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IMPACT OF FOLIAR APPLICATION OF NANO-SILICON AND POTASSIUM HUMATE ON PRODUCTIVITY AND QUALITY OF GIZA 178 RICE CULTIVAR UNDER NORTH DELTA CONDITIONS

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ABSTRACT: Applications of silicon (Si) and potassium humate (K-H) plays essential roles for enhancing many plants agronomic parameters and yield as well as quality characteristics under poor fertile soil conditions. This investigation carried out during 2019 and 2020 summer seasons at North Delta, Biyala district as a poor fertile soil located at Kafr El-Sheikh, Egypt. This investigation aims to evaluate the efficacy of foliar application of silica forms [Traditional-Si (T-Si) and Nano Si (N-Si)] with various concentrations (control, 250, 500 and 750 ppm/liter) combined with or without potassium humate (K-H) as single concentration 14 cm^3/liter through (tillering, panicle formation and heading stages) on growth, yield and grain quality of Giza 178 rice cultivar. A split-plot design based on randomized complete block for treatment arrangement with three replicates was used. Two Si forms were designated in main plots, while the concentrations along with or without potassium humate were arranged in sub plots. Data obtained revealed that foliar application of nano silica (N-Si) showed a remarkable superiority with regard to all growth, yield and grain quality parameters in both seasons of study. When the foliar application of Si concentrations increased up to 750 ppm/L cause significant increases in the growth, yield and its components as well as grain quality. Concerning interaction effect, foliar application of Nano Si with potassium humate (K-H) surpassed the remaining treatments and recorded the peak values of growth and other yield and grain quality parameters. Coefficient of determination (R^2) also illustrated that, there were obvious relationship between foliar application of silicon forms and number of panicles/m^2 (0.6431and 0.7432), panicle length (0.7556 and 0.7921), panicle weight (0.7416 and 0.6941), number of filled grains/panicle (0.7667 and 0.8586) as well as grain yield (0.8485 and 0.8793) for both traditional and nano silica foliar concentrations. In the same trend, coefficient of determination recorded a positive relationship between all silica forms and their concentrations in terms of elongation % (0.5085 and 0.5603) and vice versa was recorded in case of amylose content (0.1788 and 0.1167) for both foliar application of traditional and nano silica, respectively. Whilst, a significant sturdy positive correlation between grain yield with each of number of panicles/m^2 ($r = 0.912$), panicle length ($r = 0.913$) and panicle weight ($r = 0.857$). From the obvious results it could be conclude that foliar application of Si forms with 750/L ppm along with potassium humate with 14 cm^3/L through the vital (tillering, panicle formation and heading stages) could be the suit avenue to achieve high grain yield and pertinent quality of Giza 178 rice cultivar under poor soil fertile condition in North Delta, Egypt.

Key words: Rice (*Oryza sativa* L.), Nano-silicon, Potassium humate, Foliar application, Grain quality.

INTRODUCTION

Rice is one of the main food crops for human in the world (Fitzgerald *et al*. 2009), around three billion people depend on rice as staple food (Rehman *et al.* 2012), in Egypt it is considered as the main food stable stuff for more than 90% of capitates (Wissa 2017). Cultivated rice area in Egypt was reduced during the growing seasons 2018 (304,164 ha) compared with 2017 (451,920 ha) (FAO 2020; USDA 2021) due to the shortage

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in irrigation water. One of the crop productivity limitations is soil salinity stress that causes osmotic imbalance, decreasing nutrients uptake and ion toxicity for plants (Munns and Tester 2008; Wang *et al*. 2021). Egyptian north Nile Delta as salt affected soil area mainly is cultivated with rice in summer season, that has thick clay which forming a compact and impermeable layer (El-Shahway *et al.* 2016; Rabeh *et al*. 2021). In this condition flood irrigation is effective method for decreasing salt stress effect which lead to leach salts away from the plant root zone (FAO 2003). Under the salt stress conditions and the shortage irrigation water, rice cultivated area and production reduce. So, the application of some fertilizers such as Si and K-H can contribute and play important role to decrease soil salinity stress for rice plants.

Silicon (Si) is a beneficial element for plant growth and agronomically essential for improving and sustaining rice productivity. Several studies cleared that Si fertilizer application improves salt tolerance in many crop species including rice with considered a typical siliciphilous plant (Epstein 2001; Kheir *et al*. 2019) and could alleviate the adverse effect of salinity stress (Thorne *et al.* 2020; Li *et al.* 2022). Silicon may be increasing photosynthetic activity and stimulation of antioxidant system, by reducing salt uptake and increasing K uptake (Tahir *et al.* 2006). Das *et al.* (2018); Yan *et al*. (2020) reported that Si increased anti-oxidative enzyme activity in rice plant, which reduces the oxidative damage that occurs during salt stress and reduce the osmotic stress. Application of Si to rice plants promotes the strength of stems, thus preventing lodging, increases the erectness of leaves, thus increasing the photosynthetic rate through improving light absorption and reduces fungal and insect injuries therefore improving productivity (Ma and Yamaji 2008; Meena *et al.* 2014). Furthermore, the use of nanoparticles such as N-Si fertilizer (dimensions between 1 and 20 nm) is expected to help reduce the fertilizer dose and increase plant productivity (Kheir *et al.* 2019 and Souza Junior *et al.* 2019), this due to its distinct physicochemical properties when compared to bulk particles. Nano Si application has a positive influence on rice growth and yield by decreasing the negative effects of salt stress (Kheir *et al.* 2019 Badawy *et al*. 2021).

Application of humic acid has significant potential effects on soil quality parameters and crop agronomic performance (Ampong *et al.* 2022), increases crop growth by enhancing photosynthesis, stress resistance and nutrients metabolism which increases plant growth and promotes hormones such as auxin and cytokine (Nardi *et al.* 2021; de Castro *et al*. 2021), has a direct regulating effect on plant hormones such as auxin, ethylene, nitric oxide, cytokines, Abscisic acid and reactive oxygen species (Jorquera *et al.* 2014). Potassium humate application improved rice growth and nutrient uptake and antioxidant activities (Mridha *et al.* 2021). Furthermore, there are many advantageous of adding humic acid fertilizer that can result in enhancement of crop yield and decreased environmental hazard effects by reducing greenhouse gas emissions (Guo *et al*. 2022).

Therefore, this investigation was carried out to identify the efficacy of foliar application of silica forms (Traditional-Si or Nano Si with various concentrations combined with or without potassium humate (K-H) on growth, yield and grain quality of Giza 178 rice cultivar under poor fertile soil of North Delta, Egypt.

MATERIALS AND METHODS

Experiment design and treatments

In north Nile Delta, (poor fertile soil conditions), Kafr El-sheikh Governorate at Private Farm (Biyala district), Egypt. (31° 12' 39.6" N and 31° 13' 55.5" E). A split plot design based on a randomized complete block design (RCBD) arrangement with three replications were used in 2019 and 2020 seasons. Two forms of silica either traditional (T-Si) and Nano (N-Si) were arranged in main plots and seven concentrations of each Si form were designated in sub plots as shown in Table 1. Potassium silicate (K_2SiO_3) was used as a source of Si forms. Nanoparticles of Si were prepared by ball-milling machine (Photon Company, Egypt) according to Rabeh (2018); Sohair *et al.* (2018). Potassium humate were added according to the recommendations and dose by 7 liters/ ha of liquid potassium humate as (humic plus 20 which contains potassium (K_2O): 10% (W/V) according to the label of manufacture company (Techno Green For Industrial Production New Nubaria City, Industrial Area,80 km, Alexandria-Cairo high way, Egypt). The plot size was (20 m^2 each) and was separated by one meter between each other. Giza 178 rice cultivar indica/ japonica (I/J) type which characterized by (bright erect leaves, high tiller capacity, short grain and 130-135 days from seed to seed). At the rate of 150 kg/ ha seeds were soaked in water for 36 hours then incubated for 48 hours to hasten early germination. Pre-germinated seeds were homogeneously were manually broadcasted in presence of water after puddling in May 2nd and 4th for 2019 and 2020 seasons, respectively. Phosphorus at 75 kg P_2O_5 / ha as single calcium superphosphate (15.5% P_2O_5) was added with soil preparation. Nitrogen at a level of 165 kg N/ ha, as urea $CO(NH_2)_2$, 46.5% N which was added in three equal premiums (1/3 as basal application, 1/3 at maximum tillering stage as a top-dressing application and the remaining 1/3 at panicle primordia formation stage as the second top dressing). However, potassium at the rate of 125 kg K_2O/ ha as potassium Sulphate (48% K_2O) was added as basal application and twice sprayed by 2.5% at booting and heading stage. The volume of foliar spray solution of Si and K-H was approximately 500 liters/ha and was applied three times (at tillering, panicle primordia and heading stages). Each plot was vertically protected with a plastic sheet during spraying to prevent contamination. Potassium concentrations were balanced in the solutions applied to all treatments to negligible its effect from K_2SiO_3 and K-H fertilizer sources. All agronomic practices have been applied according to the recommended methods of rice production according to Rice Research and Training Center, (RRTC), Egypt.

Soil Sampling and analysis

A composite surface soil samples (0-30 cm depth) were collected before planting and prepared during 2019 and 2020 seasons for laboratory analyzing. Soil physical (particle size distribution) and chemical properties (pH measured in 1: 2.5 soil-water suspensions, electrical conductivity (EC) in soil paste extract, soluble Cations and Anions, Cation exchange capacity (CEC), Exchangeable Sodium Percentage (ESP%), Total $CaCO_3$, Organic matter (OM)) according to standard methods outlined by Jackson (1973) and Sparks *et al.* (1996). The amount of available nitrogen (N) by Kjeldahl procedure, available phosphorus (P) in the extract of 0.5 M NaHCO3 at pH 8.5 (Olsen *et al.*1954) and was measured calorimetrically, amount of available potassium (K) in soil extract of ammonium acetate of pH 7 by flame photometer. Physical and chemical soil analysis are presented in (Table 2).

Table 1: Details of foliar application treatments during 2019 and 2020 growing seasons.

Treatments			
No.	**Traditional silicon (T-Si) ppm/L**	**No.**	**Nano silicon (N-Si) ppm/L**
1	Control	1	Control
2	T-Si 250	2	Si 250
3	T-Si 500	3	Si 500
4	T-Si 750	4	Si 750
5	T-Si 250 + 14 cm^3/ L (K-H)	5	Si 250+14cm^3/l (K-H)
6	T-Si 500 + 14 cm^3/ L (K-H)	6	Si 500+14cm^3/l (K-H)
7	T-Si 750 + 14 cm^3/ L (K-H)	7	Si 750+14cm^3/l (K-H)

For (T-Si),(N-Si) concentration estimated by ppm/L and (K-H) concentration estimated by cm^3/L.

Table 2: Some physical and chemical properties of the experimental site during 2019 and 2020 seasons.

Soil characteristics	Seasons	
	2019	2020
Physical properties		
Sand (%)	13.2	12.6
Silt (%)	22.6	20.9
Clay (%)	64.2	66.5
Texture	Clayey	Clayey
Chemical properties		
pH (1:2.5 soil suspension)	8.35	8.47
Organic matter (%)	1.63	1.58
Calcium carbonate (%)	1.38	1.52
CEC (C mole/kg)	46.5	52.8
ESP%	22.5	19.6
EC (dS/m) (soil paste)	3.39	3.24
N (ppm)	24.96	24.78
P (ppm)	7.82	8.13
K (ppm)	153.60	138.20
Soluble Cations ($meq.L^{-1}$)		
Ca^{2+}	7.99	9.07
Mg^{2+}	6.51	5.59
Na^{+}	17.54	16.04
K^{+}	1.89	1.73
Soluble anions ($meq.L^{-1}$)		
$CO_3^{=}$	0.00	0.00
HCO_3^{-}	6.16	5.12
Cl^{-}	15.24	15.58
$SO_4^{=}$	12.52	11.73

Data collection

Growth parameters and yield components

Ten rice hills were selected randomly from each sub plot fresh leaves were collected at heading stage to estimate leaf area index (LAI). At harvest, ten hills were selected randomly from each sub plot to determine; plant height (cm), panicle length (cm), panicle weight (g), filled grains number per panicle, percentage of unfilled grains per panicle and 1000-grains weight (g), also rice plants in an area of one square meter in the center of each sub plot were taken to determine number of panicles per square meter. After threshing, grain yield was adjusted to 14% moisture content according to SES IRRI (2013), then biological yield and harvest index (%) were calculated.

Grain quality characteristics

One hundred and fifty grams of cleaned rough rice samples at moisture content 12-14% were dehulled using Asatake Laboratory Dehuller at Technology Lab., Rice Research and Training Center (RRTC) Sakha, Kafr El-Sheikh

Governorate, Egypt. Physical characteristics (hulling, milling and Head rice percentage) were calculated using the procedure of Khan and Wikramanayake (1971). Cooking and eating quality traits; Amylose content (%) was determined following the method of Williams *et al.* (1958). A scale was used for classifying amylose content (AC %), as very low amylose (7-11 %), low amylose (16.19 %), intermediate (20-25%) and high (>25%) according to IRRI (2008). Elongation percentage was measured as percentage increase in grain length after cooking.

Statistical Analysis

All data were subjected to statistical analysis of variance for both seasons, according to the procedure described by Snedecor and Cochron (1981). Significance of differences among treatments were done according to Least Significant Differences test (LSD) at 0.05 probability level. Finally, all statistical analyses were carried out using "MSTAT-C" computer software package according to Freed *et al.* (1989). Coefficient of determination (R^2) and simple correlation (r) were estimated according to the following formulas:

$$R^2 = \frac{\text{Sum of squares regression}}{\text{Total sum of squares}} \text{, and}$$

$$r = \sqrt{\frac{\text{Cov. xy}}{\text{Varx.Var.y}}}$$

RESULTS AND DISCUSSION

Rice growth characters

Plant height and leaf area index (LAI)

Rice plant height (cm) and LAI were affected by foliar application of Si forms, rates without or with K-H and their interaction, except the interaction for plant height in both seasons (Fig.1 a & b and Table 3). Foliar application of nano-Si achieved the highest plant height value (80.38 cm) and LAI (5.25) compared with T-Si treatments. This finding indicated that, foliar application of nano-Si resulted in increasing plant height by increasing bio-availability of nutrients and their uptake which may be improve rice growth by accelerating cell division and stem elongation. Increasing foliar application concentrations of individual Si forms resulted in an insignificant increase in rice plant height, except Si forms at 750 ppm compared with control. However, rice LAI significantly increased by increasing concentrations from 250 up to 750ppm compared to the control. This may be due to the important of Si as beneficial element of all cereal crops including rice plants and improved the photosynthetic activity by maintaining erect leaves that enhance LAI which improved dry matter production in rice plant (Ma and Yamaji, 2008; Brunings *et al*. 2009; Meena *et al.* 2014).

Increasing of foliar application as combination of Si concentrations from 250, 500 and 750 ppm with 14cm^3 K-H caused a significant increase in rice plant height and rice LAI compared with the control treatment, respectively. This led to the importance role of K-H to enhance plant height and LAI. As an average in both seasons Si combined with K-H resulted in an increase in plant height and LAI compared with individual Si treatments. Coefficient of determination(R^2) illustrated a significant positive relationship between Si concentrations along with K-H for rice plant height (R^2 = 0.656) and rice LAI (R^2 = 0.598) (Fig. 1c). This result is in an agreement with those obtained by Fan *et al.* (2014) who found that the foliar application of HA significantly increased leaf area of chrysanthemum. Furthermore, results obtained cleared that, foliar application of nano Si along with 14cm^3 potassium humate(K-H) at vital consequence growth plant span (tillering, panicle primordia formation as well as heading) stages recorded the highest increase in plant height and LAI compared with foliar application of traditional Si along with potassium humate in both seasons of study. The first degree of interaction between Si forms and different treatments was significant for rice LAI. Foliar application of nano-Si at 750 ppm combined with 14 cm^3 (K-H) achieved the highest value of LAI while, traditional-Si at 250 ppm recorded the lowest LAI value as tabulated in (Table 3).

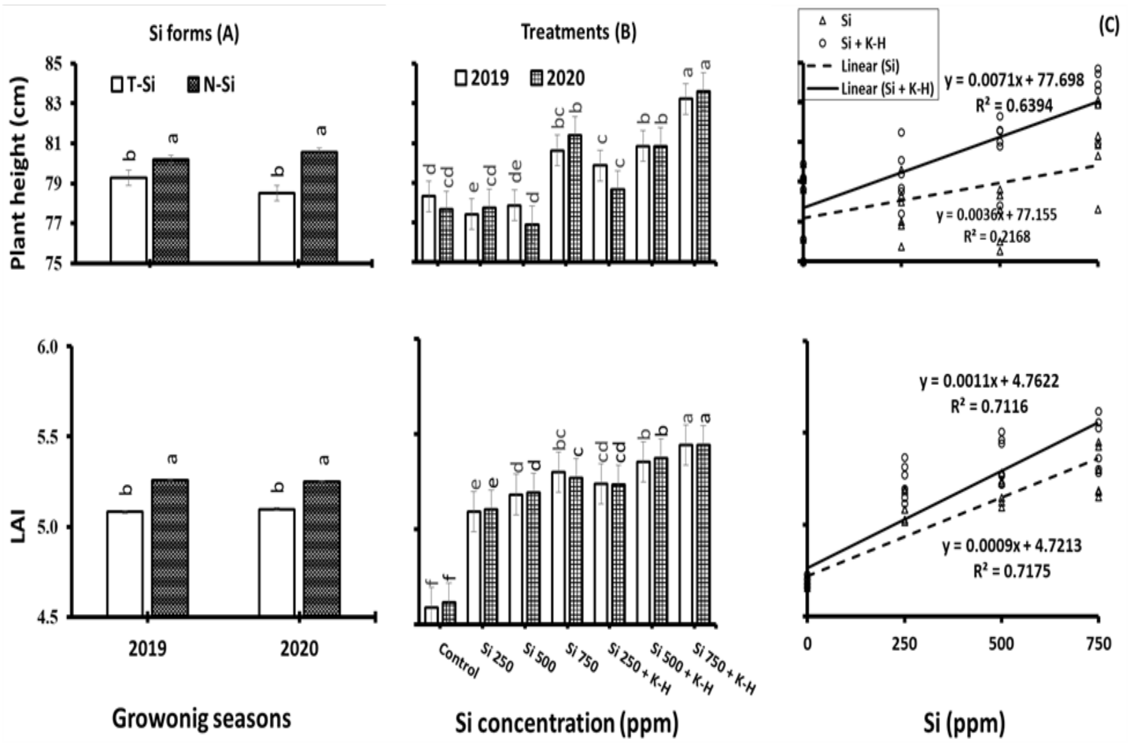

Fig 1: Means of plant height (cm) and Leaf area index as affected by foliar application of Si forms and their various concentrations without or with potassium humate(K-H) at harvest for Giza 178 rice cultivar during 2019 and 2020 growing seasons.

Table 3: Plant height(cm) and leaf area index as affected by the interaction between foliar application of Si forms and concentrations without or with potassium humate (K-H) fertilizer of Giza 178 rice cultivar during 2019 and 2020 growing seasons.

Foliar application		**Plant height (cm)**		**LAI**	
Silicon form (A)	**Treatments Si ppm/L (B)**	**Season**			
		2019	**2020**	**2019**	**2020**
Traditional (T-Si)	Control	78.00bc	77.13bcd	4.56h	4.58h
	Si 250	77.43cd	75.60a	5.05g	5.04g
	Si 500	77.67bc	76.58cde	5.12fg	5.12f
	Si 750	79.37ab	79.80b	5.18ef	5.16f
	Si 250+14cm^3/ L K-H	79.40ab	78.33bc	5.13fg	5.17f
	Si 500+14cm^3/ L K-H	80.80ab	79.47b	5.24de	5.27de
	Si 750+14cm^3/ L K-H	82.33a	82.60a	5.30d	5.34cd
Nano (N-Si)	Control	78.63c	78.17bc	4.62h	4.64h
	Si 250	77.40c	79.87ab	5.14efg	5.17f
	Si 500	78.07c	77.20bcd	5.24de	5.26e
	Si 750	81.87b	83.00a	5.41bc	5.37c
	Si 250+14cm^3/ L K-H	80.33b	79.00ab	5.34cd	5.30de
	Si 500+14cm^3/ L K-H	80.90b	82.20ab	5.47b	5.47b
	Si 750+14cm^3/ L K-H	84.10a	84.60a	5.59a	5.55a

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

Number of panicles/m^2, panicle length (cm) and panicle weight (g)

Rice is considered as a high silicon accumulating plant, foliar application forms of Si and their concentrations without or with K-H and their interactions had an obvious significant effect on panicles number/m^2, panicle length (cm) and panicle weight (g) in both seasons (Fig. 2 a & b and Table 4). There was a significant difference between foliar application at critical growth stages of rice (tillering, panicle primordia formation and heading stages) of T-Si and N-Si forms in both seasons of study. The highest values of panicles number m^2 (774), panicle length (18.48 cm) and panicle weight (2.13 g) were recorded with Nano -Si treatments and achieved the peak values of the forecasted characters over Traditional-Si form treatments, respectively.

Increasing gradually the concentrations (250, 500 and 750 ppm) of silica by foliar application at critical growth stages (tillering, panicle primordia as well as heading) individually led to a significant increase in rice panicles number/m^2, panicle length (cm), and panicle weight (g) compared to the control treatment, respectively. This indicated that, Si may be promoting early panicle formation and increase the number of matured rice grains/panicle which, led to increase panicle weight. Foliar application of Si at a pertinent physiological growth stage increased LAI by increasing the rate of photosynthetic process and biomass production that helps to increase panicles number, length and weight. Moreover, Foliar application of Si can increase the nitrogen use efficiency and enhance the growth parameters of rice crop (Ahmad *et al*. 2013; Yan *et al.* 2020). A significant positive relationship was found between LAI and number of panicles /m^2 (r = 0.933), panicle length (r = 0.867) and panicle weight (r = 0.858) as illustrated in (Fig. 3).

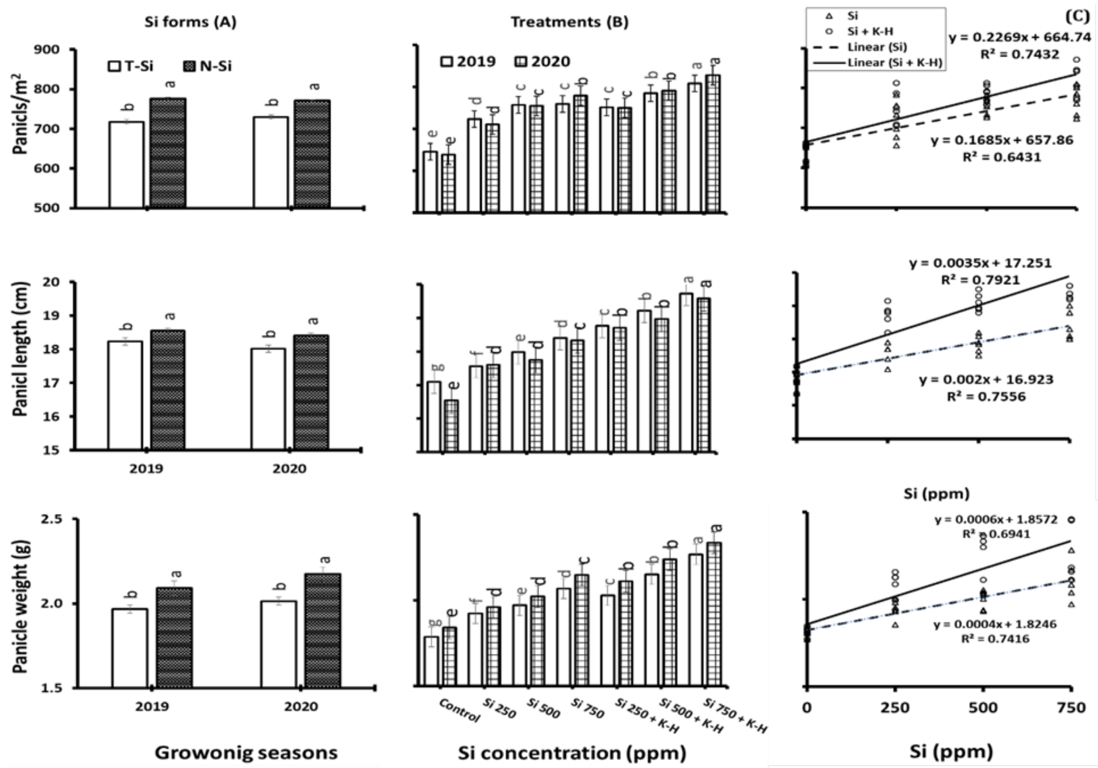

Fig 2: Means of number of panicles/m^2, panicle length(cm) and panicle weight(g) as affected by foliar application of Si forms and concentrations without or with potassium humate (K-H) during 2019 and 2020 growing seasons.

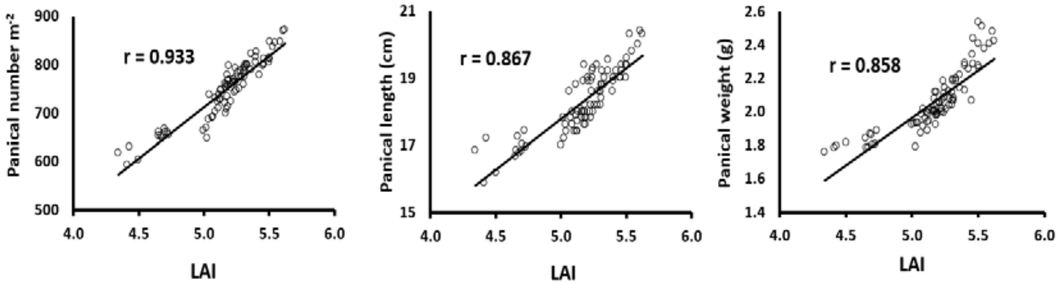

Fig 3: Positive correlation (r) relationship among rice LAI and number of panicles/m^2, panicle length(cm) and panicle weight(g).

Table 4: Number of panicles/m^2, panicle length (cm) and panicle weight (g) as affected by the interaction between foliar application of Si forms and concentrations without or with Potassium humate (K-H) of Giza 178 rice cultivar during 2019 and 2020 growing seasons.

Foliar application		**No. of panicles/ (m^2)**		**Panicle length (cm)**		**Panicle weight (g)**	
Si form (A)	**Treatments Si ppm/L (B)**	**Season**					
		2019	**2020**	**2019**	**2020**	**2019**	**2020**
Traditional (T-Si)	Control	641g	634h	16.99i	16.43f	1.78i	1.83g
	Si 250	675f	679g	17.53g	17.60e	1.90gh	1.95efg
	Si 500	743d	733f	17.83f	17.50e	1.93fg	1.98e
	Si 750	723e	755de	18.07e	18.00d	2.02def	2.05de
	Si 250+14cm^3/ L K-H	708e	729f	18.77d	18.70c	1.97efg	2.04de
	Si 500+14cm^3/ L K-H	773c	773cd	19.03c	18.73c	2.04cde	2.08cde
	Si 750+14cm^3/ L K-H	762c	806b	19.42b	19.13b	2.14c	2.16bcd
Nano (N-Si)	Control	650g	642h	17.22h	16.65f	1.80hi	1.85fg
	Si 250	772c	743ef	17.60g	17.60e	1.95efg	1.96ef
	Si 500	772c	775c	18.13e	18.00d	2.01def	2.06cde
	Si 750	796b	802b	18.73d	18.67c	2.12c	2.25b
	Si 250+14cm^3/ L K-H	795b	772cd	18.77d	18.73c	2.08cd	2.18bc
	Si 500+14cm^3/ L K-H	798b	809b	19.40b	19.20b	2.27b	2.40a
	Si 750+14cm^3/ L K-H	855a	851a	20.03a	20.03a	2.40a	2.51a

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

There was a significant positive relationship between foliar application of Si along with potassium humate (Si +K-H) with each of rice panicle numbers/m^2 (R^2 = 0.655), panicle length (R^2 = 0.699) and panicle weight (R^2 = 0.630) (Fig. 2c). A general average of both seasons cleared that, Foliar application of Nano Si combined potassium humate (N-Si + K-H) showed a remarkable superiority with raged to rice panicle numbers/m^2, panicle length(cm) and panicle weight(g) compared with (T-Si + K-H) in both seasons of study. The analyses of variance revealed that, significant differences between foliar application of Si forms and their concentrations were found where Nano silica at the concentration of 750 ppm combined with K-H achieved the highest values of number of panicles/m^2, (855 and 851), panicle length (20.03 and 20.03) and panicle weight (2.40 and 2.51) in both seasons, respectively. On the other hand, foliar application of T-Si individually at 250 ppm concentration recorded the lowest ones (675 and 679), (17.53 and 17.60) and (1.90 and 1.95) for the above-mentioned characters as showed in (Table 4) respectively.

Filled grains/Panicle, unfilled grains/ panicle and 1000-grain weight

Results listed in Table (5) and Figure (4 a & b) showed a significant effect of foliar application of Si Forms, concentrations and their interaction during the two growing seasons on filled grains/panicle, unfilled grains/panicle and 1000-grain weight. In respect to Si forms, foliar application of nano-Si at a critical growth consequence stage jointed both of vegetative and reproductive growth stages recorded the ceiling values of filled grains/panicle (85.21), 1000-grain weight (21.19 g) and lowest value in unfilled grains/panicle (10.53%) than traditional-Si treatments as average in both seasons. Duncan's multiple range test nominated that, by increasing the concentrations of single Si from 250 up to 750 ppm significantly increased rice filled grains/panicle,1000-grain weight and vice versa with regards to unfilled grains/panicle compared to control treatment in both studied seasons, respectively.

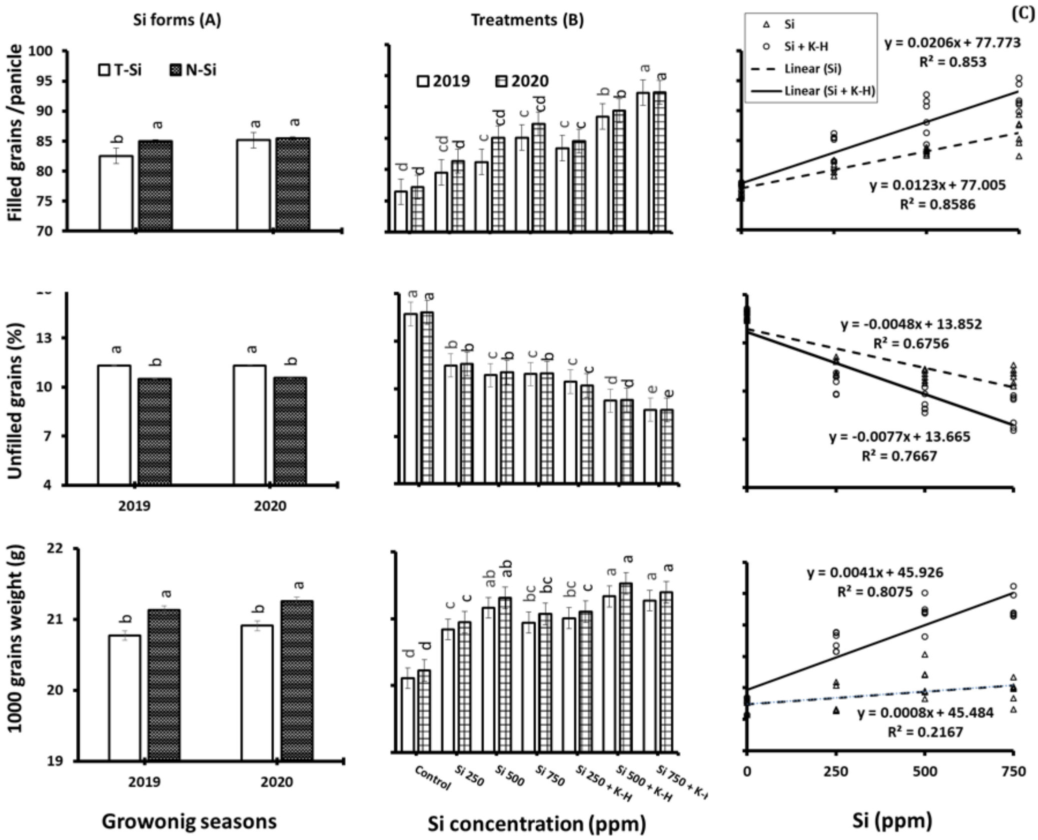

Fig. 4: Means of number of filled grains/ panicle, unfilled grains/panicle and 1000-grain weight as affected by foliar application of Si forms and concentrations without or with potassium humate (K-H) during 2019 and 2020 growing seasons.

Table 5: Filled grains/panicle, unfilled grains/panicle (%) and 1000-grain weight(g) as affected by the interaction between Si forms and their foliar application concentrations without or with potassium humate(K-H) of Giza 178 rice cultivar during the 2019 and 2020 growing seasons.

Foliar application		Filled grains/panicle (No.)		Unfilled grains/panicle (%)		1000-grain weight (g)	
Si form (A)	Treatments Si ppm/L (B)	Season					
		2019	2020	2019	2020	2019	2020
Traditional (T-Si)	Control	76.07j	77.27f	14.52a	14.73a	20.01d	20.02d
	Si 250	78.40hi	81.89de	12.05b	11.88b	20.78c	20.87c
	Si 500	80.07gh	86.42c	11.17c	11.31bc	20.81bc	20.94bc
	Si 750	84.00de	90.89b	11.17c	11.12bc	20.80bc	20.97bc
	Si 250+14cm^3/ L K-H	81.89fg	82.63de	10.93c	10.80c	20.90bc	20.96bc
	Si 500+14cm^3/ L K-H	86.42c	86.03c	9.59ef	9.71d	21.02bc	21.23b
	Si 750+14cm^3/ L K-H	90.89b	90.96b	9.56ef	9.62d	20.98bc	21.19bc
Nano (N-Si)	Control	76.80ij	77.00f	14.92a	14.93a	20.21d	20.42d
	Si 250	80.60fg	80.87e	10.90c	11.23bc	20.90bc	21.02bc
	Si 500	82.33ef	83.67d	10.56cd	10.78c	21.51a	21.68a
	Si 750	86.13c	83.60d	10.68cd	10.85c	21.09bc	21.17bc
	Si 250+14cm^3/ L K-H	84.88cd	86.50c	9.97de	9.61d	21.12b	21.25b
	Si 500+14cm^3/ L K-H	90.52b	92.77ab	8.90f	8.90d	21.65a	21.82a
	Si 750+14cm^3/ L K-H	93.67a	93.67a	7.78g	7.73e	21.56a	21.60a

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

A general average of both seasons cleared that, foliar application of Si combined with K-H at the three consecutive vital growth stages (tillering, panicle primordia as well as heading) stages recorded the highest number of filled grains/panicle,1000-grain weight and decrease in unfilled grains/panicle compared with individual foliar application of Si treatments. Duncan' multiple range test illustrated that, combination of foliar application of Si forms at 750 ppm plus K-H resulted in the highest values of filled grains/ panicle (92.3), 1000-grain weight (21.32 g) and the lowest value of unfilled grains/ panicle (8.67%). A significant positive relationship was found between Si + K-H and each of rice filled grains/panicle (R^2 = 0.779), 1000-grain weight (R^2 = 0.682) and a negative relationship with unfilled grains/panicle (R^2 = 0.539) (Fig. 4c). These results cleared that, foliar Si application to rice plant improved leaf sturdiness and erectness which help to enhance the photosynthetic activity and better assimilation of carbohydrates that promotes the growth and development of rice and finally resulted increase in grain weight. Our findings agreed with those of Mauad *et al.* (2003); Ambavaram *et al.* (2014) who reported that, Si foliar application delay senescence of rice leaves and remain for longer performing better photosynthesis, which could be results in more photo assimilates for production of carbohydrates and increasing grain weight.

The interaction between Si- forms and concentrations as foliar application differed significantly on rice filled grains/panicle and 1000-grain weight which led to recorded the highest values (93.67 and 21.58 g) under nano-Si at 750 ppm combined with K-H treatment and the lowest values (80.14 and 20.82 g) with individual traditional-Si at 250 ppm. On the other hand, unfilled grains/panicle were higher (11.97) in T-Si at 250 ppm than N-Si at 750 ppm combined with K-H (7.76) as average in both seasons of study (Table 5). These results are in harmony with those recoded by Dorairaj *et al.* (2020) who found that, Si foliar application resulted in a significant increase in percentage of rice filled spikelets and 1000 grains weight.

Rice biological yield, grain yield and harvest index

Rice biological yield, grain yield and harvest index were significantly differed by terms of forms and concentrations of foliar Si application without or with K-H in both seasons (Fig 5 and Table 6). Foliar application of N-Si had a higher rice biological yield, grain yield and harvest index than that of foliar T-Si treatments. In general, increasing individual Si application concentrations positively affected rice biological yield, grain yield and harvest index. The most evident value in biological yield (18.59 t/ha), grain yield (9.71 t/ha) and harvest index (45.89) were produced from foliar application of individual Si at the concentration 750 ppm. This difference in grains yield may be due to increasing the concentrations of foliar Si application which increased the number, length and weight of panicles which finally led to increase grain yield. A significant positive relationship was found between grain yield with each of number of panicles/ m^2 (r = 0.912), panicle length (r = 0.913) and panicle weight (r = 0.857) as draw in (Fig. 6). These results indicated that, foliar application of N-Si during pertinent consecutive growth stages (tillering, panicle primordia initiation and heading) not only enhance the strength and rigidity of cell walls, but also promote the rice growth, resulting in higher rice yield.

Combination of Si forms with K-H significantly increased biological yield and produce the peak value of biological yield (21.66 t/ha), grain yield (10.57 t/ha) and harvest index (49.21) by applying Si 750 ppm combined with K-H. A general average of both seasons cleared that, foliar application of Si combined with K-H recorded the highest values in rice biological yield, grain yield and harvest index compared with foliar single Si application treatments. Furthermore, N-Si combined with K-H recorded the highest values for rice biological yield, grain yield and harvest index compared with T-Si combined with K-H. There is a significant positive relationship between Si combined with K-H and each of rice biological yield (R^2 = 0.68), grain yield (R^2 = 0.79) and harvest index (R^2 = 0.68) (Fig. 5c). Results asseverated that, the interaction between the concentrations of Si forms were a significant in rice biological yield, grain yield as well as harvest index. As an average, the treatment of N-Si foliar application at 750 ppm combined with K-H achieved the ceiling in grain yield 10.83 t/ha while, T-Si foliar application at 250 ppm recorded the lowest grain yield 8.83 t/ha as listed in (Table 6).

Rice grain quality characters

Except the interaction there were significant differences of rice grain hulling, milling and head rice (%) as affected by foliar application of Si forms and concentrations without or with K-H during the two growing seasons as presented in (Fig. 7 and Table 7). Foliar application of N-Si form showed a remarkable superiority and produced the peak values of hulling (81.49%), milling (72.23%) and head rice (67.77%), respectively compared with T-Si treatments. Increasing foliar Si concentrations gradually led to significant increases in the rice grain hulling, milling and head rice percentages in both seasons of study. This may be due to that Si foliar application plays an important role in hull formation in rice grain by improving growth, increasing pre-heading photosynthesis rate transported from stored organs before heading and activate the current photosynthesis during filling period which caused improving grain filling that resulting an increasing thickness and weight of hull and increasing hulling, milling and head rice percentages (Shashidhar *et al.* 2008; Bhaskaran 2014; Ahmad *et al.* 2013. Combination of Si with K-H resulted in a significant increase in hulling, milling and head rice percentages. Whereas, combined N-Si with K-H achieved the highest rice grains hulling, milling and head rice percentages compared with T-Si with K-H. A positive relationship was found between Si combined with K-H and each of rice grain hulling (R^2 = 0.324) and head rice percentage (R^2 = 0.346) (Fig. 7c).

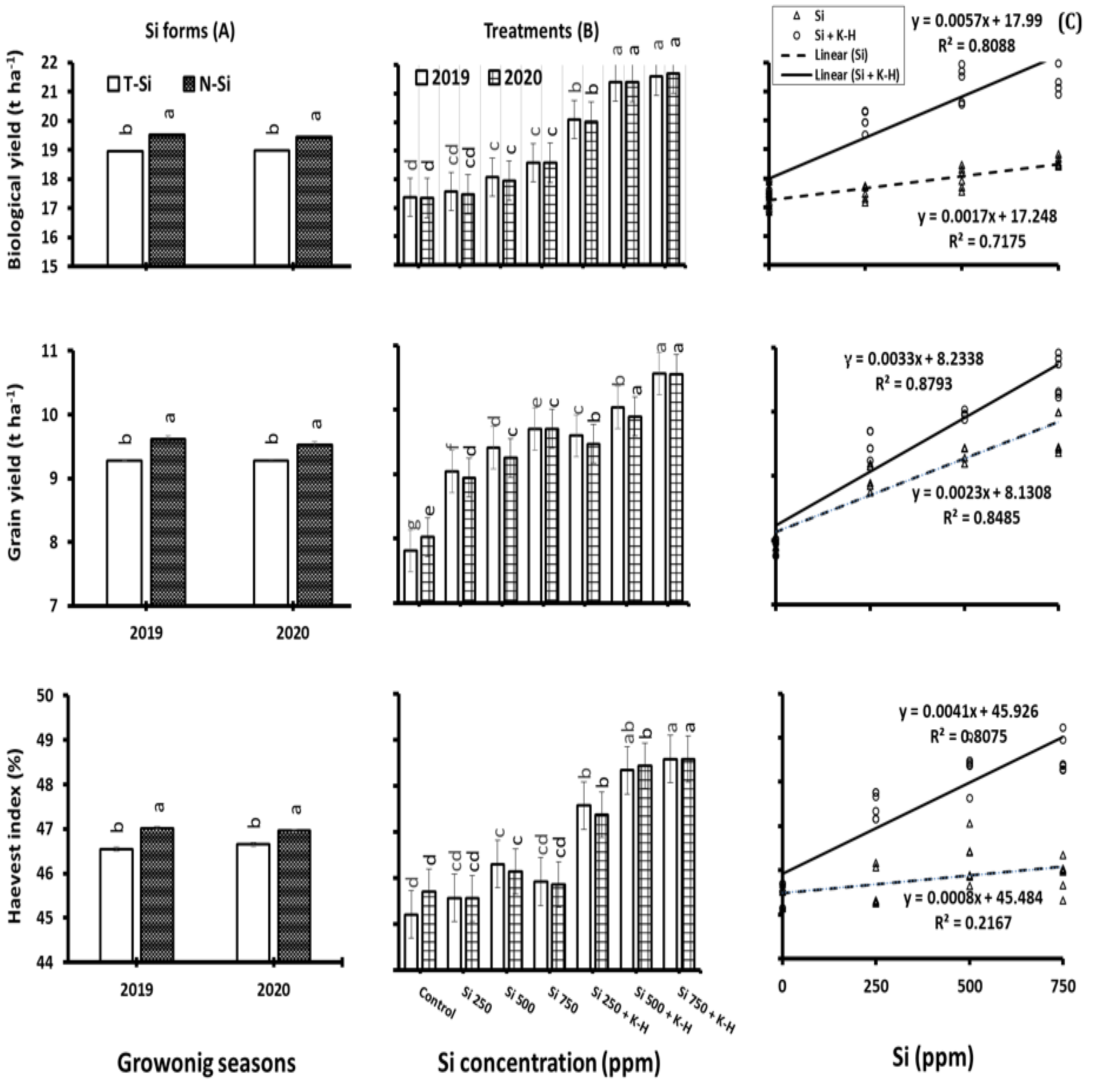

Fig 5: Means of biological yield (t/ha), grain yield(t/ha) and harvest index as affected by Si forms and their various concentrations without or with Potassium humate(K-H) during 2019 and 2020 growing seasons.

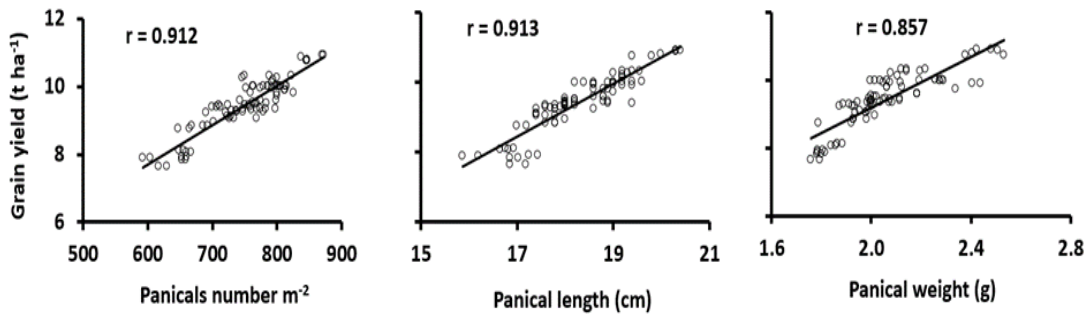

Fig 6: Simple correlation (r) among rice grain yield (t/ha) as a function of number of panicles/ m^2, panicle length (cm) and panicle weight (g).

Table 6: Biological yield(t/ha), grain yield(t/ha) and harvest index as affected by the interaction between foliar application of Si forms and concentrations without or with potassium humate (K-H) fertilizer of Giza 178 rice cultivar during 2019 and 2020 growing seasons.

Foliar application		Biological yield (t/ha)		Grain yield (t/ha)		Harvest index	
Silicon form (A)	Treatments Si ppm/L (B)	Seasons					
		2019	2020	2019	2020	2019	2020
Traditional (T-Si)	Control	17.38gh	17.33f	7.70k	8.02j	45.21e	45.69cd
	Si 250	17.34h	17.29f	8.81i	8.85i	45.25e	45.30d
	Si 500	17.84f	17.75ef	9.29gh	9.15g	46.08cde	45.89cd
	Si 750	18.51e	18.44d	9.40f	9.41f	45.76de	45.80cd
	Si 250+14cm^3/ L K-H	19.74d	19.85c	9.39fg	9.35f	47.16bc	47.27b
	Si 500+14cm^3/ L K-H	20.84bc	20.96b	10.04c	9.94cd	48.11ab	48.22a
	Si 750+14cm^3/ L K-H	21.08b	21.16a	10.30b	10.26b	48.27ab	48.37a
Nano (N-Si)	Control	17.38gh	17.38f	7.92j	8.02j	45.21e	45.69cd
	Si 250	17.80fg	17.64ef	9.28h	9.05h	45.88de	45.81cd
	Si 500	18.31e	18.14de	9.52e	9.35f	46.53bc	46.38cd
	Si 750	18.66e	18.71d	10.00c	10.00c	46.08cde	45.92cd
	Si 250+14cm^3/ L K-H	20.44d	20.20c	9.81d	9.59e	47.99ab	47.47b
	Si 500+14cm^3/ L K-H	21.98a	21.87a	10.02c	9.84d	48.56a	48.66a
	Si 750+14cm^3/ L K-H	22.13a	22.24a	10.82a	10.85a	48.90a	48.81a

Means followed by the same letter are statistically insignificant at P ≤ 0.05.

Table 7: Hulling %, Milling % and Head rice % index as affected by the interaction between foliar application of Si forms and concentrations without or with potassium humate (K-H) fertilizer of Giza 178 rice cultivar during 2019 and 2020 growing seasons.

Foliar application		Hulling (%)		Milling (%)		Head rice (%)	
Silicon form (A)	Treatments Si ppm/L (B)	Seasons					
		2019	2020	2019	2020	2019	2020
Traditional (T-Si)	Control	79.68e	79.33d	70.56b	70.71c	64.44e	65.55c
	Si 250	79.89de	79.40d	70.77b	71.21c	65.56de	66.00bc
	Si 500	80.00de	80.85bc	71.86ab	71.89abc	66.78bcd	66.89abc
	Si 750	81.00cde	81.07abc	71.22ab	71.55bc	66.78bcd	67.10abc
	Si 250+14cm^3/ L K-H	80.00de	81.07abc	72.86a	71.97abc	66.78bcd	67.11abc
	Si 500+14cm^3/ L K-H	81.07cde	80.51cd	72.84ab	72.95ab	64.44e	66.89abc
	Si 750+14cm^3/ L K-H	81.73bc	81.40abc	71.86ab	72.84ab	67.78abc	67.85ab
Nano (N-Si)	Control	79.68e	79.33d	70.56b	70.77c	64.44e	65.55c
	Si 250	80.96cde	81.07abc	71.86ab	71.93abc	66.67cd	66.77abc
	Si 500	81.03cde	82.03ab	71.86ab	71.99abc	68.44ab	68.78ab
	Si 750	81.44cde	81.39abc	72.01ab	71.21abc	67.62abc	67.48abc
	Si 250+14cm^3/ L K-H	83.09ab	82.45a	73.02a	72.99ab	69.22a	69.56a
	Si 500+14cm^3/ L K-H	82.03abc	82.45a	72.95a	73.07a	68.78a	69.11ab
	Si 750+14cm^3/ L K-H	83.28a	82.42a	72.99a	73.05a	68.89a	69.22a

Means followed by the same letter are statistically insignificant at P ≤ 0.05.

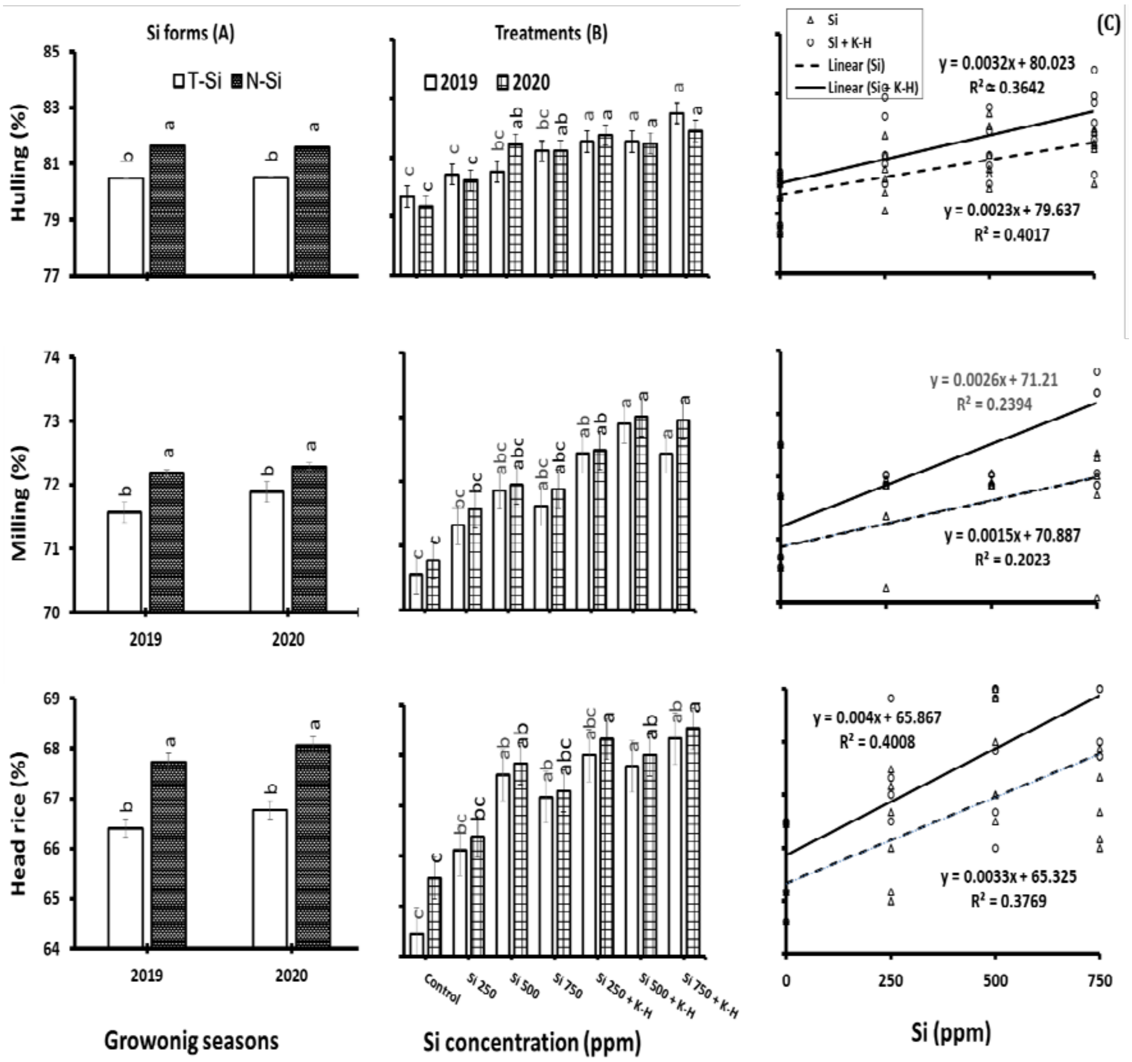

Fig. 7: Hulling (%), milling (%) and head rice (%) as affected by foliar application of Si forms and concentrations without or with potassium humate (K-H) fertilizer of Giza 178 rice cultivar in 2019 and 2020 growing seasons.

Cooking and eating quality

Foliar application of Si forms and concentrations without or with K-H and their interactions had a significant effect on amylose content (%) and grain elongation (%) in both seasons of study as draw in (Fig. 8a &b and Table 8). Duncan's multiple range test, assured that, there were an obvious superiority of foliar application in behalf of nano-Si individually or combined with potassium humate in terms of amylose content (%) and elongation (%) which came in the first rank followed by traditional Si foliar application compared with control which came in the last rank with regards to the same concern in both seasons of study. Foliar application of nano-Si surpassed the traditional one and recorded the lowest amylose content value (17.63%) and higher value of elongation (25.69%) as mean of both studied seasons Data obtained illustrated that, the foliar application of Si gradually increase amylose content in rice grains sharply decreased and vice versa with regards to grain elongation increased whereas, foliar application Si at 750 ppm concentration recorded as an average in both seasons the highest values in rice grain content of amylose (9.55%) and grain elongation percentage (13.13%) compared to the control treatment.

Combination of Si with K-H resulted in insignificantly effect in amylose content of and a significant effect in elongation percentage compared with the individual Si treatments. Also, foliar application of Si at 500 ppm combined with K-H recorded lowest percentage in content of amylose content (11.31%) and the highest value in grain elongation (22.02%) compared with the control. An insignificant relationship was found between Si combined with K-H for amylose content while, it was significant between Si combined with K-H for grain elongation percentage (R^2 = 0.560) (Fig. 8c).

The interaction between Si forms and different concentrations were significant in amylose content (%) and grain elongation (%) in both seasons of study. Foliar application of N-Si at 500 ppm combined with 14 cm^3 K-H achieved the lowest amylose content value (16.34%) and the highest grain elongation (%) value (29.87%), however foliar application of T-Si at 250 ppm recorded the highest one (20.24%) and lowest one (23.1%) for amylose content and grain elongation percentages, respectively as presented in (Table 8). Amylose content was significantly decreased in rice grains after application of silicon. Silicon might improve grain quality by decreasing amylose content of grain. It might be due to formation of complex compound made by the reaction of silicon with sugar molecules which inhibit amylase machinery (Zahoor *et al.* 2011).

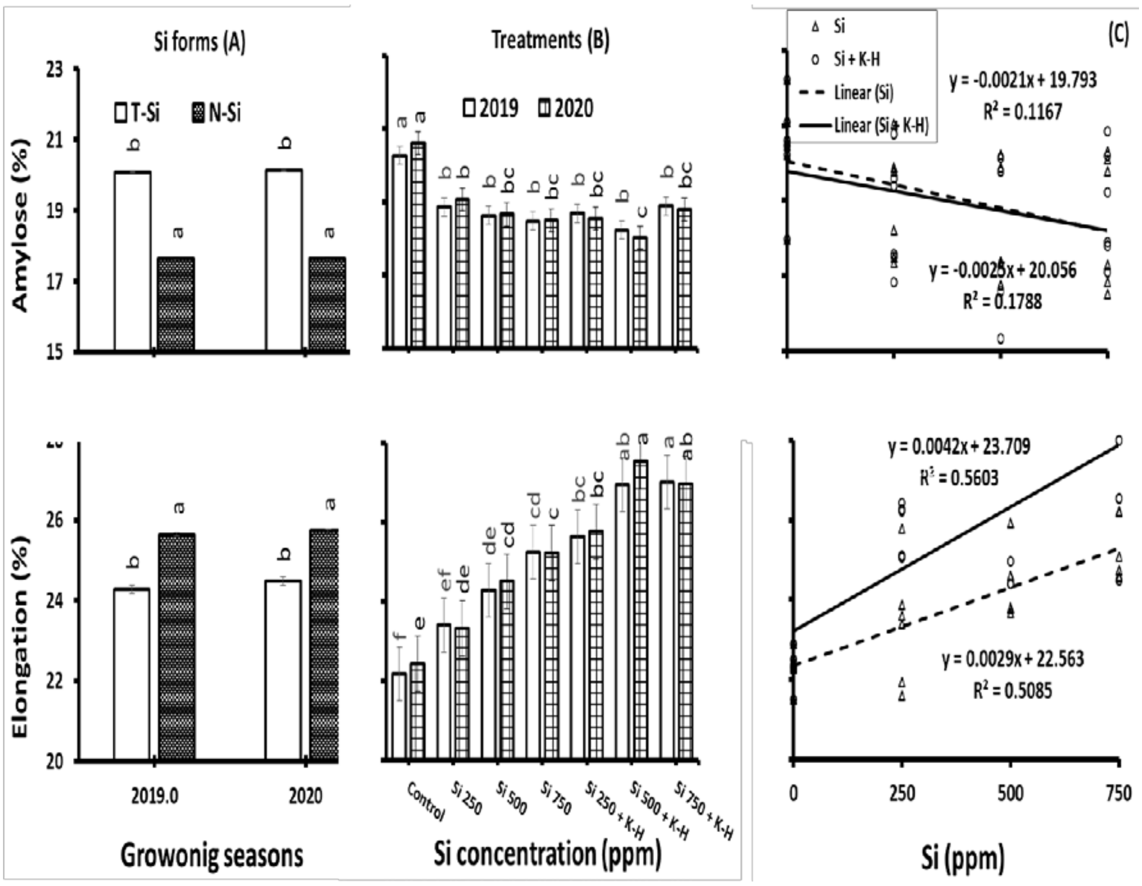

Fig. 8: Main effect of Amylose % and elongation % as affected by the interaction between foliar application of Si forms and concentrations without or with potassium humate (K-H) fertilizer of Giza 178 rice cultivar during 2019 and 2020 growing seasons.

Table 8: Amylose % and elongation % as affected by the interaction between foliar application of Si forms and concentrations without or with potassium humate (K-H) fertilizer of Giza 178 rice cultivar during 2019 and 2020 growing seasons.

Foliar applications		Amylose (%)		Elongation (%)	
Silicon form (A)	**Treatments Si ppm/L (B)**	**Seasons**			
		2019	**2020**	**2019**	**2020**
Traditional (T-Si)	Control	20.27a	20.60a	22.18f	22.43g
	Si 250	20.07a	20.40a	23.05ef	23.16fg
	Si 500	20.09a	20.13a	24.36b-e	24.58def
	Si 750	20.10a	20.03a	25.14bcd	25.21cd
	Si 250+14cm^3/ L K-H	19.99a	19.86a	25.08bcd	25.10cd
	Si 500+14cm^3/ L K-H	19.95a	19.85a	24.29b-e	24.90cde
	Si 750+14cm^3/ L K-H	20.14a	20.04a	25.80bc	25.91cd
Nano (N-Si)	Control	20.27a	20.60a	22.18f	22.43g
	Si 250	17.65b	17.72b	23.75def	23.50efg
	Si 500	17.15b	17.18bc	24.22cde	24.42def
	Si 750	16.84b	16.94bc	25.34bcd	25.23cd
	Si 250+14cm^3/ L K-H	17.38b	17.24bc	26.18b	26.42c
	Si 500+14cm^3/ L K-H	16.50b	16.17c	29.59a	30.14a
	Si 750+14cm^3/ L K-H	17.63b	17.56bc	28.22a	28.00b

Means followed by the same letter are statistically insignificant at $P \leq 0.05$.

Conclusion

Under poor fertile soils conditions at north delta, in order to overcome such circumstances foliar application of Si forms as nano (N-Si) or traditional one (T-Si) at 750 ppm/L along with 14cm^3/L potassium humate (K-H) at pertinent growth consecutive jointed both of vegetative and reproductive growth stages (tillering, panicle primordia formation and complete heading) stages is considered to be a vital avenue to improve growth of Giza 178 rice cultivar and finally led to increase the productivity and grain quality parameters.

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Declaration of interest

The authors declared that there is no conflict of interest.

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تأثير الرش بالسيليكا النانوميترية وهيومات البوتاسيوم على إنتاجية وجودة صنف الأرز جيزة ١٧٨ المنزرع تحت ظروف شمال الدلتا

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الملخص العربى

تلعب تطبيقات اضافة السيليكون وهيومات البوتاسيوم دورًا أساسيًا في تحسين العديد من صفات النمو والمحصول وصفات الجودة تحت ظروف الأراضي منخفضة الخصوبة. أجريت الدراسة خلال موسمي النمو ٢٠١٩ ، ٢٠٢٠ في منطقة شمال الدلتا بمركز بيلا- محافظة كفر الشيخ - مصر بهدف تقييم الاضافة الورقية لصور مختلفة من عنصر السيليكون سواء السيليكا التقليدية أو في صورة النانو بتركيزات مختلفة (كنترول، ٢٥٠ ، ٥٠٠ ، ٧٥٠ جزء في المليون) مع أو بدون هيومات البوتاسيوم بتركيز (١٤ سم٣/ لتر) خلال مراحل النمو (مرحلة التفريع، مرحلة بداية تكوين الدالية ، مرحلة طرد الداليات) تحت ظروف الأراضي منخفضة الخصوبة في منطقة شمال الدلتا على نمو ومحصول وجودة حبوب الأرز المنزرع (صنف جيزة ١٧٨). هذا وقد تم استخدام تصميم القطع المنشقة مرة واحدة في ثلاث مكررات بحيث تم وضع صور السيليكا (التقليدية والنانوميترية) في القطع الرئيسية بينما احتلت تركيزات السيليكا المختلفة عشوائيا في القطع الشقية مع أو بدون رش هيومات البوتاسيوم. أوضحت النتائج المتحصل عليها تفوق معاملة اضافة السيليكا النانوميترية رشا على النبات خلال مراحل النمو المختلفة بصورة واضحة لكل صفات النمو، المحصول ومكوناته وصفات الجودة في كلا موسمي الدراسة مقارنة بالصورة التقليدية. أدت زيادة تركيزات السيليكا رشا حتى تركيز ٧٥٠ جزء في المليون على نبات الارز الي زيادة معنوية فى صفات النمو، المحصول ومكوناته وصفات الجودة في كلا موسمي الدراسة. وقد تفوقت معاملة السيليكا النانوميترية مع هيومات البوتاسيوم رشا على نبات الارز وأعطت أعلي قيم للنمو والمحصول وصفات الجودة. هذا وقد أظهرت قيم معامل التقدير المحسوبة وجود علاقة ارتباط قوية بين صور السيليكا وتركيزاتها مع عدد الداليات /م٢ (٠,٦٤٣١، ٠,٧٤٣٢) وطول الدالية (٠,٦٥٥٦، ٠,٧٩٢١) وزن الدالية (٠,٧٤١٦ ، ٠,٦٩٤١) وعدد الحبوب الممتلئة بالدالية (٠,٧٦٦٧ ، ٠,٨٥٨٦) بالإضافة الى محصول الحبوب (٠,٨٤٨٥ ، ٠,٨٧٩٣) لكل من السيليكا التقليدية والنانوميترية على الترتيب. وكذلك اظهرت قيم معامل التقدير علاقة ارتباط موجب بين صور السيليكا وتركيزاتها بالنسبة لنسبه الاستطالة (٠,٥٠٨٥ ، ٠,٥٦٠٣) والعكس بالعكس لمحتوى الاميلوز فى الحبوب (٠,١٧٨٨ ، ٠,١١٦٧) لكل من مصادر السيلكا التقليدية والنانوميترية على الترتيب. اظهرت قيم معامل الارتباط علاقة ارتباط قوى موجب بين محصول الحبوب وعدد الداليات/ م٢ (٠,٩١٢) ، طول الدالية (٠,٩١٣) بالسم، ووزن الدالية (٠,٨٥٧) بالجم.

من النتائج المتحصل عليها يمكن التوصية بضرورة اضافة مصادر السيليكا بتركيز ٧٥٠ جزء في المليون/ لتر مع هيومات البوتاسيوم بتركيز ١٤ سم٣/ لتر رشا خلال مراحل النمو لنبات الارز (مرحلة التفريع، مرحلة بداية تكوين الداليات ، مرحلة طرد الداليات) والتي تعتبر الاسلوب الامثل لتحقيق أعلى محصول وجودة لصنف الارز المنزرع جيزة ١٧٨ وذلك تحث ظروف الأراضي ضعيفة الخصوبة بمنطقة شمال الدلتا.