Plant Archives Vol. 20, Supplement 1, 2020 pp. 3224-3231 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

MITIGATING THE NEGATIVE EFFECT OF WATER STRESS ON BARLEY BY NANO SILICA APPLICATION

Farid Hellal[a*], Ahmad Kh. Amer[b], Saied El-Sayed[a] and Kadria El-Azab[b]

[a]Plant Nutrition Department, National Research Centre, Dokki, El-Buhouth St., 12622, Cairo, Egypt.

[b]Soils, Water and Environmental Research Institute, Agricultural Research Center (ARC), Giza, Egypt.

*Corresponding author Email: hellalaf@yahoo.com

Abstract

Silicon nanoparticles have distinctive physicochemical characteristics and improve the plant growth and yield under unfavorable environmental conditions. Therefore, the present investigation was undertaken to study the impact of Nano Silica on drought resistance depending on the Nano-Silica dose and moisture levels. Nano Silica applied at different rates (0.0, 25, 50 and 100 ppm) and the water regime was 40, 60 and 80% of water holding capacity (WHC). Results indicated that, Nano- Silica there was an ability to reduce the drought impact on barley growth and improving the nutrient status in plants. Besides, an increment in chlorophyll content recorded with the applied Nano Silica levels. Increasing rate of applied Nano-Silica treatments associated with decreasing proline content in plants. Data indicated that most of the highest values of the growth parameters recorded for the barley varieties Giza 133 and Giza 129 with application of 100 ppm Nano silica. The barley variety Giza 129 gained the highest values of Fe and Zn content under 80% WHC and 100 ppm Nano-silica whereas the lowest values for Mn content were observed at barley Giza 133. The highest values for 1000 kernel weight, grain and straw weight observed at Giza 136 followed by Giza 133 and Giza 129 under 80% water holding capacity at 100 ppm Nano-Silica applied as foliar spray.Results concluded that, under water stress foliar application with 100 ppm of Nano-silica is the proper concentration which could have beneficial effects on yield component and resistance of barley plants to drought stress.

Keywords : Nano silica, Water stress, Chlorophyll, Proline, Potassium, Grain yield

Introduction

Different abiotic stresses significantly affect the growth and development of plants. Salinity and drought stresses are the most common abiotic stresses and important limiting factors to agricultural productivity, especially in arid and semi–arid regions, and are major constraints for barley production (Ayman EL Sabagh *et al.,* 2019). Drought is a meteorological term and is commonly defined as a period without significant rainfall or period low precipitation. Generally, drought stress occurs when the soil available water is reduced and atmospheric conditions cause continuous loss of water by evapotranspiration (Cheruth *et al.,* 2009). Drought affects the morphological (induced senescence), physiological (stomata or osmotic adjustments and translocation of nutrients from older leaves to developing tissues and seeds), and biochemical processes (changes in the ratio of chlorophyll content, beta carotenoids, and reduced photosynthesis) in plants, resulting in growth inhibition of different barley genotypes (Jaleel *et al*., 2009; EL-Shawy *et al*., 2017 and Temel *et al*., 2017).

The utilizing of nano-fertilizers causes an increase in nutrient efficiency, reduce leaching pollutants into soil and groundwater, minimizes the potential negative effects associated with over dosage and reduce the frequency of the application. Hence, nano-fertilizer has a high potential for achieving sustainable agriculture, especially in developing countries (Naderi and Danesh, 2013). Under high transpiration rates, plants are able to withstand drought by preserving the potential of foliage, photosynthesis, femoral conduction, leaf erection, and the structure of wood texture vessels due to the use of silicon application (Gong *et al.,* 2008) and (Httori *et al.,* 2005). Increasing the photosynthesis in plants may be attributed to the silicon ability to reduce the electrolyte leakage from rice leaves grown under water deficit conditions (Agarie *et al*., 1998). Silicon has important role in stomata movement and transpiration rate through stomata (Gao *et al.,* 2006). The root growth of sorghum and water movement thought the rhizosphere zone under water stress gets affected by silicon application (Lux *et al.,* 2003).

The unique physiochemical properties of nanoscale silicon particles have useful applications in different sectors, including promising applications in the agricultural sector. The unique properties of Si-NPs allow them to cope with agricultural damage that may occur through climate change and/or abiotic stress 24 (Tripathi *et al.,* 2012). The application of Si-NPs in agriculture may also lead to global food security by helping in the development of improved varieties with high productivity 16 (Parisi *et al.,* 2015).

The positive effects of Silicon (in bulk size) have been demonstrated in plants; however, the absorption of Silicon in plants is greater when nano-particles of silicon are used (Suriyaprabha *et al.*; 2012b). Nano-materials consist of particles smaller than 100 nm. The small size of Si particles implicates new physical, chemical and biological properties (Monica and Cremonini, 2009). Bao-shan *et al.* (2004) immersed the roots of Changbai larch (*Larix olgensis*) seedlings in 62–2000 μl l^{-1} concentrations of Nano silica for 6 hours. Their results clearly showed positive effects of silica nanoparticles (SNPs) on growth and quality of the seedlings. Suriyaprabha *et al.* (2012b) demonstrated greater absorption of silica in Nanoscale in maize roots and seeds treated with nano-SiO_2, than when treated with micro-SiO_2, Na_2SiO_3, and H_4SiO_4; also, SNPs have been proposed as an immediately utilizable form for plants. Also, the recent finding showed that irrigation of pear seedling with high concentrations of Nano-SiO_2 did not have any toxic effect on the plant biology (Zarafshar *et al.,* 2015). The aim of this research work was to study the effect of Nano silica application on chemical constituents of barley varieties grown under water stress.

Materials and Methods

Pot experiment carried out during the growth winter season of 2017 at Gemmeza, El-Garbia governorate, Egypt, in the open filed under natural weather conditions (climate of middle delta). Three varieties of Egyptian barley (Giza 129, Giza 133 and Giza 136) were obtained from the Agricultural Research Center, Giza, Egypt, which were selected according to their sensitivity for drought which recorded through our previous experiments. The selected barley varieties cultivated in pots experiment to test the ability of different concentrations of Nano Silica (0, 25, 50, 100 ppm) as foliar application to increase their resistance to drought stress. The field capacity of clay soil used in pots experiment determined by saturating the soil with water, the pots were covered with plastic sheets and left to drain for 3 days. Pot weights were recorded after 3 days of drainage. The weight of soil moisture at field capacity was calculated as the difference between the soil weight after drainage and soil weight after oven drying for 105 °C for 24 h. Powdered SiO_2 Nano particles were purchased from Bio Techno fine chemicals, Egypt. Particle size distribution was < 50 nm, surface area > 200 m^2 g^{-1} and BET (P/P^0: up to 0.35). The purity of SiO_2 NPs was calculated by the inductively coupled plasma mass spectrometry (ICP-MS) technique to be 99.99%.

In clean plastic pots (29 × 25 cm in diameter and depth, respectively) containing 10 kg of clay soil, 15 grains of barley were sown in each pot on 17th November 2017 and irrigated to 100% of field capacity. The field capacity of the experimental soil was 31 ml /100g soil; pH 7.8; EC 1.1 dS m^{-1} and available N was 42 mg/kg soil. The pots were placed under natural filed conditions. The pots experiment was arranged in a two-factor randomized block design with three replicates. The treatments include, three varieties of barley (Giza 129, Giza 133 and Giza 136), three levels of humidity (80%, 60% and 40% of water holding capacity (WHC)) and four concentration of Nano silica (0, 25, 50, 100 mg l^{-1}) applied as foliar application. Total pots number = (3 varieties of barley × 3 levels of water stress × 4 concentration of Nano silica × 3 replication) = 108 pots for the experiment.

After 10 days from sowing, plants were thinned to 10 plants per pot and all pots were watered till the field capacity was maintained. The water stress treatment was started after the appearance of the fourth leaf on day 15. While water was totally withheld from the stressed plants until the soil moisture content reached 60% and 40% of WHC. The stressed plants were still at this moisture content until ripening by weighing the pots weekly and watering as required (irrigated once a week). The control pots were irrigated normally (to 80% of WHC) until ripening. Different concentrations of Nano silica (0, 25, 50, 100 ppm) were added *via* a foliar application after 30, 45, 60 and 75 days from sowing. In addition, for improving and accelerating the growth of plants, the NPK macronutrient (20: 20: 20) was added to the pots by 20 g/pot through life cycle of plant devised par two times at 25 and 45 days from sowing.

Samples were taken at 90 days after the stress treatment to determine RWC, total chlorophyll and the proline content of the barley grain, straw weight recorded for the harvested plants. The harvested barley varieties were oven dried for 48 h at 70°C, dry weights recorded, grinded and samples taken for Macro and micronutrient analysis.

Biochemical Parameters

Chlorophyll content: Leaf greenness present in a plant was determined with the Minolta-SPAD Chlorophyll Meter (Minolta Camera Co., Osaka, Japan). The SPAD-502 chlorophyll meter measures the chlorophyll absorbance in the red and near-infrared regions and calculates a numeric SPAD value which is proportional to the amount of chlorophyll in the leaf (Minolta, 1989).

Proline content: First, 0.4 g of fresh plant material was homogenized in 1.5 ml of distilled water and then incubated in water bath at 100 °C for 30 min. Then, the samples were cooled to room temperature (22 °C) and centrifuged for 10 min at 4 000 rpm. Next, 1 ml of a 1% solution of Ninhydrin in 60% acetic acid was added to 0.5 ml of the supernatant and incubated at 100 °C for 20 min. After cooling to 22 °C, 3 ml of toluene was added and the samples were shaken and left in the dark for 24 h for phase separation. One ml of proline extract was introduced to a cuvette and the absorbance was measured by spectrophotometer at a wavelength of λ = 520 nm according to (Bates *et al.,* 1973 and Maria *et al.,* 2014).

Yield estimations

Number of total plants per pot, number of total spikes per pot, number of tillers per plant, 1000-grain weight, and total grain, straw weight was recorded for the harvested plants. Data was expressed as a value per different variety of barley.

Nutrient content analysis

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

Statistical analysis

Data collected from the pot experiment statistically analyzed as a two-way Randomized Complete Block Design (RCBD) 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

Photosynthetic pigments

Photosynthesis is the main metabolic process that provides biomass accumulation in plants. Its rate depends on the content of photosynthetic pigments in foliar tissues, their composition and ratio. The effect of foliar application of Nano-silica (0, 25, 50, 100 ppm) on the SPAD Chlorophyll of the selected barley under different water stress are shown in Figure (1).

Under soil drought a significant decrease in the content of chlorophyll in barley leaves of barley was observed. The highest values for SPAD Chlorophyll registered at Giza 133 followed by Giza 136 and Giza 129 for SPAD Chlorophyll under 80% WHC and 100 ppm Nano-Silica. The application of Nano Silica to substrate promoted induction of synthesis of photosynthetic pigments in leaf tissues of barley or modified ways of biosynthesis of photosynthetic pigments in the direction of enhancement of drought resistance of plants. Increase of chlorophyll in photosystems indicated the reducing of stress.

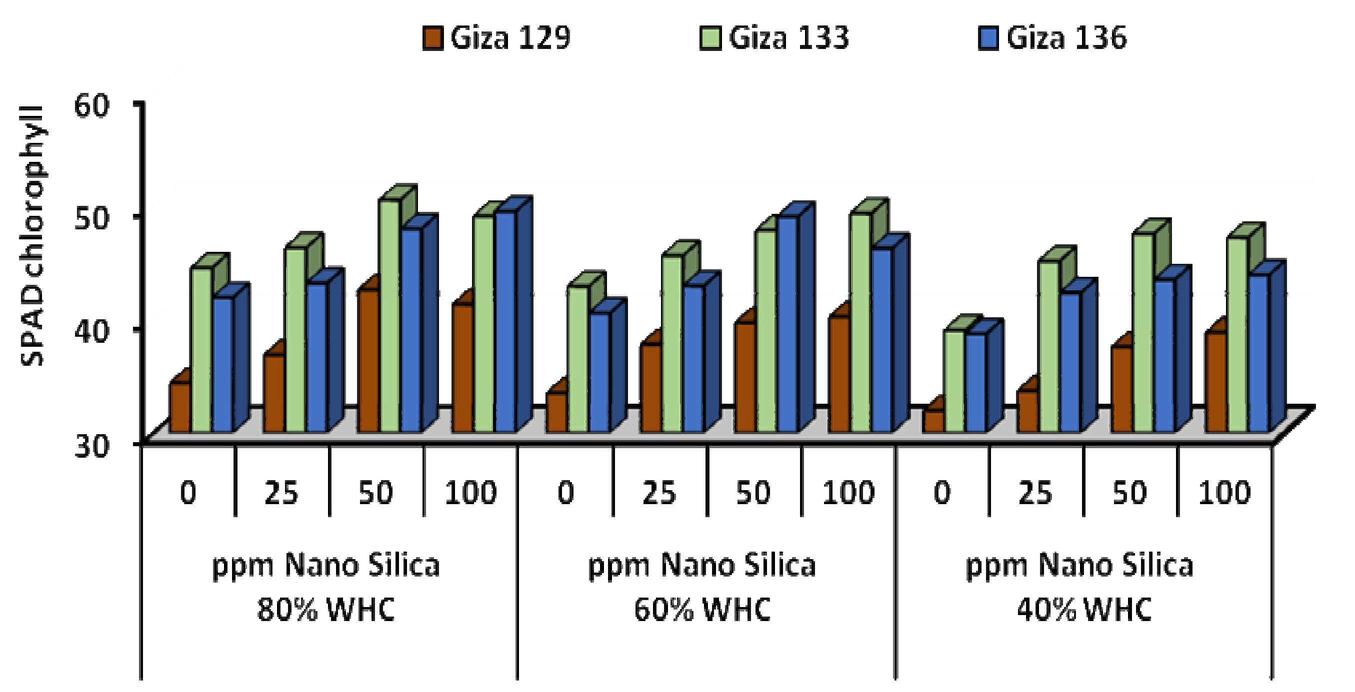

Fig.1: Chlorophyll contnet of barley as affected by Nano Si application under water stress

Also, it is clear to mention that the lowest SPAD Chlorophyll values attained at 40% WHC and zero Nano-silica for the examined varieties. It could be arranged as follow in descending order; Giza 129 < 136 < 129. Suriyaprabha *et al.* (2012) demonstrated greater absorption of silica in nanoscale in maize roots and seeds treated with nano-SiO_2, than when treated with micro-SiO_2, Na_2SiO_3, and H_4SiO_4; also, SNPs have been proposed as an immediately utilizable form for plants. Also, Zarafshar *et al.* (2015) showed that irrigation of pear seedling with high concentrations of Nano-SiO_2 did not have any toxic effect on the plant biology.

With respect to the water stress treatment and its effect on the SPAD Chlorophyll, results revealed that increasing water stress led to sever reduction in the previous chemical constituents where the highest values of them were recorded at 80% WHC and the lowest one obtained at 40% WHC treatment. Regarding to the Nano-Silica treatments, resulted data pointed out that increased Nano–silica concentration associated with increasing the previous chemical parameters. Silicon can reduce the electrolyte leakage from rice leaves and therefore promote photosynthetic activity in plants grown under water deficit conditions (Agarie *et al.,* 1998). Gong *et al.* (2003) reported higher water use efficiency by application of Si in wheat. Gao *et al.* (2006) reported that Si influences stomata movement and, therefore, affects transpiration rate through stomata. Regardless barley varieties, the highest increase percentage resulted from increasing Nano Silica was attained relative to the control and 40% water stress.

Proline content

Accumulation of proline in plant cells facilitates storage of water and is an important physiological mechanism of plant adaptation to drought (Kuznetsov and Shevyakova, 1999). In treatments with limited soil moisture the proline content noticeably increased (Fig. 2). The highest values for Proline was observed at Giza 129> Giza 133 >Giza 136 in descending order under application of 100 ppm Nano silica. Also, it is clear to mention that the lowest proline values attained at 40% WHC and zero Nano-silica for the examined varieties. It could be arranged as follow in descending order; Giza 133 < Giza 136 < Giza 129. These results fit with reports in the literature(Mauad *et al*., 2016 and Nermeen *et al.,* 2017), whose reported that the proline content in higher plants increases under different drought stresses. This result supports the view that proline accumulation is a symptom of stress-related injury. Foliar application of Nano Silica led to reduction of proline content in leaves of wheat and corn seedlings in all treatments. This indicated a lower stress level in seedlings treated with Nano Silica application and pointed to the fact that accumulation of proline is not related to the manifestation of the protective action of Nano Silica. There was not found any statistically significant correlation between the size of Nano Silica effect with its dose and soil type and moisture level.

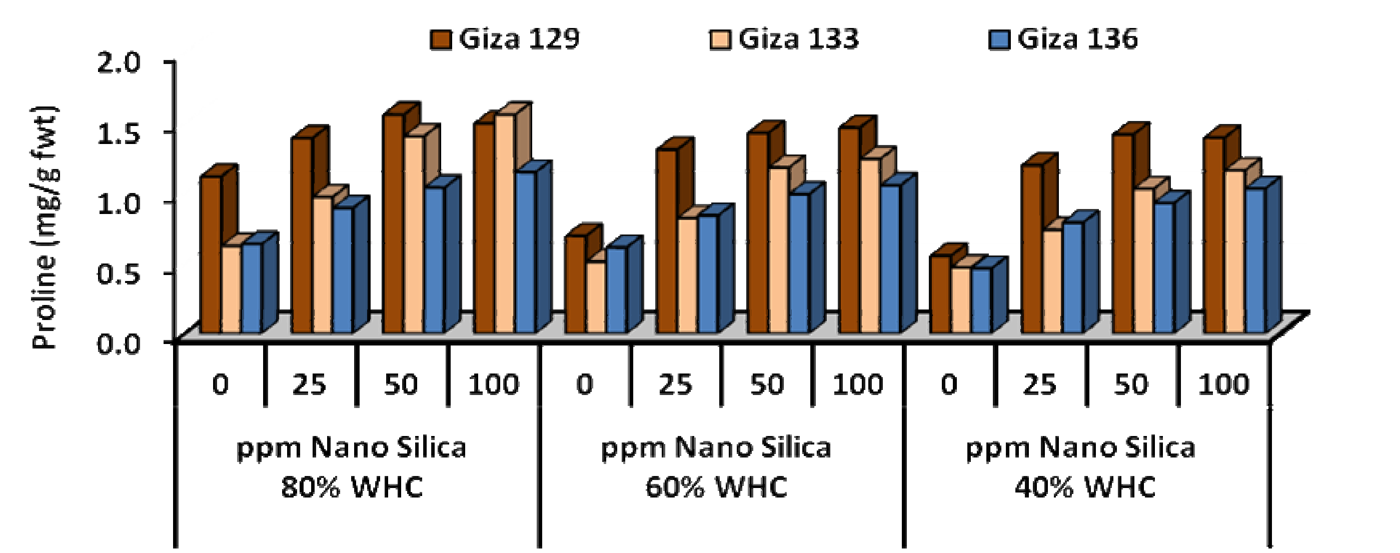

Fig. 2: Proline contnet of barley as affected by Nano Si application under water stress

Macronutrient

Table (1) illustrated the effect of Nano-silica (0: 100 ppm) and water stress (80, 60 and 40% from water holding capacity) on the plant nutrients (P, K and Ca) content of some selected Egyptian barley varieties. Data indicated that most of the highest values were recorded at barley varieties Giza 133 and Giza 129 under both 80% WHC and 100 ppm Nano silica, whereas the lowest values attained at 40% of WHC and zero ppm Nano silica. Mineral nutrition is a basic requirement for proper growth and development and survival under different environmental stress conditions. Studies have shown that mineral nutrient status in plants plays a critical role in the alleviation of a biotic stress (Nazar *et al.*, 2015).

Regardless to the examined varieties, the highest and the lowest values of P, K and Ca content were recorded at80% WHC and 100ppm Nano Silica for P, K and for Ca and the lowest values observed at 40% WHC and zero Nano silica treatments. Also, it is clear to mention that increasing water stress associated with decreasing nutrients value in plants. Regarding to the second factor in the study, Nano-silica, data observed that increasing concentration up to 100 pm combined with increase in tested plant nutrients in barley. Also, resulted data in Table (1), Ca content was found in highly concentration at Giza 129 under 40% stress and 100 ppm Nano-silica, while the lowest ones were recorded at Giza 129 und 80% water stress and zero Nano-silica. Adequate supply of Si in cereal plants is able to provide good crop yields, because with the addition of Si can increase cell strength and endurance. Si supply makes leaves more erect in the effect of high nitrogen fertilization so as to increase photosynthesis. Sufficient use of Si may reduce the likelihood of wilting plants under drought conditions due to decreased permeability of water vapor from leaf epidermal cell walls. It also affects phosphorus fixation so that its availability increases (Sumida, 2002).

Table 1: Effect of Nano Silica on macronutrient content of barley under water stress

Treatments		Phosphorus (%)			Potassium (%)			Calcium (%)		
WHC	**Nano Silica**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**
80.0%	0.0 ppm	0.182	0.576	0.192	1.60	0.89	1.32	1.09	1.65	1.42
	25 ppm	0.271	0.424	0.197	1.75	1.28	1.54	1.46	2.07	1.60
	50 ppm	0.422	0.516	0.280	1.93	1.49	1.95	1.54	2.47	1.88
	100 ppm	0.437	0.453	0.264	1.91	1.86	1.97	1.56	3.39	2.50
60.0%	0.0 ppm	0.605	0.885	0.460	1.49	0.85	1.22	1.60	1.52	1.39
	25 ppm	0.666	0.766	0.594	1.71	1.17	1.52	1.79	1.92	1.59
	50 ppm	0.759	0.772	0.628	1.98	1.32	1.80	1.92	2.38	1.86
	100 ppm	0.719	0.754	0.655	1.96	1.44	1.93	1.95	2.67	2.08
40.0%	0.0 ppm	0.105	0.249	0.247	1.37	0.75	1.12	2.05	1.28	1.16
	25 ppm	0.200	0.298	0.266	1.68	0.91	1.43	2.42	1.76	1.56
	50 ppm	0.296	0.400	0.318	1.93	1.29	1.65	2.69	2.14	1.78
	100 ppm	0.310	0.453	0.260	2.03	1.56	1.82	3.54	2.58	2.01
LSD (0.05)		**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**
		0.040	0.038	0.047	0.066	0.062	0.076	0.027	0.024	0.031
		V*WHC	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**
		0.070	0.081	ns	ns	0.132	ns	ns	0.054	ns
		V*WHC*NS			**V*WHC*NS**			**V*WHC*NS**		
		0.140			ns			ns		

V: Varieties - **WHC:**Water Holding Capacity - **NS :**Nano silica– **ns**: non-significant

Regarding to the drought stress treatments, data on hand revealed that increasing water stress led to decrease in Ca content in barley plant with increase 10% same trend was observed relative to the Nano-silica effect on Ca content as compared to the control. With respect to the ratio of K/Ca, as affected by drought stress and Nano Silica treatment, data on hand showed that the highest ratio was recorded at 80% and 100 ppm for Giza 136. While the lowest one was attained at Giza 133 under 40% water stresses and zero pm Nano-silica for both estimated ratios, respectively (Hellal *et al.*, 2019 and Hellal *et al.,* 2020 a,b).

Micronutrients

Table (2) showed micronutrient content (Fe, Zn and Mn) as affected by water stress and Nano-silica application. Resulted data indicated that Giza 129 variety gained the highest values of Fe and Zn content under 80% water stress and 100 ppm Nano-silica. While Giza 136 gained the highest values in same sequences. Whereas, the lowest values were observed at Giza 129 for Fe and Zn under 40% water stress and 0 ppm Nano-silica, and Giza 133 variety in same sequence for Mn Content. Provision of Nano silica fertilizer by spraying to its leaves aims to provide silica as a micronutrient element needed by plants which can be absorbed by the plant sufficiently so as to achieve optimal growth. Nanotechnology can be utilized to enhance the ability of plants to absorb nutrients. Nano sized fertilizers are more readily absorbed and more effective than conventional chemical fertilizers (Alejandro and Rubiales, 2009).

Regardless barley varieties, data observed that increasing both drought stress (from 80 to 40%) and Nano – Silica (0-100 ppm) associated with increasing the examined micro-nutrients (Fe, Zn, Mn), where the highest values recorded under low water stress and high concentration of Nano-silica application (100 ppm). Whit respect to the main effect (water stress), data in Table (2) pointed out that increasing drought led to dramatically decrease in the tested micro nutrient. On the other hand, increased Nano-Silica strongly increase studied micronutrients by about 10.4, 17; 15% in same sequence.

Table 2 : Effect of Nano Silica on Micronutrient content of barley under water stress

Treatments		Iron (ppm)			Zinc (ppm)			Manganese (ppm)		
WHC	**Nano Silica**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**
80.0%	0.0 ppm	63.4	46.9	46.0	17.33	13.52	11.20	3.83	3.34	3.80
	25 ppm	76.9	79.9	55.9	18.37	16.30	12.65	4.60	4.27	4.82
	50 ppm	87.5	93.0	69.0	19.33	17.02	14.48	5.32	5.07	5.90
	100 ppm	93.2	95.8	90.5	21.37	18.77	17.02	5.37	5.90	5.74
60.0%	0.0 ppm	59.4	39.6	43.6	16.82	13.32	10.80	3.59	3.17	3.50
	25 ppm	68.5	67.2	52.2	17.95	15.97	11.79	4.38	4.10	4.67
	50 ppm	88.6	89.6	65.7	18.93	16.67	13.78	5.02	4.85	5.61
	100 ppm	86.7	87.3	87.2	19.85	17.93	16.24	5.14	5.64	5.38
40.0%	0.0 ppm	50.5	34.4	40.0	15.54	12.63	10.45	3.16	2.84	3.26
	25 ppm	66.8	59.4	46.8	17.78	15.02	11.50	4.11	3.69	4.33
	50 ppm	82.1	81.9	61.8	18.60	16.47	13.18	4.85	4.50	5.10
	100 ppm	83.6	90.0	77.7	19.80	17.51	14.76	4.76	5.41	5.14
LSD (0.05)		**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**
		0.33	0.321	0.381	0.233	0.228	0.269	0.233	0.213	0.269
		V*WHC	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**
		0.552	0.572	0.64	0.403	0.466	ns	0.403	0.466	ns
		V*WHC*NS			**V*WHC*NS**			**V*WHC*NS**		
		0.66			ns			ns		

V: Varieties **- WHC:** Water Holding Capacity- **NS :**Nano silica– ns: non-significant

Yield components

The effect of Nano-silica (0, 25, 50, 100 ppm) on the yield components (plant height, number of tiller and number of spikes per pot) of the selected Egyptian barley under water stress were presented in Table (3). Data observed that the highest values for plant height, number of tiller and number of spikes per pot were registered at Giza 136 followed by Giza 133 and Giza 129 under 80% water holding capacity at 100 ppm Nano-Silica applied as foliar spray. Also, it is clear to mention that the lowest values were attained at 40% water holding capacity (sever water stress) and zero Nano-silica and for examined varieties, it could be arranged in as follow in descending order; Giza 129 < 133 < 136 for plant height, number of tiller and number of spikes per pot. Hamid *et al.* (2019) revealed that application of nano-SiO_2 solutions in semi-arid region can improve barley seed yield and can be introduced as beneficial fertilizer for foliar application.

The foliar application of Nano-silica (0, 25, 50, 100 ppm) proved better regarding barley yield (1000 kernel weight, grain and straw weight) of the selected Egyptian barley grown under water stress (Table 4). Data observed in Table (4) indicated that the highest values for 1000 kernel weight, grain and straw weight per pot were observed at Giza 136 followed by Giza 133 and Giza 129 under 80% water holding capacity at 100 ppm Nano-Silica applied as foliar spray (Farid Hellal *et al.*, 2019a,b).

Table 3 : Effect of Nano Silica on growth parameters of barley under water stress

Treatments		Plant height (cm)			No of tiller/ pot			No of Spike / pot		
WHC	**Nano Silica**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**
80.0%	0.0 ppm	51.2	53.3	56.4	44.7	38.0	34.3	26.5	25.0	24.5
	25 ppm	54.4	61.8	64.9	52.7	39.7	42.7	28.5	28.7	27.5
	50 ppm	57.6	69.2	65.5	59.0	51.0	57.5	36.3	34.5	30.0
	100 ppm	64.1	75.2	67.3	63.5	60.0	62.5	42.0	40.5	33.0
60.0%	0.0 ppm	49.9	52.1	56.4	44.5	37.0	33.5	24.0	24.0	23.5
	25 ppm	53.6	61.5	59.6	50.5	39.0	42.0	28.0	28.0	26.0
	50 ppm	57.2	65.4	63.9	55.5	49.5	47.5	33.0	30.0	29.0
	100 ppm	61.9	72.8	65.9	62.7	56.0	50.0	38.5	39.0	32.5
40.0%	0.0 ppm	48.6	50.5	54.9	43.5	33.5	33.0	20.0	18.0	23.3
	25 ppm	53.5	56.8	56.6	45.0	38.3	38.5	26.7	26.5	25.0
	50 ppm	56.3	64.3	58.5	55.0	43.0	43.0	32.5	29.0	28.5
	100 ppm	61.1	69.9	58.2	52.0	53.5	48.7	36.5	38.0	31.3
LSD (0.05)		**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**
		0.559	0.518	0.598	0.512	0.533	0.616	0.098	0.103	0.119
		V*WHC	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**
		ns	1.031	1.035	0.913	0.923	1.066	0.179	0.207	0.217
		V*WHC*NS			**V*WHC*NS**			**V*WHC*NS**		
		1.793			1.847			0.358		
V: Varieties - **WHC:**Water Holding Capacity - **NS :**Nano silica– **ns**: non-significant										

Also, it is clear to mention that the lowest values were attained at 40% water holding capacity (sever water stress) and zero Nano-silica and for examined varieties, it could be arranged in as follow in descending order; Giza 129 < 133 < 136 for 1000 kernel weight, grain and straw weight of barley grown in sandy soil. (Siddiqui and Al-Whaibi, 2014) indicated that Si-NPs may directly interact with plants and impact their morphology and physiology in various ways, including theaddition of structural color to the plants, and help in improving plant growth and yield.

Table 4 : Effect of Nano Silica on yield parameters of barley varieties under water stress

Treatment		1000 grain weight			Grain weight (g/pot)			Straw weight (g/pot)		
WHC	**Nano Silica**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**	**Giza 129**	**Giza 133**	**Giza 136**
80.0%	0.0 ppm	25.9	36.0	37.9	24.2	16.7	17.8	53.1	72.0	61.1
	25 ppm	29.1	38.9	40.3	24.6	18.0	21.6	63.0	87.6	76.5
	50 ppm	30.1	41.2	41.8	26.3	19.2	24.3	67.0	94.6	87.7
	100 ppm	32.6	42.6	42.7	29.3	20.8	28.1	70.2	93.8	85.8
60.0%	0.0 ppm	23.9	34.2	35.6	19.5	14.3	16.9	52.4	68.2	60.6
	25 ppm	29.0	38.6	39.9	24.4	17.6	21.1	57.1	75.0	75.0
	50 ppm	29.7	41.1	40.3	25.8	19.0	24.0	63.4	91.2	82.7
	100 ppm	31.6	41.9	41.9	28.6	20.7	27.4	69.2	90.6	81.3
40.0%	0.0 ppm	22.2	33.6	35.3	18.3	13.3	16.0	44.3	63.1	57.2
	25 ppm	28.3	37.9	38.1	24.2	16.9	18.3	54.8	72.4	68.2
	50 ppm	29.3	39.5	39.4	25.3	18.4	21.9	63.3	89.1	78.5
	100 ppm	30.0	40.3	39.8	25.7	20.9	20.4	67.5	88.3	81.8
LSD (0.05)		**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**	**(V)**	**WHC**	**NS**
		0.201	0.237	0.274	0.322	0.384	0.444	0.413	0.487	0.562
		V*WHC	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**	**V*WHC**	**V*NS**	**WHC*NS**
		0.411	0.427	0.475	0.666	0.746	0.769	0.843	0.913	0.974
		V*WHC*NS			**V*WHC*NS**			**V*WHC*NS**		
		0.822			1.3312			1.687		
V: Varieties - **WHC:**Water Holding Capacity - **NS :**Nano silica– **ns**: non-significant										

Protein contents

The foliar application of Nano-silica (0, 25, 50, 100 ppm) increased protein contents of the selected Egyptian barley grown under water stress (Fib. 3). The highest values protein content were observed at Giza 133 followed by Giza 129 and Giza 136 under 80% water holding capacity at 100 ppm Nano-Silica applied as foliar spray. Also, it is clear to mention that the lowest values of protein content were attained for barley variety Giza 136 at 40% water holding capacity (sever water stress) and zero Nano-silica as compare to Barley Giza 129 and 133 (Li *et al.*, 2012).

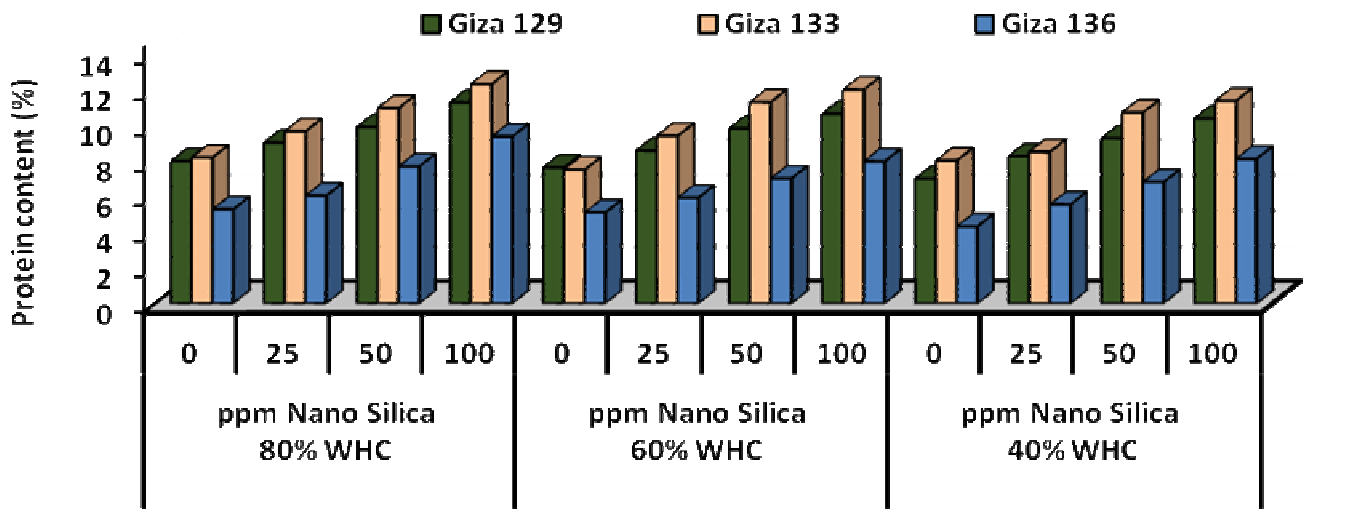

Fig. 3: Protein contnet of barley as affected by Nano Silica application under water stress

Conclusion

Nanoparticles have been proved its vital role in the agriculture system. In this present work, Nano Silica proved its significant importance for chlorophyll, nutrient content and grain and straw of barley varieties. All measured yield parameters such as grain and straw were positively affected by Nano Silica having higher values compared to without application of Nano Silica under water stress. Application of 100 ppm Nano Silica is the ideal concentration that barley plants should be treated under drought stress which had the highest values of biochemical characteristics and yield. Findings revealed that application of Nano Silica can improve barley seed yield in the arid region and can be introduced as beneficial fertilizer for foliar application.

Acknowledgement

The authors warmly thank the Agricultural Research in the Mediterranean Area 2 (ARIMNet 2) and Academy of scientific research and technology (ASRT) and National Research Centre (NRC), Egypt who have funded this research work.

References

Agarie, S.; Uchida, H.; Agata, W.; Kubota, F. and Kaufman, P.B. (1998). Effects of silicon on transpiration and leaf conductance in rice plants (*Oryza sativa* L.), Plant Production Science, 1(2): 89–95.

Alejandro, P.D.L. and Rubiales, D. (2009). Pest Management Science, 65: 540- 545.

Ayman, E.L. Sabagh, Akbar Hossain, Md. Shohidul Islam, Celaleddin, B.; Saddam, H.; Mirza, H.; Tauseef, A.; Muhammad, M.; Wajid, N.; Shah, F.; Narendra, K.; Ram, S.; Ferhat, K.; Mehmet, Y.; Disna, R. and Hirofumi, S. (2019). Drought and salinity stresses in barley: Consequences and mitigation strategies AJCS, 13(06): 810-820.

Bao-shan, L.; Chun-hui, L.; Li-jun, F.; Shu-chun, Q. and Min, Y. (2004). Effect of TMS (Nanostructured silicon dioxide) on growth of Changbai larch (*Larix olgensis*) seedlings. Journal of Forestry Research, 15: 138–140.

Bates, L.S.; Waldren, R.P. and Teare, I.D. (1973). Rapid determination of free proline for water stress studies. Plant Soil, 39: 205-207.

Cheruth, A.J.; Paramasivam, M.; Abdul, W.; Muhammad, F.; Al-Juburi, J.H.; Ramamurthy, S. and Rajaram, P. (2009). Drought Stress in Plants: A Review on Morphological Characteristics and Pigments Composition. Int. J. Agric. Biol., 11: 100–105.

Cottenie, A.; Verloo, M.; Kekens, L.; Velghe, G. and Camberlynck, R. (1982). "Chemical analysis of plants and soils", Lab. Agroch. State Univ. Ghent., 15-19.

EL-Shawy, E.E.; Sabagh, A.; Mansour, M. and Barutcular, C. (2017). A comparative study for drought tolerance and yield stability in different genotypes of barley (*Hordeum vulgare* L.). J Exp Biol Agric Sci., 5(2): 151.162.

Farid, H.; Mohamed, Abdel-Hady; Ismail, K.; El-Sayed, S. and Chedly, A. (2019). Yield characterization of Mediterranean barley under drought stress condition. AIMS Agriculture and Food, 4(3): 518–533.

Farid, H.; Hani, M.; Mohamed, Abdel-Hady; El-Sayed, S. and Chedly, A. (2019a). Assessment water productivity of barley varieties under water stress by Aqua Crop model. AIMS Agriculture and Food, 4(3): 501–517.

Gao, X.; Zou, C.; Wang, L. and Zhang, F. (2006). Silicon decreases transpiration rate and conductance from stomata of maize plants. Journal of Plant Nutrition, 29(9): 1637–1647.

Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedures for Agriculture Research. 2nd Ed., John Wiley and Sons, New York, 180.

Gong, H.; Chen, K.; Chen, G.; Wang, S. and Zhang, C. (2003). Effects of silicon on growth of wheat under drought. Journal of Plant Nutrition, 26(5): 1055–1063.

Hamid, G.; Mohsenjanmohammadi, Asgharebadi-Segherloo, Naserabaghnia (2019). Genotypic response of barley to exogenous application of nanoparticles under water stress condition. Pobrane z czasopisma Annales C – Biologia., LXXII(2): 15-27.

Hattori, T.; Inanaga, S. and Araki, H. (2005). Application of silicon enhanced drought tolerance in Sorghum bicolor. Physiologia Plantarum, 123(4): 459–466.

Hellal, F.A.; El-Sayed, S.A.A.; Abou Basha, D.M. and Abdelly, C. (2020a). Mineral nutrient status of some Mediterranean barley varieties as affected by drought stress in Egypt. Iraqi Journal of Agricultural Sciences – 2020:51 (Special Issue): 138-147.

Hellal, F.; El-Sayed A.A.; Gad, G. Abdel Karim and Abdelly, C. (2020b). Anti-transpirants application for improving the biochemical changes of barley under water stress. Iraqi Journal of Agricultural Sciences, 51(1): 287-298.

Farid, H.; Hani, M.; Mohamed, A.H.; El-Sayed, S. and Chedly, A. (2019). Assessment water productivity of barley varieties under water stress by AquaCrop model, 4(3): 501-517.

Farid Hellal, Mohamed Abdel-Hady, Ismail Khatab, Saied El-Sayed, Chedly Abdelly (2019). Yield characterization of Mediterranean barley under drought stress condition, 4(3): 518-533.

Jaleel, C.A.; Manivannan, P.; Wahid, A.; Farooq, M.; Somasundaram, R. and Panneerselvam, R. (2009). Drought stress in plants: a review on morphological characteristics and pigments composition. International Journal of Agriculture and Biology, 11(1): 100–105.

Kuznetsov, V.V. and Shevyakova, N.I. (1999). Proline under stress: Biological role, metabolism, and regulation. Russian Journal of Plant Physiology. 46: 274-286.

Li, B.; Tao, G.; Xie, Y. and Cai, X. (2012). Physiological effects under the condition of spraying nano SiO2 on to the *Indocalamus barbatus* McClure leaves. J Nanjing For Univ (Natural Science Edition) 36: 161–164.

Lux, A.; Luxov´a, M.; Abe, J.; Morita, and Inanaga, S. (2003). Silicification of bamboo (*Phyllostachys heterocycla* Mitf.) root and leaf. Plant and Soil, 255(1): 85–91.

Maria, F.; JolantaBiesaga-Kościelniak and MichałDziurka (2014). Determination of proline, carbohydrates and ethylene content and their role in drought stress in plant. *M. Surma, P. Krajewski (ed.),* Methodology of system approach to study drought tolerance in barley, Institute of Plant Genetics PAS, Poznań: 95-104.

Mauad, M.; Carlos, A.C.C.; Adriano, S.N.; Hélio, G.F. and Giuseppina, P.P.L. (2016). Effects of silicon and drought stress on biochemical characteristics of leaves of upland rice cultivars. Revista Ciência Agronômica, 47(3): 532-539.

Minolta (1989). Chlorophyll meter SPAD-502. Instruction manual. Minolta Co., Ltd., Radiometric Instruments Operations, Osaka, Japan.

Monica R.C. and Cremonini R. (2009). Nanoparticles and higher plants. Caryologia. 62:161–165.

Motsara M.R. and Roy, R.N. (2008). Guide to laboratory establishment for plant nutrient analysis. Food and agriculture organization of the United Nations Rome, 2008.

Naderi, M.R. and Danesh-Shahraki, A. (2013). Nano-fertilizers and their roles in sustainable agriculture. International Journal of Agriculture and Crop Sciences, 5(19): 2229- 2232.

Nazar, R.; Umar, S. and Khan, N.A. (2015). Exogenous salicylic acid improves photosynthesis and growth through increase in ascorbate-glutathione metabolism and S assimilation in mustard under salt stress. Plant Signal. Behav. 10: e1003751.

Nermeen, T.S. and El-Sadek, Z.H. (2017). Influence of Silicon on Tuberose Plants under Drought Conditions Middle East Journal of Agriculture Research, 06(02): 348-360.

Parisi, C.; Vigani, M. and Rodrguez-Cerezo, E. (2015). Agricultural nanotechnologies: what are the current possibilities? Nano Today 10(2):124–127.

Siddiqui, M.H. and Al-Whaibi, M.H. (2014). Role of nano-SiO2 in germination of tomato (*Lycopersicon esculentum* seeds Mill.). Saudi J Biol Sci., 21(1): 13–17.

Sumida, H. (2002). Plant Available Silicon in Paddy Soil. National Agricultural Research Center for Tohoku Region Omagari Second Silicon in Agriculture Conference (Tsuruoka, Yamagata : Japan).

Suriyaprabha, R.; Karunakaran, G.; Yuvakkumar, R.; Rajendran, V. and Kannan, N. (2012b). Silica nanoparticles for increased silica availability in maize (*Zea mays* L.) seeds under hydroponic conditions. Current Nano Science, 8: 902–908.

Temel, A.; Janack, B. and Humbeck, K. (2017). Drought Stress-Related Physiological Changes and Histone Modifications in Barley Primary Leaves at HSP17 Gene. Agron 7(2): 43.

Tripathi, D.K.; Singh, V.P.; Kumar, D. and Chauhan, D.K. (2012). Impact of exogenous silicon addition on chromium uptake, growth, mineral elements, oxidative stress, antioxidant capacity, and leaf and root structures in rice seedlings exposed to hexavalent chromium. Acta Physiol Plant, 34(1): 279–289.

Zarafshar, M.; Akbarinia, M.; Askari, H.; Hosseini, S.M.; Rahaie, M. and Struve, D. (2015). Toxicity assessment of SiO_2 nanoparticles to pear seedlings. International Journal of Nano Science and Nanotechnology, 11(1): 13–20.