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Silicon Improved Water Stress Tolerance in Rice Genotypes

D. Snehalatha [a*], J. Bharghavi [a], P. Raghuveer Rao [b], B. Srikanth [b], C. V. Sameer Kumar [a] and T. Ramesh [a]

[a] Professor Jayashankar Telangana State Agricultural University, Rajendranagar, India.
[b] ICAR-Indian Institute of Rice Research, Rajendranagar, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rice is an important cereal crop, is mostly grown as a staple food in developing nations. One of the main causes restricting rice productivity is drought, which has a detrimental effect on global food security. Silicon increases antioxidant activity and lessens plant oxidative damage. In the current study, eight rice cultivars were subjected to foliar silicon spray to evaluate its effectiveness in reducing water stress. The plants were foliar sprayed with silicon under well-watered and drought-stressed circumstances. The collected data showed that drought stress significantly reduced physiological parameters, growth, and yield. In comparison with control, silicon application (T_2) has increased LAI by 50.13%, RWC by 0.24%, total dry matter by 18.86%, productive tiller number by 30%, number of panicles m^{-2} by 26.10%, number of grains $panicle^{-1}$ by 24.60%, test weight by 29.26% and grain yield by 10.60%; water stress alone (T_3) reduced LAI by 38.06%, RWC by 21.02%, total dry matter by 38.88%, productive tiller number by 30%, number of panicles m^{-2} by 33.45%, number of grains $panicle^{-1}$ by 42.85%, test weight by 34.87% and grain yield by 40.88%; while silicon + water stress (T_4) reduced LAI by 3.41%, RWC by 16.89%, total dry matter by 8.45%, productive tiller number 0.00%, number of panicles m^{-2} by 13.97%, number of grains $panicle^{-1}$ by 18.25%, test weight by 24.50% and grain yield by 19.24% only. Overall, silicon application has

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*Corresponding author: E-mail: daravathsnehalatha653@gmail.com;

ameliorated the negative impacts of drought stress on rice and improved the growth, physiological traits and yield under both well-watered and water stress conditions. To increase the quality of the yield and to generate rice cultivars that can withstand drought stress, silicon should be incorporated into breeding programmes.

Keywords: Rice; silicon; drought; test weight and grain yield.

1. INTRODUCTION

Rice is the second-most important commercially produced cereal crop worldwide. More than half of the world's population relies on rice as their main source of nourishment and energy [50]. In order to provide food security and meet the rising demand of the increasing global population, more rice is to be produced. Over 75% of the global rice production is under flood irrigation systems [17]. Rice is substantially more sensitive drought than other crops, physiological characteristics and yield are significantly impacted by drought stress during the flowering stage [56].

Drought is one of the most catastrophic climate catastrophes that endangers global agricultural productivity [15]. Water deprivation prevents cell development, which leads to short stems, shorter internodal lengths, weakened root systems, and reduced tillering capacity [27]. It also reduces dry and fresh biomass [70]. In addition, drought stress had a negative impact on a variety of metabolic activities, including as photosynthesis, respiration, ion absorption, hormone development, and nutrient intake [18,37,98]. Drought stress can seriously harm photosynthetic pigments, gas exchange systems, electron transport systems, photosystems, carbon reduction pathways, and enzyme systems [4]. Chl a and b and carotenoids, which are necessary for photosynthesis, are frequently lost in rice leaves due to water shortage [19]. Different cereal crops have different adaptive reactions to deal with drought [33]

To counteract the negative impacts of drought stress, plants exhibit a variety of morphological, physiological, biochemical, and molecular characteristics [12]. Some of the physiological systems involved in a plant's reaction to drought stress conditions include cell and tissue water preservation, cell membrane stability, and endogenously produced growth regulators [15]. Plants modify gene expression at the molecular level to counteract the potentially harmful consequences of decreased water supply. Therefore, at various stages of plant growth, genetic variables influence these adaptive responses [12]. Relative water content (RWC) is a crucial indicator of water status and serves as a screening tool for plant tolerance to drought [12,39]. In a large-scale screening for drought tolerance in rice, the leaf rolling factor under drought stress is regarded as one of the best criteria [57].

Silica has been extensively used to increase plants resistance to environmental stress. Despite it is being not classified as an essential element for plants, it is beneficial in alleviating the negative effects of various biotic and abiotic stresses [26,39]. Numerous studies have shown that silica application to plants can control RWC, net photosynthetic ratio, intercellular CO_2 level, stomatal conductance, and transpiration ratio in addition to activating the plant defence system [11,25,29,65]. Additionally, silica is essential for strengthening the physiological activities and cellular metabolic rates in plants in response to drought stress, which improves water use efficiency, growth, and biomass [2,24,38].

In the present study, silicon application on rice genotypes under both irrigated and water stress conditions was carried out to assess role of silicon in alleviating water stress and to study its effect on morpho-physiological and yield traits of rice genotypes.

2. MATERIALS AND METHODS

Experiment was conducted during kharif-2021 at ICAR- Indian Institute of Rice Research farm, Rajendranagar, Hyderabad. The farm is geographically situated between 170 19’ N latitude and 780 29’ E longitude at an altitude of 542.7 m above mean sea level. It comes under the southern Telangana Agro-Climatic region of Telangana. During the crop growth period, the mean maximum temperature ranged from $27.5^{o}C$ to $37.0^{0}C$ with an average of $31.9^{o}C$ and the mean minimum temperature for the corresponding period varied between $18.5^{o}C$ to $24.5^{o}C$ with an average of $22.7^{0}C$. Mean RH during the crop growth period ranged from 92 to 95 percent with an average of 87.4%. The total rainfall received during the cropping period was 823.8 mm.

Soil analysis indicated that the soil was clay in texture, non-saline and alkaline in reaction (pH 8.1). It was medium in organic carbon (0.62%) and low in available nitrogen (205 kg ha^{-1}), medium in available phosphorus (65 kg ha^{-1}) and available potassium (450 kg ha^{-1}). The experiment was laid out in split plot design comprising of eight rice cultivars replicated three times with a spacing of 20 x 10 cm. All the package of practices was followed.

Main Plot Treatments:

T1: Control
T2: Spray of 0.6% silicon as foliar spray at tillering, panicle initiation, 50%flowering and milky grain stages
T3: water stress only
T4: Silicon + water stress (water stress imposed by withholding irrigation from 12 days before flowering to 10 days after anthesis (A total of 22 days water stress will be imposed)

Sub plot Treatments: 8 rice varieties.

2.1 Morpho-Physiological Parameters

Plant height was recorded with ruler from ground level to the tip of the panicle of the tallest tiller at maturity. The numbers of tillers from the tagged hills were counted at maturity. Number of days required for 50 percent of the plants to flower in a plot was recorded and expressed as days to 50% flowering. Number of days required for yellowing of the leaves and stem (symptoms of maturity) was recorded and reported as days to maturity. Chlorophyll content of the leaves on a relative basis was measured by SPAD chlorophyll meter readings which measures the green colouration. Leaf area index is the total leaf area present for unit land area and was calculated by using the formula of Watson [82].

LAI = Total leaf area / Land area

2.2 Silicic Acid in Leaves

Rapid, micro-methods to estimate plant silicon content by dilute hydrofluoric acid extraction and spectrometric molybdenum method. The method is with slight modifications to Saito [66] and silicon content in xylem sap is determined by molybdenum yellow method. The powdered straw and grain samples were dried in an oven at 65°C for two days prior to analysis. The sample (0.5 g) was digested in a mixture of 50 mL each of 10 mL of HF (46 %) + 40 ml of double distilled water and allowed for cold digestion overnight [66]. The Si concentration in the digested solution was determined as described below: 0.1 ml of digested aliquot was transferred to a plastic centrifuge tube. To this, 2 ml of 0.1 M B, and 2 ml of Mo working solution were added and allowed to stand for 1- 3 minutes. Then 4 ml of 0.1 M citric acid was added and the final volume was made up to 10 ml with distilled water. The absorbance was measured at 400 nm with a UV visible Spectrometer.

2.3 Relative Water Content in Leaves (%)

The relative water content (RWC) of a leaf is a measurement of its hydration status relative to its maximal water holding capacity at full turgidity. Fresh leaf samples of field grown crops are first weighed then placed in water, chilled overnight, and re-weighed before being oven dried and weighed a final time. The relative difference in the water content of the leaf samples provides a quantitative measure of their infield hydration status [8].

$$\mathrm{RWC}\ (\%) = \frac{(\mathrm{FW} - \mathrm{DW})}{(\mathrm{TW} - \mathrm{DW})}\ \mathrm{X}\ 100$$

where, FW- sample fresh weight, TW- sample turgid weight, DW- sample dry weight

2.4 Yield and Yield Attributes

At maturity, the plants from one-meter square demarcated area were harvested in each plot and the number of panicles were counted. The samples were dried in shade first and then dried in hot-air oven at 60°C till to attain constant weight. Sample dry weights were summed up to arrive at mean dry matter grams in individual treatment. The total number of grains from five panicles were counted and mean values were expressed as total number of grains $panicle^{-1}$. Thousand filled grains were counted from each plot and their weight was expressed in grams as test weight. Grains harvested from net plot area was thoroughly sun dried to 14% moisture content and weighed to express in g m^{-2}.

The experimental data were analyzed statistically by following standard procedure outlined by Panse and Sukhatme [58]. Significance was tested by comparing "F" value at 1 and 5 percent level of probability. The percentage values were transformed using arc sign and square root values wherever necessary [23].

3. RESULTS AND DISCUSSION

3.1 Morpho-Physiological Traits

3.1.1 Plant height (cm)

Although, plant height is genetically controlled, silicon application plays an important role in its regulation. The data on plant height of different genotypes was recorded at maturity and presented in Table 1. The difference between various treatments for plant height was found to be insignificant. Control (T_1) has recorded higher mean plant height (113.3 cm) whereas water stress alone (T_3) has recorded the lowest value (109.9 cm). Significant difference was noticed among the tested genotypes for plant height. 27P63 (119.7 cm) and SB. Dhan (119.7 cm) has recorded significantly higher mean plant height while least mean height was recorded in DRR Dhan-48 (98.8 cm). Interaction between treatments and genotypes was found to be insignificant. Least plant height (96.7 cm) was recorded in DRR Dhan- 48 with silicon + water stress (T_4) while highest plant height (122.3 cm) was observed in SB. Dhan with water stress alone (T_3). Insignificant effect of silicon application on plant height was earlier reported in rice [1,76].

3.1.2 Number of productive tillers hill^{-1}

Significant difference (Table 1) was observed among the treatments for number of productive tillers hill^{-1}. Application of silicon (13) has recorded significantly higher mean number of productive tillers hill^{-1} whereas water stress alone (7) has recorded the lowest mean number. In comparison with control, silicon application has increased the productive tiller number by 30% and water stress alone has reduced it by 30%, whereas silicon application with water stress is on par with the control. The tested genotypes have differed significantly for number of productive tillers hill^{-1}. HRI-174 and IIRRH-148 (11) has recorded higher mean number of productive tillers hill^{-1} while lowest mean number was observed in SB. Dhan (9). No significant interaction was observed between treatments and genotypes for productive tiller number hill^{-1}. Least number of productive tillers hill^{-1} (6) was recorded in SB. Dhan with water stress (T_3) while highest number of productive tillers hill^{-1} (16) was observed in HRI-174 with silicon treated alone (T_2). The increase in number of productive tillers hill^{-1} with application of silicon fertilizers is in accordance with the earlier reports [13,20,21,43,59,81].

3.1.3 Days to 50% flowering

No significant difference was observed between the treatments for days to 50% flowering (Table 1). The tested genotypes have differed significantly for days to 50% flowering. HRI-174 (99 days) has recorded maximum mean number of days to 50% flowering while minimum mean days was observed in IIRRH-143 (86 days). Interaction between treatments and genotypes was found to be non-significant for days to 50% flowering. Least days to 50% flowering (86) was recorded in IIRRH-143 with silicon treated (T_2) while highest days to 50% flowering (99) was observed in HRI-174 with water stress alone (T_3). Attainment of 50% flowering as per duration of cultivars was also reported [74] and observed considerable variation in days to 50% flowering in rice. Similar results were reported by [81] that silicon application had no valuable effect on days to heading.

3.1.4 Leaf area index

Leaf area index (LAI) is an important plant factor in estimation of dry matter production. LAI values were significantly varied among the genotypes and treatments. Silicon application (T_2) has recorded highest mean leaf area index (5.72) while lowest mean leaf area index (2.36) was observed in water stress alone (T_3). In comparison with control, silicon application (T_2) has increased LAI by 50.13%, water stress alone (T_3) has reduced LAI by 38.06% and silicon application + water stress (T_4) has reduced LAI by 3.41%. Among the genotypes, IIRRH-148 has recorded significantly highest mean LAI (4.79) whereas lowest mean LAI was noticed in SB. Dhan (3.21). Interaction between treatments and genotypes was found to be insignificant. Least LAI (1.59) was recorded in US-314 with water stress alone (T_3) while highest LAI (7.62) was observed in IIRRH-148 with silicon application (T_2). Such significant genotypic differences for leaf area index in response to silicon application were also reported earlier [47,48,59,68]. Application of silicon solubilizer might increase source and sink strength and provide resistant against disease by which leaf become healthier and mature which increases leaf area. The increase in LAI could be attributed to significant increase in leaf expansion (length and breadth), high rate of cell division and cell enlargement, rapid growth and there by improved quality of vegetative growth due to applied silicon along with RDF (Recommended dose of Fertilizer), which corroborates with the earlier results [9,31,32].

3.1.5 Chlorophyll content at flowering stage

Miah [48] reported that chlorophyll pigments play an important role in photosynthetic process as well as biomass production. In general, chlorophyll content was positively correlated with photosynthetic rate in rice leaves [41]. SPAD Chlorophyll Meter Reading (SCMR) value represents the relative content of chlorophyll, which was convenient and effective for the research of chlorophyll level without damaging rice plants organs. A strong correlation between chlorophyll content and SCMR value has been identified, the higher the SCMR value, the higher chlorophyll content was found in rice leaves [83]. As a result, SCMR value was an important element reflecting photosynthesis ability of rice leaves [40]. Data on SPAD chlorophyll meter reading (SCMR) of rice genotypes at flowering as influenced by silicon and water stress treatments is presented in the Table 1. Silicon application and water stress treatments has insignificant effect on the SCMR values. Control (T_1) has recorded higher mean SCMR value (42.1) while lower mean SCMR value (40.6) was observed in silicon + water stress (T_4). Significant variation was observed among the tested genotypes for SCMR values. US-314 has recorded higher mean SCMR value (44.7) whereas 27P63 has recorded lowest value (37.1). Interaction between treatments and genotypes for SCMR values was found to be insignificant. Least chlorophyll content (35.1) was recorded in 27P63 Si treated (T_2) while highest chlorophyll content was observed in (46.5) was observed in US-314 with control alone (T_1). In contrary, increase in SCMR value/chlorophyll content by silicon application over control was reported earlier [62,75] in rice, [7] in maize, [43] in wheat, [3] in sorghum and [28] in barley.

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3.1.6 Silicic acid in leaves

Rice depends on the availability of silicic acid at all phases of its growth as well as protection from abiotic stresses and also biotic stresses such as rice yellow stem borer (*Scirpophaga incertulas*) and blast (*Pyricularia grisea*) [52]. Xylem sap of rice plants consist of more silicon in the form of monomeric silicic acid. The rate of transpiration highly affects the absorption of silicon in both rice and wheat. In xylem sap, high concentration of silicic acid is transiently present because it starts to polymerize in vitro. Concentration of silicic acid in shoot is through loss of water (transpiration) and its polymerization. By the process of Si polymerization, silicic acids are converted to colloidal silicic acid and finally to silica gel with increasing silicic acid concentration [46]. Si needs to be absorbed in the form of silicic acid [$Si(OH)_4$], where along with water, it follows the transpiration stream to finally deposit as silica [10,67].

Data on silicic acid content of rice genotypes as influenced by silicon was recorded at flowering presented in Table 2. Significant differences were observed between the silicon and water stress treatments for silicon content (%). Silicon + water stress (T_4) has recorded highest mean silicon content (4.96 %) while lowest mean silicon content (3.51%) was observed in control (T_1). All the treatments recorded significantly higher silicon content than control (T_1). No significant variation was observed among the tested genotypes for silicon content. IIRRH-143 recoded highest mean silicon content (4.37%) while lowest mean silicon content (3.90%) was noticed in 27P63. Interaction between treatments and genotypes was found to be insignificant. IIRRH-143 in silicon + water stress (T_4) recorded significantly highest silicon content (5.60%), whereas US-314 in control (T_1) recorded the lowest silicon content (3.30%). The results are in collaboration with earlier findings [42,44,54,59,77].

3.1.7 Relative water content in leaves

The relative water content (RWC; or ‘relative turgidity’) of a leaf is a measurement of its hydration status (actual water content) relative to its maximal water holding capacity at full turgidity. RWC provides a measurement of the ‘water deficit’ of the leaf, and may indicate a degree of stress expressed under drought and heat stress. RWC integrates leaf water potential (ψ; another useful estimate of plant water status) with the effect of osmotic adjustment (a powerful mechanism of conserving cellular hydration) as a measurement of plant water status. A genotype with the ability to minimize stress by maintaining turgid leaves in stressed environments will have physiological advantages. Significant differences were noticed between treatments for relative water content (Table 2). Silicon application (T_2) recorded maximum mean RWC (82.5%) while minimum mean RWC (65.0%) was noted in water stress alone (T_3). In comparison with control (T_1), silicon application (T_2) improved RWC by 0.24% while water stress alone (T_3) reduced RWC by 21.02% and silicon + water stress (T_4) reduced RWC by 16.89%. Variation among the tested genotypes for RWC was found to be insignificant. 27P63 recorded minimum mean RWC (73.8%) whereas US-314 has noted maximum mean RWC (75.3%). Interaction between treatments and genotypes for RWC was found to be significant. DRR Dhan-48 in control treatment (T_1) exhibited highest RWC (84.3%) whereas IIRRH-143 in water stress treatment (T_3) has recorded least RWC (61.7%). Silica fertilizer has a favourable influence on RWC during drought stress [51,55]. The foliar silica nano formulation application is improved the RWC of rice under drought [61]. The application of Si and Se to rice plants increases RWC, but the combined treatment of Si and Se has a more pronounced effect on RWC [22]. Improved RWC with Si application can be attributed to the ability of Si to mitigate the effects of drought stress by enhancing water uptake and transport, regulating stomatal behavior and transpirational water loss, accumulating solutes and osmoregulatory substances, and inducing plant defense- associated with signaling events, consequently maintaining whole-plant water balance [80].

3.1.8 Total dry matter

Dry matter production and accumulation is an important factor indicating partitioning efficiency of a genotype. The dry matter of rice genotypes as influenced by silicon and water stress is presented in the Table 2. Data revealed significant differences between treatments for total dry matter. Application of silicon (T_2) recorded significantly highest mean total dry matter (1400.8 g m^{-2}) while lowest grain yield (720.3 g m^{-2}) recorded with water stress alone (T_3). In comparison with control, silicon application (T_2) has increased total dry matter by 18.86%, water stress alone (T_3) has reduced total dry matter by 38.88% and silicon application + water stress (T_4) has reduced total dry matter by 8.45%. Significant variation observed among the genotypes for total dry matter. Highest mean total dry matter (1299.9 g m^{-2}) was noticed in US-312 whereas SB. Dhan has exhibited lowest mean total dry matter (512.0 g m^{-2}). Interaction between treatments and genotypes for total dry matter found to be insignificant. DRR Dhan with silicon application (T_2) recorded highest total dry matter (1650.9 g m^{-2}) whereas SB. Dhan with water stress alone (T_3) recorded lowest total dry matter (239.7 g m^{-2}). Such significant genotypic differences for dry matter production in response to silicon application were also earlier reported [49,71,73].

3.2 Yield and Yield Attributes

3.2.1 Number of panicles m^{-2}

Results revealed that the significant variation was observed between treatments for number of panicles m^{-2} (Table 2). Maximum mean number of panicles (343) were counted with silicon application (T_2) while minimum mean number (181) were counted in water stress alone (T_3). In comparison with control (T_1), silicon application (T_2) improved number of panicles m^{-2} by 26.10% while water stress alone (T_3) reduced number of panicles m^{-2} by 33.45% and silicon + water stress (T_4) reduced number of panicles m^{-2} by 13.97%. Significant variation was observed among the tested genotypes for number of panicles m^{-2}. US-312 has recorded highest mean number of panicles (315) whereas SB. Dhan has recorded lowest mean number (219). Interaction between treatments and genotypes for panicle number m^{-2} was found to be insignificant. IIRRH-148 recorded significantly higher number of panicles m^{-2} (383) in the silicon treatment (T_2) and HRI-174 recorded lowest number of panicles m^{-2} (133) in water stress alone (T_3). Studies at IRRI indicate that Si deficiency always reduces the number of panicles per square meter [30]. The number of panicles per square meter increased by 8.92% compared with control by using silicon @ 500 kg ha^{-1} [21]**.** Similar results were reported in previous studies [13,34,59,77].

3.2.2 Number of grains panicle^{-1}

Data on number of grains panicle^{-1} pertaining to rice genotypes under different treatments is presented in Table 2. Results revealed significant variation between treatments for number of grains panicle^{-1}. Maximum mean number of grains panicle^{-1} (157) were counted with silicon application (T_2) while minimum mean number (72) were counted in water stress alone (T_3). In comparison with control (T_1), silicon application (T_2) improved number of grains panicle^{-1} by 24.60% while water stress alone (T_3) reduced number of grains panicle^{-1} by 42.85% and silicon + water stress (T_4) reduced number of grains panicle^{-1} by 18.25%. Significant differences were observed among the genotypes for number of grains panicle^{-1}. HRI-174 has recorded highest mean number of grains panicle^{-1} (141) whereas US-314 has recorded lowest mean number (81). No significant interaction was observed between treatments and genotypes for number of grains panicle^{-1}. IIRRH-148 recorded significantly higher number of grains panicle^{-1} (198) in the silicon treatment (T_2) and US-314 recorded lowest

Table 1. Effect of silicon and water stress on morpho-physiological parameters in rice genotypes

	Plant height (cm)					**Tiller number hill^{-1}**					**Days to 50% flowering**				
Varieties	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**
27P63	121.7	121.0	117.3	118.7	119.7	11	12	7	10	10	97	94	95	91	94
DRR Dhan-48	99.7	99.0	100.0	96.7	98.8	12	12	8	10	10	98	98	98	98	98
HRI-174	115.0	114.3	107.3	112.0	112.2	11	16	8	11	11	99	99	99	99	99
IIRRH-143	105.3	104.7	100.0	102.3	103.1	10	14	6	7	9	87	86	86	86	86
IIRRH-148	116.7	116.0	114.0	113.7	115.1	10	14	8	11	11	91	91	90	90	91
SB.Dhan	120.0	119.3	122.3	117.0	119.7	9	13	5	8	9	87	89	87	86	87
US-312	111.3	110.7	107.0	108.3	109.3	10	14	7	9	10	90	93	93	94	93
US-314	116.3	115.7	111.0	113.3	114.1	10	12	7	9	10	88	89	89	89	89
Mean	113.3	112.6	109.9	110.3	111.5	10	13	7	10	10	92	92	92	92	92
Treatment (T)	NS					1.59**					NS				
Variety(V)	9.60**					1.51*					2.84**				
T x V	NS					NS					NS				
CV (%)	20.41					14.96					2.47				
	Leaf area index (LAI)					**Chlorophyll content (SCMR Value)**					**Relative water content % (RWC)**				
Varieties	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**
27P63	3.49	4.76	1.98	3.41	3.41	39.4	35.1	37.1	36.7	37.1	80.3	80.0	69.7	65.0	73.8
DRR Dhan-48	4.29	6.48	2.78	3.89	4.36	38.5	36.1	38.6	38.6	37.9	84.3	83.7	63.0	66.7	74.4
HRI-174	4.37	5.87	3.02	4.05	4.33	41.3	41.8	41.8	39.0	41.0	83.0	82.3	65.3	67.0	74.4
IIRRH-143	4.45	5.24	2.78	3.65	4.03	43.1	44.6	42.1	42.7	43.1	81.7	83.7	61.7	70.0	74.3
IIRRH-148	3.97	7.62	2.86	4.71	4.79	42.1	42.9	42.2	39.6	41.7	83.0	83.7	62.7	71.0	75.1
SB.Dhan	2.70	5.08	1.83	3.25	3.21	42.7	43.1	42.8	43.7	43.1	82.7	81.0	65.7	67.7	74.3
US-312	3.57	5.95	2.05	3.41	3.75	43.0	41.6	40.1	41.6	41.6	80.7	83.0	64.3	71.7	74.9
US-314	3.65	4.76	1.59	3.10	3.27	46.5	44.1	45.0	43.2	44.7	82.3	83.0	67.7	68.3	75.3
Mean	3.81	5.72	2.36	3.68	3.89	42.1	41.2	41.2	40.6	41.3	82.3	82.5	65.0	68.4	74.6
Treatment (T)	0.99**					NS					4.10**				
Variety(V)	1.33*					3.11**					NS				
T x V	NS					NS					4.78*				
CV (%)	23.81					7.29					5.14				

Table 2. Effect of silicon and water stress on silicon content and yield traits in rice genotypes

	Silicon content (%)					Total dry matter (g m^{-2})					Panicle number m^{-2}				
Varieties	**T1**	**T2**	**T3**	**T4 +water stress**	**Mean**	**T1**	**T2**	**T3**	**T4 +water stress**	**Mean**	**T1**	**T2**	**T3**	**T4 +water stress**	**Mean**
27P63	3.37	4.10	3.47	4.67	3.90	1308.8	1505.7	1051.6	1311.9	1294.5	233	308	175	208	231
DRR Dhan-48	3.60	4.60	3.77	4.90	4.22	1247.6	1650.9	945.5	1235.0	1269.8	308	308	175	192	246
HRI-174	3.43	4.73	3.50	4.27	3.98	1312.8	1526.5	797.0	1133.9	1192.5	258	342	133	242	244
IIRRH-143	3.87	4.07	3.93	5.60	4.37	1264.9	1415.9	408.9	1104.7	1048.6	242	367	167	183	240
IIRRH-148	3.57	4.33	4.07	5.03	4.25	1310.8	1550.0	520.3	1095.2	1119.1	275	383	183	308	288
SB.Dhan	3.43	4.90	3.40	5.00	4.18	633.7	662.2	239.7	512.2	512.0	258	317	133	167	219
US-312	3.53	4.13	3.73	4.97	4.09	1125.2	1583.3	1145.5	1345.5	1299.9	333	367	267	292	315
US-314	3.30	4.60	3.33	5.27	4.13	1224.5	1312.4	654.2	892.9	1021.0	267	350	217	283	279
Mean	3.51	4.43	3.65	4.96	4.14	1178.5	1400.8	720.3	1078.9	1094.7	272	343	181	234	258
Treatment (T)	0.60**					187.68**					50.13**				
Variety(V)	NS					225.54**					53.76**				
T x V	NS					NS					NS				
CV (%)	13.72					16.02					18.18				

	Grains panicle^{-1}					Test weight (g)					Grain yield (g m^{-2})				
Varieties	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**	**T1**	**T2**	**T3**	**T4+ water stress**	**Mean**	**T1**	**T2**	**T3**	**T4 + water stress**	**Mean**
27P63	148	168	72	128	129	25.00	30.00	15.00	16.67	21.67	459.1	584.3	295.3	354.9	423.4
DRR Dhan-48	121	169	85	101	119	18.33	26.67	13.33	16.67	18.75	389.9	441.7	290.5	362.5	371.1
HRI-174	157	184	100	124	141	30.00	35.00	15.00	20.00	25.00	476.4	497.4	279.0	362.5	403.8
IIRRH-143	139	162	43	104	112	21.67	28.33	11.67	15.00	19.17	353.0	364.7	176.3	314.2	302.0
IIRRH-148	143	198	80	103	131	21.67	35.00	13.33	13.33	20.83	330.7	425.8	227.2	246.7	307.6
SB.Dhan	92	116	63	78	87	18.33	21.67	16.67	18.33	18.75	251.0	207.4	110.5	154.5	180.8
US-312	111	150	100	99	115	21.67	26.67	15.00	16.67	20.00	419.5	526.7	273.8	397.6	404.4
US-314	99	107	31	87	81	20.00	25.00	15.00	16.67	19.17	421.8	382.7	181.3	312.1	324.5
Mean	126	157	72	103	114	22.08	28.54	14.38	16.67	20.42	387.7	428.8	229.2	313.1	339.7
Treatment (T)	30.78**					3.07**					43.16**				
Variety(V)	28.40**					NS					67.87**				
T x V	NS					NS					NS				
CV (%)	25.15					14.06					11.87				

number of grains panicle^{-1} (31) in water stress alone (T_3). These results in accordance with earlier reports [16,21,47] in rice. Adequate supply of Si increases the number of panicles and number of grains per panicle [69]. Number of grains per panicle was significantly increased by application of silicon, which might have enhanced the accumulation of photosynthates under both aerobic and wetland condition [84]. Silicon is a key player to enhance number of grains in rice [36].

3.2.3 Test weight (g)

Results revealed that the treatments differed significantly for test weight (Table 2). Maximum mean test weight (28.54 g) was recorded with application of silicon (T_2) whereas water stress alone (T_3) exhibited minimum mean value (14.38 g). In comparison with control (T_1), silicon application (T_2) improved test weight by 29.26% while water stress alone (T_3) reduced test weight by 34.87% and silicon + water stress (T_4) reduced test weight by 24.50%. Variation among the tested genotypes for test weight found to be insignificant. HRI-174 exhibited highest mean test weight (25.00 g) while lowest mean value (18.75 g) is noticed in DRR Dhan-48 and SB. Dhan. Interaction between treatments and genotypes for test weight found to be insignificant. HRI-174 recorded maximum test weight (35.00 g) with silicon application (T_2) whereas IIRRH-143 recorded minimum test weight (11.67 g) with water stress alone (T_3). The increase in thousand grains weight might be attributed due to the beneficial role of silicon in improving photosynthetic activity and plant nutrition. Similar increase in thousand grains weight of paddy due to silicon application were earlier reported [73,78,79]. 1000-grain weight increased by 12% with exogenous supply of Si [14]. Even though silicon deposition on rice grain hulls was not evaluated, the likely explanation for the increase in grain mass would be the greater deposition of this element on the palea and lemmas [5]. This greater deposition is attributed to intense panicle transpiration during the grain filling stage, since the process of transportation and deposition of silicon in plant tissues depends upon the transpiration rates that occur in different plant organs [86].

3.2.4 Grain yield (g m^{-2})

Dry matter production during crop growth period and translocation of dry matter to the panicle are the major determinants of grain yield of rice [85]. Data revealed significant differences between treatments for grain yield (Table 2). Application of silicon (T_2) recorded significantly highest mean grain yield (428.8 g m^{-2}) which is on par with control (387.7 g m^{-2}) while lowest grain yield (229.2 g m^{-2}) recorded with water stress alone (T_3). In comparison with control (T_1), silicon application (T_2) improved grain yield by 10.60% while water stress alone (T_3) reduced grain yield by 40.88% and silicon + water stress (T_4) reduced grain yield by 19.24%. Significant variation observed among the genotypes for grain yield. Highest mean grain yield (423.4 g m^{-2}) was noticed in 27P63 which is on par with US-312 (404.4 g m^{-2}) and HRI-174 (403.8 g m^{-2}) whereas SB. Dhan has exhibited lowest mean grain yield (180.8 g m^{-2}). Interaction between treatments and genotypes for grain yield found to be insignificant. 27P63 with application of silicon (T_2) recorded highest grain yield (584.3 g m^{-2}) whereas SB. Dhan with water stress alone (T_3) recorded lowest grain yield (110.5 g m^{-2}). The increase in grain yield with silicon application is attributed to the increase in number of tillers hill^{-1}, number of grains panicle^{-1} and test weight. Similar increase in grain yield of paddy by silicon application were previously reported [53,60,71]. The enhanced grain yield with silicon application may also be attributed to leaf erectness which facilitated better penetration of sunlight leading to higher photosynthetic activity of plant and higher production of carbohydrates. Similar results were also noticed in earlier studies [35,42,63,64,72]. Si application in plants through various forms increases quality and yield [6].

4. CONCLUSION

The results revealed that drought stress significantly reduced growth, physiological parameters, and yield of rice. Silicon application has ameliorated the adverse impacts of drought stress on rice and improved the growth, physiological traits and yield under both well-watered and water stress conditions. Therefore, to increase the quality of the yield and to generate rice cultivars that can withstand drought stress, silicon should be incorporated into breeding programmes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ahmad A, Afzal M, M, Ahmad AUH, Tahir M. Effect of foliar application of silicon on

yield and quality of rice (*Oryza sativa* L). Cercetări Agronom În Moldova. 2013;XLVI(3) (155):21-8.

2. Ahmad F, Lah MR, Aziz T, Maqsood MA, ATahir MA, Kanwal S. Effect of silicon application on wheat (*Triticum aestivum* L.) growth under water deficiency stress. Emirates J Food Agric. 2007;19(2):1-7.
3. Ahmed M, Hassen FU, Qadeer U, Aslam MA. Silicon application and drought tolerance mechanism of sorghum. Afr J Agric Res. 2011;6:594-607.
4. Ashraf M, Harris PJC. Photosynthesis under stressful environments: an overview. Photosynthetica. 2013;51(2):163-90.
5. Balasta MLFC, Perez CM, Juliano BO, Vlllareal CP, Lott JNA, Roxas DB. Effects of silica level on some properties of Oryza sativa straw and hull. Can J Bot. 1989;67(8):2356-63.
6. Bhardwaj S, Kapoor D. Fascinating regulatory mechanism of silicon for alleviating drought stress in plants. Plant Physiol Biochem. 2021;166:1044-53.
7. Barbosa MAM, da Silva MHL, Viana GDM, Ferreira TR, de Carvalho Souza CLF, Lobato EMSG et al. Beneficial repercussion of silicon (Si) application on photosynthetic pigments in maize plants. Aust J Crop Sci. 2015;9:1113.
8. Barrs HD, Weatherley PE. A re-examination of the relative turgidity technique for estimating water deficits in leaves. Aust J Biol Sci. 1962;15(3):413-28.
9. Bisht AS, Bhatnagar A, Pal MS, Singh V. Growth dynamics, productivity and economics of Quality Protein Maize (*Zea mays* L.) under varying plant density and nutrient management practices. Madras agricultural journal. 2012;99(1-3):73-6.
10. Canny MJ. What becomes of the transpiration stream? New Phytologist. 1990;114:341–368.
11. Chen YE, Liu WJ, Su YQ, Cui JM, Zhang ZW, Yuan M et al. Different response of photosystem II to short- and long-term drought stress in Arabidopsis thaliana. Physiol Plant. 2016;158(2):225-35.
12. Choudhary MK, Basu D, Datta A, Chakraborty N, Chakraborty S. Dehydration-responsive nuclear proteome of rice (*Oryza sativa* L.) illustrates protein network, novel regulators of cellular adaptation, and evolutionary perspective. Mol Cell Proteomics. 2009;8(7):1579-98.
13. Cuong TX, Ullah H, Datta A, Hanh TC. Effects of silicon based fertilizer on growth, yield and nutrient uptake of rice in tropical zone of Vietnam. Rice Sci. 2017;24(5):283-90.
14. Dallagnol LJ, Rodrigues FA, Mielli MVB, Ma JF. Rice grain resistance to brown spot and yield are increased by silicon. Trop Plant Pathol. 2014;39(1):56-63.
15. El-Okkiah SAF, El-Afry MM, Shehab Eldeen SA, El-Tahan AM, Ibrahim OM, Negm MM et al. Foliar spray of silica improved water stress tolerance in rice (*Oryza sativa* L.) cultivars. Front Plant Sci. 2022;13:935090.
16. Esfahani AA, Pirdashti H, Niknejhad Y. Effect of iron, zinc and silicon application on quantitative parameters of rice (*Oryza sativa* L. cv. Tarom mahalli). Int J Farming Allied Sci. 2014;3(5):529-33.
17. FAOSTAT. “Food and agriculture organization of the united nations,” in FAOSTAT statistical database (Rome: FAO); 2017.
18. Farooq M, Basra SMA, Wahid A, Cheema ZA, Cheema MA, Khaliq A. Physiological role of exogenously applied glycine betaine to improve drought tolerance in fine grain aromatic rice (*Oryza sativa* l.). J Agron Crop Sci. 2008;194(5):325-33.
19. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. Plant drought stress: Effects, mechanisms and management. Agron Sustain Dev. 2009;29(1):185-212.
20. Gerami M, Fallah A, Moghadam MRK. Study of potassium and sodium silicate on the morphological and chlorophyll content on the rice plant in pot experiment (*Oryza sativa* L.). International Journal of Agriculture and Crop Sciences. 2012; 4(10):658-61.
21. Gholami Y, Falah A. Effects of two different sources of silicon on dry matter production, yield and yield components of rice, Tarom Hashemi variety and 843 Lines. Int J Agric Crop Sci. 2013;5(3):227-31.
22. Ghouri F, Ali Z, Naeem M, Ul-Allah S, Babar M, Baloch FS. Effects of silicon and selenium in alleviation of drought stress in rice. Silicon. 2021;1-9.
23. Gomez KA, Gomez AA. Statistical procedures for agricultural research. New York: Wiley Interscience, John Wiley & Sons; 1984.
24. Gong HJ, Chen KM, Chen GC, Wang SM, Zhang CL. Effects of silicon on growth of wheat under drought. J Plant Nutr. 2003;26(5):1055-63.

25. Gong HJ, Chen KM, Zhao ZG, Chen GC, Zhou WJ. Effects of silicon on defense of wheat against oxidative stress under drought at different developmental stages. Biol Plant. 2008;52(3):592-6.
26. Hamayun M, Sohn EY, Khan SA, Shinwari ZK, Khan AL, Lee IJ. Silicon alleviates the adverse effects of salinity and drought stress on growth and endogenous plant growth hormones of soybean (*Glycine max* L.). Pak J Bot. 2010;42:1713-22.
27. Hannan A, Hoque MN, Hassan L, Robin AHK. Adaptive mechanisms of root system of rice for withstanding osmotic stress. In: Ansari MUR, editor. Recent advances in rice research. London: IntechOpen; 2020.
28. Hosseini SA, Maillard A, Hajirezaei MR, Ali N, Schwarzenberg A, Jamois F, et al. Induction of barley silicon transporter HvLsi1 and HvLsi2, increased silicon concentration in the shoot and regulated Starch and ABA Homeostasis under osmotic stress and concomitant potassium deficiency. Front Plant Sci. 2017;8:1359.
29. Hussain S, Mumtaz M, Manzoor S, Shuxian L, Ahmed I, Skalicky M, et al. Foliar application of silicon improves growth of soybean by enhancing carbon metabolism under shading conditions. Plant Physiol Biochem. 2021;159:43-52.
30. Los Banos, Philippines: IRRI. Report of Effect of Si on the growth and yield of rice. International Rice Research Institute Rice Almanac. Laguna. 1993;34-7.
31. Jaliya MM, Falaki AM, Mahmud M, Abubakar IU, Sani YA. Response of Quality Protein Maize (QPM) (*Zea mays* L.) to sowing date and NPK fertilizer rate on yield & yield components of Quality Protein Maize. Savannah J Agric. 2008;3:24-35.
32. Jat NK, Kumar A, Dhar S. Influence of Sesbania green manure with or without wheat residues and N fertilization on maize-wheat cropping system. Indian J Agron. 2010;55(4):253-8.
33. Javaid MH, Khan AR, Salam A, Neelam A, Azhar W, Ulhassan Z, et al. Exploring the adaptive responses of plants to abiotic stresses using transcriptome data. Agriculture. 2022;12(2):211.
34. Jawahar S, Vijayakumar D, Bommera R, Jain N, Jeevanandham. Effect of Silixol granules on growth and yield of Rice. Int J Curr Res Acad Rev. ISSN: 2347-3215. 2015;3(12):168-74.
35. Korndorfer GH, Snyder GH, Ulloa M, Datnoff LE. Calibration of soil and plant silicon for rice production. J Plant Nutr. 2001;24:1071-84.
36. Lavinsky AO, Detmann KC, Reis JV, Ávila RT, Sanglard ML, Pereira LF, et al. Silicon improves rice grain yield and photosynthesis specifically when supplied during the reproductive growth stage. J Plant Physiol. 2016;206:125-32.
37. Lee SS, Shah HS, Awad YM, Kumar S, Ok YS. Synergy effects of biochar and polyacrylamide on plants growth and soil erosion control. Environ Earth Sci. 2015;74(3):2463-73.
38. Li Z, Song Z, Yan Z, Hao Q, Song A, Liu L et al. Silicon enhancement of estimated plant biomass carbon accumulation under abiotic and biotic stresses. a meta-analysis. Agron Sustain Dev. 2018;38(3):26.
39. Liang Y, Sun W, Zhu YG, Christie P. Mechanisms of silicon mediated alleviation of abiotic stresses in higher plants: a review. Environ Pollut. 2007;147(2):422-8.
40. Liu QH, Wu X, Li T, Ma JK, Zhou XB. Effects of elevated air temperature on physiological characteristics of flag leaves and grain yield in rice. Chil J Agric Res. 2013;73(2):-1.
41. Liu ZQ. A study on the photosynthesis characters of different plant types of rice. Sci Agric Sin. 1980;13:6-10.
42. Ma J, Nishimura K, Takahashi E. Effect of silicon on the growth of rice plant at different growth stages. Soil Science and Plant Nutrition. 1989;35(3):347-56.
43. Maghsoudi K, Emam Y, Pessarakli M. Effect of silicon on photosynthetic gas exchange, photosynthetic pigments, cell membrane stability and relative water content of different wheat cultivars under drought stress conditions. J Plant Nutr. 2016;39(7):1001-15.
44. Malav JK, Ramani VP. Yield and nutrient content of rice as influenced by silicon and nitrogen application. Res J Chem Environ Sci. 2016;4(4):46-9.
45. Malav JK, Ramani VP, Sajid M. Effect of nitrogen and silicon fertilization on growth, yield and yield attributes of rice (Oryza sativa L.) under lowland conditions. The Ecoscan. 2016;10(1 & 2):213-6.
46. Mao J, Nishimara K, Takashi E. Effect of silicon on the growth of rice at different growth stage. Soil Sci Plant Nutr. 2009;32:347-56.

47. Meena VD, Dotaniya ML, Coumar V, Rajendiran S, Ajay K, Kundu S, et al. A case for silicon fertilization to improve crop yields in tropical soils. Proc Natl Acad Sci India Sect B Biol Sci. 2014;84(3):505-18.
48. Miah MNH, Yoshida T, Yamamoto Y. Effect of nitrogen application during ripening period on photosynthesis and dry matter production and its impact on yield and yield components of semi dwarf indica rice varieties under water culture conditions. Soil Sci Plant Nutr. 1997;43(1):205-17.
49. Muriithi C, Mugai E, Kihurani AW, Nafuma CJ, Amboga S. Determination of silicon from rice by-products and chemical sources on rice blast management. In: Proceedings of the 12th kāri biennial scientific conference, Nov 8-12. Nairobi, Kenya. 2010;7-13.
50. Muthayya S, Sugimoto JD, Montgomery S, Maberly GF. An overview of global rice production, supply, trade, and consumption. Ann N Y Acad Sci. 2014;1324:7-14.
51. Nabizadeh E, Fotohi K. The effects of the amount of water usage on quality and quantity of sugar beet cultivars. J Res Crop Sci. 2011;3:131-42.
52. Narayanaswamy C, Prakash NB. Evaluation of selected extractants for plant- available silicon in rice soils of southern India. Commun Soil Sci Plant Anal. 2010;41(8):977-89.
53. Nayar PK, Misra AK, Patnaik S. Silica in rice (*Oryza sativa* L.) and flooded rice soils: effects of flooding on the extractable silica in soils and its relation with uptake by rice. Oryza. 1982;19:34-42.
54. Nhan PP, Dong NT, Nhan HT, Chi NTM. Effects of OryMaxSL and SiliysolMS on growth and yield of MTL560 rice. World Appl Sci J. 2012;19(5):704-9.
55. Othmani A, Ayed S, Bezzin O, Farooq M, Ayed-Slama O, Slim-Amara H. Effect of silicon supply methods on durum wheat (*Triticum durum*) response to drought stress. Silicon journal. 2021;13:3047-57.
56. Panda D, Mishra SS, Behera PK. Drought tolerance in rice: Focus on recent mechanisms and approaches. Rice Sci. 2021;28(2):119-32.
57. Pandey V, Shukla A. Acclimation and tolerance strategies of rice under drought stress. Rice Sci. 2015;22(4):147-61.
58. Panse VG, Sukhatme PV (Revised by Sukhatme, P.V and Amble, V.N). Statistical methods for agricultural workers. New Delhi: Indian Council of Agricultural Research. 1985;232.
59. Pati S, Pal B, Badole S, Hazra GC, Mandal B. Effect of silicon fertilization on growth, yield, and nutrient uptake of rice. Commun Soil Sci Plant Anal. 2016;47(3):284-90.
60. Prakash NB, Narayanswami C, Hanumantharaju TH. Effect of calcium silicate as a silicon source on growth and yield of rice in different acid soils of Karnataka, southern India. Int Rice Res Notes. 2010;0117-4185.
61. Raja RK, Surendar KK, Ravichandran V, Kannan M, Pushpam R. Influence of nanosilica on Physio biochemical and antioxidative enzymes in rice under drought; 2021.
62. Ranganathan S, Suvarchala V, Rajesh YBRD, Srinivasa Prasad MS, Padmakumari AP, Voleti SR. Effect of silicon sources on its deposition, chlorophyll content and disease and pest resistance in rice. Biol Plant. 2006;50(4):713-6.
63. Rani YA, Narayanan A, Devi VS, Subbaramamma P. The effect of silicon application on growth and yield of rice plants. Annu Plant Physiol. 1997; 11(2):125-8.
64. Rodrigues FA, Benhamou N, Datnoff LE, Jones JB, Bélanger RR. Ultrastructural and cytochemical aspects of silicon-mediated rice blast resistance. Phytopathology. 2003;93(5):535-46.
65. Romero-Aranda MR, Jurado O, Cuartero J. Silicon alleviates the deleterious salt effect on tomato plant growth by improving plant water status. J Plant Physiol. 2006;163(8):847-55.
66. Saito K, Yamamoto A, Sa T, Saigusa M. Rapid, micromethods to estimate plant silicon content by dilute hydrofluoric acid extraction and spectrometric molybdenum method i. silicon in rice plants and molybdenum yellow method. Soil Sci Plant Nutr. 2005;51(1):29-36.
67. Sangster AG, Hodson MJ, Tubb HJ. Silicon deposition in higher plants. In: Datnoff LE, Snyder GH, Korndorfer GH, editors. Silicon in agriculture. Amsterdam: Elsevier. 2001;85-114.
68. Sarma RS, Shankhdhar D, Shankhdhar SC, Srivastava P. Effect of silicon solubilizers on growth parameters and yield attributes in different rice genotypes.

Int J Pure Appl Biosci. 2017;5(5). 7051:2320.

69. Savant NK, Datnoff LE, Snyder GH. Depletion of plant available silicon in soils: A possible cause of declining rice yields. Commun Soil Sci Plant Anal. 1997;28(13-14):1245-52.
70. Sikuku PA, Onyango JC, Netondo GW. Physiological and biochemical responses of five nerica rice varieties (*Oryza sativa* l.) to water deficit at vegetative and reproductive stages. Agric Biol J N Am. 2012;3(3):93-104.
71. Singh AK, Singh R, Singh K. Growth, yield and economics of rice (*Oryza sativa*) as influenced by level and time of silicon application. Indian J Agron. 2005;50(3):190-3.
72. Singh K, Singh R, Singh JP, Singh Y, Singh KK. Effect of level and time of silicon application on growth, yield and its uptake by rice (*Oryza sativa*). Indian J Agric Sci. 2006;76(7):410-3.
73. Singh K, Singh R, Singh KK, Singh Y. Effect of silicon carriers and time of application on rice productivity in a rice-wheat cropping sequence. Int Rice Res Notes. 2007;32(1):30-1.
74. Sinha PK, Prasad C, Prasad K. Studies on Gora rice of Bihar III Association of panicle components Oryza. 1999;36:306-8.
75. Song A, Li P, Fan F, Li Z, Liang Y. The effect of silicon on photosynthesis and expression of its relevant genes in rice (*Oryza sativa* L.) under high-zinc stress. PLOS ONE. 2014;9(11):e113782.
76. Swe MM, Mar SS, Naing TT, Zar T, Ngwe K. Effect of silicon application on growth, yield and uptake of rice (Oryza sativa L.) in two different soils. Open Access Libr J. 2021;8(10):1-15.
77. Ullah H, Luc PD, Gautam A, Datta A. Growth, yield and silicon uptake of rice (*Oryza sativa*) as influenced by dose and timing of silicon application under water-deficit stress. Arch Agron Soil Sci. 2017:1-13.
78. Usman M, Raheem ZF, Ahsan T, Iqbal A, Sarfaraz ZN, Haq Z. Morphological, physiological and biochemical attributes as indicators for drought tolerance in rice (*Oryza sativa* L.). Eur J Biol Sci. 2013;5:23-8.
79. Vijayakumar K. Use of indigenous source of magnesium silicate as a soil amendment. M.Sc. (ag.) [thesis]. Thrissur: Kerala Agricultural University. 1977;78.
80. Wang M, Wang R, Mur LAJ, Ruan J, Shen Q, Guo S. Functions of silicon in plant drought stress responses. Hortic Res. 2021;8(1):254.
81. Waseem M, Ahmad R, Randhawa MA, Aziz T, Mahmood Z. Influence of silicon application on blast incidence and lodging resistance in rice. J Agric Res. 2016;54(3):435-43.
82. Watson DJ. The dependence of net assimilation rate on leaf area index. Ann Bot. 1958;22(1):37-54.
83. Xie XJ, Li BB, Zhu HX, Yang SB, Shen SH. Impact of high temperature at heading stage on rice photosynthetic characteristic and dry matter accumulation. Chin J Agrometeorol. 2012;33:457-61.
84. Yogendra ND, Kumara BH, Chandrashekar N, Prakash NB, Anantha MS, Jeyadeva HM. Effect of silicon on real time nitrogen management in a rice ecosystem. Afr J Agric Res. 2014;9(9):831-40.
85. Yoshida S. Climate and rice. Philippines: International Rice Research Institute; 1972;211.
86. Yoshida S, Ohnishi Y, Kitagishi K. Chemical forms, mobility and deposition of silicon in the rice plant. Soil Sci Plant Nutr. 1962;8(3):15-21.

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