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Original Article

Effect of Silicon Application on Growth and Biomass Yield of Rice Under Salinity Stress

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ABSTRACT

Abiotic stresses induce ill effects on crop growth and development. Soil salinity is the major abiotic stress in agriculture globally since it affects almost all plant functions. Silicon (Si) plays a great role in alleviating salinity stress. Therefore, a pot experiment was conducted at the net house of Patuakhali Science and Technology University, Bangladesh during *Rabi* (dry) season 2019 to evaluate the effect of Si in improving rice growth under salt stress condition. The experiment was laid out in two factor randomized complete block design replicated thrice. The first factor was salinity concentration having two levels: 0 and 6 dS/m salinity and the second factor were four levels of Si: 0, 2, 4 and 8 mM. The sources of salt and Si were NaCl and silicic acid, respectively. Salinity stress had significant impact on growth parameters of rice. Results revealed that salinity reduced the plant height, number of tillers, and fresh weight of shoot and root by about 17%, 28%, 39% and 54%, respectively. At both 0 and 6dS/m salinity condition; application of Si at 2, 4 and 8 mM progressively improved all the growth parameters over Si control. Application of Si at 8 mM silicon had the highest performance with respect to improvement in growth and development of rice. Therefore, application of Si should be recommended in rice cultivation both in non-saline as well as saline condition to alleviate the ill impact of salt stress.

Introduction

Rice (*Oryza sativa* L.) is the most important food crop of the world and the staple food of more than half of the world's population (IRRI, 2015). The Asia has the largest share in world rice production. Among the rice growing countries, Bangladesh occupies 3rd and 4th position in terms of rice growing area and production, respectively (FAOSTAT, 2019). Bangladesh produces 36.4 million tons of rice to meet out the food requirement of 161.4million people of the nation (BBS, 2019). However, the average yield is quite low as compared to other rice growing countries. Further, rice production seriously hampered by soil and water salinity in the coastal region.

Soil salinity is the major abiotic factors that limit crop growth and productivity worldwide. Indeed, soil salinity disrupts the cellular ionic and osmotic balance. High salinity causes ion imbalance and hyper osmotic stress in plants and can result in plant death. Therefore, increasing salt tolerance in rice plant is need of the hour for sustaining the rice production as well as maintaining the food supply. In this regard application of plant nutrient could play a great role. Among the different plant nutrients, silicon (Si) is the versatile nutrient which plays an important role in mitigating the biotic and abiotic stresses (Jinger et al*.,* 2017; 2020a). Although, Si is generally not considered as an essential nutrient for plant growth and development, Si application could therefore, improve crop production under adverse climate and soil conditions (Liang et al., 2007; Bauer et al*.,* 2011; Das et al., 2021). Si application also improves production and quality of the crop produce by stimulating active immune system of plant which ultimately increases plant salt resistance and neutralizes heavy metal toxicity in acid soil (Kim et al.,

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2011; Van Bockhaven et al*.,* 2013). However, pure Si crystals are rarely found in nature. Si is usually being found in the form of complex silicate minerals.

It's content in plants ranges from 0.1-10% on dry weight basis, an amount equivalent to or even exceeding several macro-nutrients (Kamenidou et al., 2009). However, despite its ubiquity and abundance in soils, Si has yet to attain the status of essential nutrient mainly because it is not involved in metabolism and moreover, the plant is able to complete its life devoid of this element (Arnon and Stout, 1939). However, recent classification by Epstein and Bloom (2005), has termed Si as quasi-essential since Si deficient plants could show symptoms of abnormalities in terms of growth and development. Rice plant is high Si accumulator and absorbs Si in the form of soluble monosilicic acid (Jinger et al*.,* 2020b Jinger et al*.,* 2021; Cuong et al*.,* 2017; Liang et al*.,* 2015). In this regard, it has been suggested that silicate fertilizer could be a good soil amendment for sustaining rice production.

Several researchers have reviewed recent advances on the beneficial roles of Si on plant growth in adverse environmental conditions (Guntzer et al., 2012; Van Bockhaven et al*.,* 2013; Dorairaj et al., 2020; Jinger et al*.,* 2020c; Mahendran et al., 2021). The silica improves the water status (Romro-Arnada et al*.,* 2006), enhances the photosynthetic activity and causes alleviation of specification effect by reducing Na^+ uptake. In Bangladesh there is no evidence of using Si to reduce salt effect in crops. The study is therefore, undertaken to determine the effects of Si in improving rice growth under salt stress condition.

Materials and Methods

Experimental location, soil and crop

The experiment was conducted during *rabi* season of 2019 at the net house of the Department of Soil Science of Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali district, Bangladesh with geographical location of 22.46°N latitude and 90.38°E longitude. The soil was collected from PSTU research farm which was a medium high land under the Agro Ecological Zone 13 (Ganges Tidal Flood Plain). Texturally the experimental soil was silty clay loam having 10% sand, 52.5% silt and 37.5% clay. The initial soil had 5.7 pH (Jackson, 1973), 0.658 dS/m electrical conductivity ($EC_{1:5}$), 1.02% organic matter (Nelson and Sommers, 1982), 0.08% total N (Bremner and Mulvaney, 1982), 2.1 ppm available P (Olsen and Sommers, 1982), 14.3 ppm available S (Fox et al., 1964), and 0.33 meq/100g exchangeable K and 8.82 meq/100g soil exchangeable Na contents (Knudsen et al., 1982). The rice variety Binadhan-8 developed by Bangladesh Institute of Nuclear Agriculture, Mymensingh was used in this experiment. This is a popular high yielding Boro rice variety in Bangladesh.

Soil collection and preparation of pot

The soil was collected in the first week of December during 2018. After transplanted Aman harvest top 15 cm depth soil was collected using a spade from a well-drained field of the PSTU farm. The collected soils were spread on the ground and allowed to drying. Soil clods were broken with a wooden hammer. Weeds and stubbles of the previous crop were removed from the soil. Five kilogram soil was taken in each of 24 plastic pots. Two water tanks were prepared with galvanized iron sheet. The size of the tank was 120cm long, 90 cm wide and 25 cm high. Two hill comprising 5 seedlings per hill was transplanted in each pot on 10 January 2019. Twelve buckets were placed in each water tank. The pots were perforated 2 cm above the soil level. The tank was filled with water. The required amount of crude NaCl was mixed with water in one tank to raise water EC of 6 dS/m. The adequate amount of water level was maintained in the water tank, so that 2 cm water height all times maintained over soil layer in buckets. Another tank was filled with fresh water.

Experimental design and treatment

The experiment was laid out in a two factor randomized complete block design with three replications. There were 8 treatment combinations with the following factors and levels:

Factor A: Salinity level (0 and 6 dS/m)

Factor B: Silicon (0, 2, 4 and 8 mM Si as H_2SiO_3)

Therefore, the 8 treatment combinations were designated as S0Si0, S0Si2, S0Si4, S0Si8, S6Si0, S6Si2, S6Si4 and S6Si8

Fertilizer application

Every pot received 1.96, 0.90, 1.56 and 0.83 g N, P, K and S, respectively. The sources of N, P, K and S were urea, triple super phosphate (TSP), muriate of potash (MoP), and gypsum, respectively. TSP, MoP, gypsum and treatment wise silicic acid were applied during pot preparation. Urea was applied in three equal splits at the rate of 0.36g, 0.36g and 1.0g during pot preparation, 30 and 50 days after transplanting of seedlings, respectively.

Intercultural operations

Algal growth was minimized by partially removing algae from the water surface daily using a small fish net filter. Weeds were removed from each pot whenever necessary. Insecticide (Virtaco) was sprayed once to control the insects.

Harvesting

The crop was harvested at panicle initiation stage on 06 April 2019. Rice plants were cut at ground level. Roots were separated from the soil and cleaned carefully. The weight of fresh shoot and root were recorded. Then the plant samples were sun dried for three days to get dry weight of the samples.

Data collection

The plant height was measured from the ground level to the top of the leaf. From each pot, plants of 2 hills were measured and averaged. The number of tillers/hill were counted from the sample hills. Number of leaves was counted in each tiller. Three tillers were considered in taking number of leaves. The fresh and dry weight of shoot and root was determined using a digital balance.

Chlorophyll determination

Chlorophyll content of leaf was determined according to method developed by Coombs et al. (1985). The fresh leaf sample of 0.05g was taken in small vials containing 10 ml of 80% acetone and covered by aluminum foil and preserved in the dark for 7-10 days. Absorbance reading was taken at 645 and 663 nm wavelength using spectrophotometer and result was expressed as mg/g fresh weight of leaf. The formula for computing chlorophyll-a, chlorophyll-b and total chlorophyll were as follows:

Chlorophyll-a= (13.19 A_{663}-2.57 A_{645}) DF

Chlorophyll-b= (22.10 A_{645}-5.26 A_{663}) DF

Total Chlorophyll= Chlorophyll-a + Chlorophyll-b

13.19, 2.57, 22.10 and 5.26 are absorption co-efficient

DF= Dilution Factor= 10/1000 0.05=0.2

Statistical analysis

Data were recorded on crop characters and plant analysis was subjected to statistical analysis through computer based statistical program STAR (Statistical Tool for Agricultural Research) following two-way randomized complete block design model. Significant effects of treatments were determined by analysis of variance (ANOVA) and treatment means were compared at 5% level of significance by Duncan's Multiple Range Test.

Results and Discussion

Plant height

Salinity reduced the plant height of rice crop significantly. Plant height was recorded highest (101.2 cm) when salinity stress was not given to the plant (Table 1). However, after application of salinity stress at 6 dS/m the plant height tend to decline and reached at 84.1 cm. Thus, salinity reduced the plant height by about 17%. Plant height tended to increase gradually with increasing of the concentration of Si. Application of 8 mM Si as silicic acid produced the highest plant height at harvest. Although, 8 mM Si as silicic acid gave the highest plant height but, it was statistically similar with 4 mM Si. In the experiment lowest plant height was found in zero mM silicon (control). This result is in agreement with the findings of Sundahri et al. (2001) who observed positive effects of sodium silicate on wheat in increasing plant height. Jinger et al. (2020b) reported increment in the plant height of aerobic rice with the increasing dose of Si from calcium silicate. Increase in plant height might be due to metabolic activity (Afzal et al*.,* 2005), increased cell division (Fageria et al*.,* 2013), elongation, expansion, photosynthesis (Singh et al*.,* 2003) caused by Si nutrition. The interaction effect of salinity and silicon was found not significant (Table 1). It means that the salinity and Si individually affected the plant height of rice. Singh et al. (2020) found that plant height was significantly influenced with the application of Si with recommended dose of NPK.

Tillers per hill

Salinity had significant effect on number of tillers. Application of salinity reduced the number of tillers per hill by 27.7% over no application of salinity (Table 1). Choi et al. (2003) observed that tiller number of rice decreased in 0.5% saline water in the soil with low salinity level. Different doses of Si had significant role on number of tillers/hill. With the increased concentration of Si, the number of tillers/hill significantly increased. Application of zero and 2mM Si produced the same number of tillers/hill (Table 1). In the absence of salt, application of zero and 2 mM Si produced the lowest number of tiller and found at par with each other. Application of 8 mM Si as silicic acid produced the highest tiller/hill. Korndorfer et al. (2004) suggested that an adequate supply of Si to rice from tillering to elongation stage increases the number of effective tiller per plant. This may be due to more absorption and utilization of available nutrients leading to overall improvement of crop growth and source-sink relationship, which in turn enhanced the yield attributes of rice (Sharma et al*.,* 2009; Jinger et al*.,* 2018). Dorairaj et al (2020) also found higher tiller number per pot and tillers per hill in Si-treated rice plants. The interaction effect of salinity and silicon showed no significant variation in respect of number of tillers per hill (Table 1).

Number of leaves per plant

Salinity had a significant impact on number of leaves per plant. Under salt stress condition, the number of leaves were reduced significantly. When salinity was not given the number of leaves per plant was 5.0 (Table 1). But with the increase of salinity (6 dS/m salinity) the number of leaves per plant was found as 4.6. Thus salinity reduced the number of leaves per plant by about 8%. Odunnaike et al. (2013) also mentioned the similar results, mentioning that increasing NaCl concentration from 0.05 % to 0.15 % reduced the number of leaves of crop. The number of leaves per plant varied significantly due to different doses of Si (Table 1). With the increased concentration of silicon, the number of leaves per plant tends to increase progressively. Application of 8 mM Si as silicic acid produced the highest number of leaves at harvest. The interaction effect of salinity and silicon with respect to plant height, tillers and leaves was found non-significant (Table 1).

Table 1. Single and interaction effect of salinity and silicon on plant height, tillers hill^{-1} and leaves plant^{-1}of rice (Binadhan-8)

Silicon concentration (mM)	Crop performance under different salt stress condition		Mean silicon effect
	0 dS/m	6.0 dS/m	
Plant height (cm)			
Si 0	96.2	81.0	88.6 B
Si 2	99.6	82.4	91.0 B
Si 4	104.6	85.2	94.9 A
Si 8	104.3	88.0	96.1 A
Mean salt stress effect	101.2 a	84.1 b	
Significance level: Salt stress -***, Silicon-**, Interaction-NS			
SE(±): Sodium-1.21, Silicon-1.71, Interaction-2.42; %CV: 3.20			
Tillers hill^{-1} (no.)			
Si 0	10.8	7.7	9.3 C
Si 2	10.8	7.7	9.3 C
4 Si	13.0	10.0	11.5 B
Si 8	15.8	11.2	13.5 A
Mean salt stress effect	12.6 a	9.1 b	
Significance level: Sodium-***, Silicon-***, Interaction-NS			
SE(±): Salt stress-0.36, Silicon-0.51, Interaction-0.73; %CV: 8.27			
Leaves plant^{-1} (no.)			
Si 0	4.4	3.6	4.0 c
Si 2	4.6	4.2	4.4 b
Si 4	5.4	5.0	5.2 a
Si 8	5.5	5.4	5.5 a
Mean salt stress effect	5.0 a	4.6 b	
Significance level: Salt stress-**, Silicon-***, Interaction-NS			
SE(±): Sodium-0.121, Silicon-0.172, Interaction-0.243; %CV: 6.25			

Similar letter in column or in a row is not significantly different at 5% level by DMRT
-Significant at 1.0% level, *- Significant at 0.1% level, NS – Not significant, SE-Standard error of means, CV-Coefficient of variation

Shoot weight

There was a significant variation in fresh and dry weight of shoot in rice crop due to salinity stress (Table 2). The salinity stress reduced fresh and dry weight of shoot by 39 and 40%, respectively. Different doses of Si played a significant role on fresh and dry weight of shoot (Table 2). Fresh and dry weight of shoot tended to increase progressively with the increase in the concentration of Si. In the experiment lowest fresh and dry shoot weight was found with zero mM Si application which was statistically at par with 2 mM Si. Application of 8 mM Si as silicic acid produced the highest fresh and dry shoot weight at harvest. The sufficient availability of Si led to vigorous and taller plants with larger leaf area, which increased the photosynthate production, resulting in enhanced dry matter production of wheat (*Jinger* et al.*, 2020c*) and aerobic rice (Jinger et al., 2021). Hoseinian et al. (2020) showed that potassium silicate treatments had the highest increase in growth and yield components of rice. The interaction effect of salinity and Si with respect to fresh and dry weight of shoot was found significant and non-significant, respectively (Table 2). Regarding fresh weight of shoot the S0Si0 combination recorded shoot fresh weight of 89.9g, which increased to 113.2g in S0Si8 combination. Similarly the S6Si0 and S6Si8 combinations recorded shoot fresh weight of 55.1 and 60.8g, respectively. The results indicated that 8 mM Si can improve shoot fresh weight by 25.9 and 10.3% under non-saline and saline condition, respectively.

Root weight

Like other parameters fresh and dry weight of root was significantly influenced by the application of salinity (Table 3). Application of salinity stress at 6 dS/m to rice crop reduced the fresh and dry weight of root by 9.30

and 17%, respectively. The fresh and dry weight was remarkably affected by different doses of Si which tended to increase gradually with the increased of the concentration of Si. Application of 8 mM Si as silicic acid produced the highest fresh and dry weight after harvest. The lowest fresh and dry weight of root was found in zero mM Si which was statistically at par with 2 and 4 mM Si. The interaction effect of salinity and Si with respect to fresh weight of root was found highly significant (Table 3). Under non-saline condition the zero silicon concentration (S0Si0 combination) recorded root fresh weight of 13.9g which progressively increased with the increasing rate of Si, and attained at highest weight of 24.6g in S0Si8 combination, which was 76.9% higher than the respective Si control treatment. However, under 6dS/m saline condition the 8mM Si (S6Si8 combination) recorded 30.8% higher root fresh weight over Si control treatment (S6Si0 combination). Ju et al. (2017) reported that fresh and dry weight of roots subjected to the 1 or 2 mM Si treatments were unchanged compared with the control. The incorporation of Si (1, 2 or 4 mM) boosted root growth and increased the Si concentration in the roots of rice seedlings (Richmond et al*.,* 2003).

Table 2. Single and interaction effect of salinity and silicon on shoot fresh and dry weight of rice (Binadhan-8)

Silicon concentration	Crop performance under different salt stress condition		Mean silicon effect
	0 dS/m	6.0 dS/m	
	Shoot fresh weight per pot		
Si 0	89.9	55.1	72.5 B
Si 2	91.3	57.5	74.4 B
Si 4	97.2	64.1	80.7 AB
Si 8	113.2	60.8	87.0 A
Mean salt stress effect	97.9 a	59.4 b	
Significance level: Salt stress-***, Silicon-**, Interaction-*			
SE(±): Sodium-2.36, Silicon-3.34, Interaction-4.72; %CV: 7.35			
	Shoot dry weight (g) per pot		
Si 0	35.8	20.3	28.1B
Si 2	35.6	20.9	28.2 B
Si 4	36.5	24.4	30.5 AB
Si 8	40.6	23.0	31.8 A
Mean salt stress effect	37.1 a	22.2 b	
Significance level: Salt stress-***, Silicon-*, Interaction-NS			
SE(±): Sodium-0.89, Silicon-1.26, Interaction-1.78; %CV: 7.34			

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*-Significant at 5.0% level, **-Significant at 1.0% level, ***- Significant at 0.1% level, NS- Not significant, SE-Standard error of means, CV-Coefficient of variation

Table 3. Single and interaction effect of salinity and silicon on root fresh and dry weight of rice (Binadhan-8)

Silicon concentration	Crop performance under different salt stress condition		Mean silicon effect
	0 dS/m	6.0 dS/m	
	Root fresh weight per pot (g)		
Si 0	13.9	13.3	13.6 B
Si 2	14.6	15.8	15.2 B
Si 4	15.6	16.0	15.8 B
Si 8	24.6	17.4	21.0 A
Mean salt stress effect	17.2 a	15.6 b	
Significance level: Salt stress-*, Silicon-***, Interaction-***			
SE(±): Sodium-0.56, Silicon-0.80, Interaction-1.12; %CV: 8.41			
	Root dry weight per pot (g)		
Si 0	5.75	5.36	5.6 B
Si 2	6.02	5.31	5.7 B
Si 4	7.49	6.63	7.1 A
Si 8	9.48	6.67	8.1 A
Mean salt stress effect	7.2 a	6.0 b	
Significance level: Salt stress-**, Silicon-***, Interaction-NS			
SE(±): Sodium-0.366, Silicon-0.517, Interaction-0.732; %CV: 13.6			
	Root:Shoot ratio		
Si 0	0.161	0.264	0.212 B
Si 2	0.169	0.254	0.212 B
Si 4	0.205	0.272	0.239 AB
Si 8	0.234	0.291	0.263 A
Mean salt stress effect	0.192 b	0.270 a	
Significance level: Salt stress-***, Silicon-**, Interaction-NS			
SE(±): Sodium-0.010, Silicon-0.014, Interaction-0.021; %CV: 10.8			

Similar letter in column or in a row is not significantly different at 5% level by DMRT

*-Significant at 5.0% level, **-Significant at 1.0% level, ***- Significant at 0.1% level, NS- Not significant, SE-Standard error of means, CV-Coefficient of variation

Root: Shoot ratio

Due to application of salinity there was a significant variation in root shoot ratio of rice crop. The root shoot ratio of rice crop increased by salinity. When salinity was not imposed the root shoot ratio was 0.192 (Table 3). But due to application of 6 dS/m salinity the root shoot ratio was found as 0.27. Thus salinity increased root shoot ratio by about 40%, which otherwise indicates that under saline condition plant developed more roots to increase absorbing surface area for existence in unfavorable situation. Different doses of Si played a significant role on root shoot ratio (Table 3). Root shoot ratio progressively increased with the increase of the concentration of Si. In the experiment lowest root shoot ratio was found in 0 mM Si which was statistically at par with 2 mM Si. Application of 8 mM Si as silicic acid produced the highest root shoot ratio at harvest (0.263). However, the reverse result was described by Gong et al. (2006). They mentioned that adding silicate (3 mM) to the saline culture solution improved the growth of the shoots, but not roots. The interaction effect of salinity and Si with respect to root:shoot ratio was found not significant (Table 3) having root shoot ratio of 0.161, 0.169, 0.205 and 0.234 in 0, 2, 4 and 8 mM silicon under non-saline condition, and 0.264, 0.254, 0.272 and 0.291, respectively under 6 dS/m salinity condition. Welfare et al. (1996) observed that salinity caused a substantial reduction in shoot and root dry weight, but the effect on root growth was proportionately less than on shoot growth and increased the root/shoot ratio.

Chlorophyll content

Chlorophyll-a, b and total content of rice was not significantly influenced by different levels of salinity. Application of salinity decreased the chlorophyll-a, b and total by 8, 9 and 14 %, respectively. Chlorophyll-a, b and total content progressively increased with the increase in the application of Si, although the rate of increment was not significant. In the experiment lowest chlorophyll-a, b and total content was found in zero mM Si. Application of 8 mM Si as silicic acid produced the highest chlorophyll-a, b and total content. The interaction effect of salinity and Si with respect to chlorophyll content was also found not significant (Table 4). Singh et al. (2020) reported that Si increase the water use efficiency of rice and it also increase the chlorophyll content and resulted in maximum production of photosynthates. Dorairaj et al. (2020) found positive result of using Si in different growth stage of rice.

Table 4. Single and interaction effect of salinity and silicon on leaf chlorophyll content of Binadhan-8 under salt stress condition

Silicon concentration	Crop performance under different salt stress condition 0 dS/m	6.0 dS/m	Mean silicon effect
Chlorophyll-a content of leaf (mg/g fresh leaf)			
Si 0	3.90	3.63	3.77
Si 2	4.07	4.14	4.10
Si 4	4.27	4.12	4.19
Si 8	4.20	4.23	4.22
Mean salt stress effect	4.11	4.03	
Significance level: Salt stress-NS, Silicon-NS, Interaction-NS			
SE(±): Sodium-0.117, Silicon-0.165, Interaction-0.234; %CV: 7.05			
Chlorophyll-b content of leaf (mg/g fresh leaf)			
Si 0	0.92	0.84	0.88 C
Si 2	0.94	0.91	0.93 BC
Si 4	1.14	1.04	1.09 A
Si 8	1.08	1.06	1.07 AB
Mean salt stress effect	1.02	0.96	
Significance level: Salt stress-NS, Silicon-*, Interaction-NS			
SE(±): Sodium-0.053, Silicon-0.075, Interaction-0.106; %CV: 13.2			
Total chlorophyll content of leaf (mg/g fresh leaf)			
Si 0	4.82	4.47	4.65 B
Si 2	5.01	5.05	5.03 AB
Si 4	5.41	5.15	5.28 A
Si 8	5.28	5.30	5.29 A
Mean salt stress effect	5.13	4.99	
Significance level: Salt stress-NS, Silicon-*, Interaction-NS			
SE(±): Sodium-0.16, Silicon-0.22, Interaction-0.32; %CV: 7.75			

Similar letter in column or in a row is not significantly different at 5% level by DMRT
NS-Not significant, *Significant at 5.0% level, SE-Standard error of means, CV-Coefficient of variation

Conclusion

Salinity stress in rice crop led to significant reduction in the growth parameters like plant height, number of effective tillers/hill and leaves/plant, shoot fresh and dry weight, root fresh and dry weight, and chlorophyll content of leaf. Whereas, application of Si significantly improved all these growth parameters of rice both in saline and non-saline conditions. The 8 mM Si as silicic acid was the best rate for higher growth and biomass yield of rice under pot culture condition.

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Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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