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Role of Arbuscular Mycorrhizal Fungi in Plant Tolerance to Sub and Supra-Optimal Temperature Stress

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ABSTRACT

Plant fitness, development, and survival are significantly influenced by different environmental factors including extreme temperature regimes. The roots of the majority of terrestrial plant species can establish mutually beneficial relationships with arbuscular rmycorrhizal fungi (AMF) and AMF symbiosis can lessen the harmful effects of sub- and supra-optimal temperature stress on plants. AMF plants produce more biomass under heat stress than their untreated counterpart. Plants colonized with AMF have improved vigor, productivity, and fruit quality under heat stress. Temperature stress causes physiological disorders and excessive production of reactive oxygen species (ROS) that disturb the delicate equilibrium between the production of ROS and plants' antioxidative capacity to remove ROS, leading to detrimental oxidative reactions such as protein oxidation and membrane lipid peroxidation. Symbiotic relationships between plants and AMF can enrich the ROS-antioxidant shield pathway, which eventually enhances plant stress tolerance. In this chapter, we summarize the role of AMF in plant tolerance to sub- and supra-optimal temperature stress. We focus on underlying molecular mechanisms and propose that further molecular knowledge of the precise kinetics of ROS metabolism in plant-mycorrhizal interactions is essential to increase plant production under challenging thermal environments.

Keywords: AMF; Colonization; *Rhizophagus Intraredices*; Heat Stress; Cold Stress; Climate Change; *Piriformospora Indica*

Abbreviations: AMF: Arbuscular Mycorrhizal Fungi; ROS: Reactive Oxygen Species; JA: Jasmonic Acid; PDHEα: Pyruvate Dehydrogenase; SOD: Superoxide Dismutase

Introduction

Plant growth environments significantly stimulate plant fitness, development, and survival. Symbiotic microorganisms, like arbuscular mycorrhizal fungi (AMF), colonize plant parts in various habitats, enhancing mineral and water availability and environmental tolerance in plant-dwelling species. Additionally, AMF symbiosis changes the connection between plants and water in both drought-stressed and well-watered environments and AMF can even increase the productivity of colonized plants under sub and supra optimal temperature stress (Duc, et al. [1]). A number of machineries were displayed to be and by AM to water deficits in AMF plants, including improved stomatal conductance, enhanced water use efficiency, and lower oxidative damage due to higher enzymatic antioxidant activities and non-enzymatic antioxidant levels. Additionally, AMF change the levels of phytohormones such as abscisic acid and jasmonic acid (JA) as well as the proline content in the host plants. There are still few studies on AMF plants in the context of high temperatures, in contrast to the many reports of AMF plants that are stressed by drought. Several studies have found that AMF colonization can lessen the detrimental effects of temperature stress on plants like rice, wheat and maize (M adouh, et al. [2]).

It was also observed that AMF plants produced higher biomass when under heat stress in comparison to untreated counterpart (Duc, et al. [1]). Mycorrhizal plant diversity, intensity and proportion of colonized roots all increase with soil temperature (Heinemeyer, et al. [3]). The inoculum potential of Montana AMF is higher in cold soils than that of Syrian AMF. Harmal, a cultivar chosen from the Syrian barley land races, showed the highest mycorrhizal fungal colonization among the cultivars tested Inoculation of AMF to barley increased yield in increasing soil temperature Based on the proportion of mycorrhizal roots and the sum of mycorrhizal plants, barley genotypes were distinguished in a warm soil. From the viewpoint of showing germplasm for mycorrhizae, however, a bigger amount of plants can be judged for the occurrence of a characteristic arbuscule than for the percentage of mycorrhizal roots in a specific time period (Grey [4]). AMF native communities and isolates from cold climates, in particular the external mycelium, have been demonstrated to exhibit severe growth reductions below 20 °C in studies. Earlier it is observed that local warming of the extraradical mycelium from 12 °C to 20 °C improved hyphal growth in a system where both the plant and the fungus were exposed to the warming treatment (Gavito, et al. [5]).

Raising the temperature had minimal effect on the growth of one isolate of *Glomus. mosseae* outside of its stimulating effect on the host plant (Gavito, et al. [5]). *G. proliferum*, however, exhibited three phases of growth: no enlargement at 6 °C or 12 °C; a rise between 12 °C and 24 °C; and a drop between 24 °C and 30 °C. Up to 30°C, *G. intraradices* extraradical mycelium mass continuously grew. Effects on root length were highly related to how temperature affected the growth of AMF isolates (Gavito, et al. [6]). Also the advance of the fungus *G. intraradices* is in three phases low at 6 °C and 12 °C, peaking between 18 °C and 24 °C, declining at 30 °C (Gavito, et al. [6]). However, to the date, studies about how AMF starts to develop and function when soil temperatures are either low (10 °C) or high (>30 °C) for prolonged periods of time during the growth season are scant. It is significant to note that there is currently little work has been done on the study of mycorrhizal plants under sub and supra optimal temperature stress. So this study is designed to extrapolate how plant, AMF and growth environment for instance temperature interact each other and help successfully tolerate the sub and supra optimal temperature situations.

How the consequences of climate change will change mycorrhizal plant-fungal interactions is a significant problem for mycorrhizal research in the new millennium. The physiology of mycorrhizal fungi as well as the species mix of these underground communities may be impacted by global temperature change, either directly or indirectly (such as hyphal development, sporulation, and nutrient uptake). Soil moisture and temperature are unquestionably two of the most crucial factors, even if other factors comprising plant nutrients, light intensity, and plant community composition have also been suggested to affect the growth of AMF and the establishment of mycorrhizae. It has been demonstrated that rising soil temperatures encourage the expansion of extraradical mycorrhizal hyphae, the length of mycorrhizal roots, and fungal structures in both soil and plant roots. Modifications in precipitation and soil moistness can also affect the composition of the litter and the quantity of fungi. The competitive dynamics among diverse AMF species and the composition of AMF communities may be affected by global warming and accompanying changes in precipitation patterns because different fungal species may need different temperatures and amounts of moisture for optimal growth (Feng, et al. [7]).

There will be obvious changes as a result of localized climate change, but it is not yet apparent how these changes will affect the argument and storage of carbon in terrestrial ecosystems. A healthy carbon cycle depends on plant communal and plant throughput composition, but soil and soil microbe responses to climate change might also be very important. Because dirt are expected to store roughly 1500 Pg of organic carbon in the upper layer, more than double what plants produce, even a very insignificant adjustment in the fraction of stored soil carbon can have a significant effect. It has been proposed that over the past 25 years, soil carbon losses may have significantly exceeded any native sinks in the temperate ecosystems (Hawkes, et al. [8]). Under more sustainable agricultural management practices, AMF are anticipated to play a larger role in the operation of biomes and the cycling of nutrients (Barrett, et al. [9]).

AMF are important symbionts of various plant species because they facilitate root access to soil derived nutrients. There are many factors that influence how AMF symbioses with plants are established. A particular AMF species can settle a wide-ranging range of plant species, although the intra- and extra-radical hyphal density and the number of spores produced can differ significantly depending on the kind of plant. The occurrence of AMF may also directly or indirectly have an effect on the larger soil microbial community by impacting nutrient availability and by influencing root characteristics like water uptake and rhizosphere carbon flux. For instance, the generalist AMF's potential for colonization is significantly influenced by the identity of the host plant (Arruda, et al. [10]). Knowing soil affect studues working of mycorrhiza under climate change may have a greater influence on study studies on has been done on the impact of elevated CO_2 than the impact of temperature on AMF performance. However, it is difficult to predict AMF to colonize the roots due to insufficient root zone temperatures, mycorrhizal benefits may still be essential for phosphorus acquisition (Carvalho, et al. [11]).

By growing increasing the activity of antioxidant enzymes in the leaves and roots, both fungal symbionts *Septoglomus constrictum* and *S. deserticola* were able to lessen oxidative stress. However, similar benefits in plants that also contained *S. deserticola* were not immediately apparent (Duc, et al. [1]). The inoculation of AM fungus also boosted the activity of the enzymes superoxide dismutase (SOD), ascorbate peroxidase, and ascorbic acid in the leaves of heat-stressed cyclamen plants, according to investigations (Matsubara, et al. [12,13]). The quantities of the antioxidant enzymes peroxidase (POD),SOD, and catalase (CAT), as well as the concentrations of the soluble sugars in the roots and leaf proline, varied in maize AM plants during temperature stress. Recent research under heat stress showed that AMF wheat produced more grains, modified the way nutrients were distributed, and altered the nutrient makeup compositions of the tiller (Duc, et al. [1]). Earlier findings verified that mycorrhizal inoculations did not affect the physiological characteristics in non-stress environments.

Yet, by decreasing lipid peroxidation level and H_2O_2 accumulation and improving the effectiveness of reactive oxygen species (ROS) scavengers, immunization treatment with *S. deserticola* and *S. constrictum* could the defense of plants against oxidative stressors (higher POD, SOD, and CAT activities in roots and leaves, as well). *S. constrictum* inoculated plants were more resistant to oxidative stressors. Heat stress was the primary stressor for this study, and mycorrhizal plant reactions to heat stress and drought were equivalent to those under heat. The host plants' stomatal conductance, water status (higher leaf water potential and relative water content), maximum PSII efficiency (raised Fv/Fm), and biomass production increased as a result of mycorrhization by S. constrictum, but these improvements were less pronounced in plants inoculated with S. deserticola (Duc, et al. [1]).

It is uncertain how temperature impacts the carbon cycle, AMF, and plant performance. Yet, the factor of environmental change that may have the biggest direct effect on these fungus is temperature. In this crucial and increasingly relevant environment, it has become necessary to examine and appreciate the potential stimulations or constraints that the rapidly shifting temperatures may impose on these symbiotic fungi. The majority of other species are generally thought to have evolved to grow and function under the local climatic conditions or to persist by only developing sometimes when specific favorable conditions occur. It is unknown which sort of organisms make up the common of AMF species or ecotypes, or both. But it is largely accepted that AMF have evolved to grow in the majority of global ecosystems and can function in a wide range of temperatures since they are so prevalent (Gavito, et al. [5]). Here, we have looked at how soil temperature affects the carbon cycle as it is facilitated by plants and AMF.

The questions we precisely addressed were whether the effects of soil temperature on AM fungi happened independently of effects on the plant, how soil temperature affected intra- and extraradical AMF structures, and how it affected the rate and extent of carbon movement through roots and AMF. To this goal, we looked at the carbon pools and fluxes for roots and fungi combined and fungi alone. Root-free compartments were retained both close to and far from the root system in order to understand how temperature affects the growth and size of the extraradical hyphal network. In order to isolate the effects of soil temperature, we adjusted the temperature below ground but not above it, and we maintained a consistent soil moisture level across all temperature treatments (Hawkes, et al. [8]).

Arbuscular Mycorrhizal Fungi and Plant Tolerance to Sub -Optimal Temperature Stress

A fundamental temperature below which no physiological action occurs must be taken into consideration. The host plant species, however, may or may not be taken into consideration when establishing the base temperature for colonization development. It follows that the plant controls how temperature affects the fungus's ability to grow as the base temperature varies depending on the type of plant. However, the root zone temperature affects AM initiation rather than the fungus (Carvalho, et al. [11]). Three different isolates of *Funneliformis mosseae* collected from Finland, Denmark and Spain displayed reduced development, and in particular, very little external mycelium growth between 6 and 12 ^{o}C, regardless of the temperatures they generally experienced in their natural environments. Also, they all had a similar pattern of growth with rising soil temperature. These results suggest that AMF have a little window of opportunity to thrive in cold areas when temperatures are frequently below 15 ^{o}C.

This window should be fully utilized, especially in agroecosystems where management is concentrated on improving crop yield and soil quality. If mycorrhizal development and benefit are properly managed in cold regions and temperatures rise, they may also increase (Gavito, et al. [5]). The Gavio Azcon Agquilar thory suggest that C mobility was involved in AMF's response to temperature changes was supported by the variations seen in root-C uptake and C translocation in the fungus. Low temperatures did not appear to have an adverse effect on the transportation of other nutrients, as evidenced by the fact that temperature had an effect on C movement to the fungus but not on root P uptake or P translocation. Another study's findings in that temperature range support the notion that there are no temperature-related effects on P absorption, translocation, or transfer between 10 and 25 °C (Gavito, et al. [6]).

The effect of freezing soil temperatures on mycorrhiza growth has practical implications when assessing the potential benefits of the symbiosis within agricultural systems. Since they may adversely affect the colonization of roots by AMF. Because only roughly one third of the Earth's land surface is covered by soils with mean annual temperatures above 15 °C, it is crucial to comprehend the effects of suboptimal root-zone temperatures. Several host plant species have reported a range of minimal temperatures that preclude AMF colonization, including 5 °C for wheat and barley, 10 to 12 °C for subterranean clover and 15 °C for soybean. AMF colonization may still take place, even if the soil temperature never rises over 5 °C. Contrastingly, a deleterious relationship was detected between soil temperature and AMF, when the soil temperature was between 4 and 16 °C. The levels of colonization in natural ecosystems can be significant throughout the winter. The AMF's biological variability, the presence of mycorrhiza in many ecoregions, and the capability of spores to sprout in cool settings all strongly imply that the smallest temperature for foundation It is widely known that strigolactones and flavonoids contained in plant root exudates are essential for plant communication and mycorrhizal establishment.

Maize's root shape was more influenced by inadequate root temperatures than wheat. Hence wheat was less affected by chilly temperatures. Here cool temperatures may mark root exudates by changing both plant activity and the structure of the root system (Carvalho, et al. [11]). The extraradical mycelium was found to be more sensitive to low temperatures than the intraradical mycelium, contrary to the common belief that the intraradical and extraradical mycelium develop in proportion. The latter developed significantly below 5 °C, but the former was typically unable to develop below 15 °C. It is important to continue researching this distinct reaction since it could have significant effects on how to understand the AM symbiosis (Gavito, et al. [6]). The properties of low temperatures on C uptake by modified roots have not been examined, despite the fact that many plants are known to absorb less ions and water at low temperatures. This information was deemed unnecessary in the vast majority of earlier research that used this system (Gavito, et al. [6]). The capacity of sink organs to absorb nutrients and the capacity of source organs to supply nutrients both work to limit yield. Therefore, any modification to the source-sink relationship, such as a change in how nutrients are delivered from source to sink or how carbon (C) is partitioned, will have an effect on the final yield. Reduced carbon (C) absorption and altered nitrogen (N) redistribution and partitioning during heat stress can affect source-sink relationships.

Additionally, it has been observed that the C sink strength of the AM symbiosis increases the photosynthetic rates. In order to offset the costs of the symbiosis, the improved C fixation improves "photosynthetic nutrient utilization efficiency," modifies source-sink interactions in the plant, and inspirations subsequent invention (Cobral, et al. [14]). Mycorrhizal roots may hold more solvauble sugar and starch than non-mycorrhizal roots even when respiration is high because the host plant's photosynthetically secure carbon was moved to the AM fungus. These improved levels of carbohydrates are employed by both the respiration of the roots and the transfer to AMF for the nutrition interchange between the two symbiotic sides. Soluble sugar and starch, which are the main carbohydrates produced during photosynthesis, are important substrates for respiration (Liu, et al. [15]).

Role of Arbuscular Mycorrhizal Fungi in Plant Tolerance to Sub -Optimal Temperature Stress

Cold stress, a significant abiotic contrain, has a detrimental influence on the productivity and development of many agricultural products crops on a global scale. During cold stress plant metabolism is impaired, cell membranes become hard and lose their ability to function, proteins and solutes leak out, sugar metabolism is reduced, and reproductive ability is lost. So it is necessary to create methods that can assist plants withstand harsh weather without reducing their productivity. There has been a lot of interest in this area on the use of AMF for minimizing cold stress in plants (Devi, et al. [16]). Most studies revealed that intraradical mycorrhizal colonization increased as temperature rose between 5 °C and 37 °C. Although some early studies suggested that native AMF isolates would be able to adapt to withstand extreme temperatures in their environment. Symbiotic efficacy, extraradical hyphae development, and root colonization were all hampered by low temperatures (5 °C-15 °C). Unfortunately, the fact that few of those studies looked at how both the intraradical and extraradical phases developed limits our understanding of the mycorrhizal mycelium's temperature dependence (Gavito, et al. [5]). The results provided conclusive evidence that the AMF isolates had not developed any tolerance to cold soil temperatures. Nonetheless of the temperatures they typically practiced in their new territories, these three isolates of the same AMF species displayed low ability to develop an external mycelium at temperatures below 12 °C, as previously reported for individual AMF Danish isolates and native communities as well as outcomes from *in vitro* cultures with isolates from different regions of the world (Gavito and Azcon-Aguilar,[5]).

The influences of CO_2 on the host plant would have less of an impact on AMF advance and nutrient application than would soil temperature. Using a lonely isolate of *Glomus caledonium* or AMF from field soil, pea plants were grown in factorial combinations at current (350 ppm) or elevated (700 ppm) atmospheric CO_2 and the corresponding current (10 °C) or elevated (15 °C) soil temperatures (Gavito, et al. [17]). The optimum temperatures for root growth in *G. intraradices* and *G. proliferum* cultures were 18 °C and 24 °C, respectively. Both the overall root length and the colonized root length in *G. intraradices* were significantly influenced by temperature. The total root length increased between 6 and 18 °C and dropped between 18 and 30°C, whereas the colonized root length enlarged linearly from

6 to 30 °C. The growth of extra-radical hyphae was affected by temperature treatments in cultures containing all three AMF isolates. The extraradical mycelium did not extend past the inoculum stopper at either 6 °C or 12 °C. However, the total root length of *G. proliferum* developed similarly to that of *G. intraradices* (Figure 1).

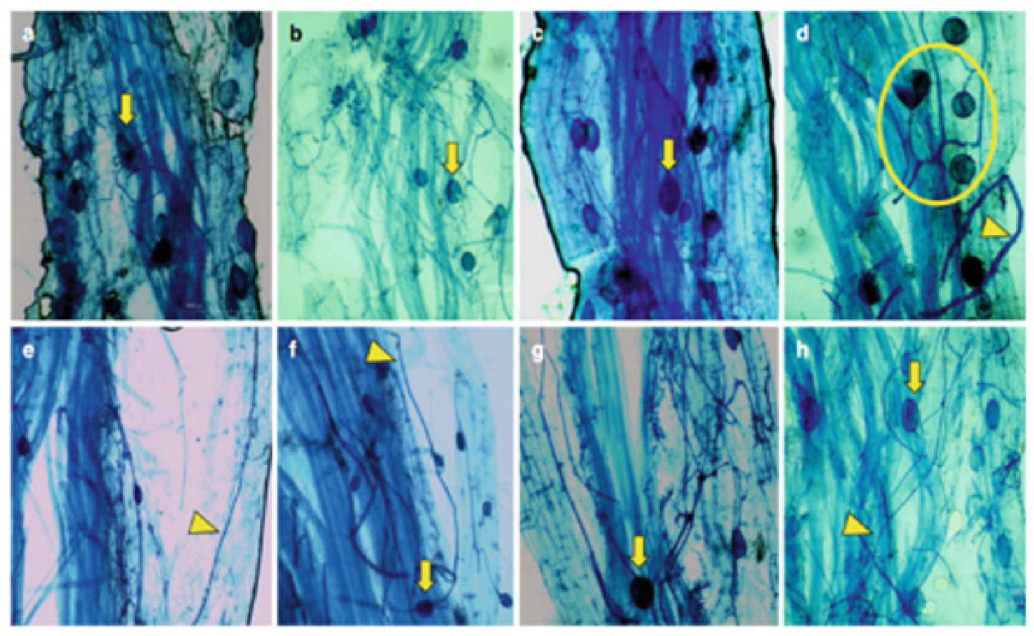
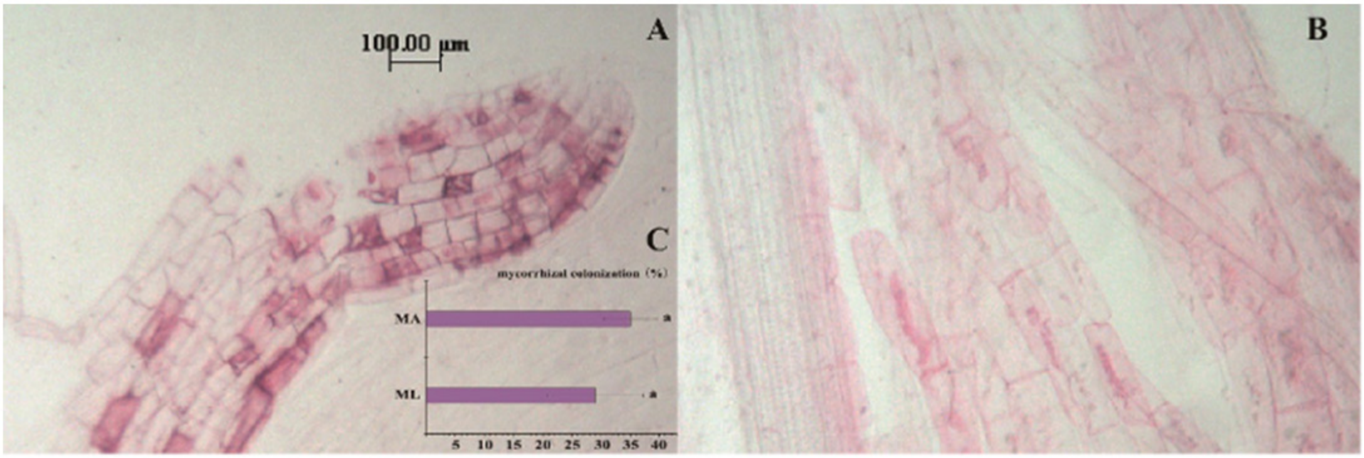


Figure 1: Mycorrhizal root colonization of pearl millet lines by *Funneliformis mosseae* (a, b, c, e, f, g) and *Rhizophagus aggregatus* (d, h) under control and high temperature treatments in culture chamber. a L253 at 32–28 °C (day-night temperature), b L220 at 32–28 °C, c L132 at 32–28 °C, d L3 at 32–28 °C, e L253 at 37–32 °C, f L220 at 37–32 °C, g L132 at 37–32 °C, h L3 at 37–32 °C. Arrow: vesicles; triangle: hyphae; circle: intraradical spore.

Low temperatures affect rice productivity in addition to grain excellence and even existence due to the physiological development of crops and the insurgence of plant uptake. Low temperatures change the equilibrium of absorbed carbon, influencing the amount of carbohydrates in the leaf and root and, accordingly, respiration. Small temperatures also reduce leaf exports of carbohydrates and sink activity. Low temperatures have also been connected to changes in the pathways that regulate respiration in addition to reducing the production of adenosine triphosphate (ATP) and respiration rate (R) (Liu, et al. [15]). Pyruvate application and the relative expression of genes related to pyruvate breakdown were measured. Intriguingly, pyruvate concentration was lesser in the roots of mycorrhizal rice than non-mycorrhizal rice at truncated temperatures. The expression levels of pyruvate kinase and pyruvate dehydrogenase (PDHEα) in mycorrhizal rice roots were found to be greater than those of non-mycorrhizal rice under low-temperature conditions. Mycorrhizal rice may have lower pyruvate concentrations than non-mycorrhizal rice because it expresses PDHEα at comparatively higher levels for pyruvate metabolism. However, because non mycorrhizal rice has a relatively lower level of PDHEα than mycorrhizal rice, it might be more vulnerable to pyruvate accumulation under low-temperature stress (Liu, et al. [15]).

As a result, it may be assumed that under low-temperature stress, AMF may initially pick up the host's "cry for help" signal and then promote greater host photosynthesis, which increases the availability of substrates for respiration (Liu, et al. [15]). There is proof that the symbiotic relationship between plant roots and AMF encourages plant growth as well as increases plants' resistance to biotic and abiotic stresses, such as cold temperatures. The use of AMF to control how plants respond to cold stress has garnered a lot of attention, in particular, over the past ten years. After receiving mycorrhizal inoculation, bean plants under cooling stress responded by exhibiting enhanced leaf water potential. AMF colonization in plant roots may increase plants' resistance to cold temperatures by lowering membrane lipid peroxidation and plasma membrane permeability as well as boosting osmolyte accumulation, antioxidant enzyme activities, photosynthesis, and secondary metabolism (Liu et al. [15]) (Figure 2).



Note:

A. Mycorrhizal colonization under ambient temperature.

B. Mycorrhizal colonization under low temperature

C. Mycorrhizal colonization of under ambient temperature and low temperature. Error bar indicates the standard deviation of three technical replicates (Source: Li et al. [50]).

Figure 2: Root colonization of maize seedlings inoculated with *Rhizophagus irregularis.*

Low temperature stress is one of the main abiotic factors that limits plant growth and natural dissemination. Likewise, chilling is one of the most severe abiotic stresses that limits crop growth and yield globally. Most plants will adjust their physiological functions, including photosynthesis and hydration status, when exposed to cold temperatures. Plant water interactions are worsened by reduced hydraulic conductivity and a lack of stomatal control brought on by low temperature. Low temperatures also hinder the production of chloroplasts, change the color of pigments, and decrease chlorophyll fluorescence, all of which decrease the capacity and effectiveness of photosynthesis (Latef and Chaoxing, 2011). The main site of cold stress hurt, is the cell membrane, which is affected by rise in permeability, electrolyte leakage, and significant changes in structure and lipid content. These improvements result in the addition of ROS, which affects cellular lipids, proteins, DNA, and other macromolecules. One of the defense mechanisms that plants have evolved to counteract excessive ROS is the synthesis of antioxidant metabolites, such as proline and soluble carbohydrates, and antioxidant enzymes, such as SOD), CAT, and APX (Pasbani et al. [18]).

In the lack of cold stress, the AMF colonization led to a large rise in the H_2O_2 level notwithstanding a contemporaneous rise in the activity of the foraging enzymes (CAT and APX). Hydrogen peroxide is a nodding molecule that activates downstream processes, comprising plant stress defense. The higher H_2O_2 concentration, which was seen here despite the absence of cold stress, may prepare mycorrhizal eggplants for diverse environmental challenges. According to the previous findings, H_2O_2 plays a vital regulatory role in mycorrhizal symbiosis, and AMF inoculation has a priming effect that raises tolerance to a variety of biotic and abiotic stresses. When compared to the control temperature (25 °C), the H_2O_2 and free phenolics content at 5 °C was much lower in the + AMF plants than the -AMF plants, which was associated with elevated CAT and APX activities. According to the findings, under cold stress conditions, the + AMF plants were able to adequately scavenge ROS because of their improved ROS scavenging ability (Pasbani, et al. [18]).

Low temperatures increased AMF aquaporin (GintAQPF) manifestation levels, and rice aquaporin (OsPIPs) expression levels were observed as compared to rice that is not mycorrhizal. The enhanced trehalose biosynthesis gene transcripts, such as OsTPS1, OsTPS2, and OsTPP1, in mycorrhizal rice roots generated more trehalose than non-mycorrhizal rice at either normal or low temperature. Exogenous trehalose was used to demonstrate how trehalose could regulate AMF and rice water absorption and enhance plant development conditions by inducing the expression of GintAQPF and a number of OsPIPs. Therefore, we suggested that AMF-enhanced trehalose accumulation was one of the methods by which AMF strengthened plant resistance to low temperature. AMF and host plant aquaporin expression may be induced as a result, which would improve water relationships in mycorrhizal plants at low temperature (Liu, et al. [19]). As a result of AMF colonization, stress also induces a discernible increase in the trehalose pool in the mycorrhizal roots (Liu, et al. [19]). Hence, studies into the accumulation of trehalose in mycorrhizal roots may provide a key insight into how AMF responds to challenging circumstances (Liu, et al. [19]).

When AMF is generated, plants are thought to perform more effectively under normal and traumatic conditions. Low temperatures (15 °C) typically prevent AMF from colonizing roots, although research has shown that mycorrhizal plants are more resilient to frozen stress. Symbiotic idea of plant roots with AMF increases cold patience through the drop of lipid peroxidation and salvation of skin truthfulness, the growth of antioxidative potential, the optimization of osmolytes intensification and instruction of root hydraulic conductance, the expansion of photosynthetic bustle and respiration rate, and assimilated transcriptional guideline of cold-receptive genes (Devi, et al. [16]). Terrestrial shrub species have changed to favor mycorrhizal symbiosis. This symbiotic message has, and probably will continue to play, an important role in decreasing the detrimental effects on plants caused by numerous abiotic stresses, particularly cold stress. Since the beginning of time, AM symbiosis has been renowned to exist and is essential to the control of terrestrial ecosystems. AMF immunization has the capacity to lessen the cold stress that plants knowledge, as has been adequately established.

Future agriculture will benefit from the association since it offers a better way for plants to adjust the demanding environmental conditions (Devi, et al. [16]). AMF symbiosis increases host plant osmotic adjustment during cold stress and increases roots' capacity to gather soil water and maintain open stomata in leaves through the addition of soluble sugar and proline. According to reports, AMF under cold stress collected with water relations increases the host plants' leaf chlorophyll concentration, photosynthesis, and antioxidant enzyme bustle. The AMF inoculation-induced increase in phenolic metabolism may be necessary for the AMF-mediated enhancement of cold stress (Chen, et al. [20]). Although low temperatures restrict plant growth, a process known as cold acclimation regular exposure to low but not freezing temperatures increases the survivability of plants after a freeze-thaw cycle. The accumulation of suitable solutes like carbohydrates and amino acids, changes in the make-up of membrane lipids, and the creation of certain proteins that prevent ice from recrystallizing are all associated with cold acclimation (Chen, et al. [20]).

Increased cell membrane permeability is the first sign of low temperature stress in plants. Additionally, a number of ROS, comprising as hydroxyl radicals, superoxide anion radicals, and H_2O_2 are generated. Membrane lipid peroxidation is caused by an imbalance between manufacture and foraging in the cell or organism. In order to avoid oxidative damage, plants adjust their osmotic potential and activate antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), ascorbaperoxidase (APX), and glutathione reductase (GR), in addition to some non-enzymatic antioxidants like ascorbic acid, a-tocopherols, phenolic compounds, and others (Latef and Chaoxing, 2011). Cold stress, which encompasses chilling (5 °C-15 °C) and freezing (<0 °C) temperatures, is one of the most frequent environmental stressors that crop plants encounter on a global scale. The effects of cold stress on plant yield and survival are quite detrimental. Due to altered pigment composition, poor chloroplastic development, decreased root hydraulic conductivity, and loss of stomatal control, cold stress lowers the capacity and efficiency of photosynthesis. Plants that are subjected to cold stress first experience impacts on their cell membrane, which results in a loss of fluidity, certain modifications to the lipid content, and membrane damage. A rise in electrolyte leakage and lipid peroxidation then follow these consequences (Hajiboland, et al. [21]).

Low-temperature stress, is a chief environmental factor that significantly hinders plant respiration, can be reduced by AMF. In the present study, a pot experiment was carried out to control changes in the metabolic capacity of mycorrhizal rice (Oryza sativa) during low-temperature stress. The results confirmed that low temperature may speed the construction of strigolactone in mycorrhizal rice roots by stimulating strigolactone synthesis gene expression, which acted as a host stress response signal. AMF also induced the host tricarboxylic acid (TCA) cycle by enhancing pyruvate metabolism, up-regulating the expression of TCA cycle genes under low-temperature stress, and affecting the electron transport chain (Liu, et al. [15]). While the alternative oxidase pathway may be the main electron transport mechanism in stressed non-mycorrhizal rice, the cytochrome c oxidase (COX) pathway may predominate in AMF mycorrhizal symbiosis. Adenosine triphosphate synthesis was increased in mycorrhizal rice in order to maintain the usual condition of respiration while under stress. Better root growth condition and lessened low-temperature stress resulted from this (Liu, et al. [15]).

Chiling injury could cause a variety of harm, including acute mechanical stress, changes in macromolecule activity, a drop in osmotic potential in the cellular setting, an increase in H_2O_2 buildup, and significant plasma membrane alteration. Freezing injury happens when the temperature drops from 1to 0 °C. Low temperatures during the winter and spring in the subtropical areas frequently endanger crop production, especially seedling growth (Chen et al., 2013). In particular, over the past ten years, the use of AMF for controlling plant responses to cold stress has attracted a lot of attention. The leaf water potential of chilling-stressed plants increased in response to mycorrhizal inoculation. By reducing membrane lipid peroxidation and plasma membrane permeability, as well as by boosting osmolyte addition, antioxidant enzyme activities, and photosynthesis, AMF colonization in plant roots may improve plants' ability to withstand cold temperatures (Chen, et al. [20]).

While changed AMF caused diverse root colonization, low temperature dramatically inhibited AM colonization. Low temperatures significantly lowered plant height and total dry weight while increasing root dry weight and the root-to-shoot ratio. Compared to non-AM plants, AM plants have a greater proline content. The maize plants inoculated with *Glomus etunicatum* and *G. intraradices* showed higher amounts of malondialdehyde and decipherable sugar when the temperature was low. The catalase (CAT) and peroxidase activities of AM-infected maize was higher than those of non-AM maize when exposed to low temperature. The chilly temperature dramatically lowered CAT's activity levels (Chen, et al. [22]). It is well known that both temperature and AM symbiosis affect plant growth. Despite the fact that low temperatures significantly harmed plant growth as measured by plant height, total dry weight, and root-to-shoot ratio, no positive plant growth responses to AM colonization were seen (Chen, et al. [22]). The short duration of the experiment and the paucity of AMF to deliver P and other types of nutrients to the plants may be to blame for this effect of AMF, which was also noted in earlier pot studies.

It is commonly known that low temperatures cause leaf tissue to deteriorate, which slows plant growth. Damage to the membranes, which increases permeability, is the principal effect of chilling stress. Although it is influenced by the age of the plant, the leaves, and their position on the plant, electrolyte leakage (EL) is a useful indicator for determining cell membrane damage. Consequently, measurements were done using the upper fully grown tomato leaves at the same seedling age (40 days after planting) (Caradonia, et al. [23]). Only the initial tests revealed a significant difference between the treatments using microorganisms. The seedlings' variable agronomic performance may help to explain this. Actually, seedlings with more development are more resistant to environmental stresses. Therefore, it is hypothesized that the higher tolerance of seedlings may have muffled or hidden the varied effects of the treatments along the course of recovery. The non-treated control's lower EL values in the second experiment compared to the first trial further supported this theory (Caradonia, et al. [23]).

The investigation's findings showed how the examined microorganisms behaved in a protective manner toward cell membranes. Environmental stresses impede plant growth and yield, which results in substantial losses. Crop growth and yield, in particular, are affected by chilling in subtropical regions (Caradonia, et al. [23]). Cold stress results from physical and chemical changes in biological molecules brought on by low temperatures. Conditions of freezing (0 °C) and chilling (10-15 °C) severely restrict the growth of plants. Low temperatures affect plant ecophysiological function, which affects crop yield loss globally as well as the fitness and dispersion of wild species. Prior studies have focused on the functional mechanisms that enable plants to withstand cold stress through a variety of morphological, physiological, biochemical, genetic, and epigenetic aspects (Acuna-Rodriguez, et al. [24]). After the chilling stress in both trials, Funneliformis mosseae primarily reduced the cell membrane damage in terms of electrolytic leakage and photosystem II efficiency. On the other hand, an application of *F. mosseae* increased photosystem II efficiency while enhancing seedling regeneration. Modern genotypes that had been infected with microorganisms also demonstrated greater seedling regeneration (Caradonia, et al. [23]). Making use of beneficial AMF could be a long-term way to decrease the demand for outside resources and boost resilience to biotic and abiotic problems.

When it came to reducing the effects of low temperature stress on barley cultivars, G. versiforme frequently outperformed *Rhizophagus irregularis*, although *R. irregularis* performed better when it came to boosting survival. This finding implies that successful application of AMF under freezing conditions depends on selecting the proper fungus type and host-plant cultivar (Hajiboland et al. [21]). While earlier research suggested that the use of AMF could reduce the effects of chilling stress, this research tended to focus on primary metabolism, such as plant growth, dietary intake, chlorophyll parameters, and antioxidant enzymes. Recent results suggest a relationship between changes in secondary metabolism and stress responses. According to reports, flavonoids have an impact on spore germination, hyphal growth, and AMF root colonization. Many theories claim that secondary metabolites including lignin, flavonoids, and phytoalexins are produced as part of defense systems (Chen, et al. [20]). Future research subjects into plant-microbial symbioses in chilled and frozen circumstances are suggested, as well as whether temperature impacts how plants respond to symbiotic microbes. Without symbionts, it is evident that studies examining how plants respond to cold and subzero temperatures are most likely artifacts. Future study should routinely incorporate symbiotic microbes in their experimental designs to appropriately assess how plants respond to chilling and freezing temperatures in the natural environment (Acuna-Rodriguez, et al. [24]).

However, compared to the room temperature, superoxide dismutase and peroxidase activity were significantly elevated in the AMF group below low temperature stress. The combination application of AMF dramatically improved catalase bustle and proline contented while lowering malondialdehyde levels in the plant leaves under low-temperature stress. As a result, AMF accelerated the growth of Lolium perenne plants and improved their resistance to salt water soil stress and low temperatures (Yan, et al. [25]). Temperature had a significant effect on the AM hyphal network, which went from having more vesicles (storage) in cooler soils to having larger extraradical hyphal networks (growth) in warmer soils. Also, it has been discovered that as soil temperature rose, there was an intensification in the rate of plant photosynthate transfer to and respiration by roots and AMF as well as an increase in the amount of carbon respired per unit hyphal length. Neither plant size nor photosynthetic rates were significantly correlated with these differences. In a warmer future, we would consequently anticipate higher atmospheric carbon losses through AMF respiration, which are unlikely to be countered by higher AMF hyphae formation (Hawkes, et al. [8]).

Despite the fact that the photosynthetic rates of the cooled treatment were only slightly (<10%) higher than those of the control group during the light intensities used for pulse-labeling, the observed increase in throughput was not likely caused by a shift in photosynthetic rates. Soil temperature may also have an effect on how much carbon is transferred from the plant to the fungus, either directly or by affecting how effective the fungal sink is. According to the $^{13}CO_2$ content of the soil air in the AMF slot, rising soil temperatures increased the transfer of carbon from plants to mycorrhizal fungus. This may be partially explained by variations in the size and investment of the extraradical mycelium (Hawkes, et al. [8]). At low temperatures, the two cultivars both showed equivalent decreases in the leaf concentrations of soluble sugars, phosphate (P), and potassium (K). However, equivalent increases were seen in the levels of malondialdehyde (MDA), H_2O_2, superoxide anion radical (O_2), and proline. The activities of superoxide dismutase, ascorbate peroxidase, guaiacol peroxidase, ascorbate, and glutathione as well as the amounts of O_2, MDA, and H_2O_2 in the leaves of the blueberry cultivars were all increased by AM inoculation. AMF caused more notable changes in leaf composition. In comparison to non-inoculated plants, plants from the blueberry cultivars "Britewell" and "Misty" that had been infected with AMF showed higher amounts of soluble sugar, proline, P, and K (Liu, et al. [26]).

So it is advisable that the application of AMF provides plant resistance to cold temperatures. Low temperature decreased soluble sugar concentration in leaves, and increased leaf proline concentration. Inoculation with AM enhanced soluble sugar and proline concentrations in the leaves of two blueberry cultivars. Conversely, under the low temperature, leaf soluble sugar concentrations of AM-inoculated 'Britewell' and 'Misty' blueberry plants increased by 15.71% and 12.21%, respectively, in comparison with non-mycorrhizal plants. Under the normal temperature, they increased by 20.63 % and 14.88 %, respectively. Proline concentration was higher in 'Britewell' leaves than in 'Misty' leaves (Liu, et al. [27]). Blueberry plants inoculated with AM displayed higher levels of leaf SOD, APX, GPX, ASA, and GSH in response to low-temperature stress than non-AM-inoculated plants, but lower levels of leaf O_2, H_2O_2, and MDA, indicating that the ASC-GSH cycle would function well in AM plants. It is thought that reducing H_2O_2 levels is one of the ways AM fungus protects plants from numerous stresses (Liu, et al. [27]).

It is common knowledge that one of the key elements of freezing tolerance mechanisms is osmotic adjustment. Sugars can serve a number of purposes, such as providing osmoprotection, energy for basic metabolism, and the production of new molecules that respond to stress. Proline, which serves as an energy sink to control redox potentials and as a hydroxyl radical scavenger, is the most significant amino acid involved in organic osmotic adjustment. It is reported that AM-inoculated The possible of arbuscular mycorrhizal fungus to increase the host plants' resistance to cold temperatures is well documented. Although the popular of lessons have outlined the favorable impact of AMF on host respiration and there are ample data describing variations in plant breathing under low-temperature conditions in both mycorrhizal and non-mycorrhizal plants, the more fundamental mechanisms remain unclear (Liu, et al. [15]). The opening contamination and subsequent colonization of barley by mycorrhizal fungi were both influenced by temperature. Although mycorrhizae can develop in a range of temperatures from 11 to 26 °C, warm temperature are when the majority of colonized roots occur. While Glomus hoi, the predominant AMF fungus from Syria, was further accepting of sincere soils at 24 to 26 °C, *G. macrocarpum*, the predominant AMF fungus from Montana, was more tolerant of cool soils at 11 to 14 °C.

Glomus species have different ideal growing temperatures for mycorrhizae, which has also been observed in wheat (Grey, [14]). Winter wheat was most effectively infected with *G. epigaeum* at a temperature of 25°C, but not at 10°C. The vast choice of temperatures suggests that various Glomus species have varying thresholds for heat (Grey, [4]). Temperature stress causes physiological problems and the production of ROS in plants. The buildup of ROS disturbs the delicate equilibrium between the production of ROS and plants' capacity to hunt for them by causing destructive oxidative processes, such as membrane lipid peroxidation and protein oxidation. Malondialdehyde (MDA) is commonly used as a marker for the degree of membrane lipid peroxidation and as its final product. So the MDA content in tomato plant leaves was assessed below low temperature stress. Low temperature stress led to a rise in leaf MDA concentrations in non-mycorrhizal plants. However, the MDA content in mycorrhizal plants persisted lower than that in non-mycorrhizal plants, suggesting that the presence of the AM fungus may have a preventative impact against membrane lipid peroxidation. Through AM symbiosis, the concentration of MDA in leaves was decreased under cold stress (Latef and Chaoxing, 2011).

Notably, H_2O_2 and malondialdehyde buildup significantly decreased following AMF inoculation, indicating that it significantly reduced the oxidative stress brought on by chilling. While AMF injection significantly decreased this leakage, watermelon seedlings grown in cold circumstances showed an increase in leaf electrolyte leakage (Bidabadi, et al. [28]). Compared to non-mycorrhizal plants, mycorrhizal plants have more soluble protein, carbohydrates, and photosynthetic pigments in their leaves, but a decreased concentration of proline. The colonization of AM increased the activity of the enzymes SOD, catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX) in leaves. The results show that by reducing membrane lipid peroxidation and increasing photosynthetic pigments, osmotic adjustment chemical accumulation, and antioxidant enzyme activity, the AM fungus can shield tomato plants from the harm brought on by low temperature stress. As a result, the development of AMF, which increased host biomass and speed up plant growth, considerably boosted the tomato plant's capacity to endure cold circumstances (Latef and Chaoxing, 2011).

Earlier reports demonstrated that under low temperature stress, carotenoids increased while chlorophyll content (chl a, chl b, and chl a+b) dropped. This suggests that there are connections between the plant physiological make-up and stress tolerance to the plant. Similarly, the amount of chlorophyll content in plant leaves showed that there were lower rates of chlorophyll synthesis and higher rates of chlorophyll breakdown under low temperature stress (Latef and Chaoxing, 2011). AMF and low temperatures change the protein makeup of tomatoes. Low temperature stress can result in substantial accumulations of proline. According to the recent findings, plants that are inoculated with AMF have less proline in their leaves than plants that are not (Latef and Chaoxing, 2011). As a result, it is possible that AMF colonization could lessen ROS damage, protect plants from oxidation damage, and ultimately improve the plants' resistance to temperature extreme. So it is possible that some antioxidant enzymes are more active as a result of how plants generally defend themselves from low temperature stress.

The AMF symbiosis may affect the production of antioxidants, osmotic regulation, membrane lipid peroxidation, and reactive oxygen metabolism in plant tissues, however this is yet unknown. Therefore, more study is needed to fully understand the mechanism by which AM symbiosis affects oxygen metabolism, membrane lipid peroxidation, and antioxidant production in plants. The changes in leaf proline show that the injuries to mycorrhizal plants were less severe, necessitating the synthesis of less proline to provide osmotic adjustment protection. There are observable changes in the relative permeability of the leaf and root membranes to high- and low-temperature stressors between mycorrhizal and non-mycorrhizal plants (Zhu, et al. [29]). How the AM symbiosis affects the generation of antioxidants, osmotic regulation, membrane lipid peroxidation, and reactive oxygen metabolism in plant leaves and roots is still unresolved. Furthermore, mycorrhizal plants exhibit lower relative membrane permeability than non-mycorrhizal plants. At low temperatures, the two cultivars both showed equivalent decreases in the leaf concentrations of soluble sugars, phosphate (P), and potassium (K).

However, equivalent increases were seen in the levels of malondialdehyde (MDA), H_2O_2, superoxide anion radical (O_2), and proline. The activities of superoxide dismutase, ascorbate peroxidase, guaiacol peroxidase, ascorbate, and glutathione as well as the amounts of O_2, MDA, and H_2O_2 in the leaves of the blueberry cultivars were all increased by AM inoculation. AMF caused more notable changes in leaf composition. In comparison to non-inoculated plants, plants from the blueberry cultivars "Britewell" and "Misty" that had been infected with AM showed higher amounts of soluble sugar, proline, P, and K (Liu, et al. [26]). So it is advisable that the application of AMF provides plant resistance to cold temperatures. Low temperature decreased soluble sugar concentration in leaves, and increased leaf proline concentration. Inoculation with AM enhanced soluble sugar and proline concentrations in the leaves of two blueberry cultivars. Conversely, under the low temperature, leaf soluble sugar concentrations of AM-inoculated 'Britewell' and 'Misty' blueberry plants increased by 15.71% and 12.21%, respectively, in comparison with non-mycorrhizal plants. Under the standard temperature, they improved by 20.63 % and 14.88 %, respectively. Proline absorption was higher in 'Britewell' leaves than in 'Misty' leaves (Liu, et al. [27]).

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While rice mycorrhizal showed higher levels of aquaporin (OsPIPs) expression than non-mycorrhizal rice. But more investigation is necessary to identify the underlying mechanisms (Liu, et al. [22]). AMF are recognized to be actual in enhancing host plants' tolerance to low-temperature stress by growing nutrient application and water immersion and inducing biochemical changes like the accumulation of proline, polyamines, antioxidants, and carbohydrates. Low temperatures seriously impair plants' ability to absorb water. There is a ton of information describing how trehalose accumulation changes in both mycorrhizal and non-mycorrhizal plants under stressful conditions, and it also shows how crucial trehalose is to AMF's improvement of plant stress tolerance (Liu, et al. [22]).

By regulating both their own aquaporin activity and the countenance of plant aquaporin genes, AMF may mend water delivery to the plant. This experiment's findings were consistent, when OsPIP1;1, OsPIP1;3, OsPIP2;1, and OsPIP2;5 expression was more highly expressed in AMF-colonized rice roots than in non-mycorrhizal rice roots. In addition, compared to non-mycorrhizal rice, low-temperature stress elevated the expression of the mycorrhizal rice genes OsPIP1;1, OsPIP1;3, OsPIP2;1, and OsPIP2;5 (Liu, et al. [22]). Therefore, trehalose's concentration in mycorrhizal roots and its biosynthesis may have a big impact on how the fungus responds to pressure. In order to comprehend the role of trehalose metabolism in mycorrhizal roots at low temperatures, the manifestation of significant genes involved in trehalose production was discovered. Rice that had been colonized with AMF had higher levels of the transcripts OsTPS1, OsTPS2, and OsTPP1 than rice that had not been colonized with AMF. In addition, in response to low-temperature stress, both mycorrhizal and non-mycorrhizal roots expressed OsTPS1, OsTPS2, and OsTPP1. Increased trehalose biosynthesis could lead to an increase in OsTPS1, OsTPS2, and OsTPP1 transcript levels, which would increase trehalose concentration (Liu, et al. [22]).

The concentration of trehalose in mycorrhizal rice roots was knowingly higher than that in non-mycorrhizal roots, which was compatible with the pattern of gene expression for trehalose production. When compared to the control, the H_2O_2 accumulation in the roots treated with AMF under low temperature was decreased by 42.44%.

H_2O_2 typically builds up on the cell walls of apoplast, and is rarely detectable in the cytoplasm or organelles of roots. Once more, AMF inoculation under low temperature significantly decreased NADPH oxidase activity involved in the production of H_2O_2. AMF inoculation significantly increased the P-type H+-ATPase, P-Ca^{2+}-ATPase, V-type H+-ATPase, total ATPase activity, ATP concentration, and plasma membrane protein content in the roots under low temperature (Liu, et al. [26]). Additionally, plasma membrane ATPase gene expression and ATP levels were increased by AMF inoculation.

By mediating AMF-mediated tolerance to chilling stress, these results imply that NADPH oxidase and ATPase may be essential in maintaining a reduced H_2O_2 accumulation in cucumber roots (Liu, et al. [22]). Root colonization, plant height, and biomass of AM all decreased as a result of the cold. N, P, K, Ca, Mg, Zn, NO3-N, and NH4+N concentrations in the shoot and N, P, K, Ca, Al, Zn, and Cu concentrations in the root were both decreased by low temperature stress. Under low temperatures, mycorrhizal plants had higher concentrations of N, P, K, and Cu in the shoot and N, P, Ca, and Zn in the root compared to non mycorrhizal plants. Low temperatures also increased NR activity, which was higher in mycorrhizal plants than in non-mycorrhizal plants. Hence AMF inoculation improves maize plants' nutritional status and enhances their capacity to function in cold climates (Liu, et al. [26]). Despite the fact that low temperatures impede the growth and physiological functions of AM plants, it has been shown that AMF applications have a positive influence on the host plants' progress and enlargement (Liu, et al. [26]).

Mycorrhizal plants showed enhanced water station than equivalent non-mycorrhizal plants regardless of temperature treatments, and significant differences in water conservation (WC) and water usage efficiency (WUE) were found. With the invasion of AM, the levels of chlorophyll a, b, and a + b increased. AM plants outperformed non-AM plants in terms of maximal fluorescence (Fm), maximum quantum efficiency of primary PSII photochemistry (Fv/Fm), and prospective photochemical efficiency (Fv/Fo), while primary fluorescence was lower in AM plants (Fo) (Zhu et al., 2010b). AM inoculation considerably increased the net photosynthetic rate (Pn) and transpiration rate (E) of maize plants. The distinction between mycorrhizal and non-mycorrhizal plants only reached statistical significance at 5°C. Mycorrhizal plants showed lower intercellular CO_2 concentrations (Ci) than non-mycorrhizal plants under stumpy temperature stress. The outcomes show that AM relationship improves maize plants' photosynthetic efficiency and hydration condition, enabling maize plants to withstand low temperature stress (Zhu, et al. [30]).

Under normal conditions, inoculation promoted cucumber development, but under cold stress, it only significantly enhanced root biomass. Mycorrhizal plants have more phosphorus than non-mycorrhizal plants, which proved that AMF delivered phosphorus to the host plant while it was under cold stress and at ambient temperatures. Therefore, even though the advantage of mycorrhiza was smaller than it would have been in ambient conditions, it nevertheless benefited the cold-stressed cucumber seedlings. As a result, at room temperature and to a lesser extent under cold stress, mycorrhiza strongly activated Pi transporter gene from the Pht1 gene family. In mycorrhizal plants that had undergone cold stress, the expression levels of the other three Pi transporters tested, which belonged to different families, were greatest. This suggests a complex interplay between mycorrhiza and cold stress on internal P cycling in cucumber plants (Ma, et al. [31]). In ERM, symbiotic P uptake and transfer have been linked to the high-affinity Pi transporter GintPT, but in IRM, its expression was considered to be linked to the reabsorption of P from the periarbuscular region and control of P release to the plant.

Alkaline phosphatase (ALP) genes, which have also been described in AMF, are associated with P metabolism. It is hypothesized that because ALP genes were shown to express under symbiotic conditions, notably in IRM, they may be involved in nutrient exchange with the host plant (Ma, et al. [31]). When the mycorrhizal pathway of Pi uptake is activated with AMF colonization, numerous H+ symporters of the Pht1 family are up- or downregulated, which influences these two Pi transporter pathways. Some Pht1 genes even only express in mycorrhizal roots, indicating that they are mycorrhiza-specific. The expression of the several Pht1 homologues maintains the equilibrium between the fungal and root epidermis absorption routes (Ma, et al. [31]). Expression of mycorrhiza-specific Pi transporters, such as MtPT4 from Medicago truncatula, are signs of a healthy relationship. Other plant Pi transporters are also in charge of internal Pi cycling in the plant and delivery to subcellular compartments and organelles, including those in the Pht2, mitochondrial phosphate transporter (MPT) and PHO1 gene families (Ma, et al. [31]). In contrast to the Pht1 gene family, little is known about how these additional Pi transporter genes respond to AMF (Ma, et al. [31]). In order to understand how AM and cold stress combine to affect cucumber development and P absorption, it is crucial to identify Pi transporters in the mycorrhizal route that have not yet been identified in this species (Ma, et al. [31]).

Low temperatures can cause a range of injuries in plants, including immediate mechanical constraints, activity changes of macromolecules, reduced osmotic potential in the protoplasm, increased hydrogen peroxide accumulation, and alternation of plasma membranes. Association with AMF has been also shown to enhance plant tolerance to low temperature despite the fact that root colonisation by AMF is often restrained at low temperatures below 15 ^{o}C. AMF were shown to alleviate the damage caused by low temperature stress by reducing membrane lipid peroxidation and increasing the amount of photosynthetic pigments, by the accumulation of osmotic adjustment compounds and by increasing photosynthesis (Ma, et al. [31]). Increased resistance of mycorrhizal cucumber seedlings to low temperature stress may depend on the maintenance of lower H_2O_2 accumulation in the roots of mycorrhizal plants. AMF were specifically suggested to play a key role in maximizing growth in cucumber by stimulating the synthesis of secondary phytomedicinal metabolites at low temperatures. Despite these results, the effects of cold stress on the P delivery of AMF to their host plants have not yet been completely investigated by research. In contrast to earlier findings that P uptake by ERM decreased at low temperatures, with an investigation of P supply to plants under cold stress found no differences in P uptake by the plants (Ma, et al. [31]).

Gene expression study revealed that low-temperature stress significantly upregulated the AMF aquaporins GintAQPF1 and GintAQPF2, with GintAQPF2 having a higher transcript level than GintAQPF1. Owing to the potential for AMF to control aquaporin expression and activity in both rice and the fungi, mycorrhizal rice was able to maintain a comparatively greater root relative water content (RWC) and root length at low temperatures, improving rice's ability to withstand cold. Mycorrhizal rice therefore seems to have a more effective water strategy than nonmycorrhizal rice . As expected, cold stress decreased chlorophyll content, net photosynthetic rate, and metrics related to photochemical quenching while increasing nonphotochemical quenching and sugar concentrations in leaves. Contrarily, AM boosted the cucumber seedlings' photosynthetic efficiency under both cold stress and at the control ambient temperature, having the opposite effect on the majority of the metrics that were examined. Stronger carbon sinks were a crucial factor in maintaining increased photosynthetic efficiency in mycorrhizal cucumber seedlings under cold stress, as we also noticed a significant reduction in the influence of cold stress on the sugar content of leaves (Ma, et al. [32]). Understanding how mycorrhiza influences numerous aspects of plant physiology at low temperatures is critical.

To examine the interplay between mycorrhiza and cold stress on cucumber photosynthesis, conducted an experiment in which mycorrhizal and non-mycorrhizal plants were subjected to cold stress in a full-factorial design. An analysis of several gas exchange and Chl fluorescence measurement-related parameters to estimate CO_2 assimilation and the effectiveness of the photosynthetic apparatus, respectively. Also, simultaneous tests of soluble sugar and sucrose concentrations were conducted to determine the metabolism of carbohydrates in cucumber leaves. Whether arbuscular mycorrhiza's advantageous effects on plant photosynthesis are maintained at low temperatures was our primary study question. Although mycorrhiza boosted both ambient and low temperatures equally, the net photosynthetic rate clearly reduced at low temperatures. Reduced CO_2 assimilation may be caused by stomatal restrictions or nonstomatal factors. Gs is the primary factor limiting CO_2 assimilation if gs and Ci are also dropping. On the other hand, if gs decreases while Ci does not change or increases, the decrease in CO_2 assimilation should be attributed to nonstomatal factors. This is consistent with past research showing that non-stomatal factors (Ma, et al. [32]). As cold stress prevented both mycorrhizal root colonization and mycorrhizal growth response, mycorrhizal plants' gs may have decreased under cold stress to the same level as non-mycorrhizal plants (Ma, et al. [32]).

Arbuscular Mycorrhizal Fungi and Plant Tolerance to Supra-Optimal Temperature Stress

It is widely known that AMF can alter the host response to temperature with altered carbon concentration in the below ground and above ground plant communities (Barrett, et al. [33]). The Glomus hoi hyphal length density was only five times higher at room temperature (about 24 °C) than it was when it was refrigerated (around 11 °C) (105 d after patch addition). In another trial, which was carried out 86 days after patch installation, there was no effect of patch compartment temperature on AMF hyphal development. These differences between tests are most likely the result of the substantial variety in the ERM produced by the different ways the organic patch was applied to duplicates. The amount of plant biomass and phosphate concentration varied depending on the temperature at which the hyphae of the two AMF species formed (Barrett, et al. [33]). When the AMF were grown at about 18 °C as opposed to about 11 °C, plant biomass increased, but it stayed the same at around 21 °C (Barrett, et al. [33]). It has been shown that the external hyphae of AMF can directly affect the related host plant growth in response to temperature fluctuations. The location and quantity of nutrients delivered, however, varied significantly between the two AMF that were compared. Global climate change is causing temperatures to rise, which has a huge effect on all biological relationships.

Ecosystems of plants and soil are suffering in this new condition, especially in semi-arid areas with limited water resources. The quantity and quality of fruit are affected negatively by rapidly rising temperatures for agricultural crops, prompting the creation of sustainable solutions to deal with these novel situations. Plants inoculated with AMF have better under heat stress because of their improved vigor, productivity, and fruit quality. In this study some ways of optimism and points to more environmentally friendly production methods that are suitable for the real scenario of global climate change have been achieved (Reva, et al. [34]). In addition to impairing photosynthesis, oxidative stress, and increasing the risk of drought, high temperatures can also have negative effects that are exacerbated in semi-arid and tropical locations. Heat stress (HS) events, which are the results of brief exposure to extremely high temperatures, are of special concern. Even if they only last a few hours, temperature peaks can have a major impact on agricultural yield (Reva, et al. [34]). We have not yet looked into the potential effects of heat stress on these alterations brought on by AM symbiosis (Cobral, et al. [14]).

Despite the recent awareness of the favorable benefits of endophytic microorganisms on plant survival, there is accumulating evidence that fungal and bacterial symbionts exhibit similar effects on a number of plant species by triggering distinct metabolic and physiological changes. Various compounds are produced by stressed microorganisms and released into the tissues of the host plant. These chemicals are subsequently incorporated into the plant's internal cell and cytosolic stress response pathways (Acuna-Rodriguez, et al. [24]). Numerous research has shown that the AMF symbiosis increases carbon use efficiency, but nothing is known about how it affects light use efficiency at high temperatures. For the most part, AM production increases plant biomass, which lessens leaf browning, and has superior HS, relative water content, and water usage efficiency. Due to improved plasma membrane preservation in AM plant cells, which protects vegetal tissues from HS, a surge in the production of osmotic-active compounds like proline, trehalose, and glomalin as well as antioxidative enzymes like superoxide dismutase, catalase, and ascorbate peroxidase occurs.

AM plants exposed to HS have equally markedly increased photosynthetic rates, stomatal conductivity, leaf transpiration, photosystem II efficiency, concentrations of chlorophyll (a and b), carotenoids, and photochemical potential. In addition to higher amounts of soluble sugars, higher rates of catabolism, gene expression, enhanced P uptake, assimilation, and utilization, and improved metabolism. AM plants being best able to endure HS and combat its negative effects since they are the richest in N (nitrate, ammonium, and amino acids). Additionally, new research has demonstrated how to lessen the negative effects of both the drought and HS. The most exciting questions for any producer remain, to our knowledge, unreported: how can AM symbiosis effect fruit yield and quality in extreme HS conditions? (Reva, et al. [34]).

Current research results clearly show that the application of the ultra-pure AM inoculant mycogel under agronomic conditions boosted plant resistance to severe HS in three agriculturally significant crops. Nearly all of the measures examined demonstrated beneficial benefits, and the treated plants outperformed the control plants in terms of fitness and shoot and root development. The majority of AM research that has been published to date for a variety of plants, soils, and environmental conditions is consistent with these findings, which included higher plant biomass and water content as well as fewer effects on AM plants from HS occurrences. Our research, however, also demonstrates that utilizing the proper AM inoculant increases fruit yield and quality, which are likely the two aspects that both growers and the plant (in terms of reproduction) value the most (in terms of income).

If we consider that AM encouraged all these benefits as a part of more considerate management of the soil, land, and ecosystem, we can conclude that AM inoculation in agriculture, with the proper inoculum source, is one of the keystones to building our next defense wall against climate change (Reva, et al. [34]). Mycorrhizal seedlings greatly outgrew non-mycorrhizal seedlings in terms of growth parameters at both optimum and high temperatures, but at low temperatures, the advantages were almost entirely lost. Mycorrhizal seedlings often showed noticeably higher root characteristics than non-mycorrhizal trifoliate orange seedlings, regardless of temperature (projected area, surface area, number of forks, and volume). Mycorrhizal colonization significantly increased the amount of soluble protein and the SOD and CAT activities at high temperatures. Only SOD activity increased at ideal temperatures, but only the amount of soluble protein decreased at low temperatures. It suggests that trifoliate orange seedlings had mycorrhizal decrease of temperature stress at high temperatures, but that it was obviously lowered at low temperatures (Wu, et al. [35]).

Non-AM lettuce produced at 35 °C had poorer thylakoid structure, a bigger buildup of starch granules, lower chlorophyll levels, and a worse net photosynthetic rate when compared to lettuce grown at 25 °C. The chlorophyll a, chlorophyll b, net photosynthetic rate, and transpiration rate of lettuce infected with *F. mosseae* increased by 4.5%, 4.5%, 7.7%, and 5.9%, respectively, in comparison to lettuce generated without the AM fungus when it was cultivated in high temperatures (Yan, et al. [36]). The chlorophyll fluorescence transient of a non-AM lettuce was demonstrated to decrease while dramatically growing under high temperatures. The maximum fluorescence (Fm) of non-AM lettuce reduced by 8.6% when the temperature was raised from 25 °C to 35 °C, but there were no discernible differences in Fm between AM lettuce grown at 35 °C and non-AM lettuce grown at 25 °C. Absorption energy flow, dissipation energy flux, and trapping energy flux per reaction center all rose as lettuce was grown at a high temperature, although quantum yield for electron transport (Eo) and performance index for energy conservation fell (Yan, et al. [36]). On the other hand, lettuce infected with *F. mosseae* in hot weather displayed the opposite effects. AM injection significantly boosted lettuce's endurance to high temperatures by enhancing photochemistry and shielding the PSII system from heat damage (Yan, et al. [36]).

Heat stress will decrease uptake even though research on the impact of heat stress on asparagus nutrient uptake has not been done. We looked into the effects of AMF, *G. intraradices*, on the development of asparagus, nutrient uptake, responses to heat stress, and antioxidative activities (*Asparagus officinalis* L.). With or without AMF inoculation, we raised asparagus plants in sand culture for 14 weeks at 20 to 25 °C. The plants were then exposed to control (20 °C/25 °C night/day), mild heating (30 °C/35 °C night/day), and severe heating (37 °C/42 °C night/day) temperatures in growth chambers. Plants were compared in terms of morphological and physiological growth parameters with and without AMF inoculation (Yeasmin, et al. [37]). The mycorrhizal symbiosis greatly boosted biomass production when compared to plants that had not received an AMF inoculation and negatively impacted plant reactions to heat stress. Plants grown without AMF inoculation showed a high incidence of leaf browning (80% to 100%) during heat stress, whereas mycorrhizal plants showed a low frequency of leaf browning.

The results showed that mycorrhizal fungal inoculated plants had greater levels of antioxidant enzymes such ascorbate peroxidase and superoxide dismutase. The 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity also responded more favorably in mycorrhizal plants than in control plants under each temperature range. By an increase in antioxidant activity, application of AMF enhanced plant nutrition and growth while minimizing the impacts of heat stress damage. The mycorrhizal association significantly improved asparagus' resistance to heat stress (Yeasmin, et al. [37]). Malondial-dehyde levels and relative membrane permeability were both decreased by AM symbiosis in leaves and roots under low temperature. Compared to nonmycorrhizal plants, mycorrhizal plants' roots had larger concentrations of proline and soluble sugars, whereas leaf proline content was lower. AM colonization increased the activity of superoxide dismutase, catalase, and peroxidase in the leaves and roots. The results show that by reducing membrane permeability and lipid peroxidation and increasing the accumulation of osmotic adjustment compounds and antioxidant enzyme activity, the AM fungus can shield maize plants from the damage caused by temperature stress. Hence, the development of arbuscular mycorrhiza significantly increased the maize plant's resistance to extreme temperatures, which increased the host biomass and promoted plant growth (Zhu, et al. [30]).

As a result, plants use osmotic adjustment and antioxidant enzyme activity to protect themselves from oxidative harm. The AM symbiosis can alter a plant's physiology to aid it in overcoming obstacles as they come up. When there is a temperature stress, it is unknown how the AM symbiosis affects the host plants' reactive oxygen metabolism. Understanding how temperature-stressed plants' lipid peroxidation and antioxidant enzyme activity are impacted by AM fungus is vital. Shoot dry weight, shoot fresh weight, root dry weight and AM colonization increased with increase in temperature up to 25 °C and decreased in 30 and 35 °C (Zhu, et al. [30]). Root colonization by AM fungus typically decreases when temperatures rise beyond 30 °C and temperatures above 40 °C are always lethal to AM fungi. Since the MDA content of mycorrhizal plants remained lower than that of nonmycorrhizal plants, it is obvious that the AM fungus' presence may reduce the peroxidation of membrane lipids (Zhu, et al. [30]).

Between mycorrhizal and non-mycorrhizal plants, there are notable differences in the relative permeability of the leaf and root membranes to high- and low-temperature stresses (Zhu, et al. [30]). Under low-temperature stress, AM colonization, plant height, and biomass all experienced a sharp decline. Compared to non-AM plants, AM plants displayed increased levels of total N, glutamate oxaloacetate transaminase, and glutamate pyruvate transaminase activity. The net photosynthetic rate (Pn) of AM plants was larger than that of non-AM plants, despite the fact that low temperatures decreased the Pn. AM plants had higher levels of root sucrose and fructose, leaf soluble sugars, reducing sugars, and amylase and sucrose phosphate synthase activity at low temperatures than non-AM plants did. Moreover, compared to non-mycorrhizal plants, mycorrhizal plants have decreased membrane relative permeability (Zhu, et al. [38]). Moreover, AM colonization lowered the root C: N ratio while raising it in the leaves of maize plants under low temperature stress. These results suggested that the C and N metabolism of maize plants varied between the ambient and low temperature regimes. The C metabolic enzymes were altered by the AM symbiosis, resulting in an accumulation of soluble sugars that may have improved maize plants' ability to withstand low temperatures and increase Pn production (Zhu, et al. [38]). An increase in the amino acids level in the root and shoot is experienced due to mycorrhizal treatments (Zhu, et al., [39]).

Role of Arbuscular Mycorrhizal Fungi in Plant Tolerance to Supra-Optimal Temperature Stress

It is challenging to directly research AMF responses to temperature since these fungi are obligate biotrophs and cannot be cultivated separately. The fungus is totally dependent on their host plant for their carbon supply. As a result, the host plant's contemporaneous response, which might change how carbon is dispersed underground, will also have an indirect impact on how the AMF responds physiologically to a change in temperature. The fungus symbiont's growth will be impacted by the rise in temperature (Barrett, et al. [33]). The sensitivity of AMF to temperature changes may have a significant impact on our comprehension of the role of the AMF symbiosis in plant nutrition, soil aggregation and exploitation, and C-cycling in regions of the world where soil temperatures below 20oC or above 40oC are typical during the growing season. Further research examining the genetic and plastic variation among these AMF is undoubtedly needed in order to fully understand the extent to which temperature may be limiting these AMF 's growth and function in diverse settings. Photosystem II is the component of the photosynthetic apparatus that is most susceptible to damage at high temperatures. This is because heat-induced changes to the fluidity of the thylakoid membrane hinder electron transport via PSII.

In a trial using heat-stressed maize plants, AMF inoculations reduced the harm to the PSII response center (Cobral, et al. [14]). The favorable plant development responses to AMF colonization are influenced by temperature, and under high temperature stress, they may even be compromised in comparison to nonmycorrhizal plants. The advantages of early root colonization in the spring, however, may help plants like grains that are normally colonized later in the growing season (Grey, [4]). To the best of our knowledge, there hasn't been any investigation into the relationship between AMF and high temperature on a variety of crop species. AMF species have been shown to vary in symbiotic efficacy, and different combinations of plant species, genotypes, and isolates may behave differently under stress. So an understanding of how plants and fungi interact is essential for the appropriate application of AMF in specific situations. The right combination of AMF species and the host plant may be able to reduce stress to some extent or completely (Hajiboland, et al. [21]).

Mechanism of AMF Driven Plant Tolerance to Supra-Optimal Temperature Stress

As a result of soil warming brought on by climate change, soils' capacity to retain carbon will probably shift due to elevated temperature. The final role that AMF play in this will depend on modifications in the structure of the AMF network and the transit of labile photosynthates from plants via the fungus. The investment and expansion of the extraradical AMF hyphal network, the rate of transfer and respiration of plant photosynthates by AMF, and the amount of carbon respired per unit of hyphal length are all affected by an increase in soil temperature, as it is mentioned (Hawkes, et al. [8]). So, it is assumed that AMF would store less carbon as the temperature rises, AMF would release plant carbon more quickly into the atmosphere through respiration. Depending on changes to the environmental conditions that were controlled in this study, such as light levels and soil moisture, the direction of this finding may change. Knowing the plant-independent reactions of AMF to changed climate conditions would surely be necessary to estimate the function of AMF in a warmer world (Hawkes, et al. [8]). No matter how the changing structure of the AM fungal networks influenced carbon throughput, soil temperature had an effect. Soil respiration peaked at 13C, two hours earlier in warmed soils than in ambient soils. Cooled soils considerably slowed and delayed the transport of carbon through the system, with the peak of 13C in soil respiration beginning 20 or more hours following warmed and ambient soils. The pulse either did not reach the AM compartment in the chilled or ambient pots during this monitoring period, or perhaps a tiny peak was missed by our sampling intervals (Hawkes, et al. [8]).

The development and maintenance of AMF symbiosis need intense coordination between the two parties. Based on a closely regulated chemical conversation between signaling molecules, strigolactones have become important cues in this coordination (Liu, et al. [15]). According to a recent study, the host plant can increase strigolactone production to attract AMF when nutrients are scarce. This aids in promoting the proliferation of fungus and the development of symbiotic partnerships. Strigolactones play a crucial role in the symbiotic interaction between the two species and act as the host's signal, according to research on the mechanism by which AMF decreases salt stress. Experiments using abiotic stress demonstrated strigolactone's crucial role in the AMF symbiont. However, there are currently no studies available on the role of strigolactone at low (Liu, et al. [15]). Strigolactones, a new class of plant hormones, are secreted into the soil where they act as root parasite plant germination stimulants as well as critical host-detection signals for AMF, encouraging their metabolism and hyphal branching (Liu, et al. [15]).

It has been suggested that mycorrhizal plants create more strigolactone while under stress environments, which is likely to promote the growth and symbiosis of AM fungus and relieve the stress (Liu, et al. [15]). Total chlorophyll, soluble sugar, and starch concentrations were analyzed, and it was found that under low-temperature stress, mycorrhizal rice had higher concentrations of these compounds than non-mycorrhizal rice. According to this research, AMF increases host photosynthesis and fortifies the C pool for respiration. Both AMF suppression and increased temperature alone reduced the community's temporal stability, but the addition of N had no impact. The main causes of community temporal stability were increased temperature, N addition, and AMF suppression that had an impact on the stability of the dominating species. AMF suppression, high temperature, which altered AMF richness connected to community asynchrony, and N addition, which affected mycorrhizal colonization, were all significant drivers, albeit to a lower extent. AMF suppression, N addition, and high temperatures in conjunction with AMF suppression all resulted in a reduction in the number of plant species, but there was no evidence linking these modifications to changes in community temporal stability (Yang et al., 2020).

Structural equation modeling (SEM) further revealed that elevated temperature, N addition, and AMF suppression controlled community temporal stability by influencing both the temporal mean and variation in community productivity. The stability of temperate meadows may be significantly impacted by changes in the global environment, according to our findings, which also highlight the significance of belowground AMF status in plant communities' reactions to temporal stability of environmental change (Yang, et al. 2020). By removing the constraint of cold temperatures, elevated temperature encourages synchronous plant growth in alpine grasslands. This decreases community temporal stability, suggesting that species asynchrony may be important in determining community temporal stability under elevated temperature. Hence, a rise in temperature that impacts species asynchrony, dominant species stability, and functional productivity of communities may also alter community temporal stability (Yang, et al. 2020). While the addition of fungicide reduced spore density, hyphal length density, AMF richness, mycorrhizal colonization, and AMF concentrations, the addition of N reduced AMF richness and mycorrhizal colonization. Temperature increase led to higher spore density but lower AMF richness (Yang, et al. 2020).

The good effect of the higher temperature on spore density, may likely due to enhanced root C allocation for AMF sporulation, or AMF may have chosen this way as a mechanism of sporulation in response to environmental stress (Yang, et al. 2020). Under the circumstances of natural vegetation regeneration, AMF diversity increased in response to increasing temperatures and precipitation. When temperatures exceeded 20 °C and there was a lot of precipitation, shrubland and mature forest had higher AMF richness than agriculture did. As a result, AMF were flexible in terms of variety to climatic changes and the recovery of the vegetation. The AMF communities' compositions were influenced by temperature and vegetation type (Xiao, et al. [40]). The relative abundances of AMF groupings such as Gigaspora, Glomus, and Septoglomus increased at temperatures higher than 18 °C. The relative abundances of the AMF genus Glomus and the diazotroph genus Bradyrhizobium were higher in cropland compared to farmland, shrubland, and mature forests, while the relative abundances of the AMF genus Septoglomus increased.

With increasing temperatures and precipitation, network complexity between AMF species grew (Xiao, et al. [40]). These results suggest that high hydrothermal zones enhance the interactions between AMF spp, especially the Glomus thereby protecting against nutritional degradation. Management to increase AMF abundance during vegetation recovery in high climatic levels may encourage nitrogen uptake and transport (Xiao, et al. [40]). It was vital to comprehend how the origin of the plant or the inoculum in connection to the temperature caused symbiotic activity. Particularly, it became clear that the plant struggled to adapt to its new surroundings when the temperature and inoculum were sympatric but allopatric to it. Further research showed that the symbiotic function was inversely associated to fungal diversity in high temperature conditions. These findings demonstrate the significance of taking into account both biotic and abiotic interactions when predicting how symbionts will react to environmental change on a global scale and imply that local adaptation is a key driver in the emergence of novel plant, inoculum, and temperature combinations (Yang, et al. 2017).

Arbuscular Mycorrhizal Fungi Interacted with Nutrients and Plant Tolerance to Temperature Stress

Internal colonization typically increases between 10 °C and 30 °C in temperature, and it is frequently documented that colonization is suppressed below 15 °C. Moreover, only at temperatures of 15 °C and higher did AMF colonization result in improved plant P arrest when related to non-AM plants. Similar to this, showed that at 17 °C but not at 12 °C, AMF colonization results in higher shoot N content (Barrett, et al. [33]). According to numerous additional research, AM plants produce worse than non-AM plants at temperatures under 15 °C but superior at temperatures over 15 °C. This shows that the advantages of exploiting an AMF to a host plant depend on temperature. Changes in the host's carbon allocation or a direct physiologic response by the fungus may be to blame for such temperature-driven alterations in mycorrhizal benefit (Barrett, et al. [33]). The growth of the extra radical mycelium (ERM) gathered when warmed by 6oC while protecting the crowd plant at an ambient temperature of 12/23 °C (night/day), in contrast it is observed that only temporary effects on the growth of the ERM from warming the ERM by 8 °C while the host plant stayed at about 12 °C. The extended roots of the specific host plant, they observe, suggest that the direct impacts of temperature on AMF advance can potentially take unintended effects on host plant growth (Barrett, et al. [33]). Because AMF are more temperature delicate than roots, it would be expected that low soil temperature would have a substantial impact on the fungal symbiont's ability to gather nutrients (Barrett, et al. [33]). Even at temperatures of 10-12 °C, *G. hoi* was found to grow and transfer nutrients to its host plant (Barrett, et al. [9]).

Temperatures higher than 18oC and lower than 30 °C were necessary for the formation and development of AMFs concluded that AMF growth was substantially more penetrating to cold temperatures than root growth, which was another finding. However, the temperature treatments utilized would also have a direct impact on root growth; hence, it is conceivable that the reaction of the roots to temperature could devour an indirect effect on the development of AMF (Barrett, et al. [33]). There was no discernible difference between the two temperatures (11 °C or 24 °C) in terms of plant biomass or total N content. Data demonstrates that growing the AMF at 18 °C was more advantageous for host plant development and P nutrition than growing the AMF at higher temperatures (>21 °C). Further proof for this can be found in the associations found in plants that have been colonized by *G. hoi* AMF (Barrett, et al. [33]). Inoculation of AMF to barley increased yield in increasing soil temperature (Grey, [4]). Based on the proportion of mycorrhizal roots and the number of mycorrhizal plants, barley genotypes were distinguished in a warm soil. From the standpoint of showing germplasm for mycorrhizae, however, a larger number of plants can be judged for the presence of a characteristic arbuscule than for the percentage of mycorrhizal roots in a specific time period (Grey, [4]).

The outcome of the mycorrhizal symbiosis as a whole is probably a combination of these reactions, even if the plant and fungal components respond to temperature in distinct ways. In other words, optimal growth would probably take place in a temperature range where each component benefits (Gavito, et al. [5]). P uptake by extraradical AMF hyphae was investigated autonomously from root P uptake in a root exclusion compartment. Intraradical colonization advanced successfully at both soil temperatures, and from 10 to 15 °C, it virtually duplicated. In the root exclusion compartment, extraradical mycelium only grew at 15 °C, making this the only temperature at which hyphal P absorption could be examined. Rising the host plants at two distinct atmospheric CO_2 levels had minimal impact despite the large differences in hyphal P absorption between inoculum types. No discernible connections between soil temperature and CO_2 were found. Knowing what happens to newly fixed carbon in soil is crucial for expecting potential carbon sequestration in terrestrial ecosystems. Latest research employing the isotope 13C has demonstrated that recent photosynthesis over the past few days dominates in regulating the rate of soil respiration. Both naturally occurring 13C and pulse labeling were used in these investigations. The interaction between temperature and the availability of photosynthetic substrate may have an impact on belowground respiration (Hawkes, et al. [8]).

The proportion of colonized roots and extra radical mycelium length were definitely interrelated with temperature while in symbiosis with Plantago. lanceolata, but fluctuations in root length colonization were a purpose of plant biomass. In the roots of Holcus lanatus, there was very little colonization and no evident effect of temperature. In the fungal partition, increased throughout time and peaked for *Glomus mosseae*. Warming the fungal compartment considerably improved the length of extraradical mycelium while having no effect on root length colonization. Yet, it is dramatically increased the amount of roots in the plant compartment, showing that the fungus controls the dynamics of symbiotic growth. From the perspective of global climate change, the effects of these temperature responses on carbon dynamics models (Heinemeyer, et al. [3]). Poorly, very little is understood about how variations in soil temperature impact on and how newly secure carbon from plants transfers to soils or how carbon is dispersed among plants and soil infectious groups.

Role of Arbuscular Mycorrhizal Fungi Interacted with Nutrients and Plant Tolerance to Temperature Stress

Temperature, developmental stage, and plant species interacted considerably with one another in terms of their effects on root density. Ornithopus compressus had the shortest root system compared to the other species, and it responded less to the temperature stress. The AMF was unable to colonize maize at 10 °C, however root growth was unaffected. The Lolium rigidum. reached its highest root density after 42 days at 20 °C. Only maize had a value for the average of the three growth phases that was considerably lower at 10 °C than at other soil temperatures. This indicator tracks how temperature affects the entire plant's morphology, specifically how the roots respond in comparison to the shoots (Carvalho, et al. [11]). It is still acceptable a more precise measurement of the host and fungal development as well as a preliminary evaluation of the role of C nutrition in AMF's reaction to temperature changes. For instance, the partners' different temperature optimum differences and the absence of any relationship among fungal progression and root development provided compelling evidence for the direct effects of temperature on AMF development. The temperature ranges from 6–30 °C were taken to produce three isolates of AMF, and growth curves and measurements of C uptake transfer translocation.

A number of experiments were conducted utilizing the model fungus isolate *Glomus intraradices* to examine the effects of temperature on lipid body and 33P mobility, as well as the effects of acclimation and incubation time (Gavito, et al. [6]). Although in certain instances obviously independent root and AMF growth responses, the absorption and translocation of 13C were also influenced within the temperature range tested. As a result, both direct and indirect effects of temperature were seen on the proliferation of AMF. Cold temperatures (18 °C) prevented the fungus from absorbing C from the roots and, to a lesser extent, translocating it. The absorption and transport of 33P by fungal hyphae, however, was equivalent at 10 and 25 °C. We come to the conclusion that temperatures between 6 and 18 °C restrict AMF growth, and that C transport to the fungus plays a role in this reaction. According to the aforementioned findings, climate change's temperature component may have a bigger influence on AMF growth and operation in the understudied system than CO_2 component (Gavito, et al. [6]). Mycorrhizal fungus has a substantial impact on how below-ground terrestrial systems adapt to environmental change, which has the potential to disrupt the carbon balance. Most land plants are believed to have arbuscular mycorrhizal (AM) fungi in their roots, which serve as a sink for 3-20% of the photosynthate produced by the host plant. They are also widely dispersed in soil, where the top 10 cm of soil worldwide has an estimated 1.4 Pg of fungal biomass. Up to 15% of the soil's organic carbon content and 20–30% of its microbial population are found in extraradical mycelium, a huge network of hyphae produced by the AM fungus (Hawkes, et al. [8]).

In pepper roots, temperature and AM fungal treatments had an effect on overall colonization, arbuscule and vesicle generation. With roots colonized by *G. intraradices* and the Glomus combination, these parameters had lower values at high temperatures than they did at low temperatures. These outcomes support a recent study discovered a negative association between increasing air temperature and the colonization of Acacia farnesiana roots by *G. fasciculatum* and *G. geosporum*. On the other hand, we found that Glomus AZ112, an isolate from a warmer area than the *G. intraradices* isolate, acted to be insignificantly promoted by high temperatures for overall colonization and arbuscule formation in roots. We didn't find any vesicles on the roots of the Glomus AZ112 isolate at any temperature. All of the non-AM control plants kept their mycorrhizal ties (Martin and Stutz, [41]). The capacity of pepper to absorb P can be enhanced by mycorrhizal fungus. Hence, we gave twice as much P manure to all non-AM plants in an effort to uncover non-P related AM fungal influences on plant development in order to account for a predicted AM boost of plant P uptake. Despite this endeavor at reparation, the levels of P in pepper leaves were affected by temperature and AM fungal treatments. Leaf P levels of mycorrhizal plants were almost 1.4 times higher than those of non-AM plants in conditions of moderate temperature, but were 20% lower in circumstances of high temperature. Non-AM control plants showed equal leaf P values in high and modest temperatures (Martin and Stutz, [41]).

Crop failure can result from changes in precipitation, and the need for water might rise as a result of warmer temperatures. Maize inoculated with AM fungus offered higher levels of antioxidants, vitamins, and minerals, as well as better plant development, revenue, and nutrient application, to improve food quality parameters. Thus AM fungi are recognized as a significant biotechnology tool in agricultural output. In order to diminish the consequences of climate change, it is important to preserve AM fungal populations in the soil, and this review highlights their crucial role in the sustainable production of maize (Silvia, et al. [42]). However, they will be less than the harms affected by climate change. The costs and benefits of mitigation technology may not be cheap or straightforward. The anticipated effects of climate change will be particularly detrimental in low- and middle-income countries, where millions of people depend on agriculture and are at danger of food insecurity. The impact on global food security, which will be connected to food supply and food quality, food access and utilization, and the stability of food security, will result in decreased per capita calorie availability, childhood malnutrition, and child mortality (Silvia, et al. [42]). Certain crops' nutritional properties may be influenced by climate change. The concentrations of minerals in different crops (including wheat, rice, and soybeans) were up to 8% lower when carbon dioxide (CO_2) levels were raised. According to studies on yields (especially those of wheat, maize, rice, and soybeans) under various climate change scenarios, these yields may gradually decline significantly (Silvia, et al. [42]).

Mechanism of Arbuscular Mycorrhizal Fungi Interacted with Nutrients and Plant Tolerance to Temperature Stress

About to 15% of the soil's organic carbon pool and 20–30% of the soil microbial population come from extraradical mycelium, a huge network of hyphae created by the AMF outside of roots. AMF can hold recently adjusted photosynthetic carbon from lipids for at least 32 days, despite the fact that fine hyphae have rapid rates of turnover and some carbon flows through them quickly. Long-term fungal carbon pools are also likely given that AM fungal tissues contain refractory materials as chitin and glomalin. In order to predict future soil carbon stocks and fluxes, it is crucial to comprehend how AM fungi will respond to environmental change (Hawkes, et al. [8]). A plant's size, photosynthetic rates, or allocation below the ground can all indirectly affect mycorrhizal fungus. For instance, a new meta-analysis of 24 research discovered that rising CO_2 amplified extraradical hyphae and the percentage of root length colonized in AM fungus in a manner that was proportional to the plant response. Also, it is possible to have a direct effect on the fungus itself (Hawkes, et al. [8]). Even though different AM fungus species had varying ideal temperature ranges, higher temperatures (between 24 and 30 °C) were typically associated with improved root colonization, more extraradical mycelium, and better sugar uptake. Soil warming directly influenced the development of the extraradical hyphal network. Since that the root does not provide protection, the extraradical mycelium may be more profound to temperature throughout the development phase than the intraradical mycelium.

It is crucial to measure AM fungus's direct response to climatic change apart from plant roots in order to comprehend the function that fungi will play in the carbon cycle in upcoming climates (Hawkes, et al. [8]). Symbiotic microbes, in general, and AMF, in specific, have been found to offer favorable methods for stress reduction that are mindful of the environment and soil homeostasis. Due to the consequences of global warming, heat stress has recently become a significant area of distress for agricultural production. In-depth research is being conducted all around the world to develop strategies for coping with abiotic challenges, including the development of heat- and drought-tolerant cultivars, modifications to crop cycles, and resource management strategies (Maya, et al. [13]). Despite the fact that most of these processes are laborious and expensive, recent research suggests that AMF may help crops cope with abiotic problems. AMF fungi have caught the attention of crop scientists due to their host plants' numerous benefits.

The AMF symbiosis, which is formed between the roots of most terrestrial plants and fungi from the *phylum Glomeromycota*, has a number of benefits for the host plant that reduce environmental stress, including improved water and mineral nutrition absorption and tolerance to different environmental stress factors (Maya, et al. [13]). Yet, some investigations have discovered that arbuscular mycorrhizal fungus has an impact on rhizospheric soil aggregation and microbial community structure. Moreover, edaphic elements like soil composition, moisture, temperature, pH, Cation Exchange Capacity (CEC), and anthropogenic stresses affect how mycorrhizal associations grow and function. The relationship between temperature and the mycorrhizal symbiosis of millet shows that how it impacts soil aggregation is poorly understood. It has been reported that a change in temperature can lead to an increase in the internal and exterior structures of AMFs (Ndeko, et al. [43]). The current study investigated the effects of temperature stress and AMF treatment on mycorrhizal fungus colonization and millet line rhizospheric soil aggregation. The research showed that among millet lines, the root colonization rate with AMF was moderate and equivalent.

After receiving the AMF inoculation, *Funneliformis mosseae* exhibited the highest percentage of root colonization. Several millet genotypes responded differently to the inoculations with *R. aggregatus* and *F. mosseae*. However, the AMF inoculation had no impact on the rhizospheric soil aggregation of the lines (MAS/RB). According to this study, temperature stress severely affected all growth and physiological markers and greatly slowed down mycorrhizal colonization and rhizospheric soil accumulation (Ndeko, et al. [43]). AMF immunization had minimal effect on plant growth when there was no stress. AMF did, however, significantly affect plant growth, mycorrhizal colonization, and millet line mycorrhizal growth response when visible to high temperatures. In terms of millet growth, this study showed that various millet lines react to AMF colonization in various ways. L132 and L220 kept their soil accumulation levels in the control, *R. aggregatus*, and *F. mosseae* treatments due to their mycorrhizal colonization rate and a positive mycorrhizal growth response to high-temperature treatment compared to other lines.

High temperature stress is one of the most significant and harmful stress among the several abiotic stresses. High temperatures are anticipated to worsen in the coming years, with long-lasting effects. This stress negatively impacts the morphological, physiological, and biochemical growth of the plant, which eventually lowers plant output. High temperatures over a certain period of time has an adverse effect on plant growth, metabolism, and general production. Plants must be tolerant to all these negative effects of high temperature due to the frequent seasonal swings, especially in tropical areas. The temperature range that controls plant species affects plant growth, development, and metabolism. Each plant species has a variety of maximum, minimum, and ideal temperature tolerance. Practically speaking, it is well recognized that plants are more harmed by short-term temperature stress than by long-term stress. The midsummer temperature changes are believed to have the most detrimental effects on plant development and photosynthesis. Crop growth and development are the primary factors of how changing environmental circumstances affect crops. All of the major grain crops are affected by climate change and rising temperatures in terms of their development and growth (Mathur, et al. [44]).

The hostile effects of rising high temperatures on plant growth (HT) are currently shown in plants. Previous research has shown that AMF have a protective effect under stressful conditions, especially affecting physiological restrictions. To ascertain the protective role of AMF under high-temperature stress, physiological traits with typical phospholipid fatty acids (PLFA) of soil microbial communities, including AMF, have not been investigated. In this study, we investigate how below-ground traits and photosynthetic properties are affected by high-temperature stress in maize plants with and without AMF. Among the photosynthetic traits that improved in AMF + HT plants but decreased in HT-exposed plants were quantum yields of PSI and PSII, electron transport, and fractions of open reaction centers. Photosynthesis is one of the processes that plants are most susceptible to heat. The photosynthetic process starts to suffer as the temperature reaches 38 °C or higher. Both light-dependent processes involving the photosystem II (PSII) and dark-dependent reactions involving the rubisco activase contain thermo-sensitive components of the photosynthetic apparatus. Heat stress lowers oxygen evolution by impairing the function of the oxidizing side of PS II as well as photosynthetic electron transport (Mathur, et al. [45]).

AMF + HT plants displayed significantly higher levels of AM-signature 16:1ω5cis neutral lipid fatty acid (NLFA), spore density in the soil, and root settlement with lower levels of lipid peroxidation than non-mycorrhizal HT plants. Improved plants were more efficient at photosynthesizing when heated because they had more living biomass that was alive. This work contributes to the empathetic of how AM-mediated plants may endure high temperatures while sustaining the firmness of their photosynthetic system. We may be able to better understand how stress affects plants and the rhizosphere thanks to this work's innovative integration of above- and below-ground elements (Mathur, et al. [45]). Research examining the role of AMF on the physiological characteristics of plants is frequently used to lessen the effects of high temperatures on plants. Yet, the microbial populations in the soil play an important part in controlling plant performance and may provide key insights into AMF-mediated stress relief.

The lipid reporting of signature markers, such as 16:1ω5cis phospholipid fatty acid (PLFA) and neutral lipid fatty acids (NLFA) in soil and roots, is used as a stress indicator and offers a detailed description of the alteration in the microbial community as a result of the stress brought on by increased temperature (Mathur, et al. [45]). PLFA stress markers that elucidate temperature impacts include cyclopropyl to monoenoic fatty acid ratios and gram-positive to gram-negative bacteria ratios. The trans/cis stress ratio and the Gram-negative stress ratio are two physiological stress indicators. The gram-positive to gram-negative ratio is an indicator of energy restriction (Mathur, et al. [45]). The presence of active hyphal biomass in AM-enriched plants contributes to the plants' increased capacity to absorb water and nutrients, improves photosynthetic efficiency, and shields the plants from oxidative damage when exposed to high temperatures. To test if plants exposed to high temperatures displayed any changes, AMF growth (root colonization, spore density, and lipid biomarkers), plant photosynthetic metrics, and variations in soil PLFA bacteria populations were also evaluated (Mathur, et al. [45]).

We provide data to support the hypothesis that high photosynthetic capacity can be promoted by arbuscular mycorrhizal fungi symbiosis (AMF enrichment) while protecting the photosynthetic apparatus. PSI and PSII were not adversely affected by high-temperature stress thanks to the enrichment of arbuscular mycorrhizal fungus. AMF + HT plants showed recovery for maize plants exposed to high temperatures for all of the parameters looked at. According to the physiological parameters, the abundance of NLFA in AMF + HT over control and high temperature exposed plants alone shows the arbuscular mycorrhizal mediated stress mitigation approach to defend itself and live under high temperature exposure (apparent from fluorescence results). Also, according to our view, one of the possible indicators that arbuscular mycorrhizal fungus helped the plants reduce high-temperature stress could be higher levels of NLFA and a higher ratio of Gram-positive to Gram-negative bacteria in stressed plants. Taking everything into account, our research demonstrates that AMF help plants maintain PSI and PSII stability, mitigate the negative impacts of high temperature disclosure, and enhance photosynthesis, soil quality, and crop growth, all of which lead to a rise in yield. In order to better understand how plants reply to stress, this work is the first to link PLFA (belowground) features with physiological plant qualities. factors delivering unique insight into plant improvement under stress situations (Mathur, et al. [45]).

Mycorrhizal symbiosis dramatically boosted biomass output and HS+ answers in plants when related to controls. Control plants displayed a significant rate of leaf burning (80-100%), in contrast to mycorrhizal plants, which under HS+ conditions displayed the slightest rate of leaf burning. In the mycorrhizal plants, there was a rise in the antioxidative enzymes superoxide dismutase and ascorbate peroxidase, ascorbic acid content, and polyphenol content. The 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity also responded more favorably in mycorrhizal plants than in control plants at each temperature setting. The results demonstrate that AM fungal colonization decreased heat stress damage in cyclamen plants by enhancing antioxidative activity, and that mycorrhizal symbiosis considerably improved temperature stress tolerance, which promoted plant growth and increased the host biomass under heat stress (Maya, et al. [13]). A temperature increase that surpasses a threshold and lasts long enough to permanently impair plant growth and development is referred to as heat stress.

Heat stress is typically understood as a momentary increase of temperatue between 10 and 15°C over the ambient temperature. However, effects could be complicated depending on the magnitude, persistence, and rate of temperature increase. The lethal ROS that are generated in plant cells as a result of heat stress are one of the primary reasons hurting plants (Maya, et al. [13]). The increased activity of enzymatic antioxidants and higher production of nonenzymatic antioxidant molecules imply that the AM symbiosis can protect plants from oxidative stress, lessen ROS damage, and improve their capacity to endure heat stress during plant growth. To completely understand how AM contributes to the production of antioxidants and the metabolism of ROS during heat stress, more research is necessary. It's possible that plants' broad defensive systems in reaction to heat stress are what's causing some antioxidants to be more active than usual. Nonetheless, the inclusive enhancement in plant progress and tolerance to heat stress in AM plants point to potential advantages of AM fungal inoculation for the production of Cyclamen under difficult climatic conditions (Maya, et al. [13]).

Second, while the four millet lines were growing in two separate growth chambers, they received two distinct temperature treatments: a control treatment at 32/28 °C for daytime temperatures and a temperature stress treatment at 37/32 °C. Several physiological, mycorrhizal, and soil parameters were assessed together with plant growth and mycorrhization rate. The findings demonstrated that millet lines' mycorrhization rates were moderate and did not significantly differ from one another.

Rhizophagus aggregatus (22.79%) and the control (9.79%) had less root colonization than *Funneliformis mosseae* (31.39%). For all of the investigated lines, the temperature stress decreased soil aggregation, shoot and root biomass, and mycorrhizal colonization rate. During the control and high-temperature treatments, L220 and L132 had higher MC rates and MGR than the other lines (Ndeko, et al., [43]). The MGR significantly outperformed the control when exposed to temperature stress conditions. Inoculation with *R. aggregatus* and *F. mosseae* improved chlorophyll content, root dry weight, and shoot dry weight in comparison to non-inoculated plants. AMF inoculation, particularly with *F. mosseae*, positively impacted millet lines' tolerance to temperature stress. Because AMF in this study demonstrates how these four millet lines significantly respond to temperature stress. As a result, AMF is essential in assisting crops in Sub-Saharan Africa to adapt to climatic changes (Ndeko, et al. [43]).

Plant morphological, physiological, and biochemical processes are negatively impacted by high temperatures, which ultimately lowers plant output (Jumrani et al. [46]). AMF may play a crucial role in deciding how the plant community will respond to rising soil temperatures brought on by global climate change. According to increased host plant provision to AMF, a lack of evidence for temperature adaptation by AMF, and variable host responses to AMF. High temperature stress affects plants globally, and elevated soil temperatures have been noted in alpine, tropical, and desert habitats burned-out forested areas. Given that it is estimated that global air temperatures will rise by around 3 °C over the next century, it is vital to appreciate how plants answer to rising soil temperatures. Plant roots especially vary in shape, pace of development, and longevity in response to elevated soil temperatures. Reduced root surface area, soil volume explored, and shorter root lifespan may be the results of these alterations, which may lead to decreased root function. Arbuscular mycorrhizae can reduce the host plant's vulnerability to environmental stress because they create symbiotic associations between the roots of most terrestrial plants and fungus from the *phylum Glomeromycota*.

AMF could increase host plants' access to water and nutrients by extending the growth of extraradical hyphae (ERH) into soils where high temperatures prevent root growth, thereby expanding the plants' available habitat. This would be the case if fungi are more tolerant of heat than plant roots, as has been proposed in agricultural systems. However, the advantages to the host plant of discovering new soil habitats may offset the carbon cost of increased fungal respiration at high temperatures. In reality, as temperatures rise, plants allocate more carbon to AMF. The host plant's cost-benefit ratio in response to AMF is dynamic and is influenced by the plant's life stage, species, fungus species and abiotic stresses (Bunn, et al. [47]). In light of these findings, the major objective of this work was to look at how the mycorrhizal symbiosis was generally affected by high soil temperatures, taking into account how both plant and fungus symbionts responded to the heat. Increasing soil temperatures increases extraradical hyphae but decreased the root length (Bunn, et al. [47]).

It is observed that AMF amelioration can support high photosynthetic capacity and guard against harm to photosynthetic equipment when showing to high temperatures. The results of this investigation may be helpful for dangerously calculating the potential role of AMF in attenuating the harmful properties of high-temperature stress. In the framework of sustainable agriculture, farmers are drawn to helpful microbes like AM fungus. This data suggested that AMF inoculation might be effective in enhancing plant development under difficult environmental conditions. By raising the amount of chlorophyll, the rate of photosynthetic activity, the stomatal conductance, the WUE, the linear electron transfer, and the seed production in soybean plants, the current study indicates the effect of AMF in enhancing their capacity to endure high temperatures (Jumrani et al. [46]).

While AMF had no result on the faces of the plants that were assessed, the biomass of the facultative thermal plants *Agrostis scabra* and *Mimulus guttatus* decreased by 50% in soils with high soil temperatures. The obligate thermal plant *Dichanthelium lanuginosum*, however, only grew in mycorrhizal, biomass, and total root length at higher soil temperatures. With rising soil temperature, mycorrhizal colonization levels and extraradical hyphae (ERH) increased in all host species. The source of the AMF inoculum had no impact on colonization level, ERH length, host plant biomass, or blooming for any host species in either temperature condition, showing that AMF from thermal soils are not well suited to higher temperatures (Bunn et al., 2009). *In situ* depth distributions of the roots and ERH of *D. lanuginosum* were identified as the AMF species that were active in the plants growing in hot soils, we collected soil cores in the field. While

ERH was only found in the hottest soils as examined, with an average temperature of 35 °C, roots were restricted to soils with an average temperature of 30 °C.

The populations of thermal AMF had both specialized and probably distinct fungus species, according to root molecular studies. Increased host plant allocation to AMF, a lack of apparent temperature adaptation by AMF, and a range of hosts all point to the possibility that AMF may play a key role in determining how the plant community reacts to higher soil temperatures. When grown at high temperatures, both plants exhibit lower respiration rates and greater total carbohydrate stores when isolated from high-temperature soils than equivalent plants from ambient soils (Bunn, et al. [47]). The effects of AMF can differ depending on the plant's tolerance to heat, as evidenced by the fact that the plant that exclusively thrives in thermal soils profited from it at higher soil temperatures, but those that prefer to avoid high temperatures did not. However, plants that showed lower growth committed more carbon to fungal structures even in high-temperature soils, and AMF displayed an rise in ERH and root migration. AMF are thought to be extra heat-accepting than plant roots, according to the field distributions of hyphal and roots.

The nonthermal and thermal AMF responded similarly in the greenhouse experiment, demonstrating their excellent temperature tolerance (Bunn, et al. [47]). In this work, pot experiments were used to determine how 44 °C of extreme temperature stress affected maize plants both with and without AMF. Several factors representing photosynthetic commotion were measured in order to determine the photosynthetic efficiency in maize plants. The quantum competence of photosystem II (PSII), linear electron transport, excitation energy trapping, performance index, and net photosynthetic rate were all observed to increase in AMF (+) plants at 44 °C 0.2 °C. The main photochemical reaction's efficiency (represented as Fv/Fo) was higher in AMF (+) plants compared to AMF (-) plants. AMF seems to have protected the water-splitting complex under high temperatures before enhancing the basic photochemistry of PSII. Then PSII's primary photochemistry at higher heat conditions follows (Mathur, et al. [44]). Basic morphological traits like leaf width, plant height, and cob number increased in AMF (+) plants when compared to AMF (-) plants. AMF (+) plants grew more quickly than AMF (-) plants because they had larger root systems. Chl concentration increased in AMF (+) maize plants compared to AMF (-) maize plants. The increase in Mg absorption brought on by AMF hyphae led to an increase in the overall chlorophyll content in AMF (+) maize plants. Hence, the output of photosynthate and biomass increased. AMF (+) plants therefore outperformed AMF (-) maize plants in terms of photosynthesis when subjected to the stress of high temperatures (Mathur, et al. [44]). In a study, Gavito, et al. [6] that temperature directly affects AM fungus growth regardless of the plant host by using cultures of the organisms with altered carrot roots [48-55].

Conclusions and Future Recommendations

Appropriate agricultural management practices can increase output, reduce erosion, improve soil fertility, and increase the ability of the land to hold onto water. Farmers generally choose to accept the agricultural systems that they are already accustomed to and that are backed by current research and industry rather than searching for critical solutions. Because they don't account for the differences in agroecological zones, cultures, and resource limitations, many of these strategies typically fail in the majority of the places where they are utilized. The fertility of the land must be improved. Thus, biologically based solutions must be used for soil fertility restoration initiatives. AMF inoculation can boost productivity under temperature extreme and this effect strongly supports the use of AMF as a biofertilizer. AMF inoculation can mitigate the detrimental effects of high-temperature stress on crop growth and productivity.

Without fact, many plants can grow much more quickly if their mycorrhizal systems are in good shape. Previous studies concluded that N addition had no effect, but temperature rise and AMF suppression had a negative impact on community temporal stability in temperate meadows. AMF richness, dominant species stability, and mycorrhizal colonization were also commonly impacted by these treatments, which suggests the importance of belowground AMF in preserving aboveground plant community temporal stability in the face of climatic change. The aforementioned findings demonstrate the need of monitoring microbial activity in response to impending environmental changes as well as their role in maintaining the structure and functions of the aboveground plant community.

It is crucially necessary to comprehend this mechanism and develop a suitable plant-AMF combination for better utilization of natural resources. Future study should therefore concentrate on holistic approaches incorporating multidisciplinary sciences, such as plant and fungal physiology, soil, and molecular biology, in order to better understand the processes in the plant-AMF-soil continuum. It is safe to conclude that AMF colonization reduced the negative impacts of temperature extreme on the design structure and functionality of the photosynthetic system. Sound agricultural management practices can increase productivity, reduce erosion, enhance soil fertility, and enhance the land's capacity to hold onto water.

Farmers frequently find it simpler to embrace the agricultural methods that they are already familiar to and that are supported by current research and businesses rather than seeking out the essential alternatives. Because they do not account for the differences in agroecological zones, cultures, and resource constraints, several of these strategies frequently fail in the majority of the places where they are applied. Increasing soil fertility is crucial. Soil fertility restoration programs must consequently include biologically based systems. It is advised that the effects of temperature on crop production with emphasis on AMF can be taken into considerably larger account in future studies.

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