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Nano-Silicon and Nitrogen Foliar Spray affects the Growth, Yield and Nutrients Content of Rice

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Abstract: Enhancing nutrients use efficiency and protecting rice from environmental stress, can be ascertained by nano fertilizers foliar application. Silicon (Si) as macronutrient has a key role in improving rice growth and sustain yield. The present study was conducted at Rice Research and Training Center during 2017 and 2018 growing seasons in order to determine the efficacy of foliar sprays of nano-Si (30 mg/L and 60 mg/L), N foliar spray (1% and 2%) and their combinations on growth parameters, rice grain yield as well as nutrients content of Giza 178 rice cultivar. A field experiment was conducted as randomized complete block design (RCBD) with nine treatments and three replications. The treatments were: control, foliar spray with 1% N (N1), 2% N (N2), 30 mg/L nano-Si (Si1), 60 mg/L nano-Si (Si2), N1Si1, N1Si2, N2Si1 and N2Si2. The results showed that the nano-Si and N foliar fertilizers spray significantly affected number of tillers, leaf area index, crop growth rate, leaf area ratio and net assimilation rate. The results indicated that rice grain yield was increased in response to application of nano-Si and N foliar fertilizers application. The results revealed that, there were significant differences in number of panicles, number of filled grains per panicle, number of unfilled grains per panicle, 1000-grain weight, grain yield, biological yield and harvest index among the different treatments. This study suggests that, the combined application of 60 mg/L as nano-Si and 2% N foliar spray resulted in an increase in grain yield and yield attributers as well as N, Si, Zn, P, Mn and Fe concentrations in rice grains.

Key words: Rice yield · Rice growth · Foliar application · Nano-silicon · Nitrogen

INTRODUCTION

Nutrient management plays an important role to increase crop production and meet the food needs of the growing population. Fertilizer application affects crop productivity through plant morphological trait such as leaf area and rooting depth, which subsequently affect physiological process such as water absorption and transpiration [1]. Fertilizers have an important role in enhancing rice production and its quality especially after the introduction of high-yielding varieties. Nano-fertilizer is defined as the materials with a single unit between 1 and 100 nm in size [2]. Some beneficial effects include increased nutrient use efficiency, high yield and reduced soil pollution [3].

Nanotechnology is one of the most modern methods in agricultural applications in the water and soil section are the use of nano-fertilizers for plant nutrition [4]. Nano fertilizers are more effective in improving plant nutrition, increasing the availability of nutrients such as N, P, K, Zn and protecting plants from environmental stresses than conventional chemical fertilizers [5]. The Maximum use of production sources, especially with the nano-fertilizers application and enhancing photosynthesis efficiency can reduce the environmental risks associated with the excessive application of chemical fertilizers [6].

Foliar application is a complementary method to soil additives to improve yield quantity and quality. Many field experiments have shown significant effects of nutrient uptake when spraying their solutions on the vegetative stage of the plant [7]. Recently, nano-fertilizers or coated nano-nutrients with effective properties have been emerging to accelerated crop growth and nutrient release on demand, control nutrient release that regulates plant growth and enhance its target activity [8].

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Silicon (Si) is the second most abundant element in the soil and it's not considered an essential element soil [9]. The Si treatments were considered beneficial to plant growth and plant production. Silicon has a key role in improving growth and increasing rice grain yield and its deficiency can make a serious problem for rice production. Silicon is useful nutrient for healthy growth and sustainable production of rice [10]. Silicon has a dual effect on the plant and soil system, which, by being absorbed in the plant, makes the plant more resistant to pests, diseases and environmental stresses and on the other hand, leads to increase soil fertility by improving water, physicochemical properties of soil and maintaining the available nutrients for the plant [11]. Studies have shown that treatment with Si significantly alleviated salt and drought stress in plants [12]. In addition, Si plays a key role in a number of metabolic and physiological activities in plants. Silicon has several benefits for rice including the reduction of the adsorption of heavy metals such as Pb, Cd and As, resistance to salt stress, increasing the extent of photosynthesis, the improvement of performance and the prevention of rice lodging [13-15].

Application of N fertilizers is an important practice for increasing rice yield. However, excess N causes lodging, mutual shading and susceptibility to rice diseases. Excessive application of N fertilizers also causes high protein content in brown rice, which affects its quality. Sufficient supply of Si to rice is effective in producing low protein rice [13]. In addition, Meena *et al*. [11] reported that, the occurrence of rice diseases was significantly inhibited by Si application in the field experiment, especially when N is applied with higher application rates. These functions of Si are especially important in the cultivation systems with dense planting and high N application.

The modern nano-Si fertilizers easily penetrate into the leaves and create a thick silicate layer on the leaf surface [11]. Silicon plays an important role in increasing the activity of antioxidant enzymes and enhancing the resistance of abiotic and biotic plant stresses [16]. Mobasser *et al*. [17] reported that, the use of Si increases the rice grain yield by increasing the number of fertile tillers per hill and the number of grains per panicle [18]. Other studies reported that the Si application significantly increased the number of tillers and Si concentration in the plant [19]. Cuong *et al*. [20] reported that increases in Si application, increases the Si absorption and other nutrients such as N, P and K in rice grain and rice straw compared to without Si application.

There is little doubt that there has been less research to evaluate the effect of foliar spray of nano-Si on growth and yield of rice. Therefore, the aims of the present study were to evaluate the effects of nano-silicon and N as foliar spray application on rice growth, yield components and nutrients concentration of N, Si, P, K, Zn, Mn and Fe.

MATERIALS AND METHODS

Experimental Site Description and Soil Samples: The field experiment was conducted during crop year of 2017 and 2018 in Rice Research and Training Center (RRTC) experimental farm, Sakha, Kafr El-Sheikh, Egypt. Representative soil samples were taken in bulk from 0-30 cm depth before the growing season. The soil samples were air-dried, ground and passed through 2-mm sieve. Composite soil samples were taken and analyzed for physical and chemical characteristics of the soil namely, electrical conductivity (EC,) pH, organic matter (OM), texture, cations and anions following the standard methods as described by Page *et al*. [21]. The physico-chemical characteristics of the soil are given in Table (1).

Experimental Layout, Design and Fertilizers Treatment: The experiment was set up as a randomized complete block design with nine treatments and three replications with a plot area of 2 x 5 m. The foliar fertilizer treatments were as follows:

Control	Without foliar
N1	1% N foliar from urea
N2	2% N foliar from urea
Si1	30 mg/L foliar from nano-Si
Si2	60 mg/L foliar from nano-Si
N1Si1	1% N foliar from urea + 30 mg/L foliar from nano-Si
N1Si2	1% N foliar from urea + 60 mg/L foliar from nano-Si
N2Si1	2% N foliar from urea + 30 mg/L foliar from nano-Si
N2Si2	2% N foliar from urea + 60 mg/L foliar from nano-Si

Phosphorus fertilizer was applied at the rate of 36 kg P_2O_5 ha^{-1} as superphosphate (15.5% P_2O_5) as soil basal application in one dose during soil preparation. Nitrogen fertilizer was applied at a rate of 165 kg ha^{-1} as urea. Two thirds of recommended N fertilizer was applied as soil basal application and the other one third was applied as top dressed 30 days after transplanting. Seeds of Giza 178 rice cultivar, at the rate of 144 kg ha^{-1}, were soaked in water for 24 hours and then incubated for 48 hours to hasten early germination. Pre-germinated seeds were sown on May 15th in both growing seasons. Seedlings of Giza178 rice cultivar (4 weeks old) were

Table 1: The physical and chemical characteristics of the soil in a depth of 0-30 cm during 2017 and 2018 growing seasons

Season	pH	EC (dS m^{-1})	Available nutrients (mg kg^{-1})			Si (%)	Clay %	Silt %	Sand %	OM %	Zn (mg kg^{-1})
2017	7.80	1.49	N	P	K	0.29	56.5	28.2	15.3	1.34	0.64
			338	13.3	327						
2018	7.89	1.55	360	14.2	350	0.31	58.5	27.2	14.3	1.39	0.69

EC = Electrical conductivity; OM =Organic matter.

transplanted at spaces of 20 x 20 cm with three seedlings per hill. All plots received identical cultural practices according to the recommendations of RRTC.

Used nano-Si was provided by National Research Centre and have characterized by specific surface area of (300-330 m^2/g), pH (4.0-4.5) and mean diameter (10 nm) and purity was 99.7%. Nano-silicon source was polyethylene glycol Salicylic acid (=PEG-sSA). Foliar sprays with stabilized Salicylic acid (sSA) was used because it is the only plant-available Si form, can be used. The foliar application of nano-Si and N were applied twice at 15 and 30 days from transplanting.

Measurements: At 45 days from transplanting, plant height and number of tillers per hill were measured. Chlorophyll a and chlorophyll b, carotenoids of leaves were determined according to the method of Arnon [22], as well as the concentration of N, Si, P, K, Zn, Mn and Fe as described by Page *et al*. [21].

Crop growth rate CGR (g/day) was computed by using the following formula;

$$W_2 - W_2 / t_2 - t_1$$

where, W1 and W2 were total rice dry weight (g/m^2) at time t_1 and t_2 of a growing period, respectively.

Leaf area index (LAI) was calculated as follows:

LAI = Leaf area / Land area occupied by a plant

Net assimilation rate (NAR) (g/cm^2/day) is the increase in weight of dry matter of rice per unit leaf area per unit time. Leaf area ratio LAR and NAR were estimated according to the formula suggested by Radford [23].

At maturity, five hills were randomly sampled from each plot to determine plant height (cm) and number of panicles per hill. Ten panicles were randomly selected from each plot to measure panicle length, number of filled grains per panicle, number of unfilled grains per panicle and 1000-grain weight. After harvesting, biological and rice grain yields were estimated from a 5m^2 area in each plot and grain yield was adjusted to 14% moisture content and converted to t ha^{-1}.

Plant Chemical Analysis: Rice samples were digested using wet digestion method as described by Chapman and Partt [24]. Concentration of Si was determined according to the method of Snyder [25]. The concentrations of Zn, Fe and Mn in rice grain were determined using Atomic Absorption Spectrophotometer. The N concentration was measured by micro-Kjeldahl method. Phosphorus and K concentration were determined according to Page *et al*. [21]. Chemical analysis of plant samples was provided by National Research Center, which is highly appreciated.

Data Analysis: All data collected were subjected to standard statistical analysis of variance following the method described by Gomez and Gomez [26]. Different means were compared by Duncan's multiple range test (DMRT) with a 5% probability level.

RESULTS AND DISCUSSION

Rice Growth Parameters: Table 2 shows effect of nano-Si and N foliar fertilizers application on agro-morphological traits of rice in the two growing seasons. The results revealed that, the most of the rice growth parameters were significantly affected by nano-Si and N foliar application rates (Table 2). The results showed that, the plant height, number of tillers, leaf area index, crop growth rate, leaf area ratio and net assimilation rate were significantly affected by the nano-Si and N foliar application rates in the two growing seasons. These effects may be attributed to the important role of N in formation of aux in which is involved in cell division and internodes elongation. These findings are in agreement with those reported by Ntanos and Koutroubas [27] and Afifi *et al.* [28]. In addition, to the important role of N for the activation of various types of enzymes, such as those required for the CO_2 assimilation pathway and chlorophyll biosynthesis. With increasing nano-Si foliar application rate from 30 mg/L to 60 mg/L, the leaf area ratio and net assimilation increased significantly. These findings are in line with those reported by Mobasser *et. al.* [17]. They reported that Si fertilizer application enhanced the rice growth characters. Similar results were reported by Shashidhar *et al*. [29]. With respect to N foliar application levels, data showed

Table 2: Plant height, number of tillers, leaf area index, crop growth rate, leaf area ratio and net assimilation rates of rice as affected by nano-silicon and N foliar fertilizers application during 2017 and 2018 growing seasons

	2017						2018				
Treatment	Plant height (cm)	Number of tillers/hill	LAI	CGR (g/day)	LAR (cm^2/g)	NAR (g/cm^2/day)	Plant height (cm)	Number of tillers/hill	LAI	CGR (g/day)	NAR (g/cm^2/day)
Control	72.1ed	22.85 i	4.30 g	0.3105 f	137.7 e	1.372 d	71.10 e	22.70 e	4.40 f	0.3210 f	1.395 d
N1	72.86 e	24.38 f	4.87 e	0.3526 e	142.8 c	1.462 b	71.80 e	24.20 d	4.50 f	0.4131 b	1.451 b
N2	73.50 de	24.95 d	5.25 d	0.3968 c	144.0 b	1.433 c	72.91 d	23.95 c	5.10 e	0.4213 b	1.460 b
Si1	69.85 g	23.25 h	4.75 f	0.3835 d	139.4 d	1.394 d	70.19 g	23.89 c	5.72 d	0.3905 d	1.424 c
Si2	71.35 f	23.32 h	4.78 f	0.3320 f	139.7 d	1.461 b	70.90 g	22.90 d	4.66 c	0.3313 f	1.462 b
N1Si1	74.36 d	24.17 g	5.18 d	0.3573 e	144.8 b	1.412 cd	73.90 d	25.00 b	4.99 b	0.3601 e	1.531 a
N1Si2	76.61c	24.62 e	5.28 c	0.3996 c	145.1b	1.413 cd	75.90 c	24.85 b	5.00 b	0.4021 c	1.433 c
N2Si1	78.87 b	25.07 c	5.39 b	0.4304 b	150.5 a	1.523 a	77.90 b	26.10 a	5.23 a	0.4326 b	1.456 b
N2Si2	80.37 a	26.25 a	5.69 a	0.4614 a	150.7 a	1.522 a	79.85 a	26.50 a	5.65 a	0.4692 a	1.551 a

LAI= Leaf area index; CGR =Crop growth rate; LAR = Leaf area ratio; NAR = Net assimilation rate. Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 3: Mean comparison of the effects of nano-silicon and N foliar fertilizers application on rice contributing characters during 2017 and 2018 growing seasons

	2017					2018				
Treatment	Plant height (cm)	Number of panicles/hill	Number of filled grains/panicle	Number of unfilled grains/panicle	1000- grain weight (g)	Plant height (cm)	Number of panicles/hill	Number of filled grains/ panicle	Number of unfilled grains/panicle	1000-grain weight (g)
Control	98.10 d	21.0 c	109.2 d	30.10 a	22.00 d	99.20 d	21.85 c	106.10 e	30.00 a	21.95 cd
N1	99.00 d	22.64 b	118.17 c	28.53 a	23.45 b	100.0 d	22.10 d	119.10 c	27.90 a	23.0 b
N2	101.50 c	23.77 ab	130.50 ab	27.50 a	23.88 bc	101.2 c	24.10 a	125.10 bc	27.10 a	23.10 bc
Si1	97.20 de	21.07 c	112.03 cd	29.57 a	22.09 d	95.10 e	22.10 c	111.10 cd	29.10 a	22.10 cd
Si2	95.40 e	22.26 bc	116.50 cd	29.20 a	22.95 cd	97.50 de	22.10 c	115.92 cd	29.00 a	22.90 bc
N1Si1	103.7 b	22.70 b	124.13 bc	27.50 a	23.34 bc	103.2 b	22.50 c	126.10 bc	27.10 a	22.80 cd
N1Si2	104.3 b	23.22 ab	125.57 bc	23.77 b	23.59 bc	104.1 b	23.50 b	129.90 b	22.90 c	23.92 bc
N2Si1	107.5 a	22.79 b	138.50 a	24.03 b	24.27 ab	106.9 a	22.90 b	139.10 a	24.01 b	24.12 a
N2Si2	109.3 a	24.53 a	139.90 a	22.70 b	24.92 a	108.2 a	24.50 a	140.00 a	22.10 b	25.10 a

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

highly significant effect for N levels on all previous mentioned rice traits. The trend of data was clear and unified, whereas means of these traits were gradually increased with increasing level of N foliar from 1% up to 2%. The combination between nano-Si foliar and N foliar application rates had highly significant effect on plant height and number of productive tillers per hill. Maximum values of number of tillers and LAI were recorded in N2Si2 treatment in the two growing seasons compared with the other fertilizer treatments. It was mentioned that, when Si is absorbed by rice, decreased cuticle transpiration and rice elongation [8]. In addition, nano-Si foliar application improved plant height and dry weight of rice [30].

Yield Attributes and Yield: Mean values of plant height, number of panicles, number of filled grains, number of unfilled grains and 1000-grain weight as affected by N and nano-Si foliar application rates in the two growing seasons are listed in Table (3). The analysis of variance showed highly significant differences among the different treatments for all previous mentioned rice traits. The results indicated that, plant height, number of panicles per hill, number of filled and number of unfilled grains and 1000- grain weight was significantly affected by N and nano-Si foliar application levels in the two growing seasons. Increased of N foliar application rates influenced plant height, number of panicles, number of filled grains per panicle, 1000-grain weight (Table 3). With increasing nano-Si foliar fertilizer application rates from 30 mg/L up to 60 mg/L, the number of filled grains per panicle decreased; this because the rice plants have not enough carbohydrates to fill up all grains. These results are in agreement of findings reported by Mobasser *et al*. [17] and Malidareh [31]. With respect of N foliar application rates, the results indicated that, with increasing the application of N foliar from 1% to 2%, number of panicles, number of filled grains per panicle and 1000-grain weight increased significantly. The highest values of yield attributers traits were obtained with N2Si2 compared to other treatments in the both growing seasons.

The rice grain yield, biological yield and harvest index were significantly affected by N and nano-Si foliar application in the two growing seasons (Table 4). The rice grain yield ranged from 8.85 to11.34 t ha^{-1} in 2017 season and from 8.90 to 11.20 t ha^{-1} in 2018 season. Application of nano-Si and N foliar resulted in increases of the rice grain yield biological yield and harvest index. The maximum values of rice grain, biological yield and harvest index were obtained with N2Si2 treatment in both growing seasons (Table 4). Increasing fertilizer rate induced an increase in rice yield and its components. These increases may be attributed to the participation of

Table 4: Mean comparison of the effects of nano-silicon and N foliar fertilizers application on rice yield, biological yield and harvest index in the two growing seasons

	2017			2018		
Treatment	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index
Control	8.85 e	19.95d	0.443 d	8.90 d	19.87 f	0.448 d
N1	9.64 bcd	20.98 cd	0.459 bc	9.59 b	20.10 e	0.477 b
N2	9.93 bc	21.10 c	0.471 ab	9.67 b	20.36 e	0.475 b
Si1	9.00 d	20.61 e	0.437 d	9.15 c	20.50 d	0.446 d
Si2	9.38 cd	20.68 de	0.454 cd	9.44 c	20.89 d	0.451 cd
N1Si1	10.08 bc	21.23 c	0.472 ab	10.15 b	21.50 c	0.472 b
N1Si2	10.16 b	22.76 b	0.446 cd	10.30 b	23.62 b	0.436 cd
N2Si1	10.89 b	23.01 a	0.473 ab	10.78 b	23.00 a	0.469 b
N2Si2	11.34 a	23.28 a	0.487 a	11.20 a	23.30 a	0.483 a

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 5: Mean comparison of the effects of nano-Si and N foliar fertilizers application on chlorophyll, total N and Si concentration of rice leaves at 45 days from transplanting during 2017 and 2018 growing seasons

	2017					2018				
Treatment	Chloro. a (mg kg^{-1})	Chloro. b (mg kg^{-1})	Carotenoids (mg kg^{-1})	N (%)	Si (%)	Chloro. a (mg kg^{-1})	Chloro. b (mg kg^{-1})	Carotenoids (mg kg^{-1})	N (%)	Si (%)
Control	2.41 e	1.17 d	0.92 d	1.92 d	1.13 d	2.36 de	1.18 d	0.89 d	1.87 d	1.16 e
N1	2.42 de	1.21 c	0.93 d	1.96 d	1.16 d	2.40 e	1.19 d	0.89 d	1.98 c	1.18 e
N2	2.44 d	1.18 d	0.96 cd	2.19 c	1.21 c	2.39 e	1.23 c	0.95 c	2.01c	1.23 d
Si1	2.41 e	1.21 c	0.93 d	1.94 d	1.22 c	2.38 de	1.22 d	0.92 c	1.90 d	1.20 d
Si2	2.43 de	1.18 d	0.96 cd	2.16 c	1.24 c	2.40 d	1.20 d	0.97 cd	2.03 c	1.28 c
N1Si1	2.48 c	1.22 c	1.00 bc	2.34 b	1.30 b	2.50 c	1.22 d	0.99 c	2.29 b	1.29 c
N1Si2	2.48 c	1.23 c	1.01 ab	2.37 ab	1.36 a	2.51 c	1.24 c	1.01 ab	2.40 a	1.35 b
N2Si1	2.68 b	1.30 b	1.06 ab	2.26 b	1.37 a	2.70 b	1.28 b	1.15 ab	2.29 b	1.39 a
N2Si2	2.73 a	1.35 a	1.11 a	2.47 a	1.39 a	2.80 a	1.32 a	1.25 a	2.50 a	1.40 a

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

N in structural functions of the plant, such as cell multiplication, differentiation, genetic inheritance and formation of tissues [17]. The results indicated that, there were significant differences in grain yield, biological yield and harvest index between the nano-Si foliar application rates (Table 4). The trend of these results regarding number of filled grains per panicle and number of unfilled grains per panicle was in agreement with that reported by Gewaily *et al*. [32], who stated that, with increase rate of N application, a significant increase in number of filled grains per panicle was observed due to high increasing in total number of grains per panicle.

The combination between foliar spray of nano-Si foliar and N application had highly significant effects on rice grain yield, biological yield and harvest index. Effects of foliar nano-Si application on rice grain yield and its components are related to the deposition of the Si under the leaf epidermis, which resulted in a physical mechanism of defense, reduces lodging, increases photosynthesis capacity and decreases transpiration losses from rice plant [33]. Shashidhar *et al*. [29] reported that, reduced amount of Si in plant develops necrosis, disturbance in leaf photosynthetic efficiency, growth retardation and reduces cereals grain yield. Plant tissue analysis has revealed the optimum amount of Si is necessary for cell development and differentiation [34, 35].

Nutrient and Chlorophyll Concentration in Rice Leaves: Mean values of chlorophyll a, chlorophyll b, carotenoids, N and Si concentration in rice leaves recorded at 45 days after transplanting are presented in Table (5). The analysis of variance indicated highly significant differences among the different treatments for all such traits. The effect of foliar application with nano-Si and N was significant on N and Si concentration in rice leaves (Table 5). Increasing the application rate of nano-Si foliar application, leads to significant increases in the contents of N and Si concentration in rice leaves at 45 days after transplanting. The combination between foliar spray of 60 mg/L nano-Si and 2% N had highly significant effects on chlorophyll a,

Table 6: Mean comparison of the effects of nano-Si and N foliar fertilizers application on concentration of P, K, Zn, Mn and Fe in rice leaves at 45 days from transplanting during 2017 and 2018 growing seasons

	2017					2018				
Treatment	P (%)	K (%)	Zn ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	P (%)	K (%)	Zn ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)
Control	0.14 d	0.97 b	24.22 c	31.90 d	63.00 f	0.14 d	0.98 c	23.90 c	31.00 c	62.10 e
N1	0.16 c	1.00 b	25.32 b	36.78 c	63.00 f	0.15 d	1.03 c	25.90 b	37.01 b	62.92 e
N2	0.20 b	1.11 a	24.30 c	39.43 a	65.20 e	0.19 bc	1.09 c	24.10 c	39.10 a	64.85 e
Si1	0.14 d	1.09 a	25.84 ab	32.14 d	63.00 f	0.15 d	1.08 c	26.10 a	31.90 c	63.10 e
Si2	0.17 c	1.11 a	28.22 a	37.00 c	75.30 b	0.16 d	1.12 b	27.90 a	36.80 b	75.00 c
N1Si1	0.20 b	1.13 a	25.04 b	39.54 a	71.90 d	0.21 b	1.12 b	25.20 b	39.01 a	70.90 d
N1Si2	0.20 b	1.15 a	25.82 ab	39.65 a	75.20 b	0.22 ab	1.16 a	25.60 b	39.85 a	74.90 c
N2Si1	0.22 a	1.13 a	26.98 a	37.77 b	74.00 c	0.23 a	1.14 a	26.92 a	37.88 b	93.92 a
N2Si2	0.22 a	1.13 a	28.50 a	39.90 a	85.10 a	0.23 a	1.14 a	27.98 a	39.78 a	84.12 b

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 7: Mean comparison of the effects of nano-Si and N foliar fertilizers application on N, P, K, Si, Zn, Mn and Fe concentration in rice grain at harvest stage

	2017							2018						
Treatment	N	Si	P	K	Zn	Mn	Fe	N	Si	P	K	Zn	Mn	Fe
	(%)				(mg kg-1)			(%)				(mg kg-1)		
Control	0.756 c	1.30 e	0.160 d	0.200 a	14.50 d	21.90 c	42.42 f	0.780 d	1.37 f	0.157 c	0.200 a	15.00 d	21.93 d	41.80 f
N1	0.970 b	1.37 e	0.200 b	0.223 a	16.03 c	22.26 c	50.73 b	0.980 b	1.39 f	0.220 a	0.201 a	15.99 e	21.95 d	48.95 b
N2	0.997 b	1.58 d	0.175 c	0.223 a	18.96 a	24.72 a	44.00 e	0.981 b	1.60 e	0.159 c	0.222 a	18.10 b	23.92 c	43.99 e
Si1	0.771 c	1.62 cd	0.195 b	0.221 a	18.75 a	22.04 c	42.53 f	0.795 d	1.66 d	0.192 b	0.231 a	18.25 b	21.90 d	41.90 f
Si2	0.829 c	1.69 c	0.160 d	0.224 a	16.97 b	22.15 c	42.53 f	0.825 c	1.70 c	0.159 c	0.221 a	17.90 c	22.01 d	41.99 f
N1Si1	1.075 a	1.63 cd	0.160 d	0.226 a	17.18 b	23.04 b	45.47 d	1.022 a	1.66 d	0.158 c	0.231 a	17.01 c	23.01 c	45.60 d
N1Si2	0.979 b	1.79 b	0.196 b	0.226 a	16.03 c	24.83 a	48.47 c	0.995 b	1.80 b	0.195 b	0.221 a	15.99 d	24.02 b	47.99 c
N2Si1	0.778 c	1.83 b	0.179 c	0.226 a	14.47 d	25.28 a	50.73 b	0.792 d	1.82 b	0.180 d	0.230 a	15.01 d	25.90 a	49.87 b
N2Si2	1.086 a	1.94 a	0.230 a	0.222 a	18.44 a	24.94 a	57.40 a	1.020 a	1.92 a	0.235 a	0.221 a	19.01 a	25.10 a	58.01 a

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

chlorophyll b, carotenoids, N and Si concentration in rice leaves at 45 days after transplanting. The maximum values of chlorophyll a (2.73, 2.80 $mg\ kg^{-1}$), chlorophyll b (1.35, 1.32 $mg\ kg^{-1}$), carotenoids (1.11, 1.25 $mg\ kg^{-1}$), N (2.47, 2.50 %) and Si (1.39, 1.40 %) were achieved with N2Si2 treatment in 2017 and 2018, respectively. These results are in agreement of findings reported by Cuong *et al*. [20]. The increase in nutrients concentration may be attributed to the positive effect of foliar application of nano-Si and N, which consequently increased the absorption of N [36]. Similar studies regarding the effects of nano-Si foliar fertilizers application on increasing the chlorophyll content of plants, which is consistent with the results of this current study [35]. Foliar application with nano-Si can stimulate the vegetative growth of plant as well as increase rice stem diameter, number of lateral shoots, root length and chlorophyll content [37]. It was reported that, Si is responsible to control stomatal activity, photosynthesis and water use efficiency (WUE) which ultimately resulted in better vegetative growth rate and hence increased rice grain yield [38].

Table (6) shows the effects of different treatments on macro and micro-nutrients of rice leaves at 45 days after transplanting. The analysis of variance indicated highly significant differences among the different treatments on the nutrients content. The combination between nano-Si foliar and N foliar application rate had highly significant effect on P, Zn, Mn and Fe concentration in rice leaves. The maximum value of P concentration (0.220, 0.230 %), Zn (28.50, 27.98 $mg\ kg^{-1}$), Mn (39.90, 39.78 $mg\ kg^{-1}$) and Fe (85.10, 84.12 $mg\ kg^{-1}$) was recorded in the N2Si2 treatment in 2017 and 2018, respectively. Nano-Si foliar application, especially at reproductive stages of rice increases the chlorophyll content and the number of tillers per hill [10]. These results may be because nano-Si mediates the synthesis of protein, amino acids, nutrient uptake and stimulates antioxidant enzyme activity [2]. In addition, Si-deprived-plants are structurally weaker than silicon-enriched plants, demonstrating reduced growth, development, viability and reproduction. Moreover, these plants are more susceptible to biotic and abiotic stresses [39 and 40].

Nutrient Concentration at Harvesting: Mean value of N, Si, P, K, Zn, Mn and Fe concentration in rice grain at harvesting stage as affected by nano-Si and N foliar application are presented in Table (7). The analysis of variance indicated highly significant differences between nano-Si and N foliar application rate in the concentration of nutrients in rice grains. Increasing application rate of nano-Si from 30 mg/L to 60 mg/L significantly increased the P, Zn, Mn and Fe concentration of rice grains. Also, the analysis of variance indicated highly significant differences between nano-Si and N foliar application rate in the nutrients content of rice grains. The combination between nano-Si foliar and N foliar application had highly significant effect on concentration of P, Zn, Mn and Fe in rice grains. The highest concentration of N (1.086, 1.020%), Si (1.94, 1.92%), P (0.230, 0.235%), Zn (18.44, 19.01 mg kg^{-1}), Mn (24.94, 25.10 mg kg^{-1}) and Fe (57.40, 58.01 mg kg^{-1}) were obtained with N2Si2 treatment in 2017 and 2018, respectively (Table 7).

Although, Si is not considered within the important nutrients required for increases of cell wall thickness below the cuticle, which imparting mechanical resistance to the penetration of fungi, decrease in plant transpiration and improvement of the leaf group, that are essential for rice growth, but its absorption have several benefits, such as the angle, making leaves more erect, therefore reducing self-shading, especially under high N application rates [41, 38]. Gradual release of nutrients during growth stages of the rice plant by nano-Si fertilizers application increases rice growth and yield [42]. Cuong *et al*. [20] reported that by adding nano-Si, rice grain yield was improved due to increasing growth, yield attributes and better absorption of N, P, K and Zn.

Several beneficial effects of nano-Si have been reported, including increased photosynthetic activity, increased insect and disease resistance, reduced mineral toxicity, improvement of nutrient imbalance such as P, Zn and enhanced drought tolerance. However, the beneficial effects of Si effects vary with the plant species. Beneficial effects are usually obvious in plants that accumulate high levels of Si in their shoots [40]. Ghasemi *et al*. [18] reported that, there is synergistic interaction between Si and other nutrients, which ultimately has contributed to increased absorption of Zn, Mn and Fe in the rice plant. Combined application of N and Si recorded the highest total N, protein content, Si, P, K, Zn, Mn and Fe concentrations in rice. The increase in these nutrients may be attributed to the positive effect of foliar application of nano-Si, which consequently increased the absorption of different nutrients [43 - 45]. It has been revealed that exogenous application of nano-Si on plants enhanced the rice growth and development by increasing accumulation of proline, free amino acids, antioxidant enzymes activity and improve photosynthesis efficiency and enhanced nutrients content including P, N and Zn [36, 46].

CONCLUSIONS

In this study, application of nano-Si in combination with N foliar as urea application rates, positively affected agronomic, yield-related traits, rice grain yield and nutrient uptakes of 178 rice cultivars. It can be concluded that application of nano-Si at the rate of 60 mg/L along with 2% N as urea foliar would help in the sustainable production of higher rice yield and the increased nutrient uptake of rice. Rice is typical crop, which can accumulate Si up to 10% Si on rice shoot. High Si accumulation of rice has been demonstrated to be necessary for healthy growth, higher and stable rice production. For this reason, Si has been recognized as an agronomically essential element in Japan and silicate fertilizers have been applied to paddy soils.

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