Impact of Arbuscular Mycorrhiza on Uptake, Growth, Yield and Water Relations of Vegetable Plants Subjected To Drought Stress: A Review

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ABSTRACT
The need of cultivation expansion in the new reclaimed lands in desert areas requires application of certain practices that could be sustainable for such arid regions. Vegetable plants, in general, are seriously affected by severe drought or even a slight shortage of irrigation water and subsequently their growth, productivity and quality are markedly reduced. Most of vegetable plants can be considered as a host for arbuscular mycorrhizal. As a result of mycorrhizal inoculation, the beneficial effects on vegetables include improving absorption of water and nutrients and enhance tolerance of various environmental stresses including drought. However, this article will focus on the effects of arbuscular mycorrhiza (A mycorrrzia) on growth, productivity, uptake and water relations of vegetable plants under drought stress conditions.

Keywords: mycorrhiza, drought tolerance, water relations, nutrient uptake, growth, yield

Introduction
Shortage of water and low nutrients are major problems that face land reclamation of the desert in many countries. This limits growth and yield of plants including vegetable crops in such conditions. However, Mycorrhizal symiosis with vegetable plants may help avoiding such stressful conditions as mycorrhiza could help plants for better uptake of water and nutrients especially during drought. Davies et al. (1992) found that A mycorrhizal hyphae increased soil water uptake by pepper plants and improved drought tolerance. As mentioned by Badr et al. (2020), eggplants inoculated by A mycorrhiza had better uptake of N and P regardless of drought severity. Moreover, inoculation by A mycorrhiza enhances drought tolerance of vegetable plants and subsequently mycorrhizal plants have better growth and yield (Borde et al. 2012), Baum et al. (2015), Oywole et al. (2017), Lone et al. (2017), Kumar (2019), El-Tohamy et al. (1999), Al-Karaki et al. (2006) and Ruiz-Lozano et al. (1995). Several investigators indicated that A mycorrhiza improved water relations and water use efficiency of vegetable plants during drought (Valle et al. 2018), Davies et al. (2002), El-Tohamy et al. (1999), Borde et al. (2012) and Badr et al. (2020).

This review will focus on the effects of mycorrhiza on drought tolerance, growth and yield of vegetable plants through the effects on uptake of water and nutrients and the effects on water relations during drought. All these effects are also related to growth, yield and quality of vegetable plants during drought.

Effects of mycorrhiza on water and nutrient uptake under drought conditions
Mycorrhiza enhances water and nutrient uptake of plants by its extraradical hyphae which facilitate the uptake from the soil especially under drought conditions. Several investigators indicated these pronounced effects, for example, Borde et al. (2012) found that when garlic plants were inoculated by Arbuscular Mycorrhizal (AM) fungi (Glomus fasciculatum), their growth was enhanced during...
drought as they absorbed more water during drought stress condition by extraradical hyphae which were spread in soil, and this helped in increasing water use efficiency of mycorrhizal garlic plants. Their work indicated that AM fungi helped the garlic plants by absorbing more water and improved plant biomass by minimizing drought stress effect also activating the antioxidant and non-antioxidant defense system to withstand drought condition. However, similar findings were mentioned by Muhsen et al. (2019) who found that the inoculation of onion plants by two types of AMF resulted in increasing plant uptake and protection against drought stress.

In a comparative study by Ruiz-Lozano et al. (1995), specific mycorrhizal fungi had consistent effects on lettuce plant growth, mineral uptake and water use efficiency under either well-watered or drought-stressed conditions.

Also, Davies et al. (1992) indicated that extraradical hyphae development and soil aggregation of VAM plants were improved by drought acclimation and suggested that these hyphae increased drought resistance by facilitating soil water uptake of pepper plants.

In another study on onion plants, Al-Karaki et al. (2006) stated that the improved yield and mineral acquisition due to AM fungi inoculation demonstrated the importance of mycorrhizal inoculation to reduce the effects of drought stress on onion plants grown under field conditions in dry and semi-dry areas.

Moreover, Badr et al. (2020) found that Eggplants plants inoculated with AM+ had a higher uptake of N and P in shoots and fruits regardless of drought severity. They added that soil with AM+ had higher extractable N, P, and organic carbon (OC), indicating an improvement of the fertility status in coping with a limited water supply.

Lone et al. (2017) found that mycorrhiza increased the growth, metabolites and nutrition of carrot plants. Kumar (2019) indicated that nitrogen and phosphorous uptake as well as growth and physiological attributes of chickpea were enhanced by AMF inoculation under drought stress.

Similar findings were achieved by Al-Hmoud and Al-Momany (2017) who found that mycorrhiza increased N in squash roots and P was also enhanced. On the other hand, Wang et al. (2008) found increased concentrations of N and P in roots and Mg, Cu and Zn concentration in shoots of cucumber by inoculation of mycorrhiza. Moreover, according to Ruiz-Lozano and Azcon (1996), mycorrhizal lettuce plants had higher nitrate reductase activity than the uninoculated treatments, particularly under water stress conditions. They concluded that drought stress decreased nitrate reductase activity, but much less in mycorrhizal than in uninoculated plants. They suggested that this effect may be a factor in the drought tolerance of mycorrhizal plants.

Effects of mycorrhiza on water relations and water use efficiency under drought conditions:
Vegetable plants inoculated with mycorrhiza show improved water status and water relations during drought and this enhances their drought tolerance. The extraradical hyphae of mycorrhiza improve uptake of water and nutrients of inoculated vegetable plants. Many researchers indicated these effects. For example, Davies et al. (2002) found that pepper plants colonized with mycorrhiza had enhanced drought resistance, as indicated by higher Ψleaf and fewest plants with visible wilting during peak drought stress. A higher root/shoot ratio occurred with mycorrhizal plants (despite equal total plant biomass among droughted plants), which may have also contributed to drought resistance.

As found by Valle et al. (2018), the leaf water potential of Cucurbita pepo was increased only by mycorrhiza under drought conditions, even under high salinity, mycorrhiza increased aerial dry weight and osmotic potential compared to non-mycorrhizal plants. They revealed that plants inoculated with native AMF, which supposedly diminish the effects of stress, exhibited low construction costs, increased photochemical capacity, and grew larger external mycelia in comparison to the exotic inoculum.

Borde et al. (2012) found that garlic plant inoculated with Arbuscular Mycorrhizal (AM) fungi Glomus fasciculatum showed improved plant growth shoot length and biomass during drought stress condition. The mycorrhizal garlic plants were absorbing more water during drought stress condition by extraradical hyphae which were spread in soil, this helps increasing water use efficiency of mycorrhizal garlic plants. Their work suggests that AM fungi helps the garlic plants by absorbing more water and improved plant biomass by minimizing drought stress effect also activating the antioxidant and non-antioxidant defense system to withstand under drought condition. In root, proline accumulation was
higher in AM garlic plants. They suggest that AM fungi help the garlic plants to greater osmotic adjustment under drought stress condition.

The improvement of water use efficiency by A mycorrhiza is also indicated in lettuce plants (Ruiz-Lozano et al., 1995). They suggested that the fungi were able to induce different degrees of osmotic adjustment. Other effects were also indicated including consistent effects on transpiration, stomatal conductance, and proline accumulation under either well-watered or drought-stressed conditions.

Similar results were obtained by Yooyongwecha et al. (2016) as they concluded that inoculation of AMF in sweet potato plants improved plant growth characteristics and enhanced water deficit tolerance via soluble sugars and free proline accumulation.

Effects of mycorrhiza on growth and yield under drought conditions:

It is believed that A mycorrhiza inoculation of vegetable plants help them tolerate drought conditions and subsequently inoculated vegetables have higher growth and yield. Generally, Begum et al. (2019) stated that mycorrhiza provides host plants with essential inorganic nutrients and thereby growth and yield of inoculated plants improved under both stressed and unstressed regimes. As indicated by Oyewole et al. (2017), mycorrhizal treated cowpea withstand the water stress and produced high yield. The simultaneous inoculated plant was the most effective in reducing disease severity. However, simultaneous treatment of G. deserticola, G. gigantea and M. phaseolina were most effective for both growth parameters and reduction of disease severity. On the other hand, Wang et al. (2008) indicated that under normal conditions, the growth of cucumber seedlings was significantly enhanced by G. mosseae, inhibited by G. versiforme, and not significantly influenced by G. intraradices. The dry weight of seedlings inoculated with G. mosseae was 1.2 times its counterparts. The concentrations of N and P in roots and Mg, Cu and Zn concentration in shoots were increased by inoculating the three AMF. They found that the weights of single fruit of plants preinoculated with G. mosseae and G. versiforme were about 1.4 and 1.3 times higher than those from the uninoculated treatment, respectively.

In a different study, Xiuxiu et al. (2019) found that plant height, stem diameter, fresh and dry weight of cucumber seedlings were improved by mycorrhizal inoculation and significantly improved the root activity, chlorophyll content and photosynthetic rate of cucumber seedlings. However, enhancement of growth and yield in response to A mycorrhiza was evident for many vegetable crops under drought conditions such as garlic (Borde et al., 2012), lettuce (Ruiz-Lozano et al. 1995), onion (Al-Karaki et al., 2006), eggplant (Badr et al., 2020), bean (El-Tohamy et al., 1999), carrot (Lone et al., 2012) and chechpea (Kumar, 2019). Also, Cakmakci et al. (2017) found that mycorrhiza improved the physiological and photosynthetic parameters of inoculated melon plants compared with non-AMF plants in water deficit conditions. Moreover, AM Fungi increased the chlorophyll content of melon seedlings. Their results indicated that AMF can ameliorate the tolerance to deficit irrigation in melon seedlings.

Conclusion

Mycorrhizal symbiosis with vegetable plants improves drought tolerance as the extraradical hyphae in the soil enhances nutrient and water uptake. These effects were evident for most vegetable plants especially when subjected to drought stress. As a result, vegetable plants inoculated with mycorzial have better water status as indicated by improved leaf water potential, relative water content and osmotic potential. Other physiological changes are also indicated including its effect on osmotic adjustment, proline accumulation, chlorophyll content, photosynthesis and stomatal conductance. Under drought conditions, the beneficial effects of mycorrhiza on water relations and uptake are reflected on growth, productivity and quality of vegetable plants. However, Arbuscular mycorrhiza can provide an excellent solutions to improve productivity and quality of vegetables under arid and semiarid regions.
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