



## Arbuscular Mycorrhizal Fungi and Glomalin

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ARTICLE INFO	ABSTRACT
<p><i>Review Article</i></p> <p>Received : 05/07/2021 Accepted : 17/11/2021</p> <p><b>Keywords:</b> Arbuscular mycorrhizal fungi Glomalin Symbiosis Soil organic matter Potential toxic element</p>	<p>The interactions between plant, soil, and mycorrhizal fungi are ecologically and agriculturally beneficial systems. Mycorrhizal fungi are capable of forming a symbiosis with the roots of many plants in nature. In this symbiosis, the plant receives help from the mycorrhizal fungus in nutrient and water uptake. On the other hand, the mycorrhizal fungi supply the assimilant products they need from the plant. In addition to the many benefits of AMF, they have very important roles in carbon (C) storage in the soil. These roles of AMF are associated with the production of a substance named "Glomalin". Glomalin, an N-linked glycoprotein that is considered to be AMF gene products, is defined as a protein secreted by AMF hyphae and spores. Glomalin significantly reduces the degradation of soil organic matter by preserving unstable compounds in soil aggregates. Glomalin, which helps soil aggregation, is also an excellent hyphae protector.</p>

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## Arbüsküler Mikorizal Funguslar ve Glomalin

MAKALE BİLGİSİ	ÖZ
<p><i>Derleme Makale</i></p> <p>Geliş : 05/07/2021 Kabul : 17/11/2021</p> <p><b>Anahtar Kelimeler:</b> Arbüsküler mikorizal funguslar Glomalin Simbiyotik yaşam Toprak organik maddesi Potansiyel toksik element</p>	<p>Bitki, toprak ve mikorizal fungus üçgeni ekolojik açıdan değerlendirildiğinde oldukça yararlı bir sistemdir. Mikorizal funguslar doğadaki pek çok bitkinin kökleriyle ortak yaşama sahip funguslardır. Bu simbiyotik yaşamda, bitki mikorizal fungustan besin elementi ve su alımı konusunda yardım almakta, mikorizal fungus ise beslenmemek için bitkiden karbon kaynağı almaktadır. AMF birçok faydasının yanı sıra toprakta karbon (C) depolamasında çok önemli rolleri vardır. AMF'nin bu rolleri, "Glomalin" adlı bir maddenin üretimi ile ilişkilidir. AMF gen ürünleri olarak kabul edilen N-bağlı bir glikoprotein olan glomalin, AMF hifleri ve sporları tarafından salgılanan bir protein olarak tanımlanır. Glomalin, toprak agregalarında kararsız bileşiklerini koruyarak toprak organik maddesinin bozulmasını önemli ölçüde azaltır. Toprak agregasyonuna yardımcı olan glomalin aynı zamanda mükemmel bir hif koruyucudur.</p>

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## Introduction

Agricultural systems based on the intensive use of pesticides and inorganic fertilizers to compensate the nutritional needs of humanity emerged a long time ago. However, high input use brings with it serious problems such as the deterioration of agricultural ecosystems and the emergence of high environmental costs. These disadvantages have led to increased demands to reorganize agricultural practices to make agricultural systems more sustainable (Lee and Eom, 2009). Arbuscular Mycorrhizal Fungi (AMF) are very important for plant physiology, plant health, nutrient cycling and soil aggregation, especially for low-input sustainable agricultural systems (Bethlenfalvay and Barea, 1994).

AMF, classified in the division Glomeromycota, are obligate symbionts that form a symbiotic associations with more than 80% of terrestrial plant families. (Smith and Read, 2008). This relationship between plants and AMF, which connects the root and soil system, has been described by Koide and Mosse (2004) as one of the most important symbiosis on earth.

AMF directly mediates the uptake of phosphorus (P), one of the essential nutrients required for plant growth, by colonizing plant roots. AM formations such as extraradical mycelium and filamentous hyphae networks that rapidly develop around plant roots increase the uptake efficiency of immobile phosphorus ions. (Sanders and Tinker, 1971; Grant et al., 2005; Smith and Read, 2008). In this respect, AMF causes hydrolysis of organic phosphate present in the soil through hyphae and providing soluble phosphate to its hosts. (Bagyaraj et al., 2015).

The effective roles of mycorrhizal fungi in increasing phosphorus uptake have been explained by some mechanisms by different researchers. These mechanisms are listed as follows: (I) AMF makes the inorganic phosphates with very low solubility useful by secreting some enzymes and acidic liquids that lower the pH in the immediate vicinity of the plant roots. (Hayman and Mosse, 1972), (II) These fungi take in the organic phosphorus compounds that are not suitable for the plant in the soil as their own nutrient requirement and then make these phosphorus compounds available within the hyphae cell and carry them to the plant roots (Hayman, 1982), (III) AMF hyphae create a continuous absorbing surface like a sponge layer on the surface of the plant roots, collect the phosphorus compounds that they have previously converted to suitable with various activities in the soil, on the root surface with the help of this absorbing surface and carry them to the plant root with the help of hyphae. (Bolan, 1991). While AM fungal colonization is inhibited at excessive phosphorus concentration, it is quite high in limited situations. AMF increases crop productivity by increasing nutrient uptake in soils with the low phosphorus content. (Grant et al., 2005).

In addition to increasing phosphorus uptake, AMF aids the host plant's uptake of mineral nitrate, potassium, and other forms of nutrients. Also, they have played an important role in increasing heavy metal and salt tolerance, increasing resistance to drought, improving resistance to pests and protecting plants against soil-borne pathogens. (Auge et al., 1994; Gange and West, 1994; Khan et al., 2000; Feng et al., 2002; Smith and Read, 2008; Atakan et

al., 2018; Atakan and Ozgonen Ozkaya., 2021). Apart from these, AMF can interact with beneficial microorganisms such as phosphate-solubilizing bacteria (Toro et al., 1998) and *Trichoderma* spp. which have beneficial effects on nutrient cycling and plant nutrition (Singh et al., 2010).

AMF exist in two different phases in soil and inside plant roots. The intraradical mycelium belonging to these fungi consists of structures such as arbuscules, which provide nutrient and carbon exchange between symbionts, and vesicle, which is the lipid storage of fungi. The extraradical mycelium is responsible for the discovery of new areas for spore formation, nutrient uptake and colonization (Rillig, 2004).

In addition to the above benefits, AMF have very important role in carbon (C) storage in the soil (Zhu and Miller, 2003; Rillig and Mummey, 2006). These roles of AMF are associated with the production of a substance named glomalin. Glomalin, an N-linked glycoprotein (Schindler et al., 2007), which is considered to be AMF gene product, is defined as a protein secreted by AMF hyphae and spores. It is measured from the soil as Glomalin-Related Soil Protein (GRSP) (Wright and Upadhyaya 1996; Rillig 2004; Singh et al., 2013).

Among soil biota, AMF are critical for soil aggregation and can alleviate plant stress. (Lehmann and Rillig, 2015; Ortiz et al., 2015). Glomalin, an important component of soil organic matter and putative gene product of arbuscular mycorrhizal fungi, contributes to better aggregate formation. (Wright and Upadhyaya, 1998). Glomalin is of great importance in determining numerous aspects of soil quality, including soil organic matter, nutrient storage capacity, and water holding capacity. Therefore, AMF are not only a factor but also a key determinant of soil quality. (Paul and Clark, 1989).

In this review, it was aimed to give some information about mycorrhizal fungi and glomalin, which is supposed to be the gene products of these fungi.

## Discovery of Glomalin and Definition

Glomalin was firstly described in 1996 as a glycoprotein secreted from AMF spores and hyphae. Since this protein is secreted by the genera *Acaulospora*, *Entrophospora*, *Gigaspora*, *Glomus* and *Scutellospora* belonging to the order Glomales, it is expressed with the name "Glomalin". (Wright et al., 1996). Monoclonal antibodies (MAb32B11) produced against spores of *Glomus intraradices* FL208 were used to detect the presence of glomalin. As a result of studies on in vitro cultures of *Rhizophagus intraradices* (N.C. Schenck & G.S. Sm.) C. Walker & A. Schüßler, it has been reported that glomalin is tightly bound to hyphae and spore walls. It has also been reported that about 80% of this protein is secreted by the hyphae and spores of AMF. (Driver et al., 2005).

Glomalin, which cannot be produced by fungi other than Glomeromycota, is a stable compound that is insoluble in water and resistant to heat degradation. (Wright et al., 1996). Glomalin can be found in agricultural soils, grasslands, forest soils, desert and uncultivated soils (Wright and Upadhyaya 1996; Rillig et al., 2003; Antibus

et al., 2006; Bai et al., 2009). Positive results have been obtained from the studies conducted to prove that glomalin is of AMF origin. In a study conducted by Steinberg and Rillig (2003), they concluded that when the development of AMF was eliminated, there was a decrease in glomalin concentration.

Glomalin is not only a component within the walls of AMF hyphae and spores, but may also exist on the surface of extraradical mycelium. By decomposition of the hyphae, glomalin penetrates into the soil and is called Glomalin-Related Soil Protein (GRSP) (Rillig, 2004; Driver et al., 2005).

Host plant species, photosynthesis and productivity, soil management and soil physicochemical properties are the factors affecting GRSP production (Treseder and Turner 2007; Violi et al., 2007; Wang et al., 2011; Wu et al., 2013). The rate of glomalin production is not always proportional to the abundance of AMF in the soil. Therefore, the permanent stocks of hyphae, the glomalin content of the hyphae, and the hyphae turnover rate determine the rate of accumulation of glomalin in the soil. Permanent glomalin stocks in the soil are determined by the production and decomposition of glomalin, and ecological conditions can affect the two situations independently (Rillig, 2004).

### Content of Glomalin and Classification

Glomalin is a hydrophobic protein. It contains iron (2–5%), oxygen (4–6%), phosphorus (0.03–0.1%), carbon (36–59%), hydrogen (33–49%) and nitrogen (3–5%). (Wright et al., 1998; Lovelock et al., 2004). The reddish-brown appearance of glomalin extracts is due to the iron content (Wright and Upadhyaya, 1998; Rillig et al., 2001). It was reported that glomalin is present in soils in concentrations that are up to four times as great as humic acid concentrations, it is persistent, and it is generally associated with the insoluble humus or mineral fractions after treating soils with sodium hydroxide (Comis, 2002).

In general, GRSP is classified as easily extractable glomalin-associated soil protein (EE-GRSP) and total glomalin-associated soil protein (T-GRSP). There is a problem of terminological confusion about the specific protein glomalin. Therefore, there are four positively correlated variables used to describe the glomalin extracted from the soil. These; It is defined as EEBRSP (easily extractable BRSP), BRSP (Bradford reactive soil protein), IRSP (immuno reactive MAb32B11 soil protein) EE-IRSP (easily extractable immune reactive MAb32B11 soil protein). An important aspect of this new terminology is that glomalin in the strict sense is expressed only as the gene product generated by AMF. However, evidence of AMF origin of GRSP is highest for monoclonal antibody immune reactive fractions (Wright and Upadhyaya, 1996; Rillig et al., 2004; Singh, 2012).

### Agricultural Importance of Glomalin

There is a strong relationship between glomalin concentration and soil aggregate stability (Wright and Upadhyaya, 1998; Wright and Anderson, 2000). Because of this role, glomalin significantly reduces the degradation of soil organic matter by preserving unstable compounds

in soil aggregates (Rillig, 2004). Glomalin, which helps soil aggregation, is also an excellent hyphae protector. Due to its high stickiness and hydrophobicity, it contributes significantly to the stabilization of soil particles. Apart from this, it represents a stable form of organic C stores, which represent a significant part of soil organic matter (Rillig et al., 2003). Soil aggregate stability positively associated with GRSP is more pronounced under drought stress. GRSP plays an important role in preventing the loss of water and nutrients from plants exposed to abiotic stress by providing the formation of a hydrophobic layer on the aggregate surface (Nichols, 2008; Wu et al., 2008). Because decomposition and death of mycorrhizal hyphae are promoted under drought stress, more GRSP is secreted in soils (Driver et al., 2005). This situation indicates both the phytopathological importance of AMF-plant interaction and the importance of interaction between symbionts under stress conditions. In this way, the preservation of water and nutrients necessary for plants is increased, and beneficial effects are provided on plant development.

Glomalin also has an important role in the formation of microbial communities in soil. Chemical fertilizers affect glomalin production as they affect the symbiotic relationships of AMF. In a study in which different nitrogen (0, 2, 6, 10 mM) levels were applied to alfalfa (*Trifolium repense* L.), plants inoculated *Rhizophagus irregularis* (Błaszk., Wubet, Renker & Buscot) C. Walker & A. Schüßler and *Rhizobium leguminosarum* pv. *trifolii*. In this study, it was reported that significant increases in glomalin production were observed with the interaction between *Rhizophagus irregularis* and *Rhizobium leguminosarum*. In addition, the percentage of root colonization increased compared to the control, depending on the increasing nitrogen levels. Since the main component of glomalin is nitrogen, the assimilant products obtained as a result of photosynthesis are transmitted to AMF via roots and used for glomalin synthesis in AMF spores and hyphae walls. After the plant assimilants are transferred to AMF, they can be converted to nitrogenous compounds if sufficient nitrogen sources are available. Accordingly, a significant amount of carbon is assimilated into AMF and soil particles (Zenoozagh, 2018). It can be concluded that carbon sequestration with this symbiotic relationship in terrestrial ecosystems can be improved by applying nitrogen fertilization at the optimum level.

The rhizosphere contains many microorganisms. It can both promote and inhibit plant growth and development through interactions between organisms. (Barea et al., 2005). The interactions between PGPR and AMF are very important because of their contribution to the productivity and sustainability of agricultural and natural ecosystems (Requena et al., 1997; Walley and Germida, 1997; Adesemoye et al., 2008). Several studies have reported that using PGPR promotes the beneficial role of AMF (Hodge, 2000; Barea et al., 2002; Barea et al., 2005).

Some PGPR produce phytohormones that increase AMF colonization by increasing root surface area and plant susceptibility to AMF penetration. (Barea et al., 2002; Dwivedi et al., 2009). For this reason, this PGPR is defined as “mycorrhization-helper bacteria” (Garbaye, 1994). AMF affect the bacterial population in the root zone and provide the accumulation of photosynthesis products in the

mycorrhizosphere (Hodge, 2000). As a result of increasing mycorrhizal colonization by PGPR, glomalin production increases (Purin and Rillig, 2007).

Another important point in terms of plant health is the presence of toxic metals such as Cu, Cd, Zn and Pb in the soil. It has been suggested that the most appropriate use for these elements is potentially toxic elements (PTEs) (Gadd, 1993; Alloway, 1995). AM Fungi are capable of absorbing Cu, and 1 g of AMF hyphae has a Cu content of 3-14 mg (Gonzalez-Chavez et al., 2002). Glomalin, gene products of AMF, are effective with mechanisms such as stabilizing PTE, optimizing the presence of PTE in the soil and reducing the risk of toxicity for other soil microorganisms and plant roots in the rhizosphere. These properties reflect another beneficial aspect of glomalin in addition to its other roles.

## Conclusion

The promotion of mycorrhizal symbiosis has great potential to benefit modern agricultural systems. Recently, increasing interest in environmental protection and eco-friendly agricultural practices are among the potential important issues by minimizing the use of mineral fertilizers and synthetic chemicals. Unlike conventional agricultural practices, mycorrhizal fungi, which is a trend approach, protect their hosts against plant pathogens by various mechanisms. AMF, which is important as an effective bio-fertilizer and bio-preservative in sustainable agriculture, is also among the most necessary factors of the modern agricultural age by interacting with other microorganisms. In addition to its other important features, the glomalin secreted by AM fungi improves the soil structure and provides optimum conditions for plant growth. In addition, the ability of AM Fungi to retain and accumulate PTEs in a non-toxic form, the benefits of improving plant health and soil quality in polluted areas can be considered as the only components of modern agriculture. It is thought that some problems brought by conventional practices can be eliminated or alleviated by giving the necessary importance to the widespread use of these symbionts, which are very beneficial to the agroecosystem. For this reason, there is a need for detailed studies on the subject.

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