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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 and four irrigation water amounts (25, 50, 75, 100% of the plant's 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 two seasons than high water deficit without ascorbic acid, i.e. $W_{(50)}AsA_{(0)}$. 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% (2550 and 2500 $m^3ha^{-1}$, respectively). In $W_{(50)}AsA_{(20)}$ treatment, the increase of seed yield ranged between 79%-107% in both seasons. Thus, such results reveal the potency of AsA to save water under low water supply in mung bean fields and increased yield kg $ha^{-1}$.

**Keywords**: Ascorbic acid, Water use efficiency, Mung bean, Crop yield

## 1. 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 methods that lead to less water consumption and meet 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 dryland tropics.

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).

Mungbean (*Vigna radiata* L.), known as a traditional soybean food, has been used as a 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). Mungbean 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 and is included in the human diet in many countries of the world, there is a need to investigate solutions to improve production concerning 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 depending 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 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, and in several of studies, for example, common beans (Gaafar et al., 2020), chickpeas (Akram et al., 2018), rape (Shafiq, 2014) and corn (Dolatabadian et al., 2010), etc. 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., (2016), 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, this research in the Safi Abad region of Dezful, which is also facing drought, aims 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

## 2. **Material and methods**

### ***2.1. Site description***

A field experiment was conducted in the seasons of 2019 and 2020 in the research farm of the Safi Abad Natural Resources Education and Research Center, Dezful, Khuzestan Province, Iran (longitude 48 degrees and 32 meters east and latitude 32 degrees and 22 meters north and 82 meters above sea level). The soil was clay loam with pH 7.1, and electrical conductivity 0.99 ds/m. 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 Sunny hours for 2019 and 2020 seasons obtained from the Research Center of Safiabad, Iran.

**Table 1**. Physical properties and water status of the soil at the Safiabad region.

| Depth (cm) | Particle Size Distribution, % | | | Texture class | $\theta_S$ % on weight basis | | | BD ($kg/m^3$) |
|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | FC(mm/m) | PWP(mm/m) | HC(mm/hr) | |
| 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 |

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 (ºc) | Maximum air temperature (ºc) | Relative humidity (%) | Wind speed (m/sec) | 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 |

***2.2 Experimental design and procedures***

This research aimed was to evaluate the interactive effect of AsA and irrigation water levels on IWUE and mung bean yield and the environmental conditions of the study area, 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. This 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) have been considered as secondary factors. The experiment was carried out for two consecutive years and finally, the data analysis was done. Each plot consisted of six stacks (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 between each other was 2 meters. The planting operation was carried out on July 20th at the rate of 25 kg per hectare by manual rowing. After the planting operation, until the plant has four leaves, the irrigation was carried out normally and the same, and then the treatments were applied. To apply drip treatments on each stack, a drip strip with

a diameter of 175 microns and a distance of 20 cm between the holes was considered. The twelve irrigation–AsA treatments involved, in the experiment, are best denoted as:

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 ($ET_0$) developed by the FAO using 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 day$^{-1}$ );

$ET_0$ = Reference evapotranspiration (mm day$^{-1}$), and

$K_c$ = Crop coefficient (1.15).

### *2.3. Sampling and assessments*

#### 2.3.1. Irrigation water use efficiency (IWUE)

To calculate IWUE in mung bean cultivation, the maximum yield produced per unit of water used by the mung bean plant was used (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 (m3) during the growing season.

#### 2.3.2. Chlorophyll and Carotenoid content

Arnon's method (Arnon, 1949) was used to measure the content of chlorophyll and carotenoids. 0.5 grams of each fresh leaf sample was homogenized in five milliliters of 80% acetone, and after this step, a centrifuge was used at 13000 rpm and 4 degrees Celsius for 15 minutes, and then its volume was reduced to 10 with acetone. It was delivered. In the next step, 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× $A_{663}$- 0.86 × $A_{645}$) V/100W

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

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

#### 2.3.3. 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

LA=Leaf Area, CLA=Cultivated Land Area

Seed yield with 17% humidity was determined by taking three square meters from the middle of each plot and then separating the seeds and weighing them separately.

### *2.4 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 graphs.

## 3. Results and Discussion

### *3.1. Irrigation Water Use Efficiency (IWUE)*

The value of IWUE in the interaction of irrigation and AsA was calculated by the method of kg seed yield per hectare (kg/hectare) of applied water ($m^3$ $ha^{-1}$) (Figure. 1). The maximum IWUE was obtained with 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 conditions (W100) and there was a significant difference between them. Therefore, with the use of AsA and the decrease in the amount of irrigation, the amount of IWUE increased. So that the highest amount of 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. (2015) in their research on tomatoes reported that the highest water efficiency index was observed in the treatment of 60% water requirement and higher water treatments, the water efficiency index decreased. El-Bially et al., (2018) in their own research entitled efficacy of ascorbic acid as a cofactor for alleviating water deficit impacts and enhancing sunflower yield and irrigation water–use efficiency, concluded that the use of AsA as a save and cheap foliar spray during the intermittent dry spells especially in vegetative crop growth stage is regarded necessary. This result 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.

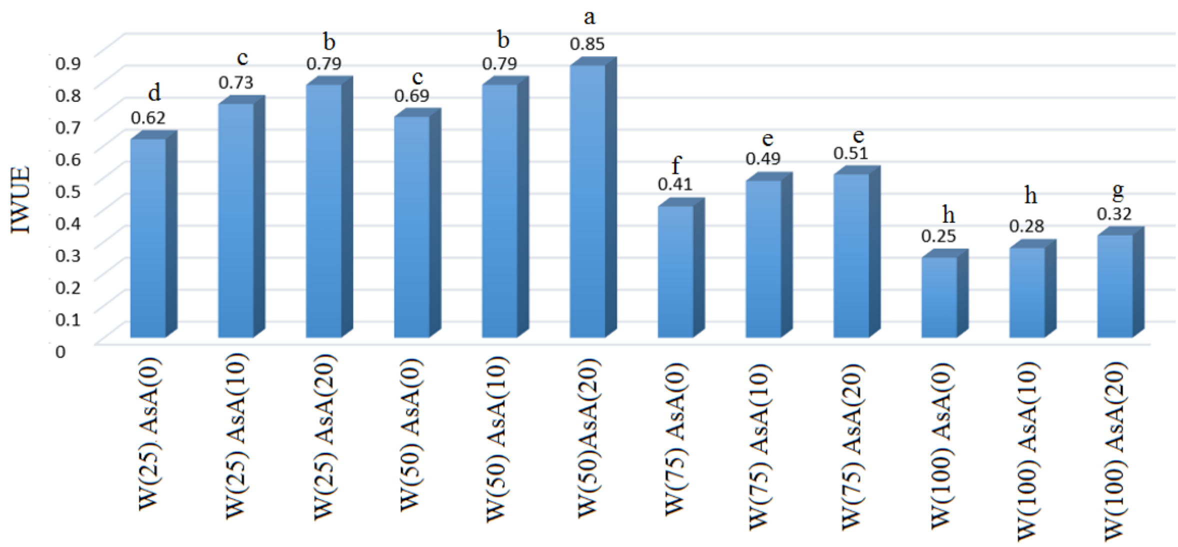
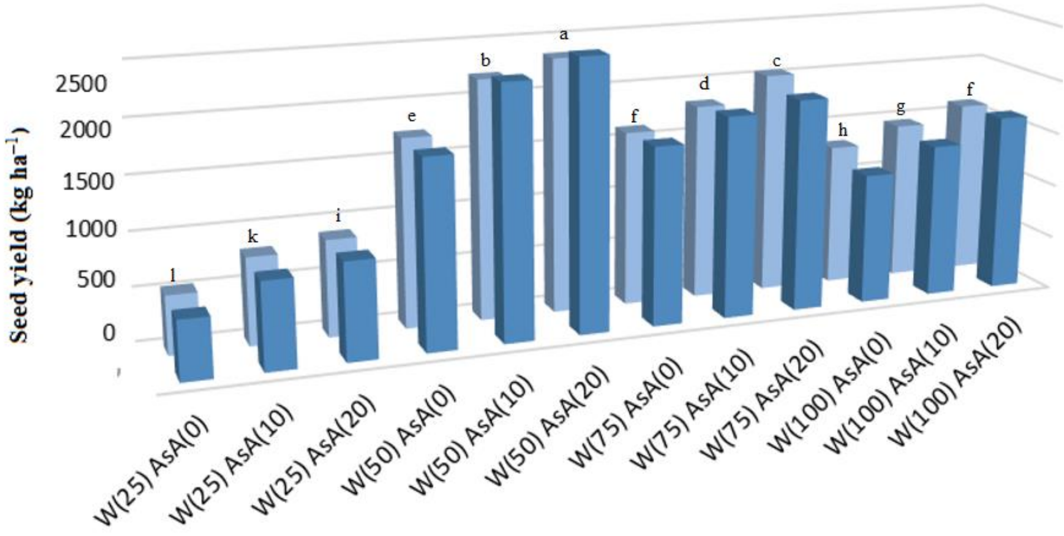



**Figure 1**. Effects of different irrigation–AsA treatments on irrigation water use efficiency (IWUE) for mung bean mean of 2019 & 2020 seasons. (Alphabet as statistic comparison)

### *3.2 Water saving and yield changes*

By evaluating the interaction of irrigation and AsA on mung bean yield (kg/hectare), it was found that the most beneficial treatment was W(50)AsA(20). The yield in this treatment in 2020 was equal to 2491 kg $ha^{-1}$ and in 2019 equal to 2350 kg $ha^{-1}$, which is the highest among all treatments in 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 has also been very impressive. Based on the results of Duncan's multiple range test, 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) irrigation-AsA treatments with the W(100)AsA(0) treatment, which indicates significant water saving despite the increase in yield due to the use of AsA (Fig. 2). Under water-stressed condition (W50), application of AsA had positive and significant effects on seed yield $ha^{-1}$ (in both seasons). W(50)AsA(20) treatment, improved seed yield by about 43.7% in two seasons than a high water deficit without AsA, i.e. W(50)AsA(0).




| | 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–AsA treatments on seed yield (kg/ha) for mung bean.

It was found that the use of AsA significantly saved water and increased yield kg ha$^{-1}$. 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% (2550 and 2500 m$^{3}$ha$^{-1}$, respectively). The crop yield in 2019 increased by 79.4% to 1040 kg ha$^{-1}$ and in 2020 by 107.1% to 1288 kg ha$^{-1}$ (Table 3).

Based on the results AsA has a beneficial effect on mung bean seed yield under water–stressed conditions. Moreover, in the case when saving water by 50.0% (amounted to 2550 m$^{3}$ ha$^{-1}$ in the 2019 season and 2500 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 fields. 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) in their research entitled Impact of ascorbic acid on growth and some physiological attributes of cucumber (Cucumis sativus) plants under water-deficit conditions, concluded that the improvement of plant growth under water stress treatments can be achieved by the application of AsA in The relative water of the leaf should be accompanied. 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.

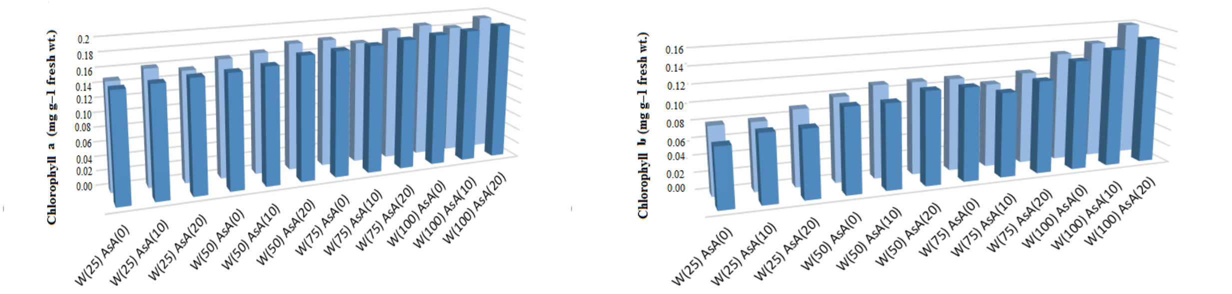
**Table 3.** Saved water and the change in seed yield of mung bean under different irrigation–AsA treatments in 2019 & 2020 seasons.

| Treatments | Saved water ($M^3$ $ha^{-1}$) | | change in seed yield (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) |

### *3.3. Chlorophyll and Carotenoid content*

#### 3.3.1 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 concern, a significant difference between irrigation-AsA treatments in chlorophyll a, b content was observed during the seasons of 2019 and 2020. In both seasons, reduction in water supply reduced chlorophyll a, b. In contrast, these effects were significantly minimized and less evident when plants were treated with AsA. In the 2020 crop season, the amount of chlorophyll a and b in the W(50)AsA(20) treatment 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 and AsA prevents the destruction of chlorophyll and indirectly increases it due to its antioxidant properties.



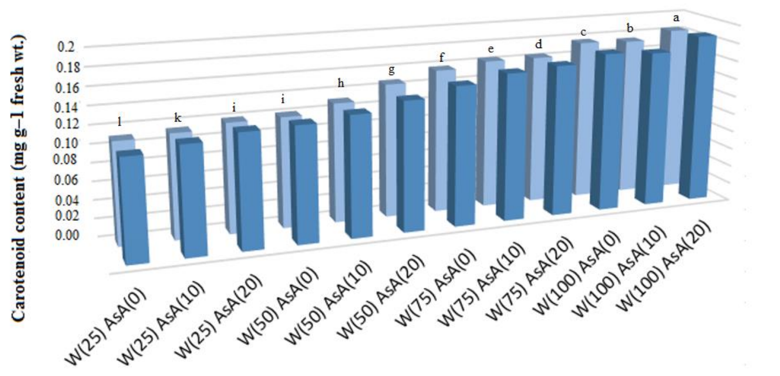

| | W(25) AsA(0) | W(25) AsA(10) | W(25) AsA(20) | W(50) AsA(0) | W(50) AsA(10) | W(50) AsA(20) | W(75) AsA(0) | W(75) AsA(10) | W(75) AsA(20) | W(100) AsA(0) | W(100) AsA(10) | W(100) AsA(20) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 0.151 | 0.154 | 0.157 | 0.159 | 0.163 | 0.173 | 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–AsA treatments in 2019 & 2020 seasons.

### 3.3.2 Carotenoid content

Carotenoids are a group of pigments that, in addition to their role in the formation of pigments, have also been reported to have 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 the crop season of 2020, the carotenoid content in the W(100)AsA(20) treatment has increased about 7% compared to the reference treatment, i.e. W(100)AsA(0). Also, in the treatment of W(50)AsA(20) compared to the treatment of W(50)AsA(0) there was an increase of about 13%. Khalid and Qader Khursheed (2014) also reported that AsA application can 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.

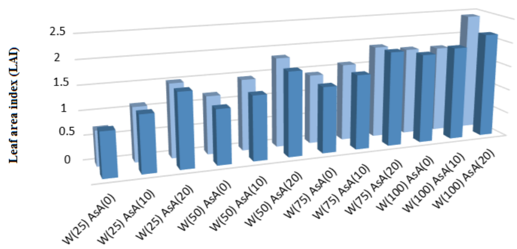



| | W(25) AsA(0) | W(25) AsA(10) | W(25) AsA(20) | W(50) AsA(0) | W(50) AsA(10) | W(50) AsA(20) | W(75) AsA(0) | W(75) AsA(10) | W(75) AsA(20) | W(100) AsA(0) | W(100) AsA(10) | W(100) AsA(20) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 0.11 | 0.117 | 0.124 | 0.126 | 0.132 | 0.142 | 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 |

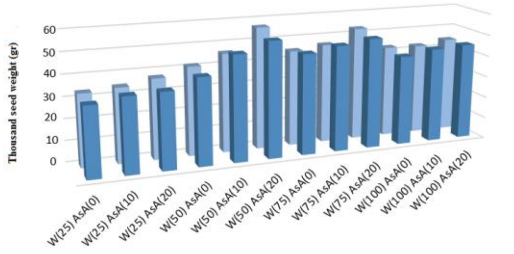
**Figure 4**. Carotenoid content of mung bean obtained from different irrigation–AsA treatments in the 2019 & 2020 seasons.

### *3.4 Plant parameters*

Leaf area index (LAI) and thousand seed weight (TSWgr) of mung bean were significantly different among irrigation-AsA treatments. In trait TSW, the highest value is assigned to W(50)AsA(20) treatment. The W(50)AsA(20) treatment surpassed all other treatments with 56.9 and 53.9 gr respectively in two seasons for TSW. In trait LAI, the highest value gained by the treatment W(100)AsA(20). Obviously, in the LAI treatment, those well-watered plants treated with AsA produced LAI significantly higher than all other treatments. Under water-stressed conditions (W50), 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) treatment, improved TSW by about 52% in two seasons than W(50)AsA(0). In favorable irrigation conditions (W100) plus applying 20 mM AsA, i.e. W(100)AsA(20) treatment, improved LAI by about 17.3% in two seasons than the same water conditions without AsA, i.e. W(100)AsA(0) (Fig. 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 this research. Regarding the TSW, our findings are in accordance with those found by Moradi Tochaei et al (2016).




| | 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 thousand seed weight of mung bean obtained from different irrigation–AsA treatments in the 2019 & 2020 seasons.

### *3.5 Protein yield (kg/hectare)*

Protein yield (kg/hectare) of mung bean were significantly different among irrigation-AsA treatments. In trait protein yield, the highest value is assigned to W(50)AsA(20) treatment. The W(50)AsA(20) treatment surpassed all other treatments with 512 and 515 kg/hectare respectively in two seasons. Under water-stressed conditions (W50), application of AsA had positive and significant effects on protein yield (in both seasons). W(50)AsA(20) treatment, improved protein yield by about 103% and 77% respectively in 2019 and 2020 seasons than W(25)AsA(0) (Fig. 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 of ascorbic acid improved chickpea yield under different moisture regimes.

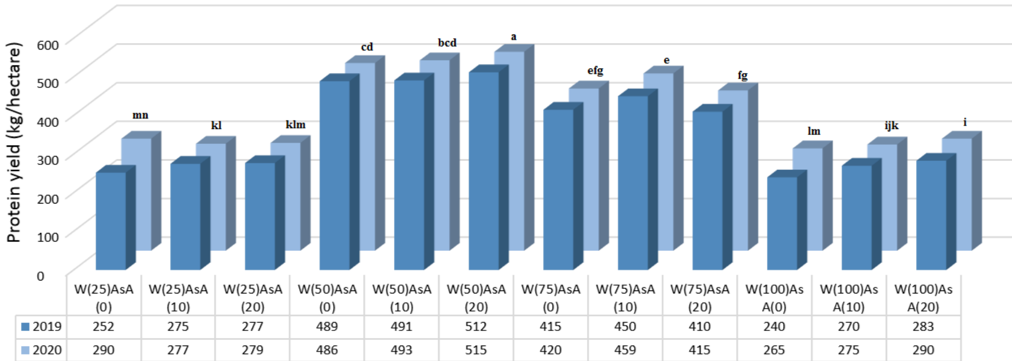



**Figure 6.** Protein yield (kg/hectar) of mung bean obtained from different irrigation–AsA treatments in the 2019 & 2020 seasons.

**4. Conclusion**

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 the research, with the use of AsA and the decrease in the amount of irrigation, the amount of IWUE increased. So 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 under other ones, resulting in higher IWUE values. Also, under water-stressed conditions (W50), the 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 two seasons than 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 kg ha-1. 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% (2550 and 2500 m3ha-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 on seed yield and 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). Thus, our study advises introducing the use AsA in irrigation programs for optimal management of water resources use and saving water consumption and relatively mitigating the detrimental impact associated with low water supply.

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

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خلاصه

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 (2019 و 2020) آزمایش مزرعه¬ای با استفاده از دوازده ترکیب از سه سطح AsAو چهار مقدار آب آبیاری انجام شد (25، 50، 75 و 100 درصد آب مورد نیاز گیاه). بر اساس نتایج، حداکثر IWUEبا 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 20 میلی مولار اسید آسکوربیک، یعنی تیمار W(50)AsA(20)، عملکرد دانه را در حدود 43.7% در دو فصل نسبت به کمبود آب بالا بدون اسید آسکوربیک، یعنی W(50)AsA(0) بهبود بخشید. در تیمار W(50)AsA(20) نسبت به تیمار مرجع، صرفه جویی در مصرف آب

در فصل زراعی 2019 و 2020 معادل 50 درصد (به ترتیب 2550 و 2500 مترمکعب در هکتار) بود. در تیمار W(50)AsA(20)، افزایش عملکرد دانه در هر دو فصل بین 79٪ -107٪ بود. بنابراین، چنین نتایجی نشان دهنده قدرت AsA برای صرفه جویی در آب در شرایط کم آبی در مزارع ماش و افزایش عملکرد در کیلوگرم در هکتار در حد مطلوبی است.

کلیدواژگان: اسید اسکوربیک، کارایی مصرف آب، ماش، عملکرد محصول