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ORIGINAL ARTICLE / ORIGINALBEITRAG

Quantitative and Qualitative Responses of Quinoa to Soil Application of Growth-promoting Microorganisms Under Water Stress

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Abstract

Quinoa (*Chenopodium quinoa* Willd) is highly resistant to a wide range of environmental stresses, including drought and salinity stresses. To evaluate the effect of bio-fertilizer and drought stress on the quantitative and qualitative traits of quinoa, an experiment was conducted on Research Farm, Shahed University in 2018. The main factors included irrigation interval 7, 10, 13, 16 days and the soil application of growth-promoting microorganisms (0, 0.1, 0.2, and 0.3% concentrations during the growth period) arranged in the sub-factor. The results showed that by increasing irrigation interval period, grain yield, 1000-grain weight and chlorophyll content decreased. The highest plant height (155.7 cm), leaves area (1543.6 cm^2/plant), 1000-grain weight (2.69 g), chlorophyll a content (19.7 mg g^{-1} FW), and seed potassium content (2.03%) were observed in 0.2% bio-fertilizer application under 13-day irrigation treatment. Application of 0.3% concentration bio-fertilizer under 13 and 16-day irrigation treatments was caused the highest grain yield (2.51 and 2.47 ton ha^{-1}) which had 14.34 and 12.95% increase compared to the control treatment. The highest percentage of accumulation of nutrients in the seed, including potassium, calcium and magnesium, was observed in the treatments of 0.3% biofertilizer with irrigation at intervals of 13 and 16 days. The results suggest that drought stress adversely affects quinoa quantitative and qualitative traits, and biofertilizer can improve quinoa plant tolerance todrought stress.

Keywords Bio-fertilizer · Chlorophyll · Drought-tolerant plant · Limited irrigation · Nutrients accumulation

Introduction

Quinoa (*Chenopodium quinoa* Willd) is a member of the Amaranthaceae family, C3 plant, and a salt- and drought-tolerant plant, which is classified as pseudo-cereal (Martinez et al. 2015). It is an annual, dicotyledonous plant and native to the Andean region (Kakabouki et al. 2019; Angeli et al. 2020). Food and Agriculture Organization (FAO) formally proposes quinoa as a complete food suitable for humans and defines it as the only monomeric plant that can run into the demand for basic human food (Xiu-shi et al. 2019). Quinoa is a traditional crop which has recently gained worldwide attention because of its ability to grow under various stress conditions like drought, salinity, acidity, frost, etc., and because of the nutritional attributes of its seeds as high protein content and good amino acid composition (Ali et al. 2019).

Quinoa is a valuable plant and it is compatible with various agro-ecological conditions. Accordingly, this plant can have a high potential for growth in arid and semi-arid regions (Hinojosa et al. 2018; Angeli et al. 2020). Environmental stresses, such as drought stress, are considered as one of the factors that reduce the growth and yield of crops (Kolenc et al. 2016; Yasmeen and Siddiqui 2018; Balbaa et al. 2022; Akhtar et al. 2022; Abdelsalam et al. 2021). Drought stress limits agricultural production and can cause morphological, physiological, and biochemical changes in the crop and drought stress will likely increase in the future (Fahad et al. 2017; Sadiq et al. 2017). The data of Ali et al. (2019) showed that quinoa drought tolerance may result from its capacity to maintain cell health status. The effect of water stress on quinoa, it was shown that reducing the amount of irrigation water reduced plant height, yield components, and grain yield (Gámez et al. 2019). It has been reported that a 50% lack of irrigation in quinoa re-

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duced plant height and 1000-seed weight and also changed physiological characteristics (Jayme-Oliveira et al. 2017).

The use of plant growth-promoting rhizobacteria (PGPR) as biological fertilizer to stimulate crop tolerance to environmental stresses, for example, drought, has been investigated by researchers as a solution (Enebe and Babalola 2018). Researchers report that biological fertilizers including mycorrhizal fungi can reduce the adverse effects of water scarcity on plants (Augé et al. 2015). In a study, a lower reduction in grain yield and high levels of magnesium, potassium, and calcium in wheat crops inoculated with Azospirillum under drought stress were reported (Galindo et al. 2020). Phosphorus-solubilizing bacteria, in addition to increasing the uptake of phosphorus in the corn crop, were able to improve plant growth and increase corn tolerance to drought stress (Ehteshami et al. 2007). Kasim et al. (2013) in a study to control drought stress in wheat using growth-promoting bacteria found that bacterial inoculation significantly reduced the damage caused by drought stress in wheat. Kasim et al. (2013) reported that the ability of certain PGPRR to attenuate several stress consequences in plants which strongly supports the potential of such an approach to control drought stress in wheat. Mycorrhiza fungi help to absorb microelements by expanding the plant's root system and exploring and searching for soil by external hyphae in the hair roots (Yooyongwech et al. 2018; Begum et al. 2019).

Soil application of biological fertilizers can moderate the adverse effects of drought stress on the plant. Also, the use of mycorrhiza fungi caused a significant increase in micro and macro elements in the shoot (Begum et al. 2019; El Kinany et al. 2019; Abbas et al. 2022). Pseudomonas bacteria increase the release of trace nutrients in the soil and increase plant access to nutrients by secreting organic acids (Rudresh et al. 2005). The results of Naseri et al. (2019) showed that the application of *Pseudomonas putida* and *Glomus mousse* bacteria had a positive and significant effect on low-consumption nutrients in wheat shoots in dryland conditions.

In organic agriculture, in addition to the quantity of production, quality, stability, and immovability in production are also considered. However, chemical fertilizers cannot be removed from crop ecosystems all at once, because sustainable agriculture requires adequate income and food security. In this regard, the combined use of mineral, organic and biological fertilizers not only reduces the rate of chemical fertilizers, but also helps to store energy, reduce environmental pollution, and improve soil physical conditions (Yang et al. 2020). Due to the scarcity of water resources and increasing population and the need for more food on the one hand and recent droughts on the other hand as well as reducing environmental impacts due to the use of chemical fertilizers and lack of adequate research on quinoa, this study aimed to investigate the effect of limited-irrigation and plant growth-promoting rhizobacteria on plant height, grain yield, the concentration of some grain elements and chlorophyll content of quinoa.

Materials and Method

This research was carried out in the Research Farm of Shahed University, Tehran, Iran (2018). The experiment was performed as a split-plot based on a randomized complete block design with three replicated. The irrigation intervals 7, 10, 13, and 16 days were applied in the main plots (Table 1). In order to avoid the effect of limited irrigation on seed germination and interference with plant density on yield, irrigation treatments were started from the stage before seeding, that is, at the stage when the plants were at a plant height of 50 cm. Sub-factors included the use of biofertilizer at four levels including no use of bio-fertilizer as a control and concentrations of 0.1, 0.2, and 0.3% during the growth period in the sub-plots.

The biofertilizer used in this study is Microact, which is a unique solution containing high-quality organic matter, humus, and water-soluble humic acid. It also contains aerobic and anaerobic bacteria and internal and external mycorrhizal fungi, which are formulated in order to supply nutrients needed by plants.

Before starting the experiment, a composite sample was taken from each soil depth of 0 to 30 cm. After air-drying and passing through a 2 mm sieve, some of its physical and chemical properties including saturation percentage, preparation of saturated extract, electrical conductivity, and pH were done as per Black (1965) method, soil texture by hydrometer method (Bouyoucos 1962), organic carbon by Walkie and Block method (Nelson and Sommers 1983) and calcium carbonate equivalent by compression calcium method (Nelson 1983) were measured. Table 2 showed some physical and chemical properties of soil.

To measure physiological traits, sampling was performed before the last stress cycle. Before harvest, sampling was performed to measure the content of photosynthetic pigments from young and terminal leaves using Arnon method (Arnon 1949). Thus, 0.5 g of fresh leaf tissue was completely extracted with 20 ml of acetone (80%) and then the chlorophyll content was read by spectrophotometer at 663 and 645 nm. Finally, the content of chlorophyll a and b were obtained from the following equations:

$$\mathrm{Cha} = 12.7\ (\mathrm{A663}) - 2.69\ (\mathrm{A645}) \times \mathrm{V}/100\mathrm{W} \quad (1)$$

$$\mathrm{Chb} = 22.9\ (\mathrm{A645}) - 2.69\ (\mathrm{A663}) \times \mathrm{V}/100\mathrm{W} \quad (2)$$

Whereas, A: the amount of light absorption, V: the volume of the extract, W: is the weight of the sample.

Table 1 Irrigation interval and soil water content in the four treatments of soil moisture depletion

Treatment	Irrigation interval (day)	Soil water potential (atm)	Soil water content of topsoil before irrigation (based on soil weight percentage)
W1	7	0.33	20
W2	10	1.10	16
W3	13	5.91	12
W4	16	15	10.3

Table 2 Some physical and chemical properties of the studied soil before treatment

CCE*	OC	SP	Sand	Silt	Clay	pH	ECe	Texture
%						–	dS m^{-1}	–
11.5	1.2	31	36	40	24	8.28	10.06	Loam

* Calcium carbonate equivalent

Leaf area was measured with an automatic area meter (AAM-8, Hayashi Denko Co. Ltd., Japan). Seed elements were measured by dry digestion in three replications. Dried seed samples at 70 °C in an electric mill were crushed enough to pass through a 20 mesh sieve (diameter 0.86 mm). Then 2 g of the powdered sample was poured into an acid-washed porcelain crucible and placed in an electric oven. The jar was set to reach 700 °C in one hour, after which the plant sample was heated at this temperature for 8 h. After this time, the cruise was removed from the oven and allowed to cool at room temperature. Then 10 ml of 1 M hydrochloric acid was added to the cruise and at the same time, it was heated on a sand bath at 80 °C until the first white vapor came out. At this time, the contents of the crucible were passed through Whatman 42 and the extract was taken to a volume of 50 ml in a balloon. The three determined elements were expressed such as potassium, calcium, and magnesium in the extracts using a 410 model Flame-photometer (CORNING) and a complex photometer (Chapman and Pratt, 1962).

To measure yield traits by removing marginal effects from each side of the plot (0.5 m), plants with an area of 4 m2 were randomly harvested from each plot at the time of physiological maturity and plant height, 1000-grain weight, and grain yield were recorded.

Statistical Analysis

Distribution normality of achieved data was done according to the Kolmogorov-Smirnov and Shapiro-Wilk test. Then the studied traits were statistically analyzed by the Statistical Analysis System software (SAS Institute, Cary, NC, USA, and Version 9.2). The differences among means were separated using multiple Duncan test at 0.05 statistical probability level. The Pearson correlation coefficient was used to measure relationships between morph-physiological traits by SAS software vr.9.2.

Results

Plant Height

As shown in Table 3, the factors of irrigation, biological fertilizer and the interaction effect of irrigation and biological fertilizer had significant effects on plant height ($p \leq 0.01$) and the highest plant height (160.78 cm) from the use of 0.3% biofertilizer at 10-day irrigation interval was obtained. Statistically, there was no significant difference with the 0.2% biofertilizer treatment at the 13-day irrigation interval, as well as the non-biofertilizer (control) treatment at the 7-day irrigation interval (Fig. 1).

Leaves Area

The results of analysis of variance showed that the interaction effect of irrigation interval and biological fertilizer on leaf area was significant ($p \leq 0.01$), but the effect of biological fertilizer on this trait was not significant (Table 3). As shown in Fig. 2, although in the 7-day irrigation interval with the increase in biofertilizer concentration, the leaf area decreased, in the 10 and 13-day irrigation intervals, the increase in the biofertilizer concentration increased the leaf area.

1000-grain Weight

The interaction effects of irrigation intervals and bio-fertilizer application were significant on 1000-seed weight (Table 3). As shown in Fig. 3, the use of bio-fertilizer under 7-day irrigation interval significantly reduced the 1000-grain weight compared to the control. While in 10 and 13-day irrigation intervals, the application of bio-fertilizer increased the means of this trait compared to the control. In other words, the bio-fertilizer application was caused a significant increase in 1000-grain weight compared to the control. However, in the 16-day irrigation interval, no significant increase in 1000-seed weight was observed with the bio-fertilizer application. Although the 1000-grain weight was not statistically significant in three irrigation intervals including 7, 10 and 13 days, it decreased significantly in the 16 day irrigation interval. In 16-day irrigation interval, the 1000-grain weight was decreased 8.72, 5.28, and 1.95% in compared to 7, 10, and 13-day irrigation intervals, respectively.

Grain Yield

As shown in Table 3, the interaction of irrigation intervals and bio-fertilizer was significant on grain yield ($p \leq 0.01$). The highest grain yield was obtained at use of bio-fertilizer with 0.3% concentration under 13-day irrigation interval. Although, the grain yield at three irrigation intervals of 7, 10, and 13 days significantly were not different, the use of 0.3% bio-fertilizer in 7 and 16-days irrigation intervals was significantly caused to increase grain yield compared to the control (Fig. 4).

Chlorophyll a and B Content

As shown in Table 3, the irrigation intervals and the interaction effect of irrigation intervals and bio-fertilizer had significant effect ($p \leq 0.01$) on chlorophyll a and b content. With increasing irrigation intervals, the chlorophyll a and b content were significantly decreased. The bio-fertilizer had not significant effect on the chlorophyll a content except for 7 and 10-day irrigation intervals, the use of bio-fertilizer at 0.1 and 0.3% concentration, respectively, increased the chlorophyll a content. At 13 and 16-day irrigation intervals, no significant difference was observed between fertilizer treatments (Fig. 5). As shown in Fig. 6, the application of biofertilizer at 7-day irrigation interval did not increase the content of chlorophyll b, while the application of biofertilizer at a concentration of 0.2 and 0.3% at 10- and 13-day irrigation intervals increased chlorophyll b content. Of course, no significant difference was observed between the levels of biofertilizers in terms of chlorophyll b in the 16-day irrigation intervals.

Seed Potassium Content

As shown in Table 3, the interaction effect of irrigation intervals and bio-fertilizer application were significant ($p \leq 0.01$) on seed potassium content. Although the use of bio-fertilizer in 7-day irrigation interval caused a significant decrease in seed potassium content, in 10, 13, and 16-day irrigation intervals, the use of bio-fertilizer significantly increased the seeds potassium content. The highest means of this trait was related to the application of bio-fertilizer

Table 3 Variance analysis of effect of bio-fertilizer application on morpho-physiological traits of quinoa under irrigation treatments

SOV	Df	Mean square								
		Plant height	Leaves area	1000-grain weight	Grain yield	Chlorophyll a content	Chlorophyll b content	Potassium content	Calcium content	Magnesium content
Block	2	7.10 ns	185.0 ns	0.002 ns	0.02 ns	10.2 ns	0.5 ns	0.1 ns	0.02 ns	0.01 ns
Irrigation (I)	3	39.8**	510,619.1**	0.01**	0.6**	18.01**	9.6**	0.7**	1.2**	0.6**
I × Block	6	2.5	451.0	0.0001	0.01	3.0	1.5	0.01	0.01	0.01
Bio-fertilizer (B)	3	31.5**	1170.0 ns	0.009**	1.0**	0.5 ns	1.2**	0.003 ns	0.06**	0.03**
I × B	9	268.5**	61,015.0**	0.03**	0.2**	5.5**	2.5**	0.2**	0.1**	0.09**
Error	40	10.3	805.6	0.003	0.01	0.2	0.01	0.001	0.001	0.001
CV (%)	–	14.5	3.73	7.64	9.80	11.33	12.20	7.21	4.02	5.74

ns non-significant,
* and ** significant at 5 and 1% probably levels respectively

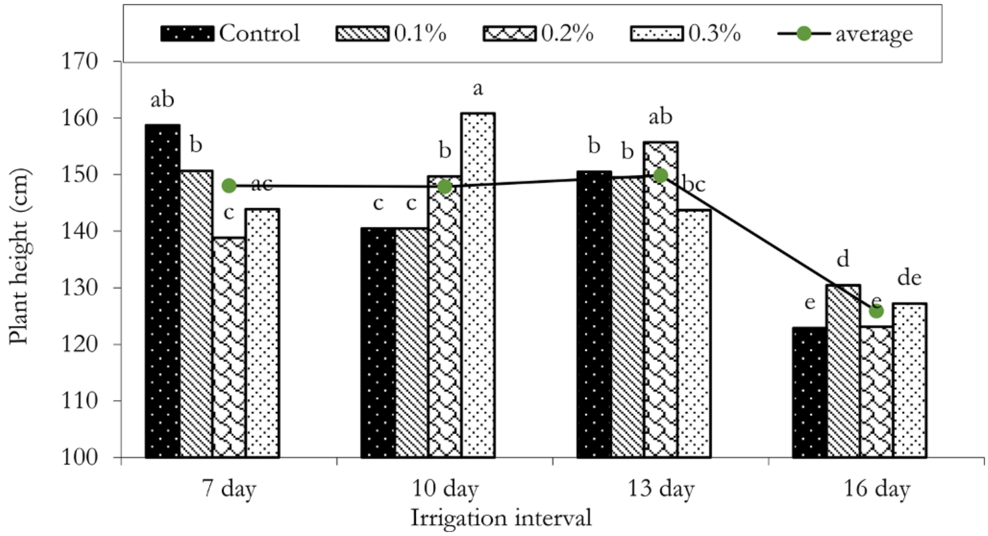


Fig. 1 Effect of different levels of bio-fertilizer and irrigation interval on plant height (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

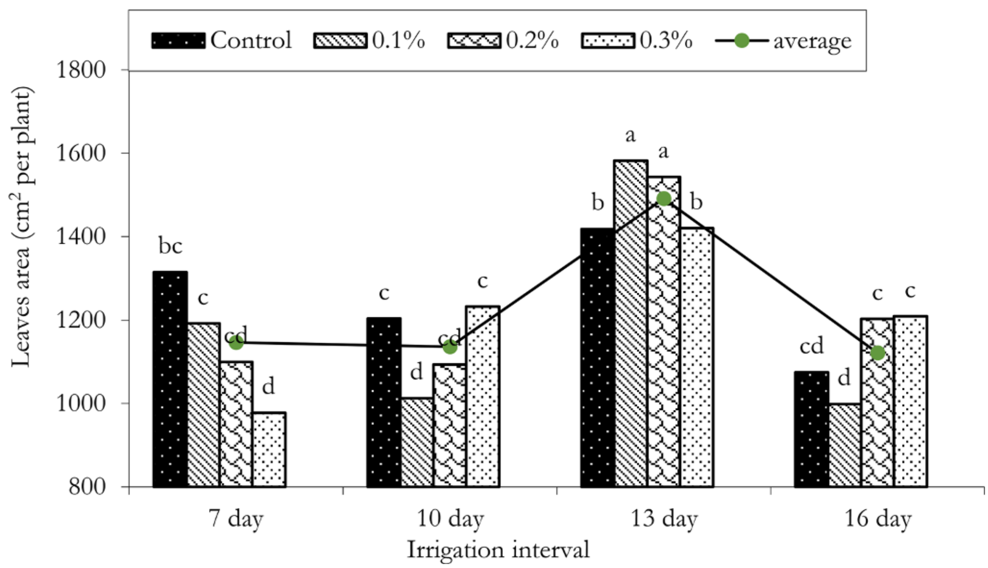


Fig. 2 Effect of different levels of bio-fertilizer and irrigation interval on leaves area (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

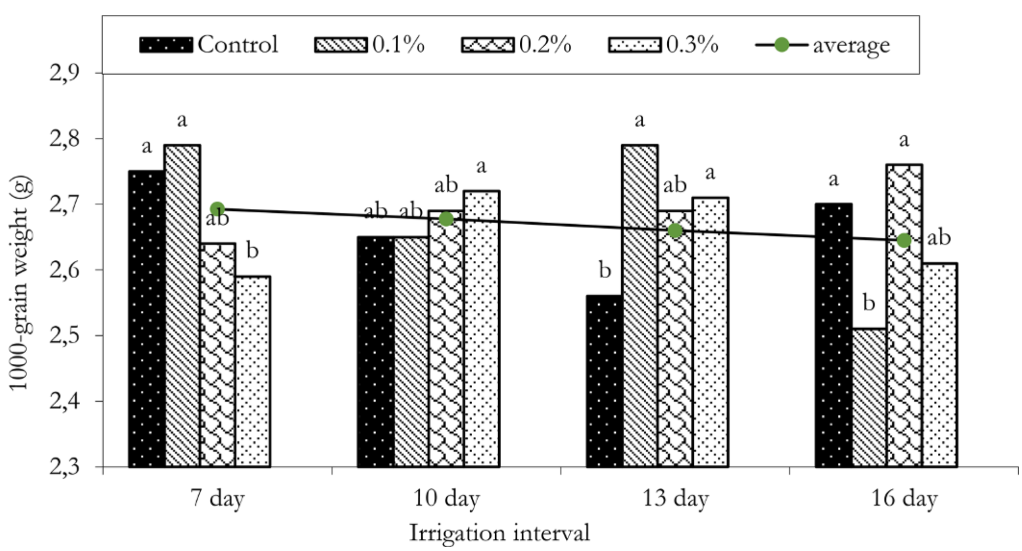


Fig. 3 Effect of different levels of bio-fertilizer and irrigation interval on 1000-grain weight (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

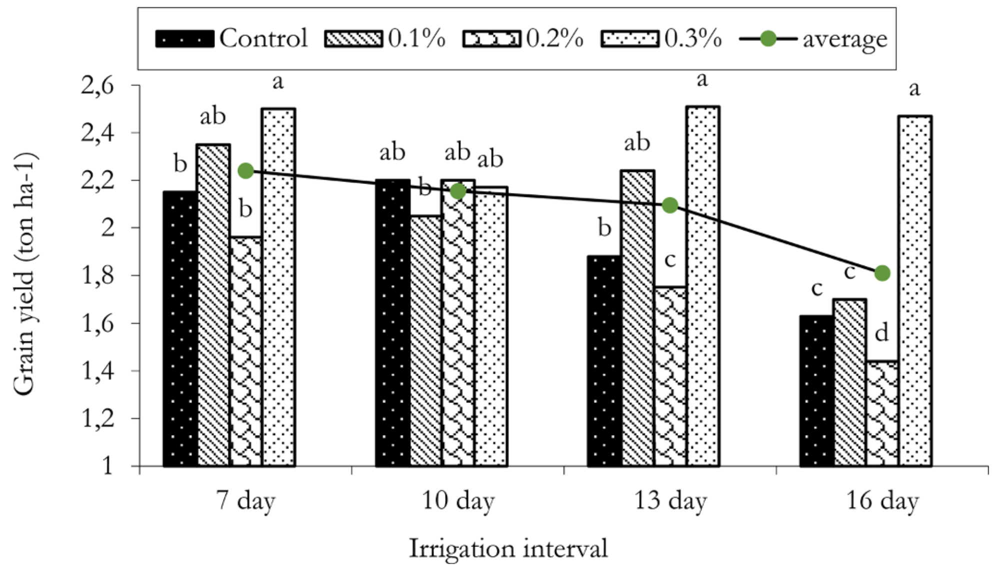


Fig. 4 Effect of different levels of bio-fertilizer and irrigation interval on grain yield (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

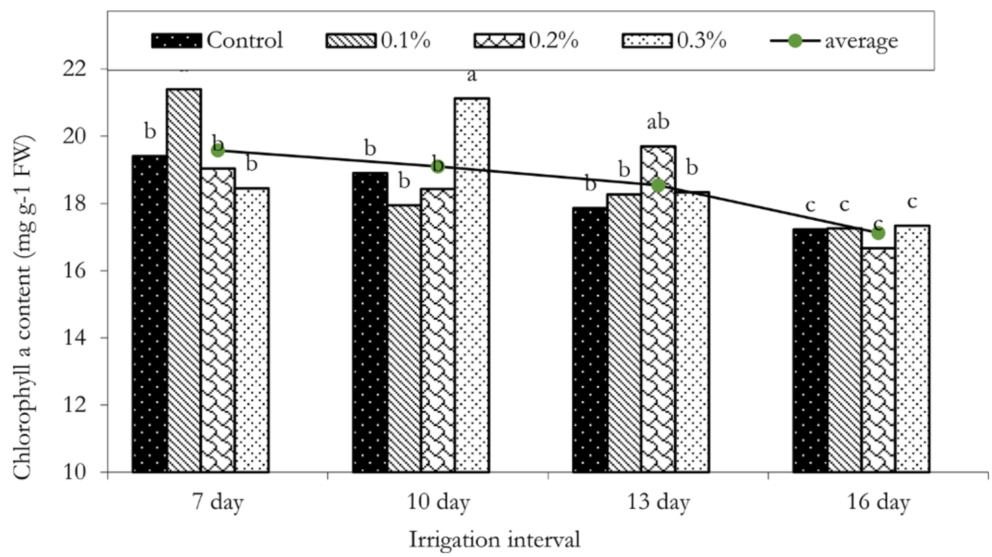


Fig. 5 Effect of different levels of bio-fertilizer and irrigation interval on chlorophyll a content (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

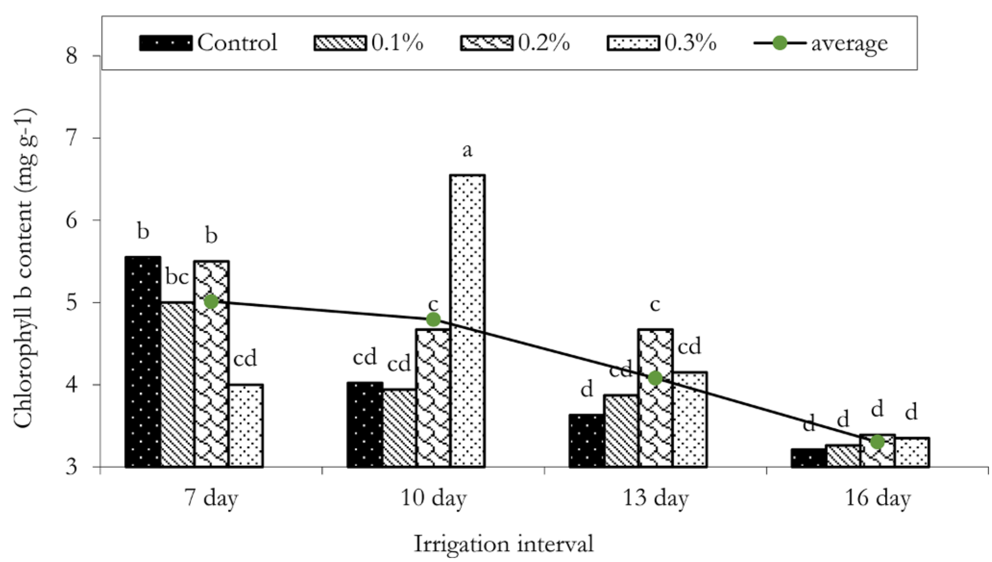


Fig. 6 Effect of different levels of bio-fertilizer and irrigation interval on chlorophyll b content (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

(0.2 and 0.3%) under 13 and 16-day irrigation treatments (Fig. 7).

Seed Calcium and Magnesium Content

As shown in Table 3, the effects of the interaction of irrigation intervals and bio-fertilizer application were significant ($p \leq 0.01$) on calcium and magnesium content of seed. According to Fig. 8, the highest calcium content (1.2%) was achieved in 0.2% bio-fertilizer concentration under 16-day irrigation interval while the lowest value (0.28%) was observed in control at 7 day irrigation interval. The results showed that the use of biofertilizer significantly increased the calcium content of seeds and it increased significantly with increasing drought stress. So that the amount of calcium decreased by 114.2, 72.1 and 20.7% in irrigation intervals of 7, 10 and 13 days compared to 16 days irrigation interval, respectively. Also, the use of 0.3, 0.1 and 0.2% biofertilizer compared to the control (without using fertilizer) increased the calcium content by 4.16, 2.70 and 4.16%, respectively. As shown in Fig. 9, the change trend of seed magnesium content was similar to that of seed calcium content. Except for the 10-day irrigation interval, the use of biofertilizer significantly increased the magnesium content of the seeds. With the increase of the drought stress level, the amount of magnesium in the seed increased significantly, so that the amount of magnesium in the seed increased by 95.7, 60.7, and 21.6% in 16-day irrigation intervals compared to 7, 10, and 13-day irrigation intervals, respectively. The highest amount of magnesium (1.04%) was observed in the consumption of 0.2% biofertilizer at the 16-day irrigation interval, which was 0.18% more than the control treatment.

Correlation Coefficients

Based on the results of this simple correlation table (Fig. 10), seed yield had a positive and significant correlation with plant height, thousand seed weight and chlorophyll A content, while it had a negative and significant

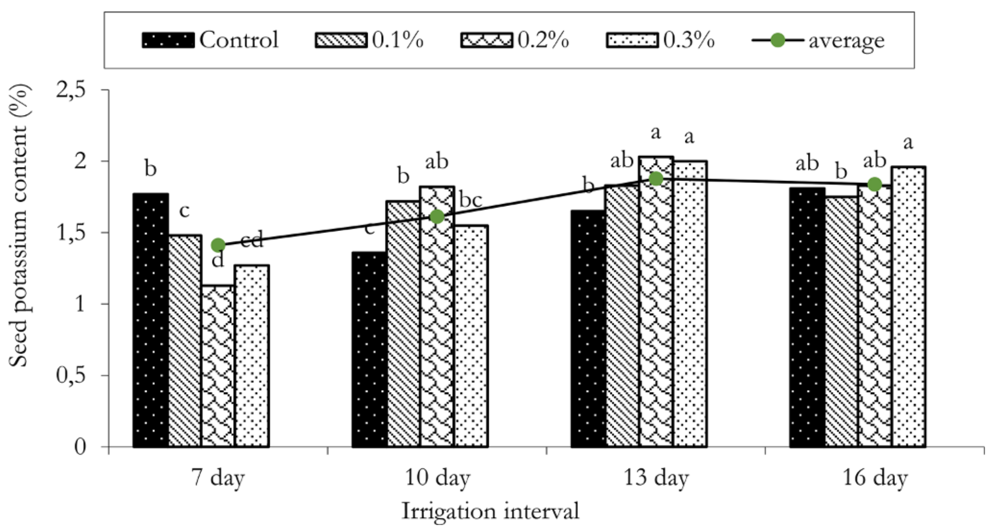


Fig. 7 Effect of different levels of bio-fertilizer and irrigation interval on seed potassium content (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

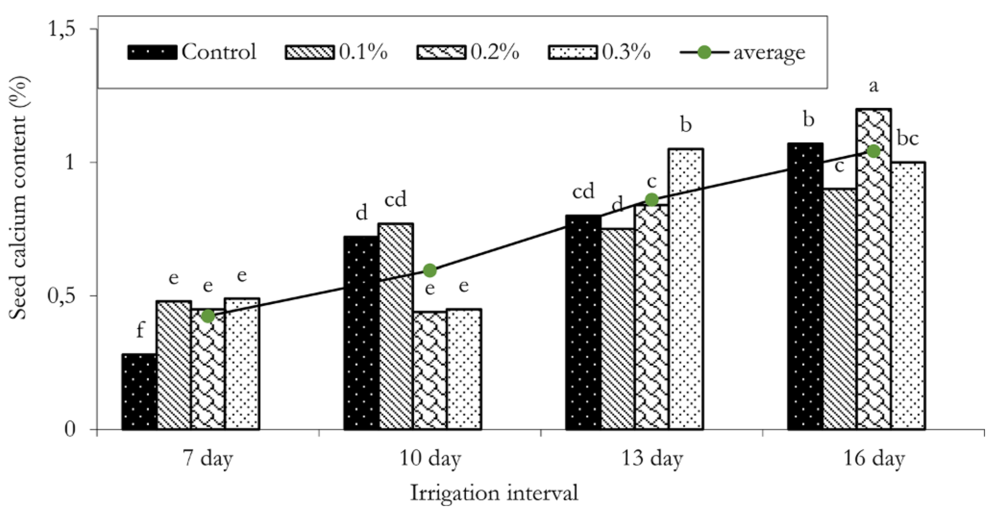
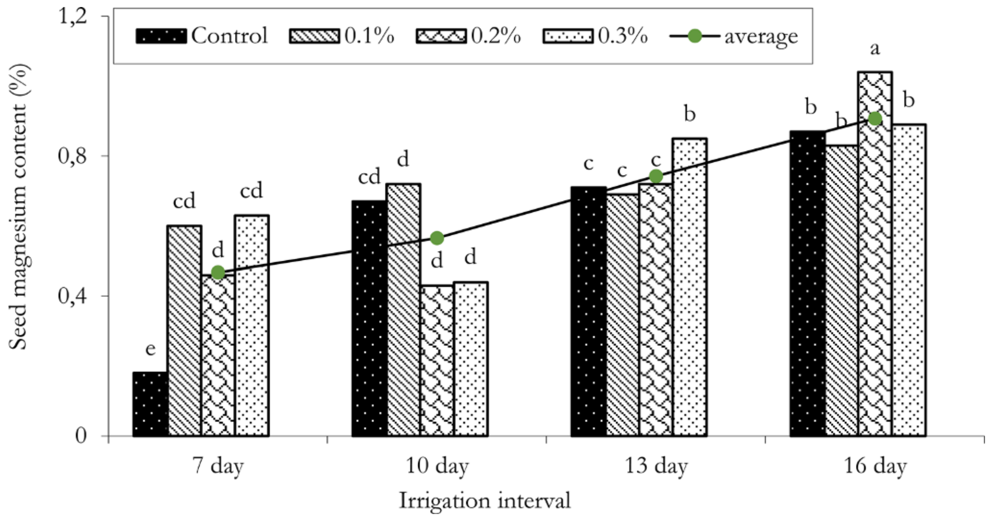


Fig. 8 Effect of different levels of bio-fertilizer and irrigation interval on seed calcium content (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)

Fig. 9 Effect of different levels of bio-fertilizer and irrigation interval on seed magnesium content (Means similar letter(s) are not significantly different level, according to the Duncan's test at 5% probability level)



	Plant height	Leaves area	1000-grain weight	Grain yield	Chlorophyll a content	Chlorophyll b content	Potassium content	Calcium content
Leaves area	0.47*							
1000-grain weight	0.29ns	0.42*						
Grain yield	0.35*	0.12ns	0.47*					
Chlorophyll a content	0.77**	0.20ns	0.41*	0.33*				
Chlorophyll b content	0.74**	0.11ns	0.38*	0.22ns	0.85**			
Potassium content	-0.01ns	0.52**	0.21ns	0.10ns	-0.29ns	-0.31*		
Calcium content	-0.15ns	0.13ns	-0.12ns	-0.30*	0.21ns	0.51**	0.51**	
Magnesium content	-0.19ns	0.01ns	-0.19ns	-0.24ns	0.18ns	0.81**	0.33*	0.95**

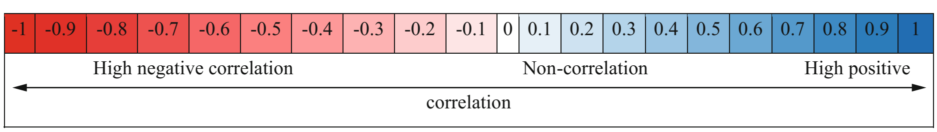


Fig. 10 Correlation coefficients among quantitative and qualitative traits of quinoa under soil application of growth-promoting microorganisms and water stress

correlation with seed calcium content. Also, the content of chlorophyll a had a positive and significant correlation with growth and yield parameters.

Discussion

These results showed that with the decrease of available water along with the increase of irrigation intervals, the use of biological fertilizers has significantly increased the height of the plant. In other words, although water stress decreased the plant height by reducing the turgor potential in plant cells and negatively affecting the growth and development of stem cells, the effects of water deficiency were reduced by applying growth stimulants under water stress conditions; and the longitudinal growth of the plant increased. A similar result was obtained from the several study such as Souza et al. (2016) on corn under drought stress, Ghorbanian et al. (2012) on corn using mycorrhiza fungus, Wang et al. (2020) on quinoa using bio-fertilizers, and also Wu et al. (2019) on *Camellia oleifera* using phosphorus soluble microorganisms. Previous studies have shown that rhizosphere bacteria stimulate plant growth by different methods such as the production of plant hormones (gibberellin and auxin) (Tsukanova et al. 2017), increasing available phosphorus through various methods such as -ACC-deaminase (Van de Wiel et al. 2016) also play a role in stimulating the growth and increasing plant height.

By reducing the amount of water available to the plant, i.e. at the 16-day irrigation interval, no significant difference was observed in the leaf area with the used biofertilizer compared to the control treatment. However, water deficit stress reduced the leaf length, leaf area and plant height of quinoa (Fghire et al. 2015) and the use of beneficial soil microorganisms such as rhizosphere bacteria that stimulate plant growth significantly affected the dry weight of the stem, leaf, whole plant, plant height and leaf area of maize were affected (Lin et al. 2018). Interestingly, the resistance of this plant against drought stress is such that even in severe drought stress, a significant decrease in the 1000-grain weight as the most important components of yield was not observed. Also, the results showed that the application of growth-promoting microorganisms were moderated the negative effects of drought stress on 1000-grain weight. Carlier et al. (2008) reported that inoculation of wheat seeds with growth-promoting bacteria increased 1000-grain weight by 6% and the number of seeds per spike by 30%. The co-application of mycorrhiza and growth-promoting bacteria increased grain yield and yield components under drought stress (Vurukonda et al. 2016). Also, Yazar et al. (2015) have reported that drought stress in the filling stage of quinoa seeds has led to a shorter growth period, accelerated aging and a decrease in the weight of the seeds (Luo et al. 2019). The decrease in yield and 1000-grain weight of quinoa under water stress has also been reported in other study (Gámez et al. 2019).

The application of irrigation interval once every 16 days compared to 7, 10 and 13-day irrigation intervals caused a decrease by 23.76, 19.89, and 19.33% of grain yield, respectively. On the other hand, application of bio-fertilizer only at the level of 0.3% caused a significant increase in grain yield. Therefore, the tolerance of this plant to drought stress is high so that only severe stress reduced yield. Geerts et al. (2008) have reported that normal irrigation is not typically a solution for water-scarce areas. But low irrigation, where water is only available during critical periods of growth, can be a viable solution. They also showed that limited-irrigation could be very beneficial for quinoa in semi-arid regions. This can be valuable for stabilizing crop production and increasing water productivity in arid and semi-arid areas. Algosaibi et al. (2017) in a study on the effect of irrigation interval on quinoa grain yield reported that this plant requires a limited amount of irrigation water and plant growth is not affected by high water. According to Dong et al. (2017), drought stress during flowering through sterilization pollen and disruption of pollination and reduction of current photosynthesis and the transfer of stem reserves spike reduced the number of grains per spike and the subsequent decrease in grain yield. As the amount of water decreased, the rate of photosynthetic material accumulation and relative growth rate decreased, and a significant decrease in relative growth rate indicated a decrease in dry matter due to reduced foliage growth in the growth stage, which can be one of the lower yield (Sah et al. 2020).

It seems that under stress conditions, the amount of chlorophyll and photosynthetic capacity decreases due to water limitation for the plant. Sharif et al. (2018) also stated that the change in chlorophyll content is a short-term response to stress and one of the important factors in the photosynthetic capacity and dry matter production in drought conditions. However, drought stress leads to a significant decrease in total chlorophyll pigments (Batra et al. 2014). On the other hand, Aslam et al. (2020) reported that the amount of photosynthetic pigments in quinoa increased significantly with PGPR inoculation. Therefore, water stress significantly increased seed potassium content. It has already been reported that the absorption of elements increases under the use of biofertilizers and growth stimulants (Abdallah et al. 2020). In a study on corn, it was found that stress had an effect on the amount of phosphorus, potassium, and sodium in the corn shoot, and the use of microorganisms such as fungi and bacteria increased these elements in the corn shoot (Rasouli et al. 2019). Fayez and Bazaid (2014) have stated that potassium plays an important role in the transfer of soluble sugars to the root end, and therefore increasing potassium content can facilitate the transport of soluble sugars and play an important role in the osmotic regulation of cells. Zhu et al. (2020) stated that the reason for increasing the amount of potassium in drought stress is the mechanism of active absorption of this ion and reported that the plant increases potassium concentration in roots and shoots by consuming energy to increase resistance to drought.

One of the most harmful effects of drought stress is the disruption of the processes such as uptake, and accumulation of nutrients that reduce grain yield (Karim and Rahman 2015). Under drought stress, calcium accumulation in the roots and leaves of some species of millet, alfalfa, and rice has been reported (Zeid and Shedeed 2006; Fahad et al. 2017). In general, the amount of calcium and magnesium increases with water restriction (Iannucci et al. 2002; Pirzad et al. 2012). Application of bio-fertilizer increased seed magnesium so that the seed magnesium content in 0.1, 0.2, and 0.3% treatments increased by 14.1, 7.5, and 12.8%, respectively, compared to the control (non-application). The findings of this study are consistent with the reports of Vinale et al. (2008), who stated that growth-promoting bacteria increase the magnesium content. It can be stated that the bacteria and fungi in bio-fertilizers by acidifying the environment around the roots cause the dissolution of phosphates and cations such as calcium, magnesium, potassium, etc., and thus increases the amount of these elements in the grain. Begum et al. (2019) reported that mycorrhizal fungus helps to absorb nutrients by absorbing nutrients through the expansion of the plant root system and exploring the soil by external hyphae in the hair roots. In this connection, use of Pseudomonas bacteria significantly increased the amount of magnesium in the aerial parts of wheat cultivars (Naseri et al. 2019). By secreting organic acids, these bacteria release and provide nutrients to the soil and provide the plant with access to nutrients such as magnesium (Jutur and Reddy 2007).

Conclusions

Overall, the results of the study showed that the most suitable irrigation interval for quinoa production was once every 13 days with the use of 0.3% concentration of the biofertilizer, which increased leaves area, 1000-grain weight, grain yield, and seed potassium content. Of course, the seed calcium content at 13-day irrigation interval was higher than that at 7 and 10-day irrigation treatments. The best grain yield in terms of quantity was related to irrigation interval of 7, 10 and 13 days. In terms of element accumulation of grain, the most appropriate treatment was related to 13 and 16 day irrigation interval. In general, the results showed that irrigation at 7 and 10 days intervals due to soil flooding and reduced soil aeration as well as irrigation at 16 days due to severe water stress in the plant reduced grain yield. Interestingly, the use of biological fertilizer increased yield when the soil was low for the plant. Therefore, water stress, including flooding conditions and low water available, had a negative effect on grain yield and should be prevented to achieve high yield.

Conflict of interest S.H. Hosseini and A. Bostani declare that they have no competing interests.

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