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Efficacy of Ascorbic Acid as a Cofactor to Increase Irrigation Water-Use Efficiency (IWUE) and Mung Bean (*Vigna radiata* L.) Yield

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ABSTRACT

Ascorbic Acid (AsA) is a water-soluble antioxidant that makes plants resistant to environmental stresses by neutralizing free radicals. However, it is unknown to what extent this antioxidant may help Improve Irrigation Water Use Efficiency (IWUE) and reduce the adverse effects of water deficit on mung bean growth and yield. In an attempt to clarify whether exogenous application of this antioxidant could alleviate the adverse effects of water deficit on mung bean plants, two seasons (2019 and 2020) of field experiments were conducted using twelve combinations of three AsA levels (distilled water as a control and 10 and 20 mM of AsA) and four irrigation water amounts (25, 50, 75, and 100% of the plant water requirement). Based on the results, the maximum IWUE was obtained with $W_{50}AsA_{20}$ in the two seasons. The beneficial effect of AsA application on IWUE was determined under water stress conditions (W_{50}). High water deficit (W_{50}) plus applying 20 mM ascorbic acid, i.e. $W_{(50)}AsA_{(20)}$ treatment, improved seed yield about 43.7% as in the two seasons compared to high water deficit without ascorbic acid, i.e. $W_{(50)}AsA_{(0)}$. In 2019 and 2020, water saving in $W_{(50)}AsA_{(20)}$ compared to the control, was equal to 50% (2,550 and 2,500 m^3 ha^{-1}, respectively). In $W_{(50)}AsA_{(20)}$ treatment, the increase of seed yield ranged between 79-107% in both seasons. Thus, the results reveal the potency of AsA to save water under low water supply and increase yield in mung bean fields.

Keywords: Mung Bean yield, Water deficit, Water saving.

INTRODUCTION

The growing threat of freshwater scarcity and persistent drought in recent years due to climate change has accelerated research on diverse irrigation management strategies and water conservation to produce more "crop per drop" (El-Bially *et al*., 2018; Li *et al*., 2022). Therefore, considering the method that leads to less water consumption and meets the full need of the crop for water is considered one of the basic tools to deal with scarce water resources by reducing the amount of irrigation water. Identifying these strategies in all products is very important due to the diverse morpho-physiological characteristics (Wang *et al*., 2023; Shirzad *et al*., 2022). Water scarcity is a major agricultural and developmental challenge for the drylands. Many of these regions are faced with growing food insecurity associated with water shortage and erratic rainfall patterns, high population growth, and dwindling land productivity (Bwambale *et al*., 2022). Iran has different climatic and geographical zones, mostly arid and semi-arid, which are suffering from land degradation. The scarcity of water, as well as the excessive use of water resources, mainly for agriculture creates negative water balances and changes in plant cover and accelerates desertification (Emadodin *et al*., 2019).

Mung bean (*Vigna radiata* L.), known as a traditional soybean food, has been used as a

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nutritional food and herbal medicine for more than 2000 years (Qin *et al*., 2022). This plant is an outstanding short-term legume crop, whose cultivation is expanding in most countries of the world due to its antioxidants, high protein, fibers, and nutrient profiles (Alghabari, 2020). Mung bean is one of the most economically important food legumes and provides part of the food requirement that grows in tropical and subtropical regions and is eaten by more than billions of people in the world (Rachaputi *et al*., 2019). Due to the importance of mungbean as a product to provide a part of human food needs, it is included in the human diet in many countries of the world. Therefore, there is a need to investigate solutions to improve its production, economic value, and reducing the effects of drought (Kang *et al*., 2014). Drought stress has a profound effect on plant ecological systems (Jaleel *et al*., 2007). Plant reactions to drought stress at different levels depend on the intensity and duration of the stress as well as on the plant species and its growth stage (Jayakumar *et al*., 2007). Knowing the response of plants to drought is of great importance and is a fundamental part of finding a solution to increase the tolerance of agricultural plants to water stress (Reddy *et al*., 2004). As an antioxidant, AsA is dependent on chloroplasts, where the effect of oxidative stress on photosynthesis is reduced. In addition, AsA reduces the change in cell division and acts as a primary substrate in the cyclic pathway of hydrogen peroxide enzymatic detoxification. Also, AsA is one of the important non-enzymatic antioxidants that play an essential role in several key metabolic processes and acts as a powerful antioxidant (Akram *et al*., 2017). AsA is commonly referred to as vitamin C. In several studies, for example, common beans (Gaafar *et al*., 2020), chickpeas (Akram *et al*., 2018), rape (Shafiq, 2014) and corn (Dolatabadian *et al*., 2010), it is known as a factor for regulating stress tolerance in plants. In addition, AsA acts as a cofactor alongside enzymes that work in various metabolic pathways (Rigano *et al*., 2017). According to research conducted by Naz *et al*. (2017), AsA is very effective in protecting proteins and lipids in plants exposed to water deficit and higher salinity regimes. Gaafar *et al.* (2020) concluded that enhanced water stress tolerance through adequate AsA application is a promising strategy to increase the tolerance and productivity of common beans under water stress. Previous research showed that AsA application under water stress increased chlorophyll a, chlorophyll b, and/or total chlorophyll contents (Madany and Khalil, 2017). Hussein and Khursheed (2014) showed that AsA protected photosynthesis and enhanced leaf photosynthetic pigments under drought conditions, controlling dry matter accumulation. In stressed plants, AsA performs a crucial function in maintaining several metabolic processes. In addition, exogenous application of AsA improved plant performance under water stress and increased crop yield in common bean (Gaafar *et al*., 2020), maize (*Zea mays*) (Dolatabadian *et al*, 2010), and wheat (*Triticum aestivum*) (Hafez and Gharib, 2016). As mentioned, Iran is located in a dry and semi-arid region. In recent years, drought has affected the agricultural sector and the yield of products. According to the results of the aforementioned research, AsA has played an effective role in increasing the tolerance of plants to drought stress. Considering this importance, the present research in the Safi Abad region of Dezful, which is also facing drought, aimed to evaluate the effect of AsA foliar application on the Irrigation Water Use Efficiency (IWUE) and reduce the adverse effects of water deficit on mung bean growth and yield

MATERIALS AND METHODS

Site Description

A field experiment was conducted in 2019 and 2020 in the research farm of Safi Abad Natural Resources, Education, and Research

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Center, Dezful, Khuzestan Province, Iran (longitude 48 degrees E and latitude 32 degrees N, and 82 meters above sea level). The soil was clay loam with pH 7.1, and electrical conductivity 0.99 ds m^{-1}. The physical properties and water status of the experimental soil are presented in Table 1. Table 2 illustrates monthly mean weather factors, i.e. maximum and minimum air temperature, relative humidity, wind speed and sun shine hours for 2019 and 2020 seasons in the Research Center of Safiabad, Iran.

Experimental Design and Procedures

This research aimed to evaluate the interactive effect of AsA and irrigation water levels on Irrigation Water Use Efficiency (IWUE) and mung bean yield and the environmental conditions of the study area in Safiabad Dezful District, Khuzestan Province, Iran. The experiment was conducted in split plots in the form of a randomized complete block design, with three replications, where irrigation levels were assigned in the main plots and AsA treatments in the subplots. The experiment consisted of twelve treatments, each showing a combination of the amount of irrigation water and AsA as follows:

1) Four irrigation Water amounts (W) (25, 50, 75, 100% plant water requirement) as the main factor.

2) Three levels of AsA (spraying solution with distilled water as a control and 10 and 20 mM in the vegetative stage before the emergence of flowers, twice with an interval of ten days), as the secondary factors.

The experiment was carried out for two consecutive years and, finally, the data analysis was done. Each plot consisted of six rows (75 cm) with a length of 10 meters, the distance between the plants on the stack was 5 cm and a planting row on the stack and the distance

Table 1. Physical properties and water status of the soil at Safiabad Region.[a]

Depth (cm)	Particle size distribution (%)			Texture class	θ_S			BD (kg m^{-3})
	Sand	Silt	Clay		FC(mm m^{-1})	PWP(mm m^{-1})	HC (mm h^{-1})	
0-15	31.1	35.2	33.7	Clay loam	340	210	17.7	1430
15.1-30	31.8	34.9	33.3	Clay loam	340	210	17.7	1430
30.1-45	32.5	34.1	33.4	Clay loam	340	210	17.7	1430
45.1-60	33.2	33.1	33.7	Clay loam	340	210	17.7	1430

[a] FC: Field Capacity, PWP: Permanent Wilting Point, HC: Hydraulic Conductivity, BD: Bulk Density.

Table 2. Means monthly minimum and maximum temperature, relative humidity, wind speed and sunny hours of the Safiabad region.

Month	Minimum air temperature (°c)	Maximum air temperature (°c)	Relative humidity (%)	Wind speed (m s^{-1})	Sunny hours (h)
First year					
July	29.2	47.6	48	0.85	338
August	25.4	35.5	62	0.95	303
September	18.7	37.5	62	0.98	283
December	14.8	29.9	60	0.83	192
November	8	21.8	61	0.87	202
Second year					
July	25.9	47.1	50	0.89	332
August	25.4	44.7	56	0.95	305
September	21.1	38.2	66	1.09	250
December	15.1	25.7	56	0.79	172
November	10.9	20.6	55	0.89	127

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between each other was 2 meters. Planting operation was carried out on July 20 at the rate of 25 kg per hectare by manual rowing. After the planting operation, irrigation was carried out normally and the same until the plant had four leaves, then, the treatments were applied. To apply drip treatments on each row, a drip strip with a diameter of 175 microns and a distance of 20 cm between the holes was used. The twelve "irrigation–AsA" treatments involved were denoted as follows:

W(100)AsA(0), W(100)AsA(10), W(100)AsA(20), W(75)AsA(0), W(75)AsA(10), W(75)AsA(20), W(50)AsA(0), W(50)AsA(10), W(50)AsA(20), W(25)AsA(0), W(25)AsA(10), W(25)AsA(20).

Irrigation water requirement for mung bean was calculated by determining daily reference Evapotranspiration (ET_0) of FAO Penman–Monteith equation (Allen *et al*., 1998) for each growing season of mung bean. From ET_0, crop Evapotranspiration (ET_c) was computed using the following equation according to Doorenbos *et al.* (1977):

$ET_c= ET_0 \times K_c$ (1)

Where: ET_c= Crop Evapotranspiration (mm d^{-1}); ET_0= Reference Evapotranspiration (mm d^{-1}), and K_c= Crop coefficient (1.15).

Sampling and Assessments

Irrigation Water Use Efficiency (IWUE)

To calculate IWUE, the maximum yield produced per unit of water used by the mung bean plant was determined (El-Bially *et al*., 2018). When calculating the seed moisture content, it was about 17%. IWUE was calculated as mung bean yield (kg) per water used (m^3) during the growing season.

Chlorophyll and Carotenoid Content

Arnon's method (1949) was used to measure the content of chlorophyll and carotenoids. Half a gram of each fresh leaf sample was homogenized in five mm of 80% acetone, then, a centrifuge was used at 13,000 rpm at 4°C for 15 minutes, and its volume was reduced to 10 mm with acetone. Next, the amount of light absorption was measured using a spectrophotometer at wavelengths of 470, 645 and 663 nm, and the concentration of chlorophyll a, b and their sum and carotenoids were obtained using the following formula.

Chlorophyll a= $(19.3\times A_{663}-0.86\times A_{645})V/100W$

Chlorophyll b= $(19.3\times A_{645}-3.6\times A_{645})V/100W$

Carotenoids= 100 (A_{470})+3.27 (chlorophyll a mg)-104 (chlorophyll b mg)/227

Plant Parameters

To measure the leaf area index, PAR/LAI Ceptometer was used to measure all the plots at a time interval of 15 days. It is the ratio of the leaf area to the area of cultivated land:

LA= LA/CLA

Where, LA= Leaf Area, and CLA= Cultivated Land Area.

Seed yield with 17% humidity was determined by weighing the seeds from 3 m^2 from the middle of each plot.

Statistical Analysis

SAS software was used for the statistical analysis of the data. Means were compared using Duncan's multiple range test at 0.05 probability level. EXCEL software was used to draw the graphs.

RESULTS AND DISCUSSION

Irrigation Water Use Efficiency (IWUE)

The value of IWUE in the interaction of irrigation and AsA was calculated by dividing kg seed yield per hectare (kg ha^{-1}) by applied water (m^3 ha^{-1}) (Figure 1). The

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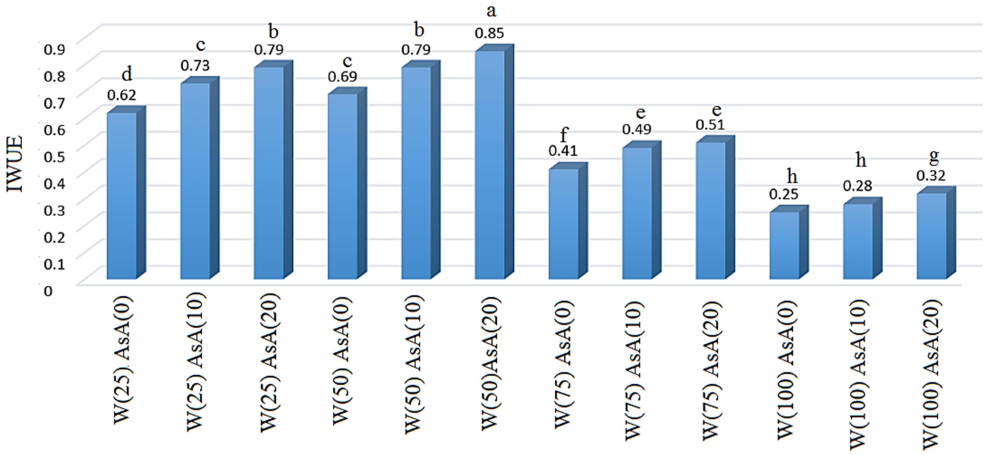

Figure 1. Effects of different irrigation–Ascorbic Acid (AsA) treatments on Irrigation Water Use Efficiency (IWUE) for mung bean mean of 2019 and 2020 seasons. (Small letters indicate statistic comparison). Duncan's multiple range test at 0.05 significant level.

maximum IWUE was obtained in W(50)AsA(20) and there was no significant difference in the two seasons. The beneficial effect of AsA application on IWUE was determined under water stress conditions (W50) compared to well-irrigated (W100), and there was a significant difference between them. Therefore, with the use of AsA and the decrease in the amount of irrigation, IWUE increased, such that the highest IWUE was in W(50)AsA(20) treatment. AsA application was more beneficial on IWUE under water-stressed (W50). The obtained result is in line with the research result of Canavar *et al*. (2014). Our findings indicated that the potency of AsA-treated mung bean plants can relatively convert applied water into the production of seeds under moderate water deficit conditions. Shahrukhnia *et al*. (2016) in their research on tomatoes reported that the highest water efficiency index was observed in the treatment of 60% water requirement, at higher water treatments, IWUE decreased. El-Bially *et al*. (2018) concluded that the use of AsA as a safe and cheap foliar spray during the intermittent dry spells, especially in vegetative stage, is regarded necessary. This confirms the result of our research. This result can be interpreted as the application of AsA is very necessary for the management of agricultural water resources and it plays an effective role in the critical conditions of water shortage.

Water Saving and Yield Changes

By evaluating the interaction of irrigation and AsA on mung bean yield (kg ha^{-1}), it was found that the most beneficial treatment was W(50)AsA(20). The yield in this treatment in 2020 was equal to 2,491 kg ha^{-1} and in 2019 was 2,350 kg ha^{-1}, which is the highest among all treatments in the two seasons, and the amount of water consumption was 50%. By using the mentioned treatment, in addition to increasing the yield, the amount of saving in water consumption was very impressive. There was a significant difference between W(75)AsA(10), W(75)AsA(20), W(50)AsA(0), W(50)AsA(10) and W(50)AsA(20) with the W(100)AsA(0) treatment, which indicates significant water saving despite the increase in yield due to the use of AsA (Figure 2). Under water-stressed condition (W50), application of AsA had positive and significant effects on seed yield ha^{-1} (in both seasons). In both seasons, W(50)AsA(20) treatment improved seed yield by about 43.7% compared with

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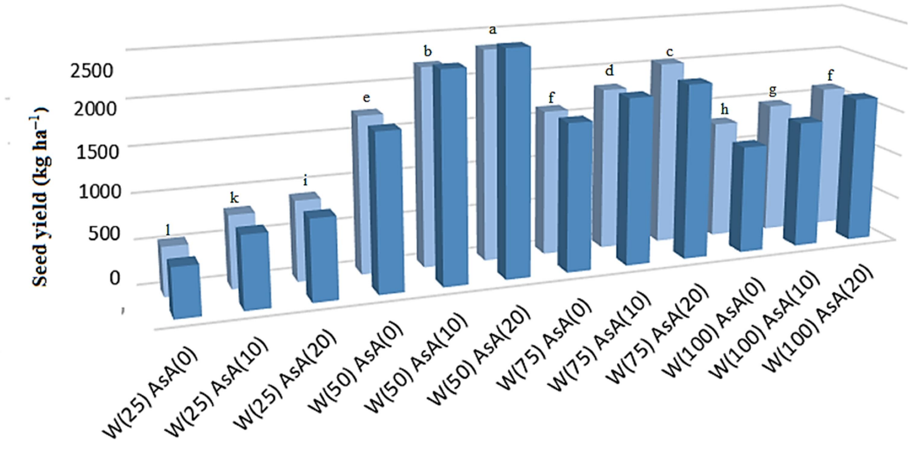


	W(25) AsA(0)	W(25) AsA(10)	W(25) AsA(20)	W(50) AsA(0)	W(50) AsA(10)	W(50) AsA(20)	W(75) AsA(0)	W(75) AsA(10)	W(75) AsA(20)	W(100) AsA(0)	W(100) AsA(10)	W(100) AsA(20)
■ **2020**	544	800	895	1733	2320	2491	1649	1864	1960	1203	1418	1637
■ **2019**	540	805	890	1740	2210	2350	1620	1810	2050	1310	1465	1610

Figure 2. Effects of different irrigation–Ascorbic Acid (AsA) treatments on seed yield (kg ha^{-1}) for mung bean. Duncan's multiple range test at 0.05 significant level; (W) Water amounts.

high water deficit without AsA, i.e. W(50)AsA(0).

It was found that the use of AsA significantly saved water and increased yield. In the W(50)AsA(20) treatment compared to the reference treatment, the water saving in the 2019 and 2020 crop seasons was equal to 50% (2,550 and 2,500 m^3 ha^{-1}, respectively). The crop yield in 2019 increased by 79.4% (1,040 kg ha^{-1}) and in 2020 by 107.1% (1,288 kg ha^{-1}) (Table 3).

Based on the results, AsA had a beneficial effect on mung bean seed yield under water–stressed conditions. Moreover, in the case when saving water by 50.0% (amounted to 2,550 m^3 ha^{-1} in the 2019 season and 2,500 m^3 ha^{-1} in 2020), for W(50)AsA(20) treatment, the increased seed yield ranged between 79-107% in both seasons. In general, such results reveal the potency of AsA to save water under low water supply in mung bean. El-Bially *et al*. (2018) stated that AsA, in a situation where the plant is under stress, can increase activity and provide performance components by modulating the negative effect of stress. Naz *et al*. (2016) concluded that the improvement of plant growth under water stress treatments can be achieved by the application of AsA. This result confirms the result of our research. According to the research results of Hafez and Gharib (2016), ascorbic acid can reduce the negative effects of water stress by acting as a growth factor to accelerate the growth of shoots and roots in water stress conditions and reduce the loss of flag leaf darkness in low stress conditions.

This result can be interpreted as the application of AsA is very necessary to increase production and improve the economic situation of farmers and agricultural water saving, and it plays an effective role in critical water shortage conditions.

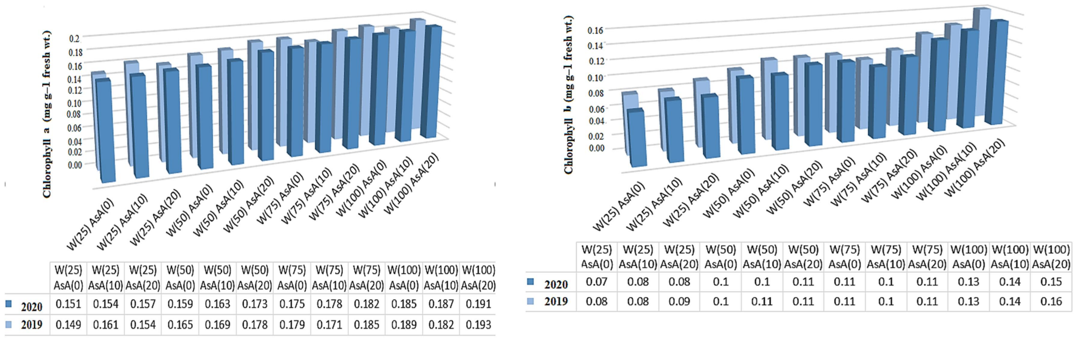
Chlorophyll and Carotenoid Contents

Chlorophyll a, b Content

The results in Figure 3 show the degradation of chlorophyll a, b content in mung bean leaves under water stress. In this regard, a significant difference between

Table 3. Saved water and the change in seed yield of mung bean under different irrigation–AsA treatments in 2019 and 2020 seasons.

Treatments	Saved water % and (m^3 ha^{-1})		Change in seed yield % and (kg ha^{-1})	
	2019	2020	2019	2020
W(100) AsA(0)	0.0% (0.0)	0.0% (0.0)	0.0% (0.0)	0.0% (0.0)
W(100) AsA(10)	0.0%(0.0)	0.0% (0.0)	11.8% (155)	17.9% (215)
W(100) AsA(20)	0.0%(0.0)	0.0% (0.0)	22.9% (300)	36.1% (434)
W(75) AsA(0)	25% (1275)	25% (1250)	23.7% (310)	37.1% (446)
W(75) AsA(10)	25% (1275)	25% (1250)	38.2% (500)	53.4% (643)
W(75) AsA(20)	25% (1275)	25% (1250)	56.5% (740)	62.5% (757)
W(50) AsA(0)	50% (2550)	50% (2500)	32.8% (430)	44.1% (530)
W(50) AsA(10)	50% (2550)	50% (2500)	68.7% (900)	92.9% (1117)
W(50) AsA(20)	50% (2550)	50% (2500)	79.4% (1040)	107.1%(1288)
W(25) AsA(0)	75% (3825)	75% (3750)	-58.8% (-770)	-54.8% (-659)
W(25) AsA(10)	75% (3825)	75% (3750)	-38.5% (-505)	-33.5%(-403)
W(25) AsA(20)	75% (3825)	75% (3750)	-32.1% (-420)	-25.6%(-308)



	W(25) AsA(0)	W(25) AsA(10)	W(25) AsA(20)	W(50) AsA(0)	W(50) AsA(10)	W(50) AsA(20)	W(75) AsA(0)	W(75) AsA(10)	W(75) AsA(20)	W(100) AsA(0)	W(100) AsA(10)	W(100) AsA(20)
■ **2020**	0.151	0.154	0.157	0.159	0.163	0.173	0.175	0.178	0.182	0.185	0.187	0.191
■ **2019**	0.149	0.161	0.154	0.165	0.169	0.178	0.179	0.171	0.185	0.189	0.182	0.193

	W(25) AsA(0)	W(25) AsA(10)	W(25) AsA(20)	W(50) AsA(0)	W(50) AsA(10)	W(50) AsA(20)	W(75) AsA(0)	W(75) AsA(10)	W(75) AsA(20)	W(100) AsA(0)	W(100) AsA(10)	W(100) AsA(20)
■ **2020**	0.07	0.08	0.08	0.1	0.1	0.11	0.11	0.1	0.11	0.13	0.14	0.15
■ **2019**	0.08	0.08	0.09	0.1	0.11	0.11	0.11	0.1	0.11	0.13	0.14	0.16

Figure 3. Leaf chlorophyll a, b content of mung bean obtained from different irrigation–Ascorbic Acid (AsA) treatments in 2019 and 2020 seasons. Duncan's multiple range test at 0.05 significant level; Water amounts (W).

irrigation-AsA treatments in chlorophyll a, b content was observed during both seasons, when reduction in water supply reduced chlorophyll a and b. In contrast, these effects were significantly minimized and less evident when plants were treated with AsA. In 2020, the amount of chlorophyll a and b in the W(50)AsA(20) increased by about 9 and 10%, respectively, compared to W(50) AsA(0). Such findings are in accordance with those found by El-Bially *et al*. (2018) and Manivannan *et al*. (2007). Dolatabadian *et al*. (2009) reported that drought stress reduces the amount of chlorophyll in corn while AsA prevents the destruction of chlorophyll and indirectly increases it due to its antioxidant properties.

Carotenoid Content

Carotenoids are a group of pigments that, in addition to their role in the formation of pigments, have also antioxidant properties. According to the research results, AsA can prevent the reduction of carotenoids both in favorable conditions and in drought-stress conditions. For example, in 2020, the carotenoid content in the W(100)AsA(20) treatment increased about 7% compared to the reference treatment, i.e. W(100)AsA(0). Also, in W(50)AsA(20) compared to W(50)AsA(0) there was an increase of about 13%. Khalid and Qader Khursheed (2014) also reported that AsA application can

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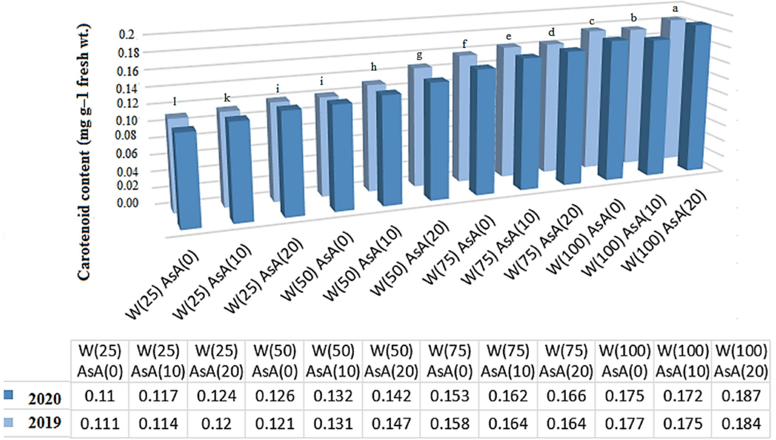
prevent the reduction of carotenoids in both favorable and drought-stress conditions. The results of the findings of Sherin *et al*. (2022) also showed that the number of carotenoids showed a significant difference under the influence of AsA (Figure 4).

Plant Parameters

Leaf Area Index (LAI) and 1,000 Seed Weight (TSW) of mung bean were significantly different among irrigation-AsA treatments. The highest TSW value was assigned to W(50)AsA(20), which surpassed all other treatments with 56.9 and 53.9 g, respectively, in the two seasons. The highest LAI value was in W(100)AsA(20). Obviously, those well-watered plants treated with AsA produced LAI significantly higher than all other treatments. Under W50 water-stressed conditions, application of AsA had positive and significant effects on TSW (in both seasons), and under favorable irrigation conditions (W100), application of 20 mM AsA had positive and significant effects on LAI (in both seasons). W(50)AsA(20) improved TSW by about 52% in both seasons compared to W(50)AsA(0). W(100)AsA(20) improved LAI by about 17.3% in both seasons compared to W(100)AsA(0) (Figure 5). Such findings are in accordance with those found by Dolatabadian and Jouneghani (2009). Also, Sajedi and Ardakani (2010) stated that drought stress reduced the LAI in saffron, which was partially resolved by using AsA, which is consistent with the findings of the present research. Regarding the TSW, our findings are in accordance with those found by Moradi Tochaei *et al.* (2016).

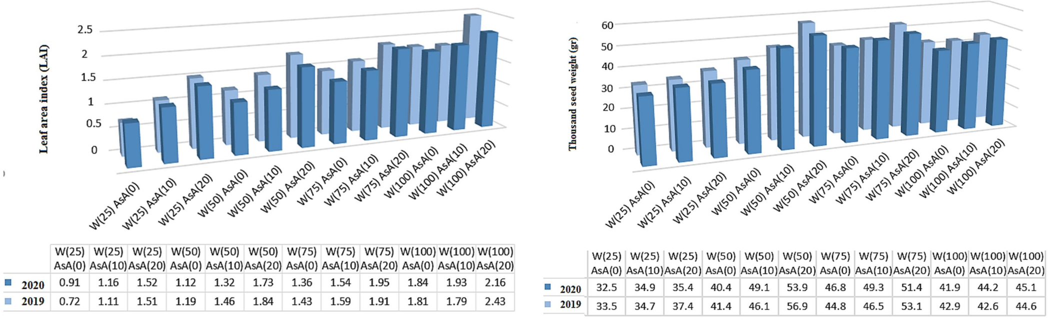
Protein Yield

Protein yield (kg ha^{-1}) of mung bean were significantly different among irrigation-AsA treatments. The highest protein yield value belonged to W(50)AsA(20). The W(50)AsA(20) treatment surpassed all other treatments with 512 and 515 kg ha^{-1}, respectively, in the two seasons. Under W50 water-stressed conditions, application of AsA had positive and significant effects on protein yield (in both seasons). W(50)AsA(20) improved protein yield by about 103 and 77% in 2019 and 2020, respectively, compared to W(25)AsA(0) (Figure 6). In line with the findings of this research, Salingpa *et al.* (2018) reported that ascorbic acid with a concentration of 300 mM led to an increase in mung bean yield under salt stress conditions. El-Beltagi *et al.* (2020) also reported that foliar application



	W(25) AsA(0)	W(25) AsA(10)	W(25) AsA(20)	W(50) AsA(0)	W(50) AsA(10)	W(50) AsA(20)	W(75) AsA(0)	W(75) AsA(10)	W(75) AsA(20)	W(100) AsA(0)	W(100) AsA(10)	W(100) AsA(20)
■ 2020	0.11	0.117	0.124	0.126	0.132	0.142	0.153	0.162	0.166	0.175	0.172	0.187
■ 2019	0.111	0.114	0.12	0.121	0.131	0.147	0.158	0.164	0.164	0.177	0.175	0.184

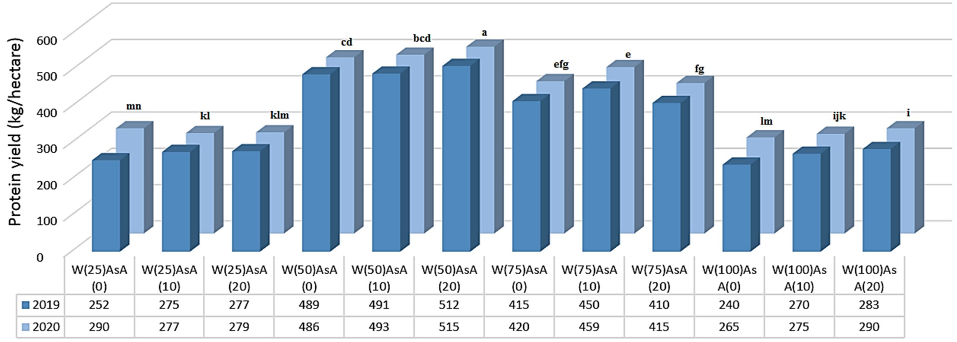
Figure 4. Carotenoid content of mung bean obtained from different irrigation–Ascorbic Acid (AsA) treatments in the 2019 and 2020 seasons. Duncan's multiple range test at 0.05 significant level; Water amounts (W).



	W(25) AsA(0)	W(25) AsA(10)	W(25) AsA(20)	W(50) AsA(0)	W(50) AsA(10)	W(50) AsA(20)	W(75) AsA(0)	W(75) AsA(10)	W(75) AsA(20)	W(100) AsA(0)	W(100) AsA(10)	W(100) AsA(20)
■ **2020**	0.91	1.16	1.52	1.12	1.32	1.73	1.36	1.54	1.95	1.84	1.93	2.16
■ **2019**	0.72	1.11	1.51	1.19	1.46	1.84	1.43	1.59	1.91	1.81	1.79	2.43

	W(25) AsA(0)	W(25) AsA(10)	W(25) AsA(20)	W(50) AsA(0)	W(50) AsA(10)	W(50) AsA(20)	W(75) AsA(0)	W(75) AsA(10)	W(75) AsA(20)	W(100) AsA(0)	W(100) AsA(10)	W(100) AsA(20)
■ **2020**	32.5	34.9	35.4	40.4	49.1	53.9	46.8	49.3	51.4	41.9	44.2	45.1
■ **2019**	33.5	34.7	37.4	41.4	46.1	56.9	44.8	46.5	53.1	42.9	42.6	44.6

Figure 5. Leaf Area Index (LAI) and 1000 seed weight of mung bean obtained from different irrigation–AsA treatments in 2019 and 2020. Duncan's multiple range test at 0.05 significant level; Water amounts (W).



	W(25)AsA (0)	W(25)AsA (10)	W(25)AsA (20)	W(50)AsA (0)	W(50)AsA (10)	W(50)AsA (20)	W(75)AsA (0)	W(75)AsA (10)	W(75)AsA (20)	W(100)As A(0)	W(100)As A(10)	W(100)As A(20)
■ 2019	252	275	277	489	491	512	415	450	410	240	270	283
■ 2020	290	277	279	486	493	515	420	459	415	265	275	290

Figure 6. Protein yield (kg ha^{-1}) of mung bean obtained from different irrigation–AsA treatments in the 2019 and 2020 seasons. Duncan's multiple range test at 0.05 significant level; Water amounts (W).

of ascorbic acid improved chickpea yield under different moisture regimes.

CONCLUSIONS

Due to frequent droughts in different provinces of the country as well as in the research area, the necessity of identifying water-use-management solutions and saving water consumption has been given more attention. Based on the results obtained from this research, with the use of AsA and the decrease in the amount of irrigation, the amount of IWUE increased, such that the highest amount of IWUE was in W(50)AsA(20) treatment. These results could be explained in the viewpoint of seed yields produced under such conditions more than the other ones, resulting in higher IWUE values. Also, under W50water-stressed conditions, application of AsA had positive and significant effects on seed yield ha^{-1} (in both seasons). High water deficit (W50) plus applying 20 mM AsA, i.e. W(50)AsA(20) treatment, improved seed yield about 43.7% in both seasons compared to high water deficit without AsA, i.e. W(50)AsA(0). It was found that the use of AsA significantly saved water and increased yield. In the W(50)AsA(20) compared to the reference treatment, the water saving in 2019 and 2020 was equal to 50% (2,550 and 2,500 m^3 ha^{-1}, respectively). Based on the results, AsA has a beneficial effect on mung bean seed yield under water-stressed conditions. In general, such results reveal the potency of AsA to save water under low water supply in mung bean fields. Under water-stressed condition (W50), application of AsA had positive and significant effects

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on seed yield and TSW (in both seasons), while under favorable irrigation conditions, W100 and application of 20 mM AsA had positive and significant effects on LAI (in both seasons). Thus, our study suggests the use of AsA in irrigation for optimal management of water resources and saving water consumption by relatively mitigating the detrimental impact associated with low water supply.

REFERENCES

1. Abdul Wahed, M. S. A., Amin, A. A. and El Rashad, S. M. 2006. Physiological Effect of Some Bioregulators on Vegetative Growth, Yield and Chemical Constituents of Yellow Maize Plants. *World J. Agric. Sci*., **2(2):** 149-155.
2. Akram, N. A., Khan, I., Javed, Z., Khan, Z., Mahmood, S., Ashraf, M., Shafiq, S. and Naz, H. 2018. Modulation in Some Key Biochemical Attributes in Drought Stressed Pea (*Pisum sativum* L.) Plants Ttreated with Different Plant Growth Regulators. *Agrochimica*, **62(4):** 337-351.
3. Akram, N.A.; Shafiq, F.and Ashraf, M. 2017. Ascorbic Acid- A Potential Oxidant Scavenger and Its Role in Plant Development and Abiotic Stress Tolerance. *Front. Plant Sci.,* **8:** 613.
4. Alghabari, F. 2020. Evaluating Mung Bean Performance under Different Types and Rates of Humic Acid Application in Arid Conditions of Saudi Arabia. *Int. J. Agric. Biol.,* **24:** 1273-1278.
5. Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. 1998. *Crop Evapotranspiration–Guidelines for Computing Crop Water Requirements*. Paper 56, FAO Irrigation and Drainage, Rome, Italy.
6. Amin, A. A., Rashad, E. M. and Gharib, A. E. 2008. Changes in Morphological, Physiological and Reproductive Characters of Wheat Plants as Affected by Foliar Application with Salicylic Acid and Ascorbic Acid. *Aust. J. Basic Appl. Sci.,* **2(2):** 252-261.
7. Arnon, D. I. 1949. Copper Enzyme Polyphenoloxides in Isolated Chloroplast in Beta vulgaris. *Plant Physiol.,* **24(1):** 1–15.
8. Baghizadeh, A. Ghorbanli, M. Rezaei, H. M. and Mozafri, H. 2009. Evaluation of Interaction Effect of Drought Stress with Ascorbate and Salicylic Acid on Some of Physiological and Biochemical Parameters in Okra (*Hibiscus esculentus* L*.). J. Biol. Sci.,* **4(4):** 380-387.
9. Barat Zadeh, S., Saki Nejad, T. and Babaei Nejad, T. 2019. Effect of Potassium Nano-Chelate and Ascorbic Acid on Grain Yield and Some Qualitative Characteristics of Cowpea (*Vigna unguiculata* L., Kamran cultivar). *J. Plant Prod. Sci.,* **9(2):** 149-160.
10. Barzegar, T., Fateh, M. and Razavi, F. 2018. Enhancement of Postharvest Sensory Quality and Antioxidant Capacity of Sweet Pepper Fruits by Foliar Applying Calcium Lactate and Ascorbic Acid. *Sci. Hortic.*, **241:** 293-303.
11. Benedetti, C. E. and Arruda, P. 2002. Altering the Expression of the Chlorophylls Gene ATHCOR1 in Transgenic *Arabidopsis* Caused Changes in the Chlorophyll-to-Chlorophyllide Ratio. *Plant Physiol.*, **128(4):** 1255-1263.
12. Burton, G. and Ingold, K. 1984. Beta-Carotene: An Unusual Type of Lipid Antioxidant. *Science,* **224 (4649):** 569–573.
13. Bwambale, E., Abagale, F. K. and Anornu, G. K. 2022. Smart Irrigation Monitoring and Control Strategies for Improving Water Use Efficiency in Precision Agriculture: A Review*. Agric. Water Manag.*, **260:** 107324.
14. Canavar, Ö., Götz, K., Ellmer, F., Chmielewski, F. and Kaynak, M. A. 2014. Determination of the Relationship between Water Use Efficiency, Carbon Isotope Discrimination and Proline in Sunflower Genotypes under Drought Stress. *Aust. J. Crop Sci.,* **8(2):** 232–242.
15. Dehgan, F., Gholami, M. and Azizi, A. 2013. Interaction Effect of Foliar Application of Ascorbic Acid and Salt Stress on Some Physiological and Biochemical Characteristics of Strawberry (Fragaria×ananassa Duch) cv. *Selva.*, *Plant Prod. Technol.*, **5(1):** 47-56.
16. Dolatabadian, A. and Jouneghani, R. S. 2009. Impact of Exogenous Ascorbic Acid on Antioxidant Activity and Some Physiological Traits of Common Bean

[DOI: 10.22034/JAST.26.3.593]

Subjected to Salinity Stress. *Not. Bot. Horti. Agrobo. Cluj-Napoca*., **37(2):** 165–172.

17. Dolatabadian, A., Modares Sanavy, A. M. and Asilan, K. 2009. Effect of Ascorbic Acid Foliar Application on Yield, Yield Component and Several Morphological Traits of Grain Corn under Water Deficit Stress Conditions. *Not. Sci. Biol.,* **2(3):** 45-50.
18. Dolatabadian, A.; Sanavy, S. A. M. M. and Asilan, K. S. 2010. Effect of Ascorbic Acid Foliar Application on Yield, Yield Component and several Morphological Traits of Grain Corn under Water Deficit Stress Conditions. *Not. Sci. Biol.,* **2(1):** 45–50.
19. Doorenbos, J., Pruitt, W. O., Aboukhaled, A., Damagnez, J., Dastane, N. G., Van Den Berg, C., Rijtema, P. E., Ashford, O. M. and Frere, M. 1977. *Guidelines for Predicting Crop Water Requirements*. FAO Irrigation and Drainage, FAO, Rome.
20. El-Beltagi, H. S., Mohamed, H. I. and Sofy, M. R. 2020. Role of Ascorbic Acid, Glutathione and Proline Applied as Singly or in Sequence Combination in Improving Chickpea Plant through Physiological Change and Antioxidant Defense under Different Levels of Irrigation Intervals. *Molecules*, **25(7):** 1702.
21. El-Bially, M., Saudy, H., El-Metwally, E. and Shahin, M. 2018. Efficacy of Ascorbic Acid as a Cofactor for Alleviating Water Deficit Impacts and Enhancing Sunflower Yield and Irrigation Water–Use Efficiency. *Agric. Water Manag.*, **208(1):** 132-139.
22. Emadodin, I., Reinsch, T. and Taube, F. 2019. Drought and Desertification in Iran. *Hydrology*, **6**: 66.
23. English, M. J. 1990. Deficit Irrigation. I. Analytical Framework. *J. Irrig. Drain. Eng.,* **116(3):** 399-412.
24. Flexas, J. and Medrano, H. 2002. Drought-Inhibition of Ohotosynthesis in C3 Plants: Stomatal and Non-Stomatal Limitations Revisited. *Ann. Bot.,* **89(2):** 183–189.
25. Gaafar, A. A., Ali, S. I., El-Shawadfy, M. A., Salama, Z. A., Sękara, A., Ulrichs, C. and Abdelhamid, M. T. 2020. Ascorbic Acid Induces the Increase of Secondary Metabolites, Antioxidant Activity, Growth, and Productivity of the Common Bean under Water Stress Conditions. *Plants*, **9(5):** 627.
26. Ghorbanli, M., Adib hashemi, N. and Peyvandi, M. 2010. Study of Salinity and Ascorbic Acid on Some Physiological Responses of *Nigella sativa* L. *Iran. J. Med. Aroma. Plants Res.,* **26(3):** 370-388.
27. Hafez, E. and Gharib, H. 2016. Effect of Exogenous Application of Ascorbic Acid on Physiological and Biochemical Characteristics of Wheat under Water Stress. *Int. J. Plant Prod.*, **10(4):** 579-596.
28. Hana, F. R., Abdo, F. A. and Anton, N. A. 2001. Response of Wheat Plant to Foliar Application with Ascorbic Acid Copper and Boron. *J. Agric. Sci.*, **26(10):** 5971-5983.
29. Helrich, K. 1990. *Official Methods of Analysis. Vitamin C (Ascorbic Acid).* 15th Edition, Association of Official Analytical Chemists, Washington, DC, USA, PP. 1058–1059.
30. Hussein, Z. K. and Khursheed, M. Q. 2014. Effect of Foliar Application of Ascorbic Acid on Growth, Yield Components and Some Chemical Constituents of Wheat under Water Stress Conditions. *Jordan J. Agric. Sci*., **10(1):** 1–15.
31. Jaleel, C. A., Manivannan, P., Sankar, B., Kishorekumar, A., Gopi, R., Somasundaram, R. and Panneerselvam, R. 2007. *Pseudomonas fluorescens* Enhances Biomass Yield and Ajmalicine Production in *Catharanthus roseus* under Water Deficit Stress. *Colloids Surf. B Biointerfaces*, **60(1):**7-11.
32. Javed, S., Bukhari, S. A., Ashraf, M. Y., Mahmood, S. and Iftikhar, T. 2014. Effect of Salinity on Growth, Biochemical Parameters and Fatty Acid Composition in Safflower (*Carthamus tinctorius* L.). *Pak. J. Bot.*, **46(6):** 1153-1158.
33. Jayakumar, K., Jaleel, C. A. and Vijayarengan, P. 2007. Changes in Growth, Biochemical Constituents and Antioxidant Potentials in Radish (*Raphanus sativus* L.) under Cobalt Stress., *Turk. J. Biol.*, **31 (3):** 112-117.
34. Kang, Y. J., Kim, S. K., Kim, M. Y., Lestari, P., Kim, K. H., Ha, B. –K., Jun, T. H., Hwang, W. J., Lee, T., Lee, J., Shim, S., Yoon, M. Y., Jang, Y. E., Han, K. S., Taeprayoon, P., Yoon, N., Somta,

[DOI: 10.22034/JAST.26.3.593]

P., Tanya, P., Kim, K. S., Gwag, J. -G., Moon, J. K., Lee, Y. H., Park, B. S., Bombarely, A., Doyle, J. J., Jackson, S. A., Schafleitner, R., Srinives, P., Varshney, R. K. and Lee, S. H. 2014. Genome Sequence of Mungbean and Insights into Evolution within *Vigna* Species. *Nat. Commun.*, **5(1):** 1-9.

35. Khalid, H. Z. and Qader Khursheed, M. 2014. Effect of Foliar Application of Ascorbic Acid on Growth, Yield Components and Some Chemical Constituents of Wheat under Water Stress Conditions. *Jordan J. Agric. Sci.*, **10(1):** 1-15.
36. Lei, Z. Y., Han, I. M., Yi, X. P., Zhang, W. F. and Zhang, Y. L. 2018. Coordinated Variation between Veins and Stomata in Cotton and Its Relationship with Water-Use Efficiency under Drought Stress. *Photosynthetica.*, **56(1):**1326–1335.
37. Li, Z., Feng, B., Wang, W., Yang, X., Wu, P. and Zhuo, L. 2022. Spatial and Temporal Sensitivity of Water Footprint Assessment in Crop Production to Modeling Inputs and Parameters. *Agric. Water Manag.*, **271(1)**: 107805.
38. Madany, M. and Khalil, R. 2017. Seed Priming with Ascorbic Acid or Calcium Chloride Mitigates the Adverse Effects of Drought Stress in Sunflower (*Helianthus annuus* L.) Seedlings. *Egypt. J. Exp. Biol. (Bot.),* **13(1):** 119 – 133.
39. Manivannan, P., Jaleel, C. A., Sankar, B., Kishorekumar, A., Somasundaram, R., Alagu Lakshmanan, G. M. and Panneerselvam, R. 2007. Growth, Biochemical Modifications and Proline Metabolism in *Helianthus annuus* L. as Induced by Drought Stress. *Colloids Surf. B Biointerfaces*, **59(1):** 141–149.
40. Moradi Topchaei, M., Saifzadeh, S., Zakirin, H. R. and Voladabadi, S. A. R. 2016. Investigating the Effect of Foliar Spraying of Methanol and Ascorbic Acid on the Growth and Yield of Peanuts under Dry Conditions. *Quarterly J. Physiol. Res. Agric. Plants*, **9 (36):** 65-82.
41. Mosleh Arany, A., Rafiei, A., Tabande, A. and Azimzadeh, H. R. 2018. Morphological and Physiological Responses of Root and Leave in *Gleditschia caspica* to Salinity Stress. *Iran. J. Plant Biol.*, **9(4):** 1-12.
42. Naz, H., Akram, N. A. and Ashraf, M. 2017. Impact of Ascorbic Acid on Growth and Some Physiological Attributes of Cucumber (*Cucumis sativus*) Plants under Water-Deficit Conditions. *Pak. J. Bot.*, **48(1): 877–883.**
43. Pazuki, A., Rezaei, H., Habibi, D and Paknejad, F. 2011. Effect of Drought Stress, Foliar Application of Ascorbate and Gibberellin on Some Morphological Traits, Relative Water Content of Leaves and Cytoplasmic Membrane Stability of Thyme (*Thymus vulgaris* L.). *J. Agric. Plant Breed.*, **8(1): 1-13.**
44. Qin, L., Chen, S., Xie, L., Yu, Q., Chen, Y. and Xie, J. 2022. Recent Advances in Mungbean Polysaccharides: Extraction, Physicochemical Properties and Biological Activities. *Proc. Biochem.*, **121:** 248-256.
45. Rachaputi, R.C.N., Sands, D., McKenzie, K., Lehane, J., Agius, P., Seyoum, S. and Peak, A. 2019. Water Extraction Patterns of Mungbean (*Vigna radiata*) in Diverse Subtropical Environments, *Agric. Water Manag.*, **219:** 109-116.
46. Reddy, A. R., Chiatanya, K. V. and Vivekanandan, M. 2004. Drought-Induced Responses of Photosynthesis and Antioxidant Metabolism in Higher Plants. *J. Plant Physiol.*, **161:** 1189-1202.
47. Rigano, D., Sirignano, C. and Taglialatela-Scafati, O. 2017. The Potential of Natural Products for Targeting PPARα. *Acta Pharm. Sin. B.,* **7(4):** 427–438.
48. Sajedi, N., Ardakani, M. R., Sajedi, A. and Bahrami, A. H. 2010. Absorption of Some Nutrients under the Influence of Mycorrhiza, Different Levels of Zinc and Drought Stress in Corn. *Agric. Res. Iran*, **8(5):** 784-791.
49. Salem, H. M., Abdel Rahman, S. and Mohamed, S. I. 2000. Response of Sugar Beet Plants to Boron and Ascorbic Acid under Field Conditions. *J. Fac. Educ. Ain Shams Univ.*, **48:** 1-20.
50. Salingpa, T. W., Lal, E. P. and Shukla, P. K. 2018. Effect of Foliar Application of Salicylic Acid on Growth, Yield, Physiological and Biochemical Characteristics of Mung Bean (*Vigna radiata* L.) under Salt Stress. *J.*

[DOI: 10.22034/JAST.26.3.593]

Pharmacogn. Phytochem., **7(6):** 1857-1860.

51. Shafiq, S., Akram, N. A., Ashraf, M. and Arshad, A. 2014. Synergistic Effects of Drought and Ascorbic Acid on Growth, Mineral Nutrients and Oxidative Defense System in Canola (*Brassica napus* L.) Plants. *Acta Physiol. Plant.,* **36:** 1539–1553.
52. Shahrukhnia, M. A., Jokar, L. and Rakhshanderoo, M. 2016. Investigating the Effect of Water Stress Using Leaf Temperature and Soil Moisture Indicators on the Yield and Efficiency of Tomato Juice Consumption. *Irrig. Water Eng. Iran.*, **6 (26):** 97-111.
53. Sharma, R. K. and Agrawel, M. 2006. Single and Combined Effects of Cadmium and Zinc on Carrots: Uptake and Bioaccumulation. *J. Plant Nutr.*, **31:** 19-34.
54. Sherin, G., Raj Aswathi, K. P. and Puthur, J. T. 2022. Photosynthetic Functions in Plants Subjected to Stresses Are Positively Influenced by Priming, *Plant Stress,* **4:** 100079.
55. Shirzadi Laskookalayeh, S., Mardani Najafabadi, M. and Shahnazari, A. 2022. Investigating the Effects of Management of Irrigation Water Distribution on Farmers' Gross Profit under Uncertainty: A New Positive Mathematical Programming Model. *J. Clean. Prod.*, **351:** 131277.
56. Wang, B., Hu. H.L., Hu, T.X., Shi, D., Hu, Y., Zhou, X. and Tan, F. 2019. Effects of Drought Stress on Photosynthetic Characteristics and Growth of *Phoebe zhennan* Seedlings. *J. Northwest A. F. Univ*., **47(2):** 79-87.
57. Wang, Q., Huang, N., Cai, H., Chen, X. and Wu, Y. 2023. Water Strategies and Practices for Sustainable Development in the Semiconductor Industry, *Water Cycle*, **4:** 12-16.

اثربخشی اسید اسکوربیک به عنوان یک کوفاکتور در افزایش راندمان آبیاری (IWUE) و عملکرد گیاه ماش (.*Vigna radiata* L)

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چکیده

اسید اسکوربیک (AsA) یک آنتی اکسیدان محلول در آب است که با خنثی کردن رادیکال های آزاد، گیاهان را در برابر تنش¬های محیطی مقاوم می¬کند. با این حال، مشخص نیست که این آنتی اکسیدان تا چه حد ممکن است به بهبود کارایی مصرف آب آبیاری (IWUE) و کاهش اثرات نامطلوب کمبود آب بر رشد و عملکرد ماش کمک کند. در تلاش برای روشن شدن اینکه آیا کاربرد این آنتی اکسیدان می تواند اثرات نامطلوب کمبود آب بر روی گیاهان ماش را کاهش دهد، در دو فصل زراعی سال های (۲۰۱۹ و ۲۰۲۰) آزمایش مزرعه ای با استفاده از دوازده ترکیب از سه سطح AsA و چهار مقدار آب آبیاری انجام شد (۲۵، ۵۰، ۷۵ و۱۰۰ درصد آب مورد نیاز گیاه). بر اساس نتایج، حداکثر IWUE با W(50)AsA(20) در دو فصل به دست آمد. اثر سودمند کاربرد AsA بر IWUE در شرایط تنش آبی (W50) تعیین شد. کمبود آب زیاد (W50)به علاوه استفاده از ۲۰ میلی مولار اسید آسکوربیک، یعنی تیمار(W(50)AsA(20 ، عملکرد دانه را در حدود ۴۳.۷% در دو فصل نسبت به کمبود آب بالا بدون اسید آسکوربیک، یعنی W(50)AsA(0) بهبود

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بخشید. در تیمار W(50)AsA(20) نسبت به تیمار مرجع، صرفه جویی در مصرف آب در فصل زراعی ۲۰۱۹ و ۲۰۲۰ معادل ۵۰ درصد (به ترتیب ۲۵۵۰ و ۲۵۰۰ مترمکعب در هکتار) بود. در تیمار W(50)AsA(20) ، افزایش عملکرد دانه در هر دو فصل بین ۷۹٪ -۱۰۷٪ بود. بنابراین، چنین نتایجی نشان دهنده قدرت AsA برای صرفه جویی در آب در شرایط کم آبی در مزارع ماش و افزایش عملکرد در حد مطلوبی است.

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