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Effects of Withholding Irrigation and Using Foliar Nano-Silicate Si As An Anti-Agent on Crop Yield and Nutrient Uptake

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Abstract

During the winter season of 2021-2022 at Giza Agricultural Research Station, ARC, Egypt, a field factorial experiment on wheat was conducted to identify the growth stages affected by irrigation water scheduling and silicate application. In addition to an untreated control, wheat plants were subjected to six irrigation regimes paired with three rates of foliar nano and ordinary silicate. Plants sprayed with either ordinary or nano-silicate produced more grain than untreated plants. This fact has been proven to be true for all irrigation water treatments. Regardless of silicate source or dose, the grand mean grain yield of silicate-treated plants was enhanced by roughly 24.7, 29.6, 30.3, 20.1, 19.2 and 28.1% over the untreated plants for I_0, I_1, I_2, I_3, I_4, I_5, and I6 i.e. withholding irrigation at none, tillering , flowering , milk and dough stage , respectively . The irrigation treatments I_2, I_1, and I_6 produced the greatest increase in grain. Regarding silicate dose and fraction, spraying nano-silicate at D3 (6mLSiL^{-1}) yielded the highest grain output. Plants treated with K silicate produced grain yields ranging from 6.116 Mg ha^{-1} obtained by $S_1D_1I_1$ to 8.615 Mg ha^{-1} obtained by $S_2D_3I_0$, showing relative increases of around 3.6 to 45.9%, 18.9%, and 32.9%, respectively, over the same non-Si treatments. To achieve the highest values of nutrient uptake and yield, wheat plants should be treated with 6 mLSiL^{-1} nano silica while withholding irrigation. According to, employing nano silica can boost wheat grain production in arid regions and can be utilized as a beneficial fertilizer for foliar application.

Keyword: Application dose, Growth stage, Irrigation regime, Nano-silicate, Nutrients, Wheat, Yield

Introduction

Wheat is one of the most significant strategic cereal crops in the world. Egypt's ability to produce wheat is limited by a lack of irrigation water. Egypt's expected 500 m3/capita/year water scarcity by 2025 has already surpassed the 1000 m3/capita/year barrier **(FAO, 2016).** Egypt must consequently discover methods to increase food production while using less water. The rationalization of the irrigation system will aid in resolving this issue. Appropriate irrigation scheduling is critical for water conservation in irrigated agriculture. Effective water management during crop growth is critical for meeting crop needs **(Du et al., 2010).** Wheat's moisture-sensitive phases include tillering, elongation, booting, and grain formation **(Ali et al., 2007)**. The growth stage, the intensity of water stress, the duration of the stress period, and cultivars all influence how plants respond to water stress **(Beltrano and Marta, 2008)**. Plant breeders can help identify the processes responsible for drought resistance by selecting the most tolerant cultivars that provide the steadiest grain production under water-stress circumstances **(Seleiman et al., 2011, El-Hag, 2017)**. Wheat yields must be maximized under stressful or non-stressful conditions **(Rashid et al., 2003)**.

Silicon (Si) is the second-most prevalent element in soil, however it is not a necessary plant nutrient **(Ma and Takahashi, 2002)**. Si may play a function in various physiological processes in drought-stressed plants, but the mechanism by which it lessens the negative effects of drought on plants is unknown **(Habibi and Hajiboland, 2013)**. According to some research **(Ma and Takahashi, 2002)**, Si improves light absorption by allowing light to pass through the mesophyll tissue. The benefits are thought to be caused by Si deposition in the cell walls of roots, leaves, culms, and hulls **(Epstein 1999)**. Silicon nanoparticles were successful because of their mesoporous character **(Al-Bourky et al., 2021)**.

The primary goals of this study were to:

1- determine the susceptibility of the different phases of the wheat plant to water stress.

2- determine the most crucial stages to the maximum duration of irrigation withholding.
3- reduce the impact of drought stress on growth and boosting production.
4- appoint at the impact of silicon fraction and irrigation regime in reducing water stress and boosting wheat productivity at critical periods.

Materials and Methods

A factorial field experiment was undertaken in Middle Egypt at Giza (Lat 30:03, Long: 31.13 and sea level 19.5 m), in 2021-2022 to discover the most crucial phases for the longest length of irrigation withholding for specific wheat cultivars. The plot measured 15.0 m^2 (3 x 5 m). The primary plots were for irrigation practices (factor A), the secondary plots for silicate sources (factor B), and the tertiary sub-sub plots for K-silicate and nano silica foliar spray rates (factor C). Six irrigation regimes, one cultivar (Masr-3), two silicate fractions sources of (K-silicate and Nano Silica), and three foliar spray rates (2, 4, and 6 mL/L). These treatments (36 treatments) reflected various combinations of the study's components. When the number of replicates is taken into account, the experiment yields a 108 plot. The seeds were sown on November 20th, and the plants were collected on May 1st. Maize was planted before wheat. All of the agronomic processes for cultivating wheat in the Giza region were followed. Maize was planted ahead of wheat in both seasons. The second irrigation signaled the start of the irrigation regime's treatments. The amounts of K-silicate and nano silica foliar spray were applied beginning with the second irrigation (**Tillering stage**).

1- Soil physical and chemical properties: -
Soil samples were taken at the depths (0-15 cm), (15-30 cm), (30-45 cm), and (45-60 cm) at the research site. Soil-water constants i.e soil field capacity (F.C) and wilting point were beside of the bulk density were determined. Particle size distribution and consequently soil texture were determined according to **(Klute, 1986)**. (Soil Ec, dS m^{-1}) in soil paste extract was determined and soil (pH) was determined in soil 1:2.5 soil-water suspension. Soluble cations and anions, were determined in soil paste extract using the procedures described by **(Jackson, 1973)**. As stated in Table 2, SO_4^{2-} was computed as the difference between determined soluble cations (mmolc^{-1}) and determined soluble anions (mmolc^{-1}).

2- Plant analyses:
Chemical components: Grain and straw samples were collected at harvest, washed with distilled water, and dried in an oven at 70^o C for 48 hours before being ground, mixed, and wet digested with hot sulfuric acid with repeated additions of 30% hydrogen peroxide (H_2O_2) as described by **Wolf (1982)**, and analyzed for N, P and K as follows:

Nitrogen content using the micro-Kjeldahl method **(Jackson, 1967)**, phosphorus content using the hydroquinine technique **(Snell and Snell, 1967)**, and potassium content using a flame photometer **(Jackson 1967)**.
Nitrogen, phosphorus, and potassium absorption values were determined by multiplying each of N, P, and K concentration by its corresponding dry matter as follows:

Uptake of element = Conc of element X dry matter yield.

3 - Agricultural practices: -
(***Triticum aestivum*** L. **Masr 3**). The agronomic practices for wheat were carried out in accordance with the standards of the Agricultural Research Centre (ARC). The experimental design was a split-split plot with three replicates, with the main plots representing the irrigation treatments, subplots representing silica fraction source, and sub-sub plots representing the foliar spray rates, as shown below:

Factor A:(main plots): irrigation regime (withholding irrigation):
I_0: No withholding of irrigation (Without withholding irrigation).
I_1: Withholding irrigation on the 20th day after sowing (tillering stage).
I_2: Withholding irrigation at the 45th day after sowing (vegetative growth stage).
I_3: Withholding irrigation on the 60th day after sowing (flowering stage).
I_4: Withholding irrigation on the 90th day after sowing (milk stage).
I_5: Withholding irrigation on the 110th day after sowing (dough stage).

Factor B (subplots): silicate source:
S_1: K-silicate
S_2: Nano-silica

Factor C (sub-subplots): K-silicate and Nano Silica foliar spray rates:
R_0: Water sprinkling (control).
R_1: Applying nano-silica to the plants at a rate of 2 ML L^{-1} of water.
R_2: Applying nano-silica to the plants at a rate of 4 ML L^{-1} of water.
R_3: Applying nano-silica to the plants at a rate of 6 ML $L^{-1}$of water.

4- Synthesis of K- silica nanoparticles: -
The sol-gel method was used to create silica nanoparticles from sodium silicate that had been hydrolyzed with H_2SO_4. In a typical synthesis, 10 mL of sodium silicate was poured into a 100 mL glass beaker, and 68% concentration H_2SO_4 was added drop by drop until the pH of the liquid reached 2 before stirring for 1 hour until thick gel formation. Finally, the gel was baked for 2 hours at

500°C in order to produce silica nanoparticles, **Abdelsamie *et al.* (2021).**

Characterization of the prepared potassium nano Silicate:

Characterization was carried out to confirm the creation of a K- nano silicate and the absence of undesirable chemicals from the synthetic product, as well as to provide information about the shape, size, surface area, roughness profile, and pore size of the nano K- silicate. The composition of nano K-silicate was determined by XRD (D8 Discovery-Bruker Company) at 40 KV and 40 AM (1600W) at speeds of 0.02 and 2theta () ranging from 10 to 80 degrees. The transmission electronic microscope (TEM) model EM-2100 was used to analyze 2D and 3D shape, agglomeration, concentration, and size. Jol 2000, Japan, conducted high-resolution imaging at a magnification of 25X and a voltage of 200 kV, as well as scanning electron microscopy (SEM).

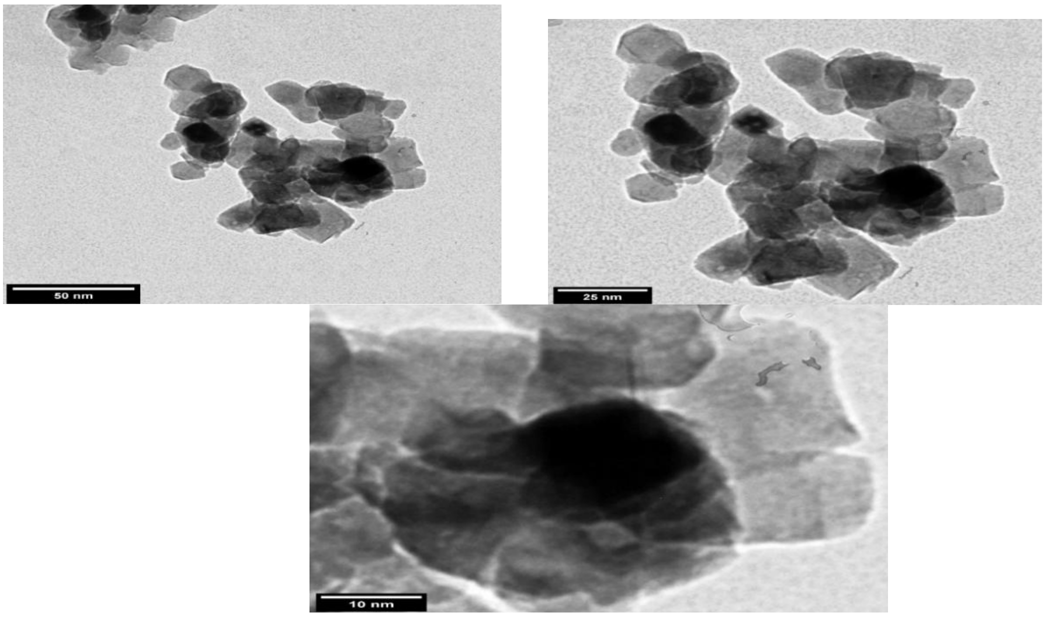

Figure 1: TEM images of K- nano Silicate

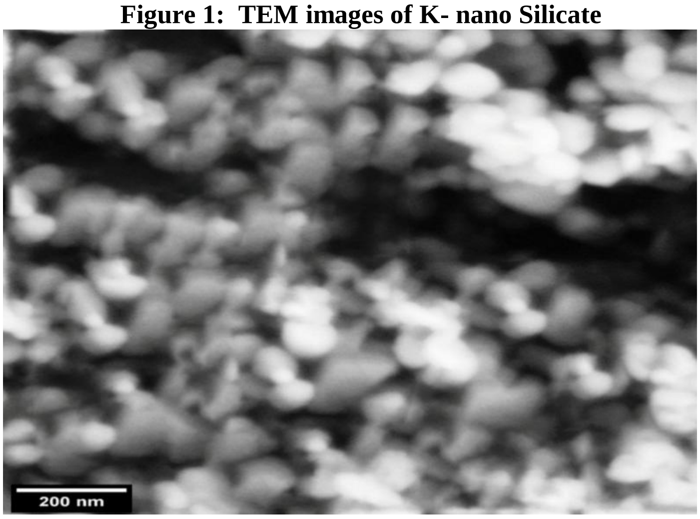

Figure 2: SEM images of K- nano Silicate

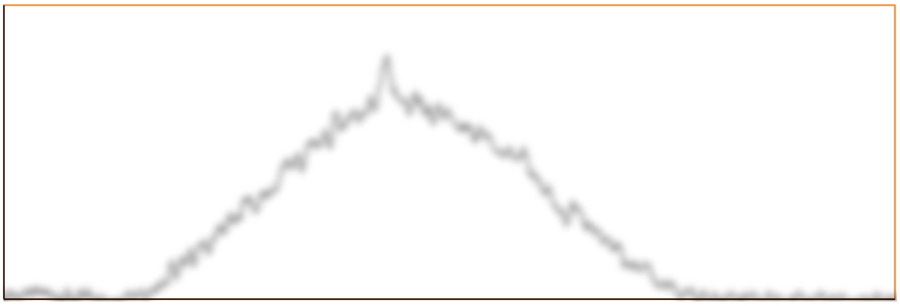

Figure 3: XRD pattern of K- nano Silicate

Table 1. Physical and chemical characteristics of the experimental soil at the site located in Giza governorate.

Measurement	Value			
Particle-size distribution	Sampling depth (cm)			
	0-15	15-30	30-45	45-60
Clay %	25.08	25.80	9.81	16.51
Silt %	45.25	41.06	28.40	69.79
Fine sand %	27.76	30.56	61.07	12.00
Coarse sand %	1.91	2.58	0.72	1.70
Textural class	CLAY	CLAY	S.C.L	CLAY
Soil chemical properties	Sampling depth (cm)			
	0-15	15-30	30-45	45-60
pH	7.52	7.56	7.66	7.71
EC dSm^{-1}	1.31	2.07	1.84	1.37
Cations and anions in soil paste extract ($mmol_cL^{-1}$)				
Cations ($mmol_cL^{-1}$) Na^{+}	5.11	10.44	10.42	6.20
K^{+}	0.08	0.04	0.02	0.19
Ca^{2+}	4.29	5.71	4.29	4.29
Mg^{2+}	5.04	5.30	5.04	2.49
Anions ($mmol_cL^{-1}$) CO_3^{2-}	0.00	0.00	0.00	0.00
HCO_3^{-}	0.94	1.89	2.83	2.36
Cl^{-}	6.78	7.63	6.78	5.93
SO_4^{2-}	6.80	11.97	10.16	4.88

*S.C.L (Silt Clay Loamy)

Table 2. Soil field capacity, wilting point, avaiable water, and bulk density at different depths.

Depth	Field capacity (FC)		Wilting Point (WP)		Available water (AW)		Bulk density
cm	% by weight	mm	% by weight	mm	% by weight	mm	(BD) Mg/m^3
0-15	40.6	69.4	18.5	31.6	22.1	37.8	1.14
15-30	38.3	67.1	17.7	31.9	19.6	35.3	1.2
30-45	37.1	63.1	16.8	31.2	17.1	31.8	1.24
45-60	36.5	66.2	17.7	33.5	17.3	32.7	1.26
Total		265.8		128.2		137.6	

Where: - F.C % = Soil field capacity, W.P % = wilting point, AW % = Available water, and BD, Mg/m^3 = Soil bulk density, N.D. means not detected
FC: moisture at a moisture tension of 33 kPa.
WP: moisture at a moisture tension of 1.5 MPa.
FC-WP = AW

Table 3. The chemical analysis of the tap water used for irrigation.

Water quality	PH	EC(dsm^{-1})	Soluble ions (mmol$_c$/ L)								
			Cations				Anions				
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	RSC	SAR
	8.0	1.18	4.85	3.20	4.43	0.39	3.30	1.86	7.71	0.00	2.21

Note RSC, residual sodium carbonate; SAR, sodium adsorption ratio; Adj, adjusted

Results and Discussion

Grain yield and nutrient uptake:

Plants that did not received ordinary silicates produced significantly lower grain yields as compared to the plants that received the k-nano silicate (Table 4). The lowest grain value (6.116 Mg ha^{-1}) was induced by spraying ordinary silicate at a rate of 2 mLL^{-1} rate under skipping irrigation at tillering (20 days after seeding "AS") ($S_1D_1I_1$), while the highest grain value (8.615 Mg ha^{-1}) was detected with spraying nano-silicate at a rate of 6 mLL^{-1} under no skipping irrigation ($S_2D_3I_0$). These two combined treatments increased grain output by roughly 18.9% and 32.9%, respectively, compared to the same untreated controls (no Si). Previously, **Sarwar et al. (2010)** reported that wheat plants received five irrigations at the crown root, tillering, booting, earing, and milking stages, yielded the highest grain yields.

The principal impact of irrigation treatments demonstrates that complete irrigation provided the highest yield, but withholding irrigation at tillering gave the lowest yield, with the following pattern: $I_0 > I_4 > I_5\ I_3 > I_2 > I_1$.

The average biggest decline accounted for 17.6% of the total, due to tillering (I_1). The highest yield obtained with no irrigation skipping (I_0) surpassed the lowest yield by roughly 21.3%. The irrigation skip treatment with the lowest yield drop (4.3%) was used at the milk stage "I_4", followed by one at the dough stage "I_5" (8.7%). The irrigation skip at the dough and the irrigation skip at the flowering phases were almost identical. Skipping irrigation at the stages of milk or dough may be advised to conserve irrigation water when water is scarce.

Wheat that received five irrigations during the crown root, tillering, booting, earing, and milking stages of growth provided the highest grain yield **(Sarwar et al., 2010)**. When irrigation was interrupted throughout the three successive periods, from early stem elongation to flag leaf emergence (FL), FL to anthesis (AS), and AS to late grain filling, respectively, wheat output decreased by approximately 36.7, 22.8, and 45.6% for the same sequence.

The nano-Si outperformed the non-nano-Si. The use of nano-Si instead of normal Si resulted in a 10.1% increase. It was also highlighted in places where a high Si dosage was used. Silicon, according to **Ma and Takahashi (2002) and Habibi and Hajiboland (2013)** can reduce the impacts of drought stress.

The main consequence of the nano application is a 10.11 percent increase. The irrigation regime I_1 (skipping at tillering), with a yield of 6.664 Mgha^{-1}, produced the lowest yield. The irrigation regime's grand mean values revealed that the application of I_0 (no irrigation withholding) gave the maximum yield of 8.086 Mgha^{-1}, representing a relative increase of around 21.34% above the irrigation regime I_1 (skipping at tillering). The principal effects of irrigation are as follows: $I_1 > I_5 > I_6 > I_4 > I_3 > I_2$.

The current findings are consistent with those obtained by **Ghanbari *et al.*, (2007), Haider *et al.*, (2007), Ghodsi et al., (2008), Geerts and Raes, (2009), Akbar *et al.*, (2010), Akram (2011), Asif *et al.*, (2012), Qamar *et al.*, (2013), Mehasen *et al.*, (2014), and Guendouz *et al.*, (2016). Sarwar *et al.*, (2010)** discovered that wheat crops that received five irrigations during the crown root, tillering, booting, earing, and milking stages yielded the best grain output in a field trial.

Aurangzaib *et al.*, (2021) proved how drought stress influenced wheat output dramatically. Instead, by improving grain output (5074.8 kg/ha), foliar sprays of 2% $K_2Si_2O_5$ effectively decreased drought-induced damages. These findings show that exogenous application of $K_2Si_2O_5$ is a quick, easy, and efficient strategy for mitigating the effects of drought on wheat output.

Recently, **Nouraldinvand *et al.*, (2021)** discovered that the use of SiO_2 NPs, particularly at rates of 30 and 60 ppm, can alleviate the deleterious effects of drought stress in wheat plants.) In general, it appears that the use of bio-fertilizers and nano silicon can be recommended as effective management elements for improving grain yield and grain-filling components of wheat under water limitation situations.

These findings corresponded with the findings of **Nouraldinvand *et al.*, (2023),** who discovered that the use of bio-fertilizers and nano silicon can be recommended as effective management elements for boosting grain yield and grain filling components of wheat under water-stressed situations. Water stress had a considerable effect on wheat growth and yield parameters, according to **Bukhari *et al.*, (2023).** Soil treated with Si during tillering yielded the highest grain production value.

Table 4. Effect of skipping (withholding) irrigations and silicate form and rate on wheat grain yield (Mg ha^{-1})

Si source (S)	Si dose (D)	Irrigation skipping (I) I_0	I_1	I_2	I_3	I_4	I_5	Mean
	D_1	7.544	6.116	6.487	6.852	7.205	6.902	**6.851**
S_1	D_2	7.912	6.482	7.059	7.198	7.562	7.196	**7.235**
	D_3	8.263	6.846	7.191	7.565	7.909	7.56	**7.556**
Mean		**7.906**	**6.481**	**6.912**	**7.205**	**7.559**	**7.219**	**7.214**
	D_1	7.925	6.478	6.816	7.198	7.558	7.185	**7.193**
S_2	D_2	8.259	6.839	7.182	7.550	7.918	7.548	**7.549**
	D_3	8.615	7.224	7.553	7.901	8.275	7.888	**7.909**
Mean		**8.266**	**6.847**	**7.184**	**7.550**	**7.917**	**7.540**	**7.551**
Grand mean		**8.086**	**6.664**	**7.048**	**7.377**	**7.738**	**7.380**	
Means of D treatments								
D_1		7.735	6.297	6.652	7.025	7.382	7.044	**7.023**
D_2		8.085	6.661	7.121	7.374	7.740	7.372	**7.392**
D_3		8.439	7.035	7.372	7.733	8.092	7.724	**7.733**
L.S.D at 0.05	**I= 0.020 ; S = 0.009 ; D = 0.007 ; IS= 1.092 ; ID = 1.796 ; SD = 1.037 ; ISD = 2.539**							
Treatments receiving no silicates (sprayed with water)								
		I_0	I_1	I_2	I_3	I_4	I_5	
		6.483	**5.142**	**5.409**	**6.141**	**6.493**	**5.759**	**5.904**

D_1,D_2 and D_3 are 2, 4 and 6mLSiL^{-1}respectively
S_1 and S_2 are k-ordinary silicate and nano silicate, receptively

I_0: No irrigation skipping (no irrigation withholding).
I_1: Skipping irrigation at tillering.
I_2: irrigation at Vegetative growth.
I_3: irrigation at Flowering.
I_4: irrigation at the Milk stage.
I_5: irrigation at the dough stage.

Results in table 5 show that withholding irrigation at tillering (I_1) and not withholding irrigation (I_0) resulted in absorption of N ranging from 139.8 to 172.0 kg ha^{-1} in plants that did not receive silicates. The N of absorption by the plants receiving silicates ranged from 137.7 for $S_1D_1I_2$ to 425.3 for $S_2D_3I_0$, an increase of 8.9%. The main effect of the K-nano silicate application is a 47.28% increase. I_1 (skipping tillering) produced the lowest yield of all irrigations, yielding 186.0 kg N ha^{-1}. The highest value of N absorption was found with I_0 (no irrigation withholding), which resulted in a 303.6 kg N ha^{-1} corresponding to a decrease in N absorption, a 63.19% increase. $I_1 > I_5 > I_6 > I_4 > I_3 > I_2$ is a nice approach to organise irrigation's key impacts.

These findings verified the findings of **Akbar et al., (2010)** who indicated that water deficiency conditions had a significant impact on wheat grain yield. In terms of yield characteristics, **Ayman et al., (2020)** Investigated the impact of nano-SiO_2 in increasing wheat growth and productivity under salt conditions. Six treatments (two classes of water quality: tap water and saline water; three additional ways for silica nanoparticles: 0, Si-soil, foliar) were tested in three duplicates. Before sowing, the soil was fertilized with nano-SiO_2 at a rate of 80 mg kg^{-1}, and the necessary NPK was applied similarly to all treatments. After a month of seeding, wheat plants were sprayed with 600 mg Si L^{-1} (10 mL pot^{-1}) nano-silica five times. The wheat plant was irrigated with tap water (0.4 dSm^{-1}) and saline water (8 dS m^{-1}). Nano-SiO_2 enhances wheat plant development and tolerance to salt stress by up to 80 mg Kg^{-1} in soil addition and 600 mg L^{-1} in foliar spray.

Table 5. N uptake (kg ha^{-1}) by grain as affected by irrigation regime, K-silicate form, and rate of it's application.

Si source (S)	Si dose (D)	Irrigation skipping (I)						
		I_0	I_1	I_2	I_3	I_4	I_5	Mean
	D_1	220.3	137.7	154.5	188.0	207.1	191.7	183.2
S_1	D_2	278.9	159.7	202.0	236.2	261.7	234.7	228.9
	D_3	320.6	173.0	243.3	266.0	288.7	268.0	259.9
Mean		273.3	156.8	199.9	230.1	252.5	231.5	224.0
	D_1	256.2	167.4	185.9	223.6	217.7	228.0	213.1
S_2	D_2	320.2	229.8	249.0	277.9	298.3	275.7	275.1
	D_3	425.3	248.7	269.6	303.9	392.8	302.3	323.8
Mean		333.9	215.3	234.8	268.5	302.9	268.7	270.7
Grand mean		303.6	186.0	217.4	249.3	277.7	250.1	
Means of D treatments								
D_1		238.3	152.5	170.2	205.8	212.4	209.8	198.2
D_2		299.6	194.7	225.5	257.0	280.0	255.2	252.0
D_3		372.9	210.9	256.5	285.0	340.8	285.1	291.9
L.S.D at 0.05	I= 1.419 ; S = 0.542 ; C = 0.560 ; I. S= 1.327 ; I.C= 1.373 ; S.C = 0.792 ; I.S.C = 1.941							
Treatments receiving no silicates (sprayed with water)								
		I_0	I_1	I_2	I_3	I_4	I_5	
		172.0	139.8	146.9	160.3	166.2	158.4	157.2
For abbreviations, see notes under Table 4.								

Table 6 indicates that Potassium uptake by grain ranged from 145.5 to 266. kg ha^{-1} in Si-untreated plants, depending on I_1 (withholding irrigation at tillering) and I_0 (no withholding of irrigation) (Table 6). Potassium uptake ranged from 168.7 supplied by $S_1D_1I_1$ to 410.3 given by $S_2D_3I_0$, representing a 43.22% increase in plants receiving silicates. The key effect of the nano application is an increase 27.59%. I_1 (skipping tillering) produced the lowest yield of all irrigations, 255.0 kgha^{-1}. The most efficient performance was I_0 (no irrigation withholding), which produced k uptake of 371.3 kgha^{-1}, an increase in K of 45.6 %. The principal effects of irrigation are classified as follows. $I_1 > I_5 > I_6 > I_4 > I_3 > I_2$.

The current findings are congruent with those previously reported by **Ali et al. (2007) and Du et al. (2010),** who stated that tillering, elongation, booting, and grain production are all moisture-sensitive growth stages. Concerning the effects of silicon, **Ma and Takahashi, (2002) and Habibi and Hajiboland, (2013)** found various physiological pathways that rendered plants more resistant to drought stress.

Table 6. K uptake (kg ha^{-1}) by grain as affected by irrigation regime, K-silicate form and rate of its application.

Si source (S)	**Si dose (D)**	**Irrigation skipping (I)**						
		I_0	**I_1**	**I_2**	**I_3**	**I_4**	**I_5**	**Mean**
	D_1	328.8	168.7	204.3	243.5	307.7	246.5	**249.9**
S_1	**D_2**	351.3	242.9	295.6	307.4	331.4	307.7	**306.0**
	D_3	400.8	265.5	315.1	339.5	362.1	339.1	**337.0**
Mean		**360.3**	**225.7**	**271.7**	**296.8**	**333.8**	**297.7**	**297.7**
	D_1	352.9	245.2	228.8	304.3	331.0	307.2	**294.9**
S_2	**D_2**	383.5	292.7	306.2	330.7	354.9	330.9	**333.1**
	D_3	410.3	315.2	330.3	353.2	386.0	353.6	**358.1**
Mean		**382.2**	**284.4**	**288.4**	**329.4**	**357.3**	**330.6**	**328.7**
Grand mean		**371.3**	**255.0**	**280.0**	**313.1**	**345.5**	**314.2**	
Means of D treatments								
D_1		340.9	206.9	216.6	273.9	319.4	276.8	**272.4**
D_2		367.4	267.8	300.9	319.0	343.1	319.3	**319.6**
D_3		405.5	290.3	322.7	346.4	374.1	346.3	**347.6**
L.S.D at 0.05	**I= 0.845; S = 0.430; C = 0.546; I. S= 1.053; I.C= 1.337; S.C = 0.772; I.S.C = 1.891**							
Treatments receiving no silicates (sprayed with water)								
		I_0	**I_1**	**I_2**	**I_3**	**I_4**	**I_5**	
		266.6	145.5	151.4	203.0	210.4	206.4	**197.2**

For abbreviations, see notes under Table 4.

Irrigation regimes of withholding irrigation at tillering (I_1) and not withholding irrigation (I_0) resulted in a range of 14.49 to 17.63 kg ha^{-1} P uptake by the grain of plants not treated with silicates, as shown in Table 7. Silicates improved grain phosphorus uptake by 20.97%, with values ranging from 18.57 for $S_1D_1I_1$ to 41.04 for $S_2D_3I_0$. The K-nano application resulted in a 29.18% rise. I_1 (skipping at tillering) had the lowest yield among all the systems, which is 22.26 kg ha^{-1}.The highest uptake was attained of I_0, which resulted in an increase in P uptake of 32.83 kg ha^{-1}, corresponding to 47.47%. The primary consequences of the irrigation treatment are listed below: $I_1 > I_5 > I_6 > I_4 > I_3 > I_2$.

In this regard, **Rea *et al*., (2022)** demonstrated that Si increased crop development and productivity under severe climatic conditions. Silicon improves the availability and accumulation of both macronutrients (nitrogen, potassium, calcium, and sulphur) and micronutrients (iron and manganese). It promotes drought resistance by enhancing plant water usage efficiency and lowering water loss during transit. Because of all of these benefits, silicon treatment is an important part of crop productivity. Similarly, **Dhakate *et al*., (2022)** reported that silicon nano forms improved plant growth, primarily by increasing photosynthesis rate and increasing nutrient uptake.

Table 7. P uptake (kg ha^{-1}) by grain as affected by irrigation regime, K-silicate forms, and rates.

Si source (S)	Si dose (D)	Irrigation skipping (I)						
		I_0	**I_1**	**I_2**	**I_3**	**I_4**	**I_5**	**Mean**
	D_1	26.40	18.57	20.35	22.43	24.19	22.41	**22.39**
S_1	**D_2**	29.28	21.05	23.70	24.95	27.07	25.02	**25.18**
	D_3	37.62	23.62	25.65	27.64	34.62	27.82	**29.49**
Mean		**31.10**	**21.08**	**23.23**	**25.01**	**28.63**	**25.08**	**25.69**
	D_1	29.83	21.03	22.81	24.98	27.64	24.72	**25.17**
S_2	**D_2**	32.79	23.62	25.52	27.61	29.93	27.73	**27.87**
	D_3	41.04	25.67	27.64	29.84	37.85	29.61	**31.94**
Mean		**34.55**	**23.44**	**25.33**	**27.47**	**31.81**	**27.35**	**28.32**
Grand mean		**32.83**	**22.26**	**24.28**	**26.24**	**30.22**	**26.22**	
Means of D treatments								
D_1		28.11	19.80	21.58	23.70	25.91	23.56	**23.78**
D_2		31.03	22.33	24.61	26.28	28.50	26.37	**26.52**
D_3		39.33	24.64	26.65	28.74	36.23	28.71	**30.72**
L.S.D at 0.05		**I= 0.080 ; S = 0.036 ; C = 0.036 ; I. S= 0.089 ; I.C= 0.087 ; S.C = 0.050 ; I.S.C = 0.123**						
Treatments receiving no silicates (sprayed with water)								
		I_0	**I_1**	**I_2**	**I_3**	**I_4**	**I_5**	
		17.63	14.49	15.15	15.69	16.32	15.74	**15.84**

For abbreviations, see notes under Table 4.

Conclusion

The aforementioned results, reveal that it is possible to infer that using nano K- silicate at a rate of 6 mLL^{-1} is the most effective for withholding irrigation during most wheat growth stages. Furthermore, because tillering is the most crucial stage of wheat growth, it is not suggested to withholding irrigation during this time. Nanoparticles have been demonstrated to play a vital role in agriculture. Nano silica was found to be important for nutrient uptake and wheat grain in this study. All yield metrics assessed under water stress, such as grain and nutrient uptake, were positively affected by nano silica, with greater values compared to when nano silica was not sprayed. To achieve the highest values of nutrient uptake and yield, wheat plants should be treated with a concentration of 6 mLL^{-1} nano silica while not being irrigated. According to these findings, employing nano silica can increase wheat grain production in arid regions and can be utilized as a helpful fertilizer for foliar application. Based on the findings of this study and under the same conditions, foliar spraying with potassium silicate (D_3) at a rate of 6 $mLSiL^{-1}$ enhanced grain production and nutrient uptake of wheat in both seasons in Giza Governorate, Egypt.

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