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Efficacy of ascorbic acid as a cofactor for alleviating water deficit impacts and enhancing sunflower yield and irrigation water–use efficiency

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ABSTRACT

Ascorbic acid (AsA) is considered as one of the most important and profusely known occurring water soluble antioxidants in plants, however, it is not well known to what extent this antioxidant might contribute in alleviating the adverse effects of water deficit on plant growth, yield and irrigation water use efficiency (IWUE). In attempt to clarify whether exogenous application of AsA could alleviate the adverse effects of water deficit on sunflower plants, two seasons (2014 and 2015) of field experimentation were conducted using six combinations of two AsA levels ($AsA_{(-)}$ and $AsA_{(+)}$, i.e. zero and 450 ppm AsA, respectively) and three irrigation water amounts (I_{100}, I_{85}, and I_{70}, i.e. 100, 85 and 70% of crop evapotranspiration, respectively). Under water shortage, leaf chlorophyll content increased but proline content lowered in AsA–treated plants compared to the untreated ones. Lower values of LAI, head weight, seed yield ha^{-1}, and oil yield ha^{-1} were recorded with decreasing water supply, while the highest values were gained when supplying plants with sufficient water (I_{100}) plus application of AsA (i.e. $AsA_{(+)}$), i.e., $I_{100}AsA_{(+)}$. Plants under the latter treatment grew well and possessed higher yields compared to that of suffering from deficit water without AsA application, i.e. $I_{85}AsA_{(-)}$ or $I_{70}AsA_{(-)}$. Head weight and seed as well as oil yields ha^{-1} produced in 2014 season under sufficient water supply without AsA application ($I_{100}AsA_{(-)}$) could be achieved under moderately water–stressed condition in conjunction with applying AsA ($I_{85}AsA_{(+)}$). Implication of AsA tends to minimize the reduction in seed yield due to insufficient water supply, where $I_{85}AsA_{(+)}$ and $I_{85}AsA_{(-)}$, each saved same percentage of water (15.0%) but the reduction in seed yield associated the former treatment was less than that under the latter one. On the other hand, IWUE reached the maximal values in both seasons under $I_{100}AsA_{(+)}$ treatment but, however, without marked differences in comparing to those recorded $I_{85}AsA_{(+)}$ in 2014 season. Moreover, the differences in IWUE values exhibited by $I_{100}AsA_{(-)}$ and $I_{85}AsA_{(+)}$ did not reach the $P < 0.05$ level of significance in 2015 season, which could reveal the positive role of AsA in alleviating water stress.

1. Introduction

Plants in nature are continuously exposed to several biotic and abiotic stresses. Due to the detrimental impacts of these stresses food productivity is decreasing; therefore minimizing these losses is a major area of concern to ensure food security. Among biotic and abiotic stresses that plants encounter, drought stress is one of the most adverse factors of plant growth and productivity and considered a severe threat for sustainable crop production in the conditions on changing climate (Anjum et al., 2011).

Sunflowers are grown in warm to moderate semi–arid climatic regions of the world from Argentina to Canada and from central Africa to the Commonwealth of Independent States (FAO, 2010). Sunflower is one of the fantastic oil crops has strategic ballast in human nutrition in Egypt and worldwide as well. Its oil is mightily desired not only for human consumption but for chemical and cosmetic industries also. Great assertion must be given towards such crop in attempting to close the gap between oil production and consumption. So, boosting productivity is considered the optimal solution, but water shortage is a major yield limiting factor.

Growing menaces of freshwater shortage and more continual and cruel drought due to climate change has catalyzed research into water–saving irrigation strategies aiming at producing more ‘crop per drop’ (Dodd, 2009; Morison et al., 2008). Thus, the usage water below full crop–water requirements is considered one of the substantial tools to face scarce water supplies through lowering irrigation water amounts (Fereres and Soriano, 2007; Kang et al., 2000). Such strategy designed to improve water savings in agriculture (Bashir and Mohamed, 2014)

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but it should be managed with a crop in mind. In addition, usually using less irrigation water amounts synchronizes with yield and water use efficiency (WUE) reductions. Several studies indicated that with water stress the shortage in sunflower growth and yield is realized. Significant reductions in plant height and plant dry matter (Ahmad et al., 2009), leaf area index (Karam et al., 2007), net photosynthetic rate (Dekov et al., 2000) and weight of 1000 seeds, head diameter and seed yield (Chimenti et al., 2002; Erdem et al., 2006; Roshdi et al., 2006) occurred due to water stress. Under drought stress, sunflower seed yield reduced by 83.0% (Jabari et al., 2007). With 36% deficit in. irrigation water, 15% decrease in sunflower yield occurred (Sezen et al., 2011).

Several reactive oxygen species (ROS), such as superoxide radical (O_2•−), hydroxyl free radical (OH•), singlet oxygen ($^1O_2$) and hydrogen peroxide (H_2O_2), are continuously produced as byproducts of plant cellular metabolism (Mahalingam and Fedoroff, 2003; Mittler et al., 2004). However, various environmental stresses lead to excessive production of ROS causing redox imbalance, progressive oxidative damage, peroxidation of plasmalemma, DNA mutation, protein denaturation, and ultimately cell death (Fridovich, 1998; Sharma et al., 2012). It is well documented that various abiotic stresses (including drought, excess light, temperature extremes, ultraviolet radiation, salinity) lead to overproduction of ROS. Elevated levels of ROS lead to the inactivation of proteins and inhibit the activity of multiple enzymes involved in metabolic pathways, and result in the oxidation of other macromolecules including lipids and DNA (Hossain et al., 2014). ROS may affect cell membrane properties and cause oxidative damage to proteins, lipids, nucleic acids, carbohydrates which ultimately results in cell death (Gill and Tuteja, 2010). Thus, it is a quite indispensable to quench the surplus ROS for plant growth and development. However, as a defense for survival, plants developed non–enzymatic antioxidants and the enzymatic scavenging systems to detoxifying ROS (Mittler, 2002; Mittler et al., 2004). Indeed, plant cells are equipped with excellent antioxidant defense mechanisms to detoxify the harmful effects of ROS. The antioxidant defenses could be either non–enzymatic (including ascorbic acid, carotenoids, glutathione, proline and α–tocopherols) or enzymatic (e.g. superoxide dismutase, catalase, ascorbate peroxidase, glutathione reductase, monodehydroascorbate reductase, dehydroascorbate reductase, glutathione peroxidase, guaicol peroxidase, and glutathione–S–transferase). These very efficient antioxidant defense systems work in concert to control the cascades of uncontrolled oxidation and protect plant cells from oxidative damage by scavenging of ROS (Gill and Tuteja, 2010).

The biochemical functions of ascorbate or ascorbic acid (AsA), also commonly known as "vitamin C", involve its roles as an antioxidant, enzyme cofactor, and electron transport (Prasad and Upadhyay, 2011). AsA directly neutralizes ROS by acting as a secondary antioxidant during the reductive recycling of the oxidized form of α–tocopherol (Noctor and Foyer, 1998). In plants, AsA and glutathione are the most abundant soluble antioxidants and are the major antioxidants in photosynthetic and non–photosynthetic tissues. They are able to detoxify ROS by a direct scavenging or by acting as cofactors in the enzymatic reactions that involved ascorbate peroxidase and glutathione reductase enzymes (Laspina et al., 2005). Ascorbic acid treatment reduced the damaging action of drought and decreased enzyme activity due to scavenging of reactive oxygen species; thereupon it may be effective for the improvement of stressed maize plants in arid and semi-arid regions (Dolatabadian et al., 2009). Moreover, Aziz et al. (2018) recorded remarkable enhancement in quinoa plants growth with application of AsA being reduced adverse effects of drought stress.

The objective of this study was to evaluate whether treatment of AsA could mitigate the adverse effects imposed on sunflower productivity due to water deficiency and boosting irrigation water use efficiency (IWUE). Besides, determination of the possibility of inclusion of AsA in crop irrigation programs as an antioxidative defender to support plants exposed to periods of water stress in areas with limited water resources.

2. Material and methods

2.1. Site description

Over two years, a field experiment was conducted during 2014 and 2015 seasons at the experimental farm of National Research Centre, El Nubaria region, El Behaira Governorate, Egypt (latitude 30° 30 1.4` N, longitude 30° 19 10.9` E, and mean altitude 21 m above sea level). The soil was sandy with pH 8.3 and salt content 0.38 dS m^{-1} which measured as described by Jackson (1973). Physical properties and water status of the experimental soil are presented in Table 1. The study area belongs to arid regions with no rainfall and hot dry in summer (April–September). Table 2 illustrates monthly mean weather factors, i.e. maximum and minimum air temperature, relative humidity, wind speed and solar radiation for 2014 and 2015 seasons obtained from Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation, Egypt. The preceding cultivated crop was wheat in both seasons.

Table 1
Physical properties and water status of the soil at El Nubaria region.

Depth (cm)	Particle Size distribution, %				Texture class	θ_S % on weight basis			BD (g cm^{-3})
	Coarse Sand	Fine Sand	Silt	Clay		FC	PWP	AW	
0-15	8.4	79.6	6.5	5.5	Sandy	12	4.1	7.9	1.55
15-30	8.5	78.9	7.2	5.4	Sandy	12	4.1	7.9	1.58
30-45	8.6	78.5	7.8	5.1	Sandy	12	4.1	7.9	1.62
45-60	8.9	77.6	7.6	5.9	Sandy	12	4.1	7.9	1.62

FC, Field capacity, PWP, Permanent wilting point, AW, Available water, HC, Hydraulic conductivity, BD, Bulk density.

Table 2
Means monthly minimum and maximum temperature, relative humidity, wind speed and solar radiation of El Nubaria region in 2014 & 2015[a].

Month	Minimum air temperature (°c)	Maximum air temperature (°c)	Relative humidity (%)	Wind speed (m sec–^{1})	Solar radiation (MJ m–^{2}day–^{1})
2014					
April	16.12	29.62	48.60	0.72	21.71
May	19.36	32.84	46.26	0.78	21.17
June	22.00	35.22	47.70	0.86	23.64
July	23.58	35.59	55.71	0.96	23.09
August	24.36	36.41	56.23	0.84	21.90
September	22.75	34.58	53.47	0.72	19.71
2015					
April	14.32	26.03	46.57	0.77	25.11
May	14.64	27.02	47.97	0.79	25.57
June	17.30	28.63	50.15	0.92	26.15
July	19.20	30.63	55.24	0.77	26.81
August	22.25	33.62	50.90	0.61	23.15
September	20.47	32.78	52.10	0.42	18.97

[a] Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation, Egypt.

2.2. Experimental design and procedures

The present study aimed to investigate the interactive performance of ascorbic acid (AsA) and irrigation water levels on sunflower (*Helianthus annuus*) yield and IWUE under the environmental conditions of the studied area, El Nubaria region. As shown in Fig. 1, the experiment was established within split plots in a randomized complete block design, in four replicates, where irrigation levels were arranged in the main plots and ascorbic acid treatments were allocated in the sub–plots. The experimental unit area was 12.25 m^2, involving five ridges each of