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A review on antioxidant activity mechanisms for tolerance to water-deficit stress in wheat inoculated with arbuscular mycorrhizal fungi

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Abstract
The present review emphasized on the demand is much higher than the availability for wheat which is projected to continue to grow over the coming decades, particularly in the developing world to feed an increasing population and with wheat being a preferred food, continuing to account for a substantial share of human energy needs in 2050. Biofertilizers are applied in the agricultural field as a replacement to our conventional and synthetic fertilizers. Bio-fertilizers are one of the best modern tools for agriculture that is used as sources to improve plant nutrients in sustainable agriculture. *Arbuscular Mycorrhizae* (AM) fungi provide a variety of benefits to their hosts, including increased nutrients uptake under low input condition. Water uptake may be improved by mycorrhizal association, making more resistant to drought condition that ultimately causes to increase quality of wheat. In order to study in this review antioxidant status of wheat to bio-inoculants application under water limitation condition, Treatments included water limitation, but activity of catalase (CAT), peroxidase (POD) and proline content were increased. Similar results were observed in CAT and POD activities due to bio fertilizers and AM fungi application. Besides the water limitation effects, generally, it was concluded that the application of bio fertilizers can be a proper tool for increasing wheat yield under water limitation. Antioxidants status like hydrogen peroxide, catalase, peroxidase, total soluble sugar, proline content, total soluble protein and peroxidase activity showed increasing trends with drought condition or deficit moisture levels whereas. The similar response was observed with bio-inoculants having AM fungi with recommended dose of fertilizers.

Keywords: antioxidant activity mechanisms, tolerance, water-deficit stress, arbuscular mycorrhizal fungi

Introduction

Wheat as an important cereal

Wheat is one of most important cereal crop and considered as a staple food of the vast majority of the human population including urban and rural societies as well as major source of straw for animal feeding (Sharma *et al.*, 2012) [20]. Wheat is one of the world's most important food crop providing 20% of all calories and 20% of all protein in developing and developed countries (http://faostat.fao.org). It is major source of starch, protein, sugar and provides food for human population (Liu *et al.*, 2016 and Yu *et al.*, 2017) [35]. It plays a key role in economic activity about 45% of global population and changes in consumption preferences so; there has been need to substantial increase in demand for wheat during the past 50 years worldwide.

According to the most recent, the global population has quadrupled, there are 7.3 billion people and we may reach 9.7 billion by 2050 (Schierhorn *et al*., 2016) [26]. The average global yield of cereal for 2017 forecasted is 2594 million tonnes in which 743.2 million tonnes are wheat. Global food security is being haunted by the rapid increase in population and drastic changes in the climate (Lesk *et al*., 2016) [17]. Food demand is expected to increase from 59% to 98% by 2050. So, 1.6% annual increase is required to fulfill increasing demand of food for growing population. According to the report of The International Food Policy Research Institute, 2015, nearly one in nine people worldwide are chronically undernourished and 3.1 million children die of malnutrition each year. The growing population will result in considerable additional demand for food and it will also contribute towards changing climate, which is an alarming issue to the world's food safety.

Wheat response to drought stress

Currently, the scarcity of water is a problem seen around the world and it is expected that climate change will accelerate the severity of droughts (Lizarazo *et al.*, 2016) [19].

The reduced precipitation and changed rainfall patterns are also causing the frequent onset of drought condition (Lobell *et al.,* 2011) [21]. Mainly water is considered as one of the most important components for plants to perform biological activities.

At present, drought stress has become the main one in abiotic stresses, and could restrain growth and yield of wheat (Gong, 2014). Now, it becomes an increasingly severe problem in many regions of the world.

Drought being the most important environmental stress severely impairs plant growth and development, limits the performance and productivity of wheat plants more than other type of environmental factors such as high temperature, high salinity and heavy metals (Song *et al.,* 2011) [29].

Drought stress mainly affects plant growth and nutrition and it results in reduced photosynthetic activity and an increase in oxidative stress in plants that induces an array of antioxidant enzymes (Ortiz N. *et al.,* 2015). During drought, the plant suffers from dehydration of cells and tissues.

The effect of drought on crop plants is complex and responds with many protective adaptations. In plants, metabolism of reactive oxygen species (ROS), such as superoxide radicals, hydrogen peroxide and hydroxyl radicals is kept in dynamic balance. Under water stress conditions, the balance is broken and antioxidant systems are needed to decrease the damage to tissues peroxidase (POX), antioxidants include superoxide dismutase (SOD) and catalase (Ahmed *et al.,* 2008). AM fungi protected host plants against oxidative damage was due to increments of enzymatic antioxidants. Water deficiency is generally considered as one of the limiting factors for crop productivity which directly affects physiological and biochemical processes in wheat. So, there is critical need to balance water availability, water requirement and water consumption (Song *et al.,* 2001). Thus, the water conserving is becoming a decisive consideration for agricultural practices.

Implication of drought stress

Water-deficit stress is the most important abiotic stress that limits plants growth and development (Yang *et al.,* 2008) [33]. In the agricultural use of water is limited, resulting in an increase in areas affected by water deficits, causing significant losses in crops and reducing average yields by more than 50% (Wang *et al.,* 2003) [31]. For these reasons, water-deficit stress is the most important.

One of the main effects of water-deficit stress on plant development is related to a restriction in water uptake and, therefore, in the nutrient uptake (Sardans *et al.,* 2007). Since crops production and, therefore, food security depend on the management of limiting factors, it is necessary to develop efficient strategies that allow for the improvement of crop yield under water-deficit stress (FAO, 2012).

Much effort is being made by agricultural researchers around the globe to reduce water use by crops to address the challenges that especially affect farmers in drought-prone environments across the developing world. By 2025, around 1800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions (FAO Water; www.fao.org/nr/water/issues/scarcity.html).

Recently, it has been observed that the symbiotic interaction of plants with AM fungi, in addition to being important from the agricultural and ecological point of view (Yang *et al.,* 2008) [33], it could be a sustainable mitigation practice for water deficit stress (Aroca, 2012).

Sustainable Farming

Sustainable production of food requires new approaches to enhance the use efficiencies of all inputs, including water and nutrients. These approaches are vital not only to achieve enhanced agricultural productivity, but also to protect environmental quality (Saeidnejad *et al.,* 2013). Exploiting and increasing production in these areas are necessary to bridge the gap between production and consumption. Therefore, food security depend on the management of limiting factors, it is necessary to develop efficient strategies that allow for the improvement of crop yield under water-deficit stress (FAO, 2017) [11].

AM fungi are especially important for sustainable farming systems because AM fungi are efficient when nutrient availability is low and when nutrients are bound to organic matter and soil particles (Rigi et al., 2014) [23]. Many important agricultural crops can benefit from AM fungi, including wheat, maize, potato, sunflower, onion, leek and soybean, especially under conditions where nutrient availability is limiting plant growth. Moreover, AM fungi not only can promote via directs effects, but there are also a number of indirect effects such as a stimulation of soil quality and the suppression of organisms that reduce crop productivity (Dodd, 1983) [10].

To alleviate the problem of drought stress, there are many strategies like nitrogen fertilizers, seed hardening, development of resistant genotype and use of antitranspirants and alcohol. On the other hand bio-fertilization of wheat by nitrogen fixing bacteria received a great attention from the last decades (Almagrabi and Abdelmoneim, 2014).Bio-fertilizers are products of different type of microorganisms which have an ability to convert nutritionally important elements from unavailable to available form through biological processes (Kaur *et al.,* 2014) [16].

Wu *et al.,* put forward a hypothesis that AM fungi protected host plants against oxidative damage was due to increments of enzymatic antioxidants. AM fungi are major component of rhizosphere micro-flora in ecosystem and have been reported obligate symbiotic association with most of angiosperm plants (Soha *et al.,* 2015).

Antioxidants activity mechanism

Under drought conditions, plant requires antioxidant systems would able to work in a coordinate form to provide the best scavenging systems and plant defense. Peroxidation of membrane lipids is an indicator of oxidative stress in plants and hence determination of malondialdehyde in plants reflects the extent of oxidative damage (Anjum *et al.,* 2011) [5].

The ROS content reduced in plants colonized with AM fungi under various abiotic stresses as studied in wide range of species like maize, lettuce, rice, chickpea and wheat (Li *et al*. 2012). It might be due to the protective role of bio-inoculants under abiotic stress.

Beltrano *et al.,* 2008 reported that SOD catalyzes the dis mutation of superoxide into molecular oxygen (O_2^-) and H_2O_2 that will be subsequently dis muted into H_2O and oxygen by catalase. The catalase activity was more reduced in the plants associated with the most beneficial microbial treatments and this suggests that APX is important in H_2O_2 scavenging and may be the result of a higher reduction in the oxidative stress (Maheshwari and Dubey, 2009). However, the coordination between different antioxidant activities for ROS removal network of plants is complex and the cooperation between them may be critical in the stress response.

Microbial inoculants applied play an important role in orchestrating antioxidant activities in shoot and roots of associated plants in the process of drought tolerance. These results indicate the different capacity to efficiently detoxify ROS in the production site according to microbial inoculants applied.

Lipid peroxidation is expressed as malondialdehyde (MDA) content which is a decomposition product of polyunsaturated fatty acids hydrogen peroxides, has been utilized very often as a suitable biomarker for lipid peroxidation, which is an effect of oxidative damage. The amount MDA has also been reported to be reduced in chickpea when colonized with *Glomus* species under drought stress (Sohrabi *et al*. 2012).

Benhiba *et al.* (2015) observed that under drought stress MDA content was found to be lower in AM fungi treated leaves than untreated leaves of date palm. Similar results were also observed in pistachio plants (Abbaspour *et al.* 2012) [1], in citrus seedlings (Wu *et al*. 2006) [32], under drought stress.

Plants with high level of antioxidants, either constitutive or induced have been reported to display greater resistance to oxidative damage caused by environmental stresse.

Fattah *et al.,* 2013 found that the mycorrhizal inoculation treatments increased proline and protein levels of wheat plants as compared with the untreated plants.

The increment of proline content is always high in mycorrhizal plants then nonmycorrhizal ones and increases with the stress level and the proline content of nonmycorrhizal plants increases of 155% and 269% for average and severe water stress respectively, by inoculation it increases of 107%, 623% and 875% for low, average and severe water stress respectively. The increase in proline on leaves is a good indicator of the exposure of plant to water stress in wheat (Abdelmoneim *et al.*, 2014).

Proline is an important compatible osmolyte normally produced in higher plants in response to environmental stresses (Rhodes *et al.,* 1999). Accumulation of proline increased considerably in wheat plants as a consequence of water stress and mycorrhizal inoculation (Ahmed *et al.,* 2008).

Drought tolerance can be mediated by biochemical compounds such as amino acids like proline, organic acids and sugars by acting as compatible solutes to maintain cellular functions production of sugar and proline was increased.

Farshadfar *et al.,* 2014 reported a positive correlation between the degree of proline accumulation and drought tolerance. Wheat genotypes having more accumulation of proline under drought have ability to bear drought. This phenomenon varies among the wheat genotypes because different genotypes have variable water stress threshold. Hence, proline accumulation is a useful trait for selecting drought tolerant wheat genotypes.

According to Kadam *et al.,* 2017 [15], proline plays an important role in water stress tolerance mechanism in plants due to its ability in opposing oxidative stress and this is considered as the most important strategy in plants to overcome water deficit effects and due to its ability in opposing oxidative stress and considered this as the most important strategy in plants to overcome water deficit effects. Proline, now considered as a potent antioxidant and potential inhibitor of programmed cell death.

The increase of the soluble sugars in water deficient in wheat could be attributed to the stimulation of conversion of starch in sucrose at the carbon dioxide compensation concentration presumably for osmotic adjustment (Shao *et al.*, 2009), helping the movement of water and it may also contributes to maintain the size of metabolic pools of the photosynthetic carbon reduction cycle.

Chaudhari *et al.,* 2017 observed that the soluble carbohydrate concentration in well-watered wheat plants was lower than those of stressed plants and exhibited drought tolerance and accumulate higher concentration free proline, total soluble sugars and potassium content, hence accumulation of these organic and inorganic substances help to maintain osmo-regulation under water stress, moreover higher concentration of these solutes gives advantage tolerate under drought stress meanwhile other wheat genotypes (Huang *et al.,* 2006).

The colonization of roots by AM fungi in various plant species induces proline accumulation when water is limiting (Ruiz-Lozano *et al*. 1995 and Yooyongwech *et al.* 2013). The enhanced accumulation of proline in these studies was linked to AM fungi-induced drought resistance where proline acts as osmoprotectant. Conversely, in several studies, proline content increased in response to water deficit, a lower accumulation of proline has also been observed in mycorrhizal plants relative to nonmycorrhizal counterparts (Ruiz-Sanchez *et al*. 2010; Abbaspour *et al*. 2012; Asrar *et al*. 2012) [1], suggesting that AM fungi symbiosis enhanced host plant resistance to drought.

Total soluble sugar is one amongst the most important cyto-solutes and accumulates in higher plants during the adaptation to various abiotic stresses especially during drought stress (Vendruscolo *et al.,* 2007).

In wheat, Ashraf and Mehmood (1990) reported that higher degree of drought resistance was associated with higher proteins content. However, the nature of plant species and the type of tissue modulate the concentration of soluble proteins under water stress.

Antioxidative system or Avoidance of oxidative stress through preventing ROS accumulation as the most effective approach used by mycorrhizal plants to cope with drought stress (Ruiz-Lozano 2003 and Abbaspour *et al*. 2012) [24, 1]. Among the antioxidant enzymes, SOD constitutes the first line of defense against ROS, it converts $O_2^{\cdot -}$ into H_2O_2 which is then eliminated by catalase (CAT), peroxidase (POX) that dismutase H_2O_2 into water and oxygen (Sharma *et al*. 2012) [20]. Plants with high level of antioxidants, either constitutive or induced have been reported to display greater resistance to oxidative damage caused by environmental stresses. Within a cell, it constitutes the first line of defense against ROS.

Abo-Ghalia 2008 [2] showed that the treatment with these fungi increased the accumulation of some metabolic products (proline; free amino acids; crude and soluble proteins; total carbohydrates; soluble and insoluble sugars) and enhanced the induction of some defense enzymes (peroxidase and catalase) in wheat plants, which may be attributed to the improvement in the osmotic adjustment. The mycorrhizal inoculation significantly increased the contents of some metabolites (proline; free amino acids; total soluble and crude proteins; total carbohydrate; total soluble and insoluble sugars) in wheat plants and enhanced the activities of some antioxidant enzymes such as peroxidase (POX) and catalase (CAT) as compared with stressed control, especially at heading stage of plant growth. Catalase activity was significantly higher in drought tolerant cultivar.

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