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BARLEY RESPONSES TO POTASSIUM FERTILIZATION UNDER WATER STRESS CONDITION

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Abstract

Field experiment was conducted at the experimental research farm of National Research Centre, Nubaria region, Beheira governorate, Egypt to study the effect of potassium fertilizers (K-Silicate, K-Citrate and K-Nitrate)on biochemical changes of growth and yield parameters of some sensitive barley varieties (Giza 125, Tombari, Ksar Megrine, Tamellat) under water stress conditions (40 and 75% of water use efficiency). Water stress has a negative effect on the most of the studied yield characters of the investigated barley varieties. Results indicated that barley variety Giza 125 scored the highest values of grain yield, harvest index and water use efficiency as compare to the other investigated varieties. Application of K Citrate followed by K Silicate gained the highest values of the yield and yield components under water stress treatment, while the opposite was true in case of the control. Nitrogen, phosphorus and protein content in barley grain of the examined varieties were higher under normal than water stress ones, where barley Giza 125 scored the highest nitrogen values and protein content under water stress conditions. The barley varieties Tombari and Ksar Megrine gained the highest values for most studied stress tolerance indices indicating enhancement in their drought tolerance after application of K-Citrate and the opposite was true in case of K Silicate applied for barley Giza 125 and Tamellat.

***Keyword*:** barley**,** water stress, potassium citrate, proline, nutrient content, grain yield

Introduction

Barley (*Hordeum vulgare* L.) is a typical crop of marginal areas in North Africa and Mediterranean regions specially in the Northern coastal areas which precipitation fluctuated from year to year and in most years the barley cultivated area, as in Egypt, that suffer from lack of water in the time of sowing and/or at the later stages of growth which need supplemental irrigation. Water deficit induced obviously effects on the concentration and content of minerals in cereal plants (Hussein *et al.*, 2006). Barley in Egypt is grown under wide range of environmental conditions. It is grown in areas where water supply is limited and where crop production depends mainly upon rain-fed in the Northern coastal region and in the marginal areas (Nile Valley and Delta and in the new reclaimed soils).

Drought is one of the major constraints on agricultural productivity worldwide and is likely to further increase. Several adaptations and mitigation strategies are required to cope with drought stress (Sai Shiva *et al.*, 2016). Drought represents the most important a biotic stress factor worldwide, that affects yield stability, severely limits plant growth and development as well as agricultural characteristics including the final yield productivity of crops in Mediterranean areas, where drought is a severe inhibitor of sustainable agriculture (Fita *et al.*, 2015). Water deficit led to decrease in photosynthesis, transpiration and other biochemical processes that highly correlated with plant growth, development and crop productivity (Tiwari *et al.*, 2010).

Potassium plays an important role in combating the adverse effect of water stress through its effect on different physiological process. The availability of potassium to the plant decreases with decreasing soil water content, due to the decreasing mobility of potassium under these conditions. Low levels of soil moisture reduced root growth and the rate of potassium inflow in plants in terms of both per unit of root growth and per unit of root length. Under water stress, wilting in plants suggests possible potassium deficiency (Hu and Schmidhalter, 2005).

Potassium is an essential plant nutrient and is also the most abundant cation in plants. The concentration of Potassium in the cytoplasm has consistently been found to be between 100 and 200 mM (Shabala and Pottosin, 2010), and apoplectic K^+ concentration may vary between 10 and 200 or even reach up to 500 mM (White and Karley, 2010). Potassium plays vital roles in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance and stress resistance (Marschner and Marschner, 2012). Potassium is also essential to the performance of multiple plant enzyme functions, and it regulates the metabolite pattern of higher plants, ultimately changing metabolite concentrations (Mengel, 2001).

Therefore, the present study was conducted to evaluate the role of potassium fertilization on biochemical changes and yield of some Mediterranean barley varieties grown under water stress conditions.

Material and Methods

Experimental design

Field experiments were conducted during two winter seasons of 2017/2018and 2018/2019 to evaluate the effect of potassium fertilization on the biochemical changes and grain yield of Mediterranean barley varieties grown under water stress condition at the experimental farm of National Research Centre, Nubaria region, Egypt (latitude 30.87 N, and longitude 31.17 E, and mean altitude 21 m above sea level). The soil of experimental site is classified as sandy soil. The field capacity and available water of the experimental soil was 16.8 and 12.1 ml /100g soil (Klute, 1986), respectively. Soil pH was 8.02; electrical conductivity (EC) 0.97 dSm^{-1} (Hanna Instruments HI2550 pH/ORP/EC/ TDS/NaCl Benchtop Meter) and available N, P and K were 2.89, 0.51 and 19.1 mg/100 g soil, respectively.

Treatments details

The experiment was arranged in a split plot design with four replicates where the varieties origin (countries) in main plot and the water regimes (75 and 40% of water holding capacity)which named as normal sufficient irrigation and water stress condition imposed in sub main plot. The experiment was drip irrigated with tow emitters discharge (2; 4 liter/h) to resemble normal and stress conditions, respectively, lateral length (25 m) and a meter among. The net area of each experimental plot was 10.5 m^2. The Mediterranean barley varieties were the Giza 125 (Egypt), Tombari (Tunis), Ksar Megrine (Algeria) and Tamellalet (Morocco). The Potassium fertilizers (K Silicate, K Citrate and K Nitrate) applied as foliar fertilization at 2% concentration. The assigned levels of potassium fertilizers were foliar sprayed twice during the growth period of barley plant after 40 and 60 days from sowing date.

Estimation during growth stages

(i) Chlorophyll content

Leaf greenness present in a plant at stem elongation, booting and ear emergency stages determined according to Minolta (1989).

(ii) Relative water content

Leaf relative water content (RWC) estimated at ear emergence, according to Castillo (1996), RWC calculated using the following formula: RWC = (FW-DW)/(TW-DW) × 100.

(iii) Determination of proline

Proline was estimated at booting and ear emergence stages, according to Maria Filek *et al.* (2014).

Yield components estimation

At harvest in both years, the total area of each plot was harvested to determine potential grain yield (Yp) and stress yield (Ys) per plot and then converted to grain yield ton $acre^{-1}$. Ten individual plants were selected at harvest time as random from the middle of each plot to estimate: Plant height (cm),Number of spikes, Spike weight (g), 1000-kernel weight (g), Grain yield and Biological yield.

Harvest index: HI =grain yield/biological yield into 100.

Water use efficiency: WUE, expressed in; (kg m^{-3} of irrigation water) on grain basis was determined by dividing the grain yield (kg $acre^{-1}$) by quantity of water applied (m^3 $acre^{-1}$).

Drought tolerance indices: It was calculated by the equations cited in Table (1).

Table 1 : Stress tolerance indices for the evaluation of barley to drought tolerance

Stress tolerance indices	**Equation**	**Reference**
Stress susceptibility index	SSI = 1– (Ys/Yp)/1– (Ŷs/Ŷp)	Fischer and Maurer (1978)
Mean productivity	MP = (Ys + Yp) / 2	Rosielle and Hambline (1981)
Stress tolerance	TOL = Yp – Ys	Rosielle and Hambline (1981)
Geometric mean productivity	GMP = (Yp * Ys)1/2	Fernandez (1992)
Stress tolerance index	STI = (Yp * Ys)/(Ŷp)2	Fernandez (1992)
Yield index	YI = Ys / Ŷs	Gavuzzi*et al.* (1997)
Yield stability index	YSI = Ys / Yp	Bouslama and Schapaugh (1984)
Harmonic Means	MP = 2(Ys * Yp) /(Ys + Yp)	Kristin *et al.* (1997)

Ŷs and Ŷp are mean grain yield of all genotypes in stress and non-stress conditions.

Nutrient content analysis

At harvest stage, representative grain samples were analyzed for the nutrient content (N, P, K, Ca as macro and Fe, Mn; Zn as micronutrients) in barley varieties and determined according to Cottenie *et al.,* (1982) and Motsara and Roy (2008).

Statistical analysis

Two factors were four potassium fertilizers treatments (in man plot) and 4 barley varieties (in sub main plot) with four replicates and put in randomized complete plot design (RCBD) in factorial analysis. The data collected from two seasons were statistically analyzed using analysis of variance (ANOVA) and the means of varieties included in this trial compared using fisher test run by Least Significant Difference (LSD) at ($P \leq 0.05$) according to Gomez and Gomez (1984).

Results and Discussion

Pigment contents

Data in Table (1) showed the effect of foliar spray of potassium fertilizers (K Citrate, K Nitrate and K Silicate) as well as untreated one (control) on the chlorophyll content during the barley growth stages. Data revealed that spraying the barley variety Tombari with K Silicate and barley Giza 125 with K Citrate recorded the highest values of Chlorophyll content at the studied growth stages, under both water stress and normal irrigation condition. Whereas, the lowest ones were attained under control (no potassium applied) at normal and water stress treatments. Potassium is essential for many physiological processes, such as photosynthesis, translocation of photosynthesis into think organs, maintenance of turger, activations of enzymes, reducing of some ions in soils suffer from environmental stress (Hussein *et al.* 2013).

Regarding to the effect of water stress treatments on the chlorophyll content, data on hand noticed that the a great reduction percentage were found at barley variety Giza 125 and Tamellat control for stem elongation, booting and ear emergency, respectively. Whereas, the minimum reduction occurred at barley Ksar Megrine + K Nitrate (2.2%), Giza 125 + K Nitrate (9.2%) and Giza 125 + K Citrate (12.1%). Also, the increase of chlorophyll value might be due to the potassium affects photosynthesis at various levels (Abou El-Yazied and Mady, 2012).

Table 1 : SPAD Chlorophyll of barley varieties under water stress

Varieties	Treatment	Stem elongation		Booting		Ear emergency	
		Normal	Stress	Normal	Stress	Normal	Stress
Giza 125	Control	43.6	28.5	48.0	40.1	45.6	38.6
	K-citrate	51.6	39.5	61.2	49.3	54.2	47.7
	K-nitrate	47.7	33.5	51.3	46.5	51.2	42.6
	K-silicate	45.2	32.0	50.7	42.8	49.0	42.2
Tombari	Control	45.6	35.6	38.0	31.1	45.4	35.3
	K-citrate	50.6	44.6	46.4	35.7	48.0	37.1
	K-nitrate	53.2	44.9	48.9	37.7	51.8	41.0
	K-silicate	65.2	52.2	52.3	39.9	53.5	43.1
Ksar Megrine	Control	45.3	38.1	38.2	30.8	38.4	32.5
	K-citrate	47.0	42.0	43.0	31.7	43.5	37.0
	K-nitrate	50.9	49.7	49.8	41.6	50.7	42.3
	K-silicate	49.8	44.4	44.6	37.5	49.5	37.5
Tamellat	Control	46.3	40.0	42.9	30.9	43.9	32.6
	K-citrate	55.7	48.7	51.0	38.4	51.1	44.9
	K-nitrate	55.1	47.1	47.9	36.5	49.1	36.9
	K-silicate	48.8	45.3	45.5	31.2	45.8	36.9
LSD (0.05)	**(V)**	0.13	0.75	0.026	1.07	0.013	1.17
	(T)	0.033	0.06	1.30	0.56	0.14	0.08
	(V * T)	2.06	1.59	2.33	3.31	3.19	2.71

Regardless the potassium application, data indicated that Tombari followed by Tamellat and Giza 125 gained the highest values under normal condition while the lowest values were observed at Giza 125, Tamellat, and Ksar Megrine, under water stress condition at the studied growth stages, respectively. Foliar application of potassium silicate has many benefits in improving leaf erectness, and enhancing photosynthesis efficiency also reducing capability to lodging in grasses (Ahmad *et al.,* 2013). In addition, it offers benefits in many agricultural applications e.g. increases growth and yield, improves strength, minimize climate stress and provides impedance to mineral stress.

Relative water content

The relative water content (RWC) of barley varieties grown under water stress as affected by potassium fertilizer application at booting growth stage indicated in Table (2).Regarding to RWC, the highest values of (94.9%) recorded for barley variety Ksar Megrine sprayed with K Nitrate and the lowest values 72.3% observed for barley variety Tombari without potassium application. Whereas, the maximum RWC values (85.8%) recorded for Ksar Megrine sprayed with K citrate and the minimum one (62.0%) was for Giza 125 control treatment under water stress condition. The highest decreased percent in RWC (24.5%) observed for barley Giza 125 sprayed with K Citrate and the lowest one (8.6%) recorded for Tombari sprayed with K Silicate. Regardless potassium application, the barley Tombari followed by Ksar Megrine which registered the lowest decrease percent in RWC as affected by water stress condition. The positive influences of K Citrate on total soluble carbohydrates, phenolic compounds and total soluble protein may be attributed to the importance of potassium as a cation (+) and/or citrate anion (-) in the different physiological processes: Potassium plays a major role in the transport of water and nutrients throughout the xylem Malvi (2011), Capelo *et al*., (2012).

Proline content

The drought stress had a promotive effect on the proline content at booting and ear emergency stages where data in Table (2) supported which indicated that the maximum values of proline content (3.98 mg/g fresh weight) at ear emergence stage were recorded at control (untreated) of Tamellat barley variety while the lowest ones were obtained for Tamellat variety after spraying K Silicate under water stress condition. The maximum and minimum increase percent were recorded for Tombari sprayed with K Silicate and Tamellat sprayed with K Nitrate, respectively. The increase of proline concentration in cotton plants enabled the water stressed plants to maintain low water potentials by decreasing water potentials, proline accumulation involved in osmo-regulation appeared to allow additional water to be taken up from the environmental Gebaly *et al*., (2013). Potassium citrate is potassium salt of citric acid which considered one of the most important organic acids in the respiratory pathways into plant cell. The mitochondrial citric acid cycle provides the energy for ATP synthesis which is essential for different biochemical and physiological processes (Taiz and Zeiger, 2002).

Table 2 : Relative water and proline of barley varieties under water stress

Varieties	Fertilizers	RWC% at booting stage		Proline mg/ g fresh weight at booting stage		Proline mg/ g fresh weight Ear Emergence	
		Normal	*Stress*	*Normal*	*Stress*	*Normal*	*Stress*
Giza 125	Control	79.08	61.97	1.59	3.98	1.99	4.20
	K-citrate	86.18	65.03	0.96	2.94	1.50	3.67
	K-nitrate	88.16	74.60	0.79	2.69	1.81	4.15
	K-silicate	91.25	79.12	0.64	2.46	0.80	3.31
Tombari	Control	72.31	64.25	1.28	3.94	2.03	4.62
	K-citrate	81.58	72.82	1.15	2.75	1.81	4.22
	K-nitrate	87.54	77.97	1.21	2.83	1.83	4.48
	K-silicate	84.91	77.59	0.66	2.52	0.64	4.20
Ksar Megrine	Control	86.54	74.20	1.70	3.24	2.67	4.75
	K-citrate	94.52	85.77	1.11	2.74	2.33	4.46
	K-nitrate	94.87	80.81	1.19	2.23	2.33	4.28
	K-silicate	89.00	78.40	0.81	2.12	1.39	3.19
Tamellat	Control	75.60	65.30	1.38	3.20	2.56	5.97
	K-citrate	85.70	74.80	0.43	3.87	2.37	4.87
	K-nitrate	83.45	66.50	0.53	2.28	1.92	3.24
	K-silicate	92.46	79.48	0.42	2.00	1.36	3.10
LSD (0.05)	(V)	1.49	2.65	0.29	0.28	0.62	0.71
	(T)	0.97	1.62	0.27	0.29	0.53	0.79
	(V * T)	2.24	3.88	0.50	0.52	1.05	1.36

RWC: Relative water content

Resulted data observed that the highest values of proline content (3.98 mg/g fresh weight) at booting stage and (5.97 mg/g fresh weight) at ear emergence stage were recorded at control (untreated) of Giza 125 and Tamellat barley varieties while the lowest ones were obtained for Tamellat variety after spraying K Silicate under water stress condition. The maximum and minimum increase percent were recorded Tombari sprayed with K Silicate and Tamellat sprayed with K Nitrate, respectively. Spraying Potassium citrate registered the lowest amount of proline content indicating their importance in alleviating the water stress in plants.

Yield parameters

Data in Table (3) indicated that the influence of foliar application of potassium in different sources (Citrate, Nitrate; Silicate) in addition to control on barley yield parameter under water stress condition on barley growth characters. Data on hand revealed that the values of barley growth characters under normal irrigation are greater than that under water stress condition. It is clear to mention that the control treatment of the studied barley varieties recorded the lowest values of barley growth characters, while the highest values were mainly attained after foliar application of KCitrate for the examined barley varieties. Zewail *et al.* (2011) found that foliar application of K Citrate increased plant height, number of branches, total leaf area and dry weight of leaf and stems of faba bean plants. These results may be attributed to the positive effect of citric acid as antioxidant which has an auxin action that improved vegetative growth parameters. Sun and Hong (2011) stated that foliar application of citric acid significantly improved the plant growth by increasing the activities of antioxidant enzymes.

Table 3 : Influence of Potassium on barley yield parameters under water stress

Variety	Fertilizer	Plant height (cm)		Number of Spike (per m^{-2})		Spike length (cm)		1000 kernel weight (g)	
		Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Giza 125	Control	72	62	164	133	10.1	8.1	47.2	33.0
	K-citrate	80	72	235	205	9.7	9.1	55.5	48.8
	K-nitrate	70	67	208	188	10.1	9.2	54.0	37.4
	K-silicate	75	68	196	189	10.1	9.2	54.6	37.7
Tombari	Control	68	57	300	240	9.1	7.4	39.2	29.4
	K-citrate	78	73	328	270	10.4	9.1	52.8	50.2
	K-nitrate	73	63	304	285	9.4	9.2	48.3	43.6
	K-silicate	82	72	325	269	10.6	10.1	48.3	40.2
Ksar Megrine	Control	72	55	219	186	9.1	7.1	47.0	36.2
	K-citrate	82	75	275	221	10.1	9.7	56.2	53.5
	K-nitrate	87	73	268	211	9.1	7.4	50.6	50.1
	K-silicate	81	77	271	220	10.7	9.1	53.8	49.6
Tamellat	Control	62	53	297	220	8.1	6.4	35.1	26.2
	K-citrate	75	67	389	353	9.7	8.4	47.9	39.9
	K-nitrate	77	72	366	332	8.7	8.1	42.9	33.0
	K-silicate	67	62	399	350	9.4	8.4	40.2	39.1
LSD (0.05)	(V)	0.036	0.096	1.9	1.02	0.06	0.098	0.052	0.048
	(T)	0.038	0.075	1.62	1.17	0.92	1.01	1.035	0.079
	(V * T)	NS	NS	12.2	16.2	2.17	1.86	8.17	7.05

Grain yield and water use efficiency

Data in Table (4), illustrated the effect of foliar application of different potassium sources (citrate, nitrate, silicate) on biological yield of the selected barley varieties (Giza 125, Tombari, Ksar Megrine and Tamellat) grown under normal irrigation and water stress condition. Results indicated that the water stress negatively affected the grain yield, biological yield, harvest index and water use efficiency (WUE) as compare to under normal irrigation condition.

The highest values of grain and biological yield and water use efficiency were recorded mainly after potassium citrate foliar application treatment under both normal irrigation and water stress condition with some exception. Similar results observed by Ahmed *et al*. (2014) which concluded thatgrain yield increases could be attributed to the effect of potassium on new growth and nutrient uptake which caused favorable effects on the number of opened bolls per plant and boll weight, leading to higher cotton yield. Spraying mango trees with Potassium citrate was very effective in improving yield as number of fruits and increased fruit weight (Ebeed and Abd El-Migeed, 2005).

Table 4 : Influence of Potassium on biological yield of barley under water stress

Varieties	Treatment	Biological yield (ton fed)		Grain yield (ton/fed)		Harvest Index		WUE (kgm^{-3})	
		Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Giza 125	Control	3.68	3.28	1.83	1.07	49.7	32.8	1.52	1.49
	K-citrate	4.20	3.90	2.23	1.34	53.1	34.4	1.86	1.86
	K-nitrate	4.23	3.00	2.20	1.25	52.1	41.7	1.83	1.74
	K-silicate	4.06	3.44	2.16	1.28	53.2	37.2	1.80	1.78
Tombari	Control	3.56	2.64	1.34	1.16	37.8	43.8	1.12	1.60
	K-citrate	4.69	3.74	2.32	2.25	49.5	60.1	1.94	3.12
	K-nitrate	4.58	3.50	2.07	1.79	45.2	51.2	1.73	2.49
	K-silicate	4.05	3.46	2.18	1.75	53.8	50.6	1.82	2.43
Ksar Megrine	Control	3.48	2.52	1.38	1.32	39.6	52.2	1.15	1.83
	K-citrate	4.32	3.35	2.28	1.86	52.8	55.6	1.90	2.58
	K-nitrate	4.08	3.10	1.91	1.82	46.9	58.8	1.59	2.53
	K-silicate	3.96	3.31	2.13	1.72	53.8	52.0	1.78	2.39
Tamellat	Control	3.41	2.81	1.08	0.85	31.6	30.2	0.90	1.18
	K-citrate	4.28	3.66	2.19	1.41	51.2	38.5	1.83	1.96
	K-nitrate	3.97	2.95	1.56	1.04	39.2	35.1	1.30	1.44
	K-silicate	4.19	3.49	1.97	1.17	47.1	33.5	1.64	1.63
LSD (0.05)	(V)	0.023	0.097	0.68	0.064	0.211	0.204	0.086	0.093
	(T)	0.096	0.078	0.055	0.051	0.096	0.07	0.071	0.087
	(V * T)	1.98	1.46	0.98	0.89	3.22	3.09	0.120	0.130

WUE: water use efficiency

Macronutrient in barley grains

The effect of foliar application of potassium in different sources on the grain N, P and K content of barley was represented in Table (5). Date on hand revealed that K-citrate enhanced plant nutrient content (in grain) at studied barley varieties, except Tamellat variety, where K-Nitrate gave the higher K content in grain under both water stress conditions. Mostly the N, P and K content was higher under normal irrigation than water stress conditions. Potassium citrate is potassium salt of citric acid which considered one of the most important organic acids in the respiratory pathways into plant cell (Ibrahim *et al*., 2015).

Regarding to the N, P; K content in barley varieties under water stress condition, results showed that the barley varieties Giza 125 and Ksar Megrine scored the highest values, while the lowest one were observed at Tamellat except under normal irrigation condition regarding P content for all varieties. Potassium citrate increase leaf area, improves leaf mineral content, enhancing yield and improved fruit quality as well as physical and chemical properties of mango trees (Taha *et al*., 2014).

Potassium silicate treatments recorded more potassium percent compared to the control as it contained potassium along with silicon. The previous mentioned results are in conformity with the findings of (Salim *et al*., 2013). The enhancing effect of potassium on plant growth might be attributed to its association with the efficiency of leaf as an assimilator to CO_2, activating phyto-hormone, regulation of cellular pH, enhancing N uptake, and acting as an activator to enzymatic systems (Sadak and Orabi, 2015).

Micronutrients content of grain at harvest stage

Data in Table (6) showed the effect of K fertilizers on the Fe, Mn; Zn content of some barley varieties under normal and water stress conditions. Results indicated that the highest values were attained after spraying K Nitrate (Tamellat), K Silicate (Ksar Megrine) and K Citrate (Tombari) under normal and water stress conditions, respectively whereas, the lowest values were obtained at control (Giza 125) for Fe; Mn and for Zn at Ksar Megrine. It is clear that water stress condition had a negative effect on the studied micronutrients content relative to the normal condition.

Regardless water stress condition, data on hand revealed that the highest values were observed at K Citrate (Tamellat), K Silicate (Ksar Megrine) and K Citrate (Tombari), respectively whereas; the lowest values were observed at control for Fe, Mn and Zn, respectively. According to the barley varieties, data noticed that Tamellat, Ksar Megrine and Tombari gained the highest values of Fe, Mn and Zn and Giza 125 ad Ksar Megrine scored the lowest values in same sequence, respectively. Regarding to the micronutrient content as affected by K fertilized, data on hand revealed that K-silicate scored the highest values of Fe and Mn and K citrate for Zn, while control was the lowest one.

Table 5 : Influence of potassium application on grain nutrient of barley.

Varieties	Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
		Normal	Stress	Normal	Stress	Normal	Stress
Giza 125	Control	1.25	0.95	0.123	0.097	0.480	0.425
	K-citrate	2.37	1.77	0.172	0.147	0.603	0.451
	K-nitrate	2.04	1.52	0.143	0.129	0.489	0.471
	K-silicate	1.50	1.27	0.149	0.141	0.562	0.482
Tombari	Control	1.34	0.98	0.135	0.110	0.497	0.365
	K-citrate	1.65	1.52	0.163	0.139	0.548	0.434
	K-nitrate	1.44	1.36	0.153	0.138	0.545	0.478
	K-silicate	1.49	1.19	0.155	0.130	0.544	0.515
Ksar Megrine	Control	1.25	0.99	0.140	0.119	0.480	0.383
	K-citrate	1.70	1.51	0.170	0.159	0.520	0.489
	K-nitrate	1.41	1.16	0.145	0.130	0.506	0.433
	K-silicate	1.52	1.24	0.154	0.137	0.509	0.487
Tamellat	Control	1.26	0.91	0.117	0.096	0.456	0.396
	K-citrate	1.93	1.57	0.173	0.167	0.537	0.439
	K-nitrate	1.27	0.96	0.169	0.129	0.545	0.469
	K-silicate	1.17	1.13	0.161	0.138	0.453	0.420
LSD (0.05)	(V)	0.097	0.04	0.009	0.011	0.051	0.046
	(T)	0.087	0.23	0.008	0.009	0.047	0.033
	(V * T)	0.0165	0.02	0.013	0.014	0.082	0.072

Table 6 : Influence of potassium application on grain micronutrient contents (ppm) of barley

Varieties	Treatment	Iron		Manganese		Zinc	
		Normal	Stress	Normal	Stress	Normal	Stress
Giza 125	Control	60.1	54.4	1.38	1.18	25.0	21.3
	K-citrate	89.7	72.3	1.93	1.55	27.7	32.5
	K-nitrate	74.3	66.0	1.80	1.37	28.6	22.6
	K-silicate	86.9	67.7	1.56	1.29	22.0	33.6
Tombari	Control	68.4	63.4	2.72	2.25	34.8	21.4
	K-citrate	79.0	68.5	2.93	2.67	25.8	35.5
	K-nitrate	84.2	79.4	3.34	3.13	31.4	26.8
	K-silicate	105.5	87.1	3.65	3.27	25.9	32.5
Ksar Megrine	Control	72.3	62.4	3.08	2.63	17.8	14.9
	K-citrate	76.0	74.9	3.94	3.19	18.0	17.1
	K-nitrate	85.8	80.9	3.48	3.31	18.8	16.7
	K-silicate	105.2	84.3	4.21	3.90	24.2	23.5
Tamellat	Control	100.2	97.9	2.31	2.18	22.5	21.8
	K-citrate	122.3	116.1	2.95	2.48	31.7	28.6
	K-nitrate	118.8	102.3	2.62	3.25	27.1	26.7
	K-silicate	118.6	99.5	3.41	3.26	25.0	23.2
LSD (0.05)	(V)	0.41	0.32	0.37	0.65	0.38	0.31
	(T)	1.24	0.96	0.86	0.44	0.27	0.26
	(V * T)	1.51	1.19	1.15	1.04	0.62	0.54

Regardless the water stress effect, Tombari + K Silicate, Tombari + K Citrate and Ksar Megrine + K Citrate save the highest values of Fe, Mn and Zn content, while the lowest values were recorded at control treatment, especially Giza 125, Tamellat and Giza 125 in same sequence.The finding results are in conformity with Eraslan *et al.* (2008) in spinach and Milne *et al.* (2012) in lettuce. The optimization of silicon nutrition has positive effects and plays an important role in the balancing of micronutrients in plants. Si presence in nutrient solutions affects the absorption and translocation of several macro and micro-nutrients in different plants (Epstein, 1999).

Stress tolerance indices

Data in Table (7) showed that the stress tolerance indices of the examined barley varieties as effected by water stress and foliar K application. Obtained date pointed out that mostly the highest values were attained after K Citrate application at all studied barley varieties, except SSI (K Silicate), YSI (control) for Ksar Megrine and Tamellat, while the lowest values were observed at control treatments.

Regarding to the effect of barley varieties on stress tolerance indices, results revealed that Tombari scored the highest values except SSI (Tamellat) and TOL (Giza 125).

The increase percentage of the stress tolerance indices relative to lowest values, 25, 80, 32, 35, 50, 50, 58; 37%, respectively while the lowest values were attained at Tamellat, except SSI (Ksar Megrine). According to the potassium sources application on the stress tolerance indices, data pointed out that the highest values were recorded at control treatments, while the highest on were obtained at K-Citrate (SSI, STI, GMP, YI), TOL and K-Silicate (YI, YSI, HM). The differences between the highest and lowest values were 60, 67, 54, 52, 55, 36, 91 and 53 for SSI – HM, respectively. Simple correlation was estimated among the stress tolerance indices and data revealed that YI positively correlated with STI (0.954), MP (0.908); GYP (0.935) and negatively with SSI (-0.589). Also, HM correlated positively with STI (0.995), MP (0.991), GMP (0.998); Yi (0.956).

Conclusion

Water stress had a negative effect on the most yield parameters and nutrient content of the investigated barley varieties. Barley varieties Ksar Megrine and Tombari scored the highest values under normal irrigation and water stress condition. Application of the K Citrate followed by K Silicate gained the highest values of the grain yield and yield components with or without water stress. Barley Giza 125 scored the highest values for N and protein under both water stress conditions, while Tamellat and Ksar Megrine gained the highest values for P content in same sequence. Tombari gained the highest values of stress tolerance indices for most studied stress indices.

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Conflict of Interest

"The authors declare that there are no conflicts of interest regarding the publication of this manuscript"

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