugarcane, and maximum spore density occurred towards the end of the growing season, but the abundance of three of these raised almost to the maximum during vegetative growth [53].

The different cropping patterns in the same ecosystem can also influence the community of AM fungi [54]. The AM inoculum potential was strongly affected by the pH level of soil, not by moisture regime [55]. Furthermore, a direct correlation between moisture availability and growth of AM fungi was also described [56]. AMF colonization varies seasonally and depends on factors like climate, edaphic, plant host relationship, and species diversity [57]. A greater number of AMF species has been reported in winter season followed by the summer season and rainy season in Vindhyan soil [58]. Among the AM fungal species, *Glomus* species dominate, followed by *Acaulospora* spp., then *Gigaspora* spp. and *Scutellospora* spp. are poorly distributed. The relationship among soil properties, plant nutrition, and AM symbiosis in temperate grassland along hydrologic, saline, and sodic gradient with the changing season has been well documented [59, 60]. The factors such as rainfall patterns and moisture can influence AMF communities [61, 62]. The earlier worker took into account the stage of development of the host plant, environmental variables, and physiochemical characteristics of the soil to describe that maximum spore density and root infection occurred during the fruit-bearing period and flowering period of a plant, respectively [63].

Diversity and dynamics of AM fungi in different host plant species in a particular agro-climatic zone with seasonal changes are very important in order to evaluate the natural status of these fungi in that region. Such a study is important in identifying and utilizing the most suitable AM fungal species for large-scale inoculation programs for the conservation of medicinal plants. The AM sporulation and root colonization have seasonal dynamics, which is directly or indirectly influenced by different intervals of year, soil temperature, soil pH and soil moisture [64]. The seasonal changes and different range of spore density and root colonization are due to a wide range of hosts. The investigation believed that the AMF sporulation and colonization are seasonal and dependent on host plant species, and maximum sporulation and percent colonization of AMF was registered in the rainy season in the case of *Theobroma grandiflorum* and *Paullinia cupana* [36].

Gautam and Roy also studied the seasonal diversity in arbuscular mycorrhizal fungi with some medicinal plants and observed maximum sporulation and root colonization in rainy season [65]. The maximum sporulation in this season could be correlated with the fact that most photosynthate is allocated to roots and rhizomes during this period, which helps fungal symbionts produce more spores [66]. The seasonal behavior of AM fungi also showed minimum sporulation in summer and winter in the case of *Tectona grandis* and *Dendrocalamus strictus*, respectively [41]. The level of AM fungal association depends upon root morphology, metabolism rate of plant growth, and specific soil-plant system in terms of the chemical nature of root exudates [67, 68]. The seasonal fluctuations of mycorrhizal association were also found to be closely related to plant phenology [46]. The maximum AM sporulation and root colonization was observed in the winter season in the case of wheat [69]. The AMF community composition in roots was significantly different between spring and autumn; however, no significant differences were detected in soil propagules [70]. The higher number of vesicles, arbuscules, and maximum root colonization during the summer season were also explored, while the seasonal variation of AM fungi was studied in mountain grassland [71].

The higher root colonization may be attributed to the capacity of AM fungi to obtain higher profits and growth at higher temperatures and abundant rainfall. However, the variation in AM colonization and sporulation pattern among different plants could also be attributed to the ability of individual AM species to compete out with other species at certain times for host cortical cells or to lessen the degree of simultaneous competition for substrate from host at sporulation. AM sporulation is not always correlated with the extent of percent root colonization during different stages of months [72, 73]. Alternatively, seasonal fluctuations in environmental conditions can promote shifts in diversity and composition of soil fungal communities or changes in their activity [74, 75].

Soil pH significantly influenced AM spore population as well as the activity of extra radical mycelium [76]. The higher pH resulted in an increase in AM sporulation and percentage of root colonization. Extra radical mycelium formed at higher pH is well supported [77]. The pH of soil between 7.5- 8.5 was found to be the best salinity level for fungal growth [78]. The intensity of AM root colonization and spore density has been shown to depend on soil pH [79]. An increase in the AM spore population with increasing pH has been well examined [80]. The influence of pH on AM spore population may be due to the alteration in the concentration of many nutrients and ions in the soil solution. The pH-induced differences in nutrient availability in soil are responsible for stimulation or inhibition of VAM fungal spore germination81. The response of AM fungi to soil pH may depend upon the species and strains constituting the indigenous AM flora [82]. A maximum number of AM spores and root colonization was reported at pH 7.2- 7.4, whereas pH 6- 7 was reported to be the best for mycorrhizal development [83, 84]. A survey of different localities of Rajasthan revealed that VAM sporulation and root colonization in *Acacia nilotica* were positively correlated with soil pH [85]. However, no such definite correlation was found between soil pH and VAM development and sporulation [86].

Temperature fluctuations with different seasons influence the AM spore population and root colonization directly or indirectly. The intensity of mycorrhizal fungi alters with an increase or decrease in temperature [87]. AM fungal communities are sensitive to variable conditions of temperature and moisture [88, 89]. The effect of 10 ºC, 15 ºC, and 23 ºC temperatures on AM colonization was evaluated, and significant activity at 23 ºC and reduced activity at 10 ºC were noted [90]. The number of mycorrhizal plants, as well as the proportion and intensity of roots colonization, increased with a soil temperature of 11-20 ºC [91]. The temperature range between 28-34 ºC also showed a greater extent of VAM root colonization [92]. A significant correlation of AM root colonization with temperature has been observed in *Plantago lanceolata,* while there was no significant effect of temperature on *Holcus lanatus* [93].

Soil moisture had a profound influence on the VAM spore population as well as the colonization of host plants. It is suggested that mycorrhizal status and succession could vary depending upon moisture and nutrient conditions of soil [94]. High moisture resulted in decreased spore population and percentage of root colonization by VAM fungi [76]. Percent infection and number of resting spores in the rhizosphere increased in sunflower plants grown under the water-stressed condition of 10 percent soil moisture level [95].

Better AMF development at reduced soil water could be attributed to better soil aeration. The observation also showed a low AMF development under flooded conditions [96]. Furthermore, there is no direct relationship between AMF colonization and soil moisture [97]. It is possible that the low moisture did not cause a significant reduction in aeration to the point of compromising the mycorrhizal association in these varying environmental conditions. The relationship between AMF colonization and soil moisture may also be associated with the development of the plant root system due to an increase in the water content of soil and with the formation of new roots, and there will be a simultaneous increase in nutrient absorption and liberation of root exudates, stimulating mycorrhizal spore germination and subsequent infection [98]. Seasonal periodicity of AM fungi with different levels of pH, temperature, and soil moisture in wild legume Canavalia maritime was also studied [99]. In recent years, seasonal dynamics in AMF have been widely examined, and researchers concluded that the biotic and abiotic factors strongly affect AM fungal communities [100]. AM fungal network structure was significantly different between seasons, and the number of links between species significantly increased with time [101].

CONCLUSION: Seasonal variations and yearly fluctuations have a significant effect on AMF sporulation, hyphal colonization, vesicular formation, and arbuscular mycorrhizal structures, which are subjected to some the factors like plant growth stages, species diversity, edaphic factors, and climatic conditions. The changes of AMF are the product of the interaction between host phenology, soil characteristics, and habitat. The studies regarding the seasonal dynamics of AM fungi are useful as we may predict the season and edaphic conditions crucial for the development of AM fungi and further recommend that particular period or season for the propagation of plant species. More refined and targeted approaches focusing on ecology and intricacies of the association may provide an accurate picture of AM fungal formation and function under prevailing edaphic- climatic conditions.

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