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A ROLE OF AM FUNGI IN ALLEVIATING THE ABIOTIC STRESS

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Abiotic stresses are a global environmental problem. It is common in all environments and the adverse effects are best documented in agricultural systems where abiotic stresses can cause losses in the yield of food crops up to 70 % (Mantri *et al.* 2012). Drought (Pardo 2010; Cramer *et al.* 2011), temperature (Weis and Berry 1988), salinity (Munns and Tester, 2008), pH (Hinsinger *et al.* 2003) and nutrient deficiency or excess, all affect the plants health negatively. It has been reported that the abiotic stresses generate the reactive oxygen species in plant cell and cause oxidative stress in plant (Li *et al.* 2018). They cause damage to the DNA and harm the repair system of DNA, hamper the functional integrity of plasma membrane and disturb the activity and function of protein (Tamás *et al.* 2014). Alternatively, plants also develop several structural, morphological, physiological and biochemical modifications to avoid and minimize the stress caused by various abiotic stresses (Ruiz-Lozano *et al.* 2006, Fusconi and Berta 2012, Patakas 2012). There are various sustainable efforts to alleviate the stress caused by abiotic factors. In this context, the association of arbuscular mycorrhizal (AM) fungi with plant roots has been reported to improve growth and yield of the plant under stressful conditions (Abdel Latef 2011, 2013; Abdel Latef and Chaoxing 2011a, 2014; Jeffries and Barea 2012; Hajiboland 2013, Akhtar *et al.* 2019).

AM fungi are obligate biotrophs, belonging to the phylum Glomeromycota (Schüßler *et al.* 2001, Kehri *et al.* 2018) form an association with the roots of the higher plants. AM fungi have been reported from the Devonian period (Taylor *et al.* 1995, Phipps and Taylor 1996). In association with the roots of the host plant, AM fungi produce various types of structures such as hyphae, arbuscules, vesicles and spores (Plate 1). Hyphae of AM fungi colonize the cortical cells of root and form highly branched structures called arbuscules inside the host cells. Arbuscules are considered as the main site of nutrient exchange (Balestrini *et al.* 2015). AM fungi improve the growth of the host plant through increased nutrient (phosphate and nitrogen) and water uptake in exchange for photosynthetic product from their host (Smith *et al.* 2010, Gianinazzi *et al.* 2010; Baum *et al.* 2015). Apart from an increased nutrient status, AM fungi-colonized plants often show improved root growth and branching as compared to non-colonized plant (Gamalero *et al.* 2010, Orfanoudakis *et al.* 2010; Gutjahr and Paszkowski 2013) (Plate 2). The extraradical AM fungal mycelium can acquire nutrients from soil volumes that are inaccessible to roots (Plare 3) (Smith *et al.* 2000) as AM fungal hyphae are considerably thinner than roots and are therefore able to penetrate through smaller pores (Allen 2011). Besides improved nutrient and water supply, AM association also improved stress tolerance in plants (Augé 2001, 2004; *Porcel et al. 2011; Augé et al.* 2015, Pozo and Azcón-Aguilar, 2007). There have been various reports on the effect of AM fungi in alleviating abiotic stress in plants (Augé 2001, Ruiz-Lozano 2003, Ruiz-Lozano and Aroca 2010, Bárzana *et al.* 2012, 2015; Ruiz-Lozano *et al.* 2012, Calvo-

Polanco *et al.* 2014, Saia *et al.* 2014, Augé *et al,* 2015, Sánchez-Romera *et al.* 2015). AM fungi are reported to alleviate heavy metal toxicity in the host plants (Göhre and Paszkowski, 2006; Lingua *et al.* 2008, Cornejo *et al.* 2013, Tamayo *et al.* 2014, Meier *et al.* 2015, Akhtar *et al.* 2020). Furthermore, AM fungi are of great ecological significance (Xie *et al.* 2014) as they improve the plant growth, uptake of nutrition and eventually improve the productivity under normal as well as stressful environmental conditions (Abdel Latef 2011, 2013; Abdel Latef and Chaoxing 2011a, 2014; Jeffries and Barea 2012, Hajiboland, 2013; Abdel Latef and Miransari 2014).

AM fungi versus Salinity stress: Salinization of soil is a serious land degradation problem and is increasing in many parts of the world (Giri *et al.* 2003, AlKaraki 2006, Sheng *et al.* 2008). Saline soils occupy 7 % of the earth's land surface (Ruiz-Lozano *et al.* 2001) and 50 % loss of arable land will be there by the middle of the 21st century (Wang *et al.* 2003). According to Sheng *et al.* (2008) out of 1.5 billion hectares of cultured land around the world about 5 % is affected by salinity. Scientists say there is no early solution to soil salinity and waterlogging. Only 800 to 1,000 hectares can be reclaimed in a year (Plate 4).

Excessive salts in soil reduce plant water and nutrient uptake and disrupt the distribution of ions. Such drastic changes result in stunted plant growth and development and can lead to death of the plant. Higher accumulation of salts like Na^+ and Cl^- in plant tissues leads to oxidative damage (also considered as secondary stress), affecting integrity of plant membranes (damage to lipids, proteins and nucleic acids), impairing activities of biocatalysts and functioning of photosynthetic apparatus, which is ascribed to the deleterious effects of the reactive oxygen species (ROS) often generated by salt stress (Zhu 2001, Kumar *et al.* 2015). The rhizosphere, an area in the immediate vicinity of the plant root is predominantly affected by the activities of soil microbes. These microbes *viz*., nitrogen-fixing bacteria, phosphate solubilizers, and mycorrhizae can be useful, which alleviate detrimental effects of biotic and abiotic stresses.

AM fungi have been shown to promote plant growth and salinity tolerance by many researchers. They promote salinity tolerance by utilizing various mechanisms, such as: (a) enhancing nutrient uptake; (b) producing plant growth hormones; (c) improving rhizospheric and soil conditions; (d) improving photosynthetic activity or water use efficiency (e) accumulation of compatible solutes, and (f) production of higher antioxidant enzymes. As a result, AM fungi are considered suitable for bioamelioration of saline soils.

AM fungal activity increases the phosphorus concentration available in the rhizosphere, lower the root zone pH by selective uptake of NH_4^+ (ammonium-ions) and by releasing H^+ ions, decreased soil pH, increases the solubility of phosphorus precipitates, the hyphal NH_4^+ uptake also increases the nitrogen flow to the plant as the soil's inner surfaces absorb ammonium and distribute it by diffusion.

Application of AM fungi can result in a more efficient assimilation of N in the host plants, due to the (a) nitrate assimilation in the extra radical mycelia through the activity of nitrate reductase located in the arbuscular containing cells (b) increased production of enzymes controlling the primary nitrogen fixation in the extra-radical mycelia, (c) decreasing the toxic effects of Na ions by reducing its uptake and this may indirectly help in maintaining the chlorophyll content of the plant Improved P uptake by AM fungus in plants grown under saline conditions may contribute to the integrity maintenance of vacuolar membrane and facilitate the Na^+ ions compartmentalization within vacuoles. This prevents Na^+ ions from interfering in metabolic pathways of growth, thereby reducing the negative impacts of salinity.

Mycorrhizal fungi can enhance K absorption under saline conditions and prevent the

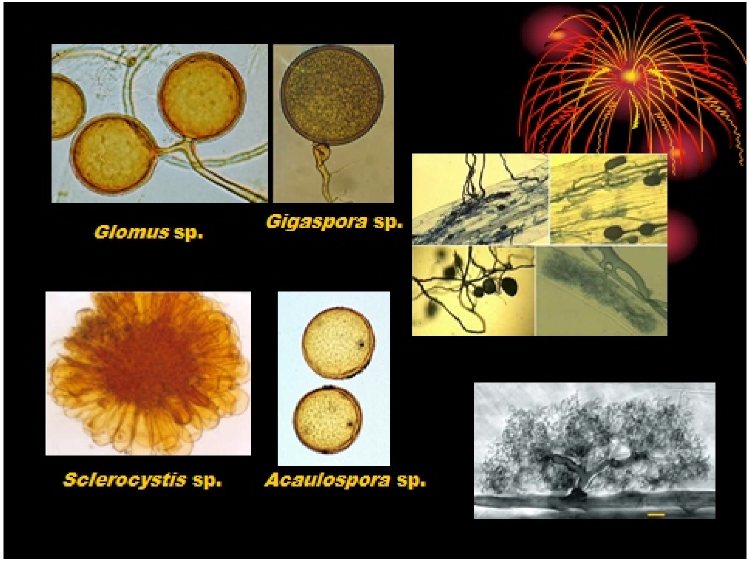

Plate 1 : VAM Fungal Structures, Spores, Vesicles and Arbusvules

Plate 2 : Improved root groth un mycorrhizal plants than non-mycorrhizal plants

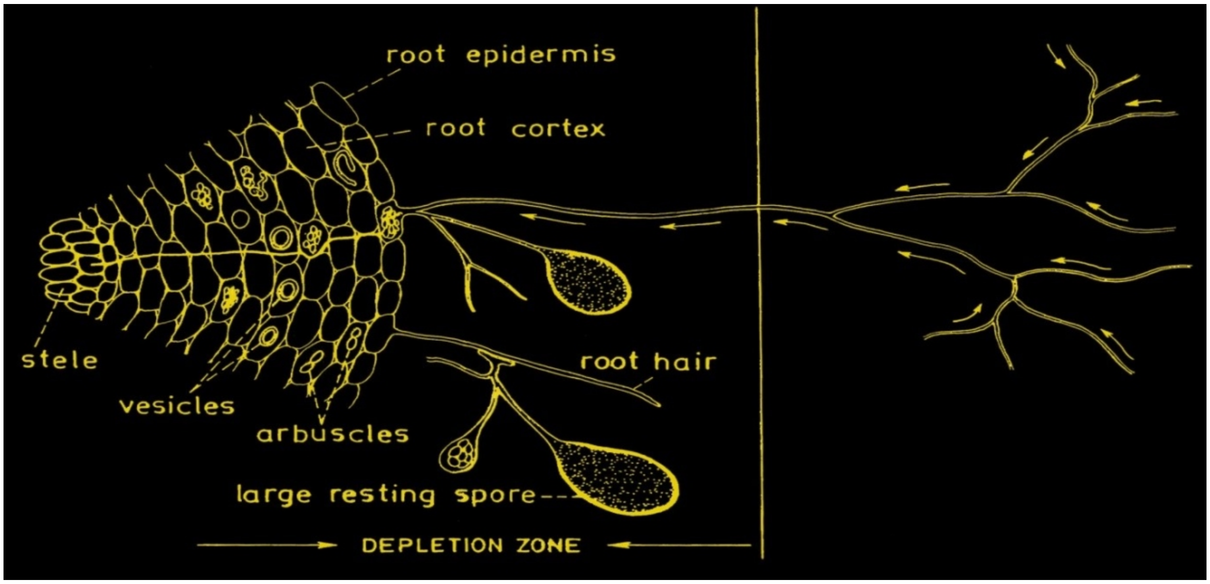

Plate 3 : The ectramatrical AM fyngal myceliu, acquiring nutrients from soil volime that is unaccessible to roots

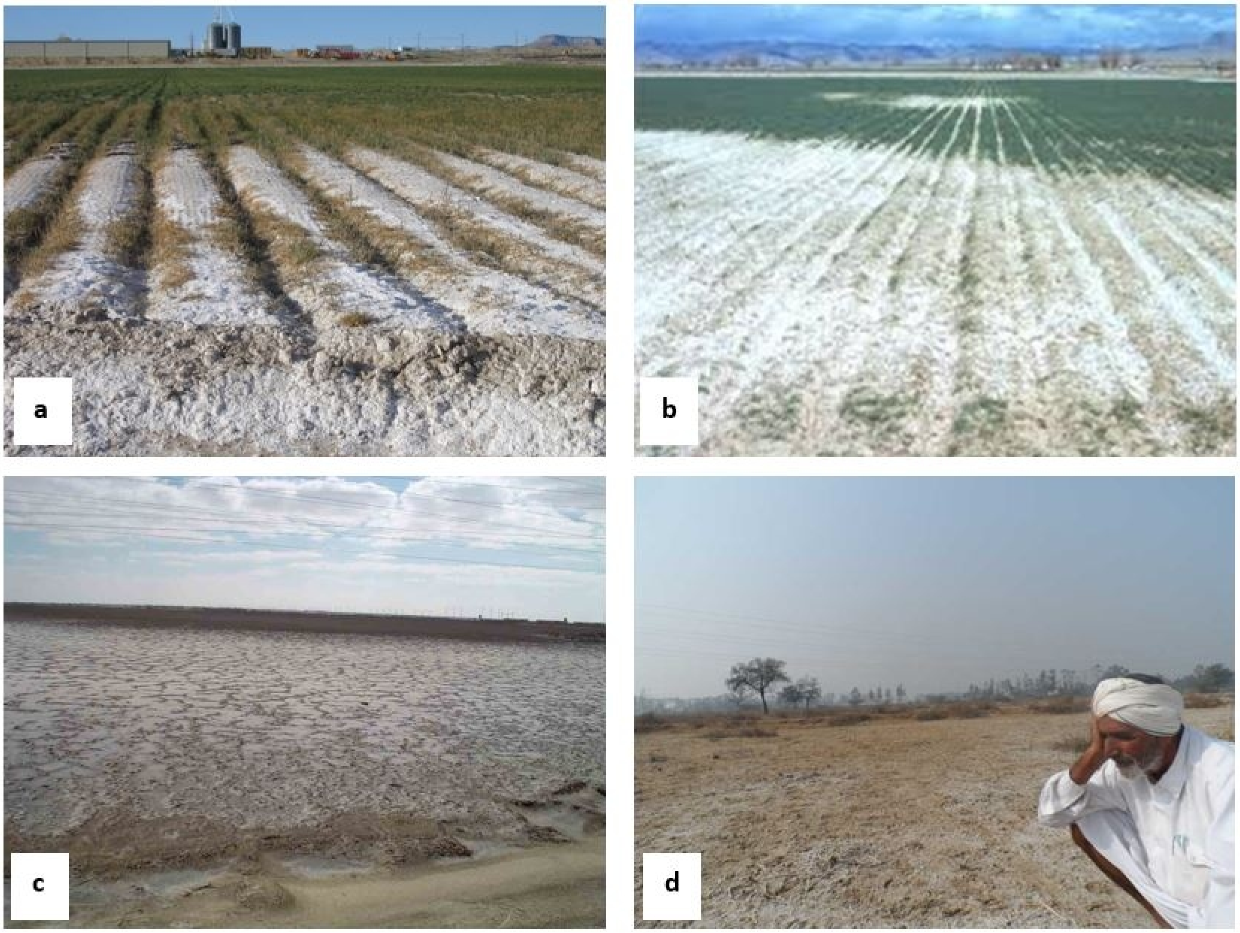

Plate 4. Showing various saline fields. **a** and **b:** Salinity stressed cultivated fields, **c:** Saline/alkaline field of our country, and **d:** A farmer in debt

translocation of Na to shoot tissues. Higher K accumulation by mycorrhizal plants in a saline soil could be beneficial by maintaining a high K^+/Na^+ ratio and by influencing the ionic balance of the cytoplasm or Na efflux from plants. Magnesium is a macronutrient and forms the integral part of the chlorophyll molecule. Mycorrhizal fungi can increase chlorophyll concentration, by increasing the uptake of Mg^{2+} by the host plant. This suggests that salt interferes less with chlorophyll synthesis in mycorrhizal than nonmycorrhizal plants. The enhanced Mg^{2+} uptake can increase the chlorophyll concentration and hence improve photosynthetic efficiency and plant growth. In saline regions, the high concentration of Cl^- may limit plant growth and can be toxic to crop plants. Such a stress can be alleviated to some extent by using AM fungi, which can reduce the uptake of Cl ions. In mycorhizal plants, the ability of the host plant increases and hence compartmentalize higher rate of Cl^- in the vacuoles, thereby preventing the ions from interfering with the metabolic pathways in the plant. Under salinity stress, the overproduction of different types of compatible organic solutes by plant increases. Generally, they protect plants from stress. Some of these solutes are called osmoprotectants because they protect cellular components from dehydration damage. These solutes include proline, soluble sugars, polyols, trehalose, and quaternary ammonium compounds (QACs) such as proline-betaine, alanine-betaine, glycine-betaine, pipecolate-betaine, and hydroxyproline-betaine. Production of different solutes, plant hormones, antioxidant products, the adjusted

Plate 5: Showing various sources of heavy metal pollution in the agricultural soils. **a-c:** heavy metal contaminated effluent used for irrigation **d-f:** illegal source of heavy metal contamination

rate of K^+/Na^+, extensive network of the mycorrhizal plant roots, and enhanced nutrient uptake are all among the processes that make the plant to survive under stress.

A number of AM fungi have been reported in saline soils (Khan 1974, Allen and Cuningam 1983; Pond *et al.* 1984, Rozema *et al.* 1986; Sengupta and Chaudhuri 1990, Carvalho *et al.* 2001, Hilderbrandt *et al.* 2001, Harisnaut *et al.* 2003, Yamato *et al.* 2008). Salinity stress sometimes reduce the average density of AM spores (Barrow *et al.* 1997, Carvalho *et al.* 2001). Moreover, Aliasgharzadeh *et al.* (2001) reported the *Glomus intraradices, G. versiform* and *G. etunicatum* was most predominant species of AM fungi in the severely saline soils of the Tabriz plains. They further reported that the number of AM fungal spores did not significantly decrease with the salinity. However, Wilde *et al.* (2009) reported that 80 %, on average, AM spores belonged to *Glomus geosporum*. However, Fuzy *et al.* (2008)

reported that an isolate of *G. geosporum* does not confer salt tolerance in plants. Tian *et al.* (2004) reported that *G. mosseae* isolated from salt stress soil had an inferior ability to improve salt stress in cotton. Porras-Soriano *et al.* (2009) tested the efficacy of *Glomus mosseae*, *G. intraradices* and *G. claroideum* to alleviate salinity stress and they reported that *G. mosseae* shows the best result among the tested spp. and improves the performance of olive tree against the detrimental effects of salinity. Salt stress, also affects the growth of AM fungi. It can inhibit the AM colonization, spore germination and hyphae growth. Various researchers have reported the deleterious effects of salt stress on microbes (Hirrel 1981, Estaun 1989, McMillen *et al.* 1998, Jahromi *et al.* 2008). In the presence of NaCl AM colonization in the roots of plant was reduced (Hirrel and Gerdemann, 1980; Ojala *et al.* 1983, Menconi *et al.* 1995, Poss *et al.* 1985; Rozema *et al.* 1986, Duke *et al.* 1986, Giri *et al.* 2007, Juniper and Abbott 2006, Sheng *et al.* 2008) indicating that in the presence of salt, growth of AM fungi reduce (Tian *et al.* 2004; Sheng *et al.* 2008). It has also been reported that suppression of AM fungi under salt stress also depends on the on the timing of the observation, as there is more inhibition in the early than in the later stages of colonization (McMillen *et al.* 1998). Moreover, the AM association with plant roots may also be influenced by other factors such as topographical and root biochemical factor and phenology of host plants (Wilson and Hartnett, 1998; Gadkar *et al.* 2001, Carvalho *et al.* 2001). AM fungi are also known to colonize the plant that grown in salinity and such plant are called halophytes (Khan 1974, Hoefnagels *et al.* 1993, Brown and Bledsoe 1996). Several researchers have reported that AM inoculated plants grow better than non-inoculated plants under salt stress (Al-Karaki 2000, Cantrell and Linderman 2001, Giri *et al.* 2003, Sannazzaro *et al.* 2007, Zuccarini and Okurowska 2008). AM colonization improves the growth of the plant and it has been observed in the seedling of *Acacia nilotica* that show higher root and shoot dry weight than the non-colonized seedlings (Giri *et al.* 2007). Similarly, Colla *et al.* (2008) reported improved growth, yield, water status, nutrient content and quality of fruits of *Cucurbita pepo* plants colonized by *Glomus intraradices* under salinity stress. AM fungi have been found to improve salt tolerance in different plant species such as tomato, cucumber, maize, lettuce, clover, fenugreek, sesbania and acacia (Ruiz-Lozano *et al.* 1996, Al-Karaki 2000, Feng 2002, Giri *et al.* 2003, Sharifi *et al.* 2007. Giri and Mukerji 2004, 2007). The application of AM fungi offers a cheaper and cost-effective alternative to counteract the problem of stress. Hajiboland *et al.* (2010) studied the effect of *R. intraradices* on the growth of tomato plants under low, medium and high salinity stress using salt-sensitive and salt-tolerant genotypes. Further, they reported that inoculation of *R. intraradices* plays an important role in alleviating salt stress by increasing P, Ca and K uptake and Ca/Na and K/Na ratios, while also promoting carbon assimilation by increasing the stomatal conductance. Improved growth of AM colonized plant is due to enhanced P acquisition nutrition (Plenchette and Duponnis 2005; Sharifi *et al.* 2007). Under normal as well as salinity stress conditions AM fungi reported to enhanced synthesis of chlorophyll pigments in *Solanum lycopersicum* (Hajiboland *et al.* 2010). Furthermore, inoculation of AM fungi reported to improve the functioning of photosystem (PSI and PSII) and boost the chlorophyll and carbonic anhydrase content (Talaat and Shawky 2014). In addition to improved mineral nutrition and photosynthetic capacity AM fungi also improves the stomatal conductance, root hydraulic conductivity, water use efficiency, accumulation of enzymatic and non-enzymatic antioxidants, compatible organic solutes (help in detoxification of damaging reactive oxygen species), and osmotic adjustment (protect integrity of cell membrane and organelle and stabilize proteins) (Sharifi *et al*. 2007, Sheng *et al.* 2008; Evelin *et al.* 2009, Porcel *et al.* 2012, Kumar *et al.* 2015, Auge *et al.* 2014;

Latef *et al.* 2016, Saxena *et al.* 2017, Atakan *et al.* 2018). Moreover, Daei *et al.* (2009) and Mardukhi *et al.* (2015) concluded that the adverse effects of salt could be nullified if correct combination of AM fungi and plant genotype are used.

AM fungi versus Heavy Metal Stress: Heavy metals occur naturally in the soil and are constantly being added to the soil by various sources (use of chemical fertilizers and pesticides, application of sewage and industrial effluents, production of batteries and mining and smelting of metals) (Shen 2002) (Plate 5).

Heavy metals are nonbiodegradable, persistent inorganic chemical constituents whose atomic mass is over 20, density higher than 5 g/cm^{-3}. They are able to form sulfides and are cytotoxic, genotoxic and mutagenic, affects humans or animals and plants. Heavy metals influence food chains, soil, irrigation or potable water, aquifers and surrounding atmosphere.

Heavy metals at toxic level hamper normal plant functioning, act as an impediment to metabolic processes, cause disturbance or displacement of building blocks of protein structure, hinder functional groups of important cellular molecules, disrupt functionality of essential metals in biomolecules (such as pigments or enzymes) adversely affect the integrity of the cytoplasmic membrane (result in the repression of vital events in plants such as photosynthesis, respiration, and enzymatic activities). Heavy metals at toxic levels have the capability to interact with several vital cellular biomolecules such as nuclear proteins and DNA, leading to excessive augmentation of reactive oxygen species (ROS). This would inflict serious morphological, metabolic, and physiological anomalies in plants ranging from chlorosis of shoot to lipid peroxidation and protein degradation.

Elevated levels of heavy metals increase generation of reactive oxygen species (ROS) such as superoxide free radicals, hydroxyl free radicals, or non-free radical species (molecular forms) such as singlet oxygen and hydrogen peroxide (H_2O_2) Increase cytotoxic compounds like methylglyoxal (MG), which can cause oxidative stress via disturbing the equilibrium between pro-oxidant and antioxidant homeostasis within the plant cells, cause multiple deteriorative disorders such as, oxidation of protein and lipids, ion leakage, oxidative DNA attack, redox imbalance, denature of cell structure and membrane, ultimately result in activation of programmed cell death (PCD) pathways.

Increase of heavy metals in the soil may changes the physico-chemical properties of soil (Koomen *et al.* 1990) thereby enhanced the bioavailability of metals (Birch and Bachofen, 1990). Heavy metals are non-degradable in nature and its presence at higher concentration in soils adversely affect growth and development of plants by inhibiting the enzymatic activities (Foy *et al.* 1978) thereby the productivity (Pandolfini *et al.* 1997, Keller *et al.* 2002, Voegelin *et al.* 2003, Kabata-Pendias and Mukherjee 2007). Alternatively, heavy metals could also be toxic for soil microorganisms (Chaudri *et al.* 1993, McGrath *et al.* 1995, Dai *et al.* 2004). Nevertheless, heavy metals exposure may result in the development of metal tolerant/resistant AM fungi. It has been reported by various authors that AM isolates, particularly found in heavy metal contaminated soils can tolerate and accumulate heavy metal (Gildon and Tinker 1981 Weissenhorn *et al.* 1993, Joner and Leyval 1997, Smith and Read 1997, Zhu *et al.* 2001, Jamal *et al.* 2002, Akhtar *et al.* 2019). AM fungi have also been associated with metallophyte (*Viola calaminaria*) plants (Tonin *et al.* 2001). Phytoremediation is one of the best strategies to remediate heavy metal contaminated soil by using AM fungi (Joner and Leyval, 2001). This method is ecofriendly that uses plants to remove the heavy metals from contaminated soil to level that makes them available for private and public use. Khan *et al.* (2014) conducted an experiment to determine the role of AM fungi in phytoremediation of heavy metals contaminated soil and concluded that AM fungi inoculated plants show better result as compare to non-inoculated plants. Similarly, Yang *et al.* (2016), studied the role of AM fungi for the phytoremediation of lead (Pb) and concluded that AM colonized plant accumulate more PB in root and shoot as compare to non-inoculated plant. Moreover, Kaur and Garg (2013), reported the negative effects of Zn and Cd stresses on plants growth and its metabolism. Further, they reported that AM inoculation improved metal tolerance and uptake of nutrients in plant under stress condition.

AM fungi plays an important role in alleviation of heavy metal toxicity in plants (Zhang *et al.* 2010, Garg and Bhandari 2014, Miransari, 2017). AM fungi could protect plants against harmful effects of heavy metals by several mechanisms. Zhu *et al.* (2001) reported the immobilization of metals in the fungal biomass. According to Joner *et al.* (2000) AM fungi binds the heavy metals in their fungal structures which serves as a biological barrier. AM fungi produce glomalin (insoluble glycoprotein) a soil protein that can bind heavy metal beyond the plant rhizosphere (Gonzalez-Chavez *et al.* 2004; Gohre and Paszkowski 2006). Gonzalez- Chavez *et al.* (2004) reported that 1 g of glomalin could extract up to 4.3 mg Cu, 0.08 mg Cd and 1.12 mg Pb from polluted soils. Structures of AM fungi particularly, vesicles provide an extra detoxification site for storing toxic compounds. AM fungi alleviates the metal toxicity in plants by altering the physiology and metabolism of the plant (Paradi *et al.* 2003). AM association with plants did not influence shoot concentration of heavy metals, but concentration in roots was increased in AM colonized plants (Joner and Leyval 1997). Beside this there are various factors such as AM symbiont, inherent heavy metal-uptake capacity of plants and soil absorption or desorption characteristics also influence heavy-metal uptake in plants.

Principlal mechanisms adopted by mycorrhizal fungi to cancel out impacts of HM stress on plants include (i) acting as a barrier by depositing metals within cortical cells, (ii) binding metals to cell wall or mycelium as well as sequestering them in their vacuole or other organelles (iii) releasing heat-shock protein and glutathione, (iv) precipitating or chelating metals in the soil matrix via producing glycoprotein or making phosphate-metal complexes inside the hyphae, and (v) reducing the strength of metals by heightened root and shoot growth (vi) Metallothionines like polypeptides are known to cause Cd and Cu detoxification in AM fungal cells. (vii) There are also some reports of expression of genes in AM plants encoding proteins metallothionein, heat shock protein, Glutathione-S-transferase in response to metallic stress. This indicates that proteins of these expressed genes may help in the immobilization of toxic heavy metals in plant rhizosphere.

AM fungi and Drought Stress: Drought is a constant period of dry condition and becoming a global environmental problem (Piao *et al.* 2010, Trenberth *et al.* 2014, Mathur *et al.* 2018). The main cause of drought is climatic alteration, i.e., escalating temperature that changed the soil moisture. Due to the unavailability of water for plant net primary productivity was decrease (Moussa and Abdel-Aziz 2008, Hasanuzzaman *et al.* 2013) and the plant suffers from oxidative stress (Impa *et al.* 2012, Hasanuzzaman *et al.* 2013). There are various reports on AM fungi improves the growth of plants under drought conditions (Baum *et al.* 2015, Zhao *et al.* 2013, Bowles *et al.* 2018). It has been reported that AM fungi can improves the growth of the plant by improving the root length, leaf area, biomass production, and uptake of essential nutrients under drought condition (Al-Karaki *et al.* 2004, Gholamhoseini *et al.* 2013, Kapoor *et al.* 2013). AM inoculation also reported to enhance the formation of extensive hyphal networks which improves the water uptake capacity (Miransari 2010, Gholamhoseini *et al.* 2013, Gong *et al.* 2013, Pagano 2014). There are various physiological and biochemical mechanisms including (a) uptake and transfer of water and nutrients, (b) improved osmotic adjustment, (c) protection against oxidative damage , (d) greater leaf water potential, (e) improved gas exchange, (f) accumulation of compatible solutes (osmolytes), (g) increased stomatal conductance, transpiration and photosynthetic rates (Rapparini and Peñuelas 2014, Lee *et al.* 2012, Gholamhoseini *et al.* 2013, Abbaspour *et al.* 2012, Baslam and Goicoechea 2012, Yooyongwech *et al.* 2016, Augé *et al.* 2015; Pedranzani *et al.* 2016, Duc *et al.* 2018). AM fungi modify the hormonal level such as strigolactones, jasmonic acid (JA) and abscisic acid (ABA) in the host plant under drought stress condition (Fernández-Lizarazo *et al.* 2016). Xu *et al.* (2018) reported that in *Solanum lycopersicum*, inoculation of AM fungi enhanced the expression of 14-3-3 genes (*TFT1-TFT12*) involve in ABA signaling pathway. ABA also influence the conductance of stomata and other physiological process in plants raised under drought stress (Doubková *et al.* 2013). Additionally, the uptake of water by root from soil and its circulation in different part of plant is regulated and facilitated by water channels forming integral membrane proteins called aquaporins (Nehls and Dietz 2014, Quiroga *et al.* 2017, Xie *et al.* 2018). Aquaporin present in all living cell including plant and categories into five subfamilies (Maurel *et al.* 2008; Reuscher *et al.* 2013; Chitarra *et al.* 2016). *Zea mays* plants colonized by *Glomus intraradices* show two aquaporin genes (*GintAQPF1* and *GintAQPF2*) in drought exposed plant (Li *et al.* 2013). Earlier studies revealed that symbiosis of AM fungi regulated the expression of aquaporin encoding gene (*LeNIP3;1*) (Chitarra *et al.* 2016). Contrary to this, in drought condition *Funneliformis mosseae* displayed maximum expression of root *PtTIP1;2*, *PtTIP1;3*, and *PtTIP4;1* of *Poncirus trifoliata* L. and while minimum expression of root *PtTIP2;1* and *PtTIP5;1* gene (Jia-Dong *et al.* 2019). Aroca *et al.* (2007) reported the expression of *GintAQP1* gene was decreased in lettuce roots in water deficit condition, even the root AM colonization was enhanced. Thus, AM fungal association with the host plant either increase or decrease the expression of aquaporin gene however, the function of aquaporin in AM symbioses is still poorly understood.

AM fungi versus Nutritional Deficiency

Nutrient deficiency has been reported to affects the plant growth by changes in chemical composition, pattern of growth and antioxidant activity of plant (Hajiboland 2012). There are two types of nutrient; i. micronutrients and ii. macronutrients. Micronutrients are required in trace amounts for the normal growth and development of plant while macronutrients required in large amounts. AM fungi play an important role in the acquirement of nutrients (Marschner and Dell 1994). AM fungi enhanced the uptake of micro and macronutrients in plant fertilized with low level of nitrogen and phosphorous (Baslam *et al.* 2013, Ortas and Ustuner 2014, Xie *et al.* 2014). The uptake of phosphorus (P) in plants has been well established advantageous effect of AM symbiosis (Karandashov and Bucher 2005, Cardoso and Kuyper 2006, Medina *et al.* 2007). In several plant P transporters (Pi) induced in cortical cells colonized by AM fungi and thus responsible for the transfer of Pi from apoplast to plant cytoplasm (Rausch *et al.* 2001, Harrison *et al.* 2002, Paszkowski *et al,* 2002, Nagy *et al.* 2005). AM fungi also ameliorates the negative effect of low pH of soil by the uptake of P through extensive extraradical hyphae (Muthukumar *et al.* 2014). Likewise, Rohyadi (2008) observed that the maize plant colonized by *Gigaspora margarita* show enhance P uptake under acidic conditions. Contrary to this, it has also been reported that AM fungi not provided benefit to plant under acidic condition (Yano and Takaki 2005, Suri *et al.* 2011; Muthukumar *et al.* 2014). Apart from benefiting effect of P, nitrogen (N) is required for the formation of amino acids, purines and pyrimidines and thus indirectly involved in protein and nucleic acid synthesis. AM uptake and assimilate ammonium (NH^{4+}), nitrate (NO^{3-}) and amino acids in their extraradical hyphae (Ames *et al.,* 1983, George *et al.* 1992, Johansen *et al.* 1992, 1993, 1996; Frey and Schüpp,1993; Bago et al., 1996; Hawkins *et al.* 2000; Hodge *et al.* 2001) and translocate it to the different part of plant (Hawkins *et al.* 2000, Azcón *et al.* 2001; Vazquez *et al.* 2001, Reynolds *et al.* 2005). AM fungi also increase the availability of different forms of N to plants (Hodge *et al.* 2001). Beside the uptake of N, and P, AM fungi also enhanced the acquisition of several mineral nutrients (including Zn Mn, Ca, Fe, Mg and Cu) in plant under acidic condition (Wang *et al.* 1997, Mendoza and Borie 1998). AM fungi play a key role in improvement of uptake of nutrients other than P by altering acquisition mode of the absorbing system (Rhodes and Gerdemann 1980 Gildon and Tinker 1983, Harley and Smith 1983). They have been shown to be involved in the uptake of Cu, Zn and other trace elements having low mobility in soil. They have also been shown to increase iron and sulphate uptake (Rhodes and Gerdemann 1980 Ortas *et al.* 1996, Liu *et al.* 2002) and other nutrients such as Cadmium (Guo *et al.* 1996). Increased uptake of sulphate has been attributed to an improved phosphate nutrition mediated by AM fungi (Harley and Smith 1983).

AM fungi and Cold Stress

Cold stress (temperature <20°C) can also be one of the abiotic factors that affects the plant growth. Cold stress affect the cellular metabolism (Thakur and Nayyar, 2013) and reduced the osmotic potential of cell (Wu and Zou 2010, Chen *et al.* 2013), cause solidification of plasma membrane (Janicka-Russak *et al.* 2012, Chen *et al.* 2013), generate ROS and cause deterioration of protein complexes (Liu *et al.* 2013, Thakur and Nayyar 2013). Additionallly, clod stress also decreases the growth (Sowinski *et al.* 2005; Rymen *et al.* 2007), causes wilting and yellowing of leaf (Thakur and Nayyar 2013) by decreasing the photosynthetic efficiency of the plant raised in cold stress conditions (Farooq *et al.* 2009, Zhu *et al.* 2010a, Abdel Latef and Chaoxing, 2011b). Notably, AM fungi improves the plant growth under cold stress (Gamalero *et al.* 2009; Liu *et al.* 2011, Birhane *et al.* 2012, Chen *et al.* 2013, Liu *et al.* 2013). Beside this, at 5-15°C temperature AM colonization, growth of extraradical hyphae and symbiotic efficiency were suppress (Wu and Zou 2010, Gavito and Azón-Aguilar 2012). Zhu et al. (2010a) reported that the colonization in root by *Glomus etunicatum* did not affected at 5°C for 1 week. It has also been reported by several authors that at low temperature AM inoculated plant show better growth than non-inoculated plants (Zhu *et al.* 2010a, Abdel Latef and Chaoxing 2011b; Liu *et al.* 2011, Chen *et al.* 2013). AM colonization enhanced the chlorophyll content (Zhu *et al.* 2010a, Abdel Latef and Chaoxing, 2011b), increase the protein content (Abdel Latef and Chaoxing 2011b), provoke the accumulation of phenolics, flavonoids and lignin and enhanced the antioxidant activity (Zhu *et al.* 2010, Abdel Latef and Chaoxing, 2011b) in AM colonized plant under cold stress condition (latef *et al.* 2016).

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