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Influence of silica nanoparticles on germination and early seedling growth of *Sorghum bicolor* L. under water stress

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Abstract

Drought stress is one of the most adverse factors of plant growth and productivity. Plant growth and development are negatively affected by a wide range of external stresses, including water deficits. Advanced technologies, such as nanotechnology plays a key role in agricultural soil and could partly help the plant to tolerate different stresses. The role of nanoparticles in the improvement of plant tolerance to environmental stresses such as drought and salinity remains unclear. This study was conducted to investigate effects of application of silicon oxide nanoparticles on germination and growth parameters of white maize (Sorghum *bicolor* L.). Water stress at three levels (control, 25 and 50% water deficit) and nanosilica applied at four concentrations (0, 5, 10 and 20 ppm) were conducted. The results suggested that the drought stress at (25 and 50%) decreased the germination percentage by 80% in comparison to control treatment (86%). The maximum effect of nanosilica on increasing germination percentage (96.6%) was found at 5 ppm treatment in case of full water treatment. The results showed that the water deficit at 50% highly decreased grain root length by 6.83 cm in comparison to the control (11.50 cm). Positive effect of nanosilica application (12 cm) was detected in 25% water stress stage at 10 ppm. The present work clearly showed that shoot length of grains was markedly inhibited by water stress (0.20 cm) at 50% water deficit. The shoot length was improved by (6.60 cm) after exposure to 5 ppm nanosilica under full application of water (100%). Regarding the effect of water stress on the seedling weight, the obtained data indicating clearly seedling weight reduction by 1.12 gm under 50% water deficit, and this effect was alleviated by 3.20 gm after exposure to 20 ppm nanosilica under 100% water treatment.

Keywords: *Sorghum bicolor*, nanosilica, water deficit stress, germination, growth parameters

Introduction

Plants are largely constituted of water; it accounts for 80-90% of their entire weight. Water is essential for photosynthesis, nutrient absorption, transpiration, and temperature adjustment in plants [1]. Climate change has influenced various environmental factors, such as temperature, humidity, precipitation and evaporation resulting in environmental issues, especially depletion of water resources [2]. Therefore, droughts are a major abiotic stress factor that induces a significant change in the biological activity of plants. When plants are exposed to a drought condition, their related adaptive and biological responses over the short and long term can be observed [3]. Nanotechnology is a very promising field of science and technology has the potential to open up new applications in the field of agriculture and biotechnology [4]. Utilization of nanoparticles in germination and growth of plants and for the control of stress-plants is a recent practice [5]. Some investigations had revealed good positive effects of nanoparticles on germination and growth of plants [6]. As positive impact of nanoparticles on plant with its potential, it can be used as future nanofertilizer [7]. The agri-nanotechnology has many environmental and agricultural challenges including agri-sustainability, management of plant diseases and crop production. On the other hand, nanomaterials under certain concentrations may generate and exhibit many toxic effects on plant due to inducing different reactive species like oxygen and nitrogen [8]. Natural nanoparticles are native components of biological systems which have diverse structures with wide spectrum biological roles [9, 10]. Next to oxygen, silicon is the most abundant element on the surface of the earth. Silicon can be effective against both biotic and abiotic stresses, including insects, herbivors, bacteria, fungi, wind, cold, heat, water logging, salinity, mineral, water shortage and toxicity [11, 12]. Although silicon is not considered as an essential element for higher plants, this element has major roles in leaf turgidity of monocots and cell wall structure as well as improvement growth of wheat in arid or semi-arid areas [11, 13]. It is also investigated that nano silicon enhanced drought tolerance in two cultivars of *Sorghum bicolor* by extracting a large amount of water from drier soil and maintaining a higher stomatal conductance [14]. It has been reported that silicon oxide nanoparticles increased seed germination and dry weights in the shoot and root tissues of wheatgrass [15]. Some results showed that nanosilica treatment caused a higher chlorophyll content of ryegrass plants under water stress conditions [16]. Silicon, as a physicomechanical barrier, is part of the epidermal cell walls and vascular tissues in stems, pods, leaves and barks [17]. Silicon might decrease the negative effects of oxidative stress and offer resistance to some abiotic and biotic plant stressors. Thus, using Si instead of herbicides and pesticides could reduce harmful environmental effects [18, 21]. The beneficial effects of the Si (in bulk size) investigated; however, compared with Si bulk size, absorption of Si in plants is greater when Si NPs are used [22]. Silicon nanoparticles having smaller size than 100 nm, and implicates new physical, chemical and biological properties [23]. The biological role of Si in plants has not been deeply studied because it has not been classified as essential plant element [24]. Thus, the present study aims to investigate the effect of Si NPs on germination and early seedling growth of white maize grains (*Sorgum bicolor* L).

Materials and Methods

Plant material

White maize (*Sorghum bicolor* L.) grains were collected from Agriculture Research Center, King Saud University, Riyadh, Kingdom of Saudi Arabia.

Size and Shape of Nanomaterial

Silicon oxide nanoparticles (SiO_2NPs) used were purchased from Nanotech Egypt for Photo Electronics, Cairo, Egypt. TEM were performed on JEOL JEM-2100 high resolution Transmission Electron Microscope at an accelerating voltage of 200 KV Nanotech Company for Electronics. The average size of nanoparticles (TEM) is less than 100 nm. The shape (TEM) of used nanoparticles is spherical. The aim of the current study was to investigate the effect of silicon nanoparticles at different levels (5, 10 and 20 ppm) on white maize plant.

Experimental design

Germination conditions

The current investigation was carried out on May 2019 within the Lab. of Biology, College of Sciences and Arts, Qilwah, Al-Baha University. Equal sizes of viable maize grains were collected, surface sterilized with 10% Sodium Hypochlorite for 5 minutes washed thoroughly with distilled water and rinsed three times. Sterilized grains were placed in equal size petridishes containing moister Wattman paper. Pure distilled water was used for the control (untreated) experiments whereas drought stress severity including 25 and 50% water stress and nanoparticles of silicon oxide concentrations as 5, 10 and 20 ppm was used for treatments. Two groups of treatments were prepared, the first group represented water stress levels (0, 25 and 50 % water), whereas mixtures of prepared nanoparticles (5, 10 and 20 ppm) with each of drought stress treatments represented the second group. All experiments (control and treatments) were kept and allow for germination at 23°C. Germination grains were counted based on 2 mm radical emergence [25] until the number of germinated grains was constant in last two days. After two days, germination percentages (%) were calculated as the proportion of the grains that germinated to total number of grains multiplied by 100.

Seedling growth

On the fourth day of experiment, root and shoot length (s) were measured in all treatments and respective controls using centimeter ruler and expressed in centimeter (cm). Fresh weights of seedlings were taken for all treatments as well as their respective control and were expressed in gram (gm).

Data analysis

Each treatments was conducted three times and data presented are means of four independent repeats ± (n=4), where ± standard deviation of means.

Results and Discussion

Germination percentage

The obtained data (Table 1& Figure 1) clearly showed decreases in germination percentage with increasing drought severity from 86% in control to 80% at 25&50% water shortage. In this concern, some investigators reported that germination was decreased under drought stress [26, 27]. The reduction in germination percentage may be attributed to decrease in imbibitions of seeds and water uptake under stress conditions [28], or to metabolic disorders such as reservoirs hydrolyzed nutrient for embryo development [29]. Therefore, it can be resulted that enzymatic activities decrease under drought and reduction in osmotic potential can be occurred [17]. In this study, silicon NPs caused increases in germination percentages and the highest value (96.6%) achieved by applying 5 ppm of nanosilica (fig. 1 and table 1). The same results were obtained by many investigators [15, 16, 30, 31]. These beneficial effects could be due to the increase of plant mineral nutrients, gas exchange which return to osmotic adjustment, stress reduction and gene expression modification in plant [32].

Growth parameters

Comparing to the no stressed treatments, this context, clearly showed that increasing water stress level reduce root and shoot lengths as well as seedling biomass (table 2&3and figure 2&3). The lowest values of root (6.83cm) and shoot (0.20 cm) length were recorded at 50% water deficit. Also, drought stress application at 50% decreased seedling biomass to the lowest value (1.12 gm). The obtained results showed that nano Si treatments caused obvious reductions of drought effects and could improve all studied traits. The highest value of root length (12.0 cm) was recorded after treatment with 10 ppm nano silica at (25%) water stress whereas the highest reading of shoot length (6.60cm) was investigated after adding 20 ppm of SiNPs at full water content (100% water). The results revealed that seedling biomass has increased after nano Si treatment with 20 ppm at full water treatment (table 4 and figure 4). These results corroborate with those reported by many investigators [30, 31, 33]. As already reported, Si NPs treatment improved the deleterious effect induced by drought stress and enhanced photosynthesis and stomatal conductance [34, 36]. The use of nanoparticles in the growth of plants and for the control of plant diseases is a recent practice and has been given much attention by plant biological researchers [37].

Conclusion

Seed germination and early seedling growth are among the most important plant growth stages for plant establishment and are extremely affected by abiotic stresses mainly drought [26&27]. Germination also is important for determining the final plant density [28]. Silicon oxide nanoparticles (SiO_2NPs) may interact with plant and alter growth responses as well as physiological changes in dose dependent manner. Moreover, nanosilica may help in formulation of new nano growth promoter and nanofertilizers for agricultural use. Therefore, it could reduce fertilizer wastage and in turn environmental pollution. In addition, NPs were more effective than bulk (normal form), which may be due to their shape, size, distribution and characteristics. Further studies must be done as the interactive effects of different plant (*spp.*) to ENPs under multiple types of environmental stresses to evaluate its expected applications in agro -ecosystems which could be used in smart farming or agriculture future.

Table 1: Effect of nanosilica on percentage of germination (%) of *Sorghum* under water stress condition.

Water levels	Concentration of nanosilica	Percentage of germination
Full water condition	0 ppm	86.6 %
	5 ppm	96.6 %
	10 ppm	86.6 %
	20 ppm	76.6 %
25 % water stress	0 ppm	80 %
	5 ppm	85 %
	10 ppm	93.3 %
	20 ppm	96.6 %
50 % water stress	0 ppm	80 %
	5 ppm	83.3 %
	10 ppm	93.3 %
	20 ppm	93.3 %

Data within table illustrated the mean of four replicates.

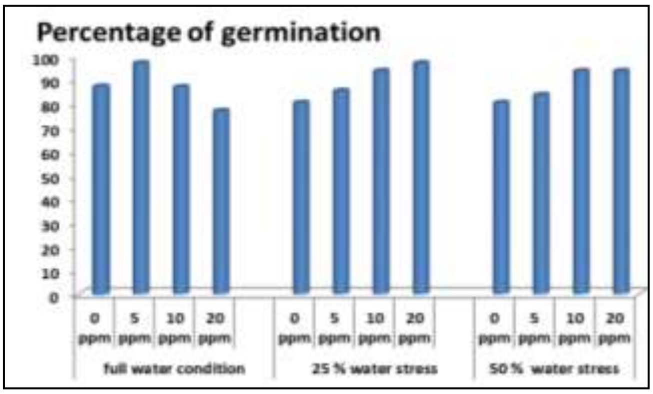

Fig 1: Effect of nanosilica on percentage of germination (%) of *Sorghum* under water stress condition.

Table 2: Effect of nanosilica on root length in (cm) of *Sorghum* under water stress condition.

Water levels	Concentration of nanosilica	Root length
Full water condition	0 ppm	11.50 ± 1.3
	5 ppm	10.60 ± 0.76
	10 ppm	10.03 ± 2.34
	20 ppm	11.50 ± 0.5
25 % water stress	0 ppm	11.50 ± 1.25
	5 ppm	10.83 ± 0.76
	10 ppm	12.00 ± 1.32
	20 ppm	10.83 ± 0.76
50 % water stress	0 ppm	6.83 ± 0.28
	5 ppm	7.36 ± 0.32
	10 ppm	7.33 ± 0.29
	20 ppm	8.50 ± 0.05

Data within table illustrated the mean of four replicates ± standard deviation (SD).

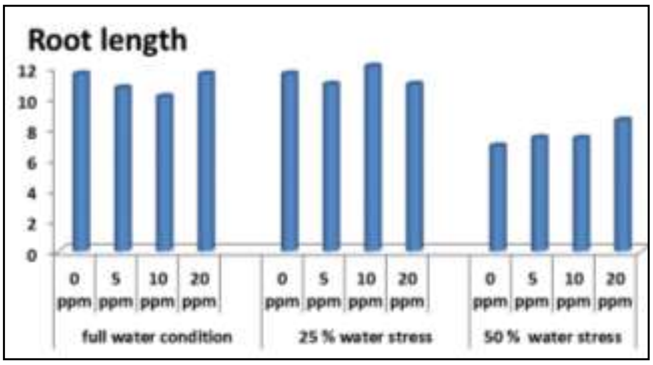

Fig 2: Effect of nanosilica on root length in (cm) of *Sorghum* under water stress condition

Table 3: Effect of nanosilica on shoot length in (cm) of *Sorghum* under water stress condition.

Water levels	Concentration of nanosilica	Shoot length
Full water condition	0 ppm	6.00 ± 1.00
	5 ppm	6.00 ± 0.50
	10 ppm	6.60 ± 0.28
	20 ppm	6.60 ± 1.50
25 % water stress	0 ppm	1.83 ± 0.57
	5 ppm	3.50 ± 1.32
	10 ppm	4.16 ± 2.00
	20 ppm	4.50 ± 1.22
50 % water stress	0 ppm	0.20 ± 0.01
	5 ppm	0.84 ± 0.02
	10 ppm	1.01 0.05
	20 ppm	1.30 ± 0.05

Data within table illustrated the mean of four replicates ± standard deviation (SD)

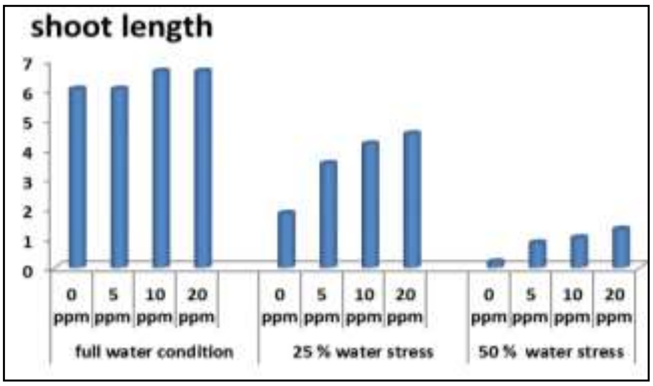

Fig 3: Effect of nanosilica on shoot length in (cm.) of *Sorghum* under water stress condition

Table 4: Effect of nanosilica on seedling weight in (gm) of *Sorghum* under water stress condition.

Water levels	Concentration of nanosilica	Seedling weight
Full water condition	0 ppm	2.60 ± 0.15
	5 ppm	2.74 ± 0.41
	10 ppm	2.47 ± 0.38
	20 ppm	3.20 ± 1.01
25 % water stress	0 ppm	1.77 ± 0.6
	5 ppm	2.00 ± 0.12
	10 ppm	2.10 ± 0.33
	20 ppm	2.26 ± 0.84
50 % water stress	0 ppm	1.12 ± 0.1
	5 ppm	1.17 ± 0.01
	10 ppm	1.25 ± 0.3
	20 ppm	1.26 ± 0.4

Data within table illustrated the mean of four replicates ± standard deviation (SD).

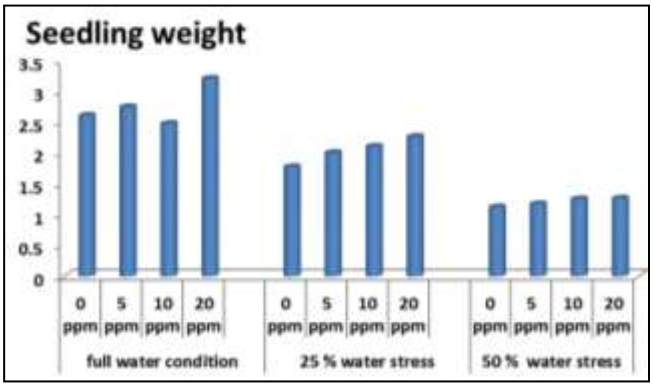

Fig 4: Effect of nanosilica on seedling weight in (gm) of *sorghum* under water stress condition

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