SILICON IMRPOVED WATER STRESS TOLERANCE IN RICE GENOTYPES

ABSTRACT

Rice isanimportant 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 thatdrought 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 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 andgrain yield

Introduction

Rice is the second most important commercially produced cereal crop in the world. Rice is the main source of nutrition and energy for more than half of the world's population **(Muthayya*et al*., 2014)**. More rice will be produced in order to provide food security and meet the growing demand of the world's population. Flood irrigation systems account for more than 75% of global rice production **(FAOSTAT, 2017)**. Rice is significantly more drought-susceptible than other crops, and drought stress has a significant impact on physiological and productive traits during the flowering stage **(Panda *et al*., 2021)**.

Drought is one of the most serious climate disasters, threatening global agricultural productivity **(El-Okkiah*et al*., 2022)**. Water scarcity inhibits cell growth, resulting in shorter stems, shorter internodes, weakened root systems, and lower tillering potential **(Hannan*et al*., 2020)**. It also reduces dry and fresh biomass **(Sikuku*et al*., 2012)**. Moreover, drought stress compromised a number of metabolic activities, including photosynthesis, respiration, ion uptake, hormone development, and nutritional intake **(Farooq *et al*., 2008; Osman *et al*., 2013; Lee *et al*., 2015)**. Drought stress has the potential to severely damage photosynthetic pigments, gas exchange systems, electron transport systems, imaging systems, carbon reduction pathways, and enzyme systems **(Ashraf and Harris, 2013)**. Due to scarcity of water, chlorophylls a and b, as well as carotenoids, are commonly lost in rice leaves **(Farouk *et al*., 2009)**. Distinctive cereal crops have distinct drought-adaptive responses **(Javaid*et al*., 2022)**.

Plants display a variety of morphological, physiological, biochemical and molecular characteristics to combat the adverse effects of drought stress **(Choudhary*et al*., 2009)**. Conservation of water in cells and tissues, cell membrane stability, and endogenously produced growth regulators are some of the physiological systems involved in plant response to drought stress conditions **(El-Okkiah*et al*., 2022)**. Plants alter gene expression at the molecular level to mitigate potentially harmful effects of reduced water supplies. As a result, genetic factors influence these adaptive responses at different stages of plant development **(Choudhary*et al*., 2009)**. Relative water content (RWC) is an important indicator of water status and can be used to screen plants for drought resistance **(Liang *et al*., 2007; Choudhary*et al*., 2009)**. Leaf rolling factor under drought stress is one of the best parameters in a large-scale examination of drought resistance in rice **(Pandey and Shukla, 2015)**.

Silica has long been used to enhance plant resilience to environmental stress. Despite the fact that it is not considered an essential element for plants, it is effective in mitigating the effects of several biotic and abiotic stresses **(Liang *et al*., 2007; Hamayun*et al*., 2010)**. Several studies have shown that applying silica to plants can control RWC, net photosynthetic ratio, intercellular CO level, stomatal conductance, and transpiration ratio, in addition to activating the plant defence system **(Romero-Aranda *et al*., 2006; Gong *et al*., 2008; Chen *et al*., 2016; Hussain *et al*., 2021)**. Furthermore, silica is required for plants to enhance their physiological activities and cellular metabolic rates in response to drought stress, which enhances water use efficiency, growth, and biomass **(Gong *et al*., 2003; Ahmad *et al*., 2007; Li *et al*., 2018)**.

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.

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 was823.8 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

Morpho-physiological parameters

At maturity, plant height was measured with a ruler from the ground to the apex of the tallest tillering spikes. At maturity, the number of tillers was counted from the tagged hills. The number of days required for 50% of plants in the plot to flower was recorded and recorded as days to 50% flowering. Days to ripening were calculated by recording the number of days required for leaf and stem yellowing (ripe symptoms). The relative chlorophyll content of leaves was determined using SPAD chlorophyll meter readings, which measure green color. The leaf area index is the total leaf area present per unit area and was derived using **Watson's (1958)** formula.

LAI=Total leaf area / Land area

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 *et al*., 2005)** 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 **(Saito *et al*., 2005)**. 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.

Relative water content in leaves (%)

A leaf's relative water content (RWC) is a measure of its wetting state in comparison to its maximum water-holding capacity at full affinity. Fresh leaf samples from field-grown crops are first weighed, then immersed in water, cooled overnight, and weighed again before being oven-dried and weighed again. The relative difference in water content between leaf samples provides a quantitative indicator of hydration status in the field**(Barrs and Weatherley, 1962)**.

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

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

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 (1985)**. 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 **(Gomez and Gomez, 1984)**.

Results and Discussion

Morpho-physiological traits

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 reported in rice by **Ahmad *et al*. (2013) andSwe*et al*. (2021).**

Number of productive tillers hill^{-1}

Significant difference **(Table 1)**was observed among the treatments for number of productive tillershill^{-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 (**Gerami*et al*., 2012;Pati*et al*., 2016;Waseem *et al*., 2016;Gholami and Falah 2013;Malav*et al*., 2016;Cuong*et al*., 2017)**.

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 by **Sinha *et al*. (1999)**and observed considerable variation in days to 50% flowering in rice. Similar results were reported by **Waseem *et al*. (2016)** that silicon application had no valuable effect on days to heading.

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 by **Pati*et al*. (2016), Sarma*et al*. (2017) andMeena*et al*. (2014)**. Application of silicone solute may enhance source and sink strength and confer disease resistance, resulting in healthier, more mature leaves with increased leaf area. The rise in LAI may be attributed to a significant increase in leaf expansion (length and width), higher rate of cell division and cell enlargement, rapid development, and thus increased quality of vegetative growth as a result of silicon application in conjunction with RDF (Recommended Dose of Fertilizer), which corroborates with the results of **Jaliya*et al*. (2008), Jat*et al*. (2010) and Bisht*et al*. (2012)**.

Chlorophyll content at flowering stage

Miah *et al*. (1997) reported that chlorophyll pigments are vital in both the photosynthetic and biomass generation processes. In rice leaves, chlorophyll content was found to be positively associated with photosynthetic rate **(Liu, 1980)**. The SPAD Chlorophyll Meter Reading (SCMR) value represents the relative amount of chlorophyll and was useful for researching chlorophyll levels without harming rice plant organs. There is a substantial association between chlorophyll content and SCMR value; the greater the SCMR value, the higher the chlorophyll content in rice leaves **(Xie*et al*., 2012)**. As a result, SCMR value was a significant factor in determining rice leaf photosynthetic ability **(Liu *et al*., 2013)**. In **Table 1** shows data on SPAD chlorophyll meter reading (SCMR) of rice genotypes at flowering as modified by silicon and water stress treatments. The effects of silicon application and water stress treatments on SCMR values are negligible. The control (T_1) had a higher mean SCMR value (42.1), but the silicon + water stress (T_4) had a lower mean SCMR value (40.6). For SCMR levels, there was significant heterogeneity among the tested genotypes. US-314 had a higher mean SCMR score (44.7), while 27P63 had the lowest (37.1). For SCMR values, the interaction between treatments and genotypes was determined to be negligible. The lowest chlorophyll concentration (35.1) was found in 27P63 Si treatment (T_2), while the maximum chlorophyll content (46.5) was found in US-314 with control alone (T_1). Previously, **Ranganathan*et al*. (2006) and Song *et al*. (2014)** reported an increase in SCMR value/chlorophyll content by silicon application over control in rice,**Barbosa *et al*. (2015)** in maize, **Maghsoudi*et al*. (2016)** in wheat, **Ahmed *et al*. (2011)** in sorghum, and **Hosseini *et al*. (2017)** in barley.

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 (*Scirpophagaincertulas*) and blast (*Pyriculariagrisea*) **(Narayan and Prakash, 2010)**.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 **(Mao *et al*., 2009)**. 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 **(Canny 1990; Sangster *et al*., 2001)**.

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 **(Ma *et al*., 1989;Pati*et al*.,2016;Nhan*et al*., 2012;Malav and Ramani, 2016; Ullah*et al*., 2017)**.

Relative water content in leaves

A leaf's relative water content (RWC; also known as ‘relative turgidity') is a measurement of its hydration status (actual water content) in relation to its maximal water retaining capacity at full turgidity. RWC measures the leaf 'water deficit' and may reflect the degree of stress manifested under drought and heat stress. As a measurement of plant water status, RWC combines leaf water potential (another important estimate of plant water status) with the effect of osmotic adjustment (a powerful way of conserving cellular hydration). A genotype that can reduce stress by keeping turgid leaves in stressed situations will have physiological advantages. There were significant variations in relative water content between treatments **(Table 2)**. The silicon application (T_2) had the highest mean RWC (82.5%), while water stress alone (T_3) had the lowest mean RWC (65.0%). In comparison to the control (T1), silicon application (T_2) increased RWC by 0.24%, water stress alone (T_3) decreased RWC by 21.02%, and silicon + water stress (T_4) decreased RWC by 16.89%. The variation in RWC genotypes was determined to be minimal. 27P63 had the lowest mean RWC (73.8%), whereas US-314 had the highest mean RWC (75.3%). For RWC, the interaction between treatments and genotypes was found to be significant. DRR Dhan-48 in the control treatment (T_1) had the highest RWC (84.3%), while IIRRH-143 in the water stress treatment (T_3) had the lowest RWC (61.7%). Silica fertilizer improves RWC during drought stress **(Othmani*et al*., 2021; Nabizadehand Fotohi, 2011)**. The application of foliar silica nano formulation improves rice RWC during drought **(Raja *et al*., 2021)**. The application of Si and Se to rice plants improves RWC, but the combination treatment has a more dramatic effect on RWC **(Ghouri*et al*., 2021)**.

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 reported by **Singh *et al*. (2005), Singh *et al*. (2007) and Muriithi*et al*. (2010).**

Yield and yield attributes

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 **(IRRI, 1993)**. The number of panicles per square meter increased by 8.92% compared with control by using silicon @ 500 kg ha^{-1}**(Gholami and Falah, 2013).** Similar results were reported by**Pati*et al*.(2016), Coung*et al*. (2017), Ullah*et al*. (2017) and Jawahar*et al*. (2015).**

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 number of grains panicle^{-1} (31) in water stress alone (T_3).These results in accordance with **Gholami and Falah(2013), Esfahani*et al*. (2014), Meena*et al*. (2014)** in rice. **Savant *et al*. (1997)** reported that an adequate supply of Si increases the number of panicles and number of grains per panicle. **Yogendra*et al*. (2014)** reported that number of grains per panicle was significantly increased by application of silicon, which might have enhanced the accumulation of photosynthetic under both aerobic and wetland condition. **Lavinsky*et al*. (2016)** mentioned silicon as a key player to enhance number of grains in rice.

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 reported by **Vijayakumar (1977) and Singh *et al*. (2007). Dallagnol*et al*. (2014)** also mentioned 12% increase in 1000-grain weight with exogenous supply of Si.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, as reported by **Balastra*et al*. (1989)**. 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 **(Yoshida *et al*.,1962)**.

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 **(Yoshida, 1972)**. 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 reported by **Nayar*et al*. (1982), Singh *et al*. (2005) and Prakash *et al*. (2010)**. 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 by **Ma *et al*. (1989), Rani *et al*. (1997), Korndorfer*et al*. (2001), Rodrigues *et al*. (2003) and Singh*et al*. (2006)**.

Conclusion:

Drought stress severely affected rice growth, physiological parameters, and yield, according to the findings. Silicon treatment has reduced the negative effects of drought stress on rice growth, physiological characteristics, and yield under both well-watered and water-stressed circumstances. As a result, silicon should be integrated into breeding programs to improve yield quality and create rice cultivars that can survive drought stress.

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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**	**Mean**	**T1**	**T2**	**T3**	**T4**	**Mean**	**T1**	**T2**	**T3**	**T4**	**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**	**Mean**	**T1**	**T2**	**T3**	**T4**	**Mean**	**T1**	**T2**	**T3**	**T4**	**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**	**Mean**	**T1**	**T2**	**T3**	**T4**	**Mean**	**T1**	**T2**	**T3**	**T4**	**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-	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	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**	**Mean**	**T1**	**T2**	**T3**	**T4**	**Mean**	**T1**	**T2**	**T3**	**T4**	**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-	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	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				

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