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Silicon application stimulated rice growth and physiological responses in normal and water-stressed conditions

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Abstract

During the kharif season of 2020 and 2021, a field trial was conducted at the Dr. Norman E. Borlogue Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (Uttrakhand), India. In this study, we found that Si application rose dramatically in eight rice genotypes that were given various treatments, including control (T1), Si (0.6% Ortho silicic acid) (T2), Si (0.6% Ortho silicic acid) + water stress (T3), and water stress only (T4). The finding of the study shows that the fertilization of silicon (0.6%) increased plant growth, MSI and RWC content in rice as compared to control. Silicon (0.6%) supplemented plants (T2) showed a maximum increment in growth rate of US-312 (22.33%) and IRRH-314 (20.98%) at tillering, IIRRH-148 (14.42%) and US-314 (14.91%) at panicle initiation for plant height, and US-312 (32.18% and 28.85%) for MSI and DRR Dhan (8.43% and 8.33%) for RWC as compared to control (T1) in 2020 and 2021. The goal of this study was to observed beneficial effects of silicon on growth rates and physiological responses in different rice genotypes.

Keywords: Silicon, Rice, Plant height, MSI and RWC

Introduction

Prolonged, large-area drought events are among India's costliest natural disasters, having major impacts on sectors such as agriculture, ecosystems and wildlife (Kumar *et al.* 2016). Rice (*Oryza sativa* L.) is a major staple food crop for more than two-thirds of Southeast Asia's population, and it plays a critical role in national food security and provides a source of income for millions of India (Pati *et al.* 2018) [31]. The world's food security is being threatened by rapid population expansion, urbanization, and recent climatic variation (Nadeem *et al.* 2019) [27]. Due to the ever-increasing population and changes in eating habits, the requirement will be increased by 50% by 2050. Rice, being a water-loving crop, has a higher intrinsic sensitivity to water deficiency stress (Ghaderi *et al.* 2018) [16]. Drought affects plant metabolism, resulting in morphological, biochemical, and physiological changes that reduce production and yield (Akram *et al.* 2019) [4]. Physiological stages of rice are affected by various abiotic stresses especially water deficiency that have harmful effects on various parameters like growth, development and metabolic traits. Drought is the most dissociating problem for agricultural production throughout the world (Ghori *et al.* 2021). The investigation's findings could be useful for rainwater collection, as well as good crop planning and management, and water resource storage structures (Kumar *et al.* 2022).

Silicon is advantageous to higher plants, especially under stressful environments, where plants absorb silicon in the form of soluble monosilicic acid (H_4SiO_4) (Chen *et al.* 2018) [11]. Silicon subsidizes stress tolerance by physical and mechanical protection (SiO_2deposits) and by inducing biochemical responses thereby triggering metabolic changes. Silicon is reported to increase drought tolerance in plants by maintaining leaf water potential, photosynthetic activity, stomatal conductance, leaves erectness and maintaining structure of xylem vessels under high transpiration rates (Luyckx *et al.* 2017) [22]. Silicon can alleviate the drought stress by decreasing transpiration by forming silicon cuticle double layer (Tripathi *et al.* 2016; Gokulraj *et al.* 2018) [42, 19]. The administration of Si to plants under stress has shown to improve tolerance to a variety of stresses in monocotyledons and dicotyledons (Coskun *et al.* 2019) [12]. Plant drought resistance is improved by increasing water status, osmotic adjustment, photosynthetic activity, antioxidant defence system, and nutrient absorption balance, all of which help to preserve crop output (Sattar *et al.* 2020; Souri *et al.* 2020) [35, 39].

Morphophysiological, Plants under drought have lower germination index, plant height, and biomass morphology. Meanwhile, physiological and biochemical impacts result in lower levels of chlorophyll, stomatal conductance, water potential, relative cell water content, and increased ABA levels, resulting in lower photosystem I and II activity (Pandey and Shukla, 2015) [29]. Si treatment has been shown in several experiments to enhance the water content of numerous plant types under drought conditions (Ahmed *et al.* 2014) [3]. Electronic leakage (EL) of the cell increases in this condition, indicating oxidative stress damage to cell membranes. This is due to water restrictions or a drop in relative water content in drought-stricken vegetative plants (Yang *et al.* 2016) [44]. Drought-tolerant rice plants are characterized by their ability to carry out adaptation and tolerance strategies in the form of adjustment of water osmotic potential and relative water content (RWC) of leaves, and also morphological and anatomical adaptations in the form of changes in plant organ structure and biochemical adaptation through activation of oxidative defense mechanisms (Swapna and Shylaraj, 2017) [40]. Silicon can provide environmentally beneficial alternatives to various synthetic fertilizers without polluting the environment (Song *et al.* 2021) [38].

Materials and Methods

During the Kharif season of 2020 and 2021, a field experiment was conducted at the Dr. Norman E. Borlogue Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (Uttarakhand), India (June to November). A split-plot design was used in the field, with three replications of each treatment. It featured 12 major plots, each with a gross plot size of 44.4m x 31m and 8 sub-plots (3x2.5m) separated by a 0.6m wide bund for sup-plots and 0.7m for main plots. There were 96 subplots in total, and the main and subplot were both chosen at random. T1, T2, T3, and T4 were the four treatments available. T-1-Control (does not use any chemicals and follows the same set of techniques), T-2 silicon sprays (0.6% Ortho silicilic acid) @ 400 ml in 200 litres/acre water at tillering, panicle initiation (PI), 50% blooming, and milky grain stages T-3 silicon sprays + water deficit (water stress will be administered by delaying irrigation 12 days before flowering and again 10 days after anthesis for a total of 22 days of stress), T-4 water stress only Seedlings were grown in a nursery before being transplanted to the main field at a spacing of 10 cm x 20 cm. The Indian Institute of Rice Research, Rajendranagar, Hyderabad, provided seeds of 27P63, HRI-174, DRR Dhan-48, IIRRH-143, IIRRH-148, US-312, US-314, and SAHABHAGIDHAN rice genotypes. To apply nitrogen, phosphorus, and potassium, chemicals such as urea, single superphosphate (SSP) @ 45 kg/ha, and muriate of potash (MOP) @ 60 kg/h were given. MOP and SSP were applied as basal doses, whereas urea (100 kg/ha) was applied in three stages: 50% after 15 days, 25% at active tillering, and 25% at the PI stage.

Growth Parameter

Plant height was defined as the distance between the base of the topmost fully expanded leaf and the ground level. It was recorded by averaging the heights of three randomly chosen plants on a meter scale at active tillering and 50% flowering from each of the three replications of each treatment.

Physiological parameters

Relative Water Content (RWC)

The method of Slatyer and Barrs (1965) for determining the relative water content of rice flag leaves was applied at the anthesis. The leaves (100mg) were cut into 3-4 cm long sections and weighed for fresh weight (FW). Leaf samples were saturated in 50 ml distilled water for 4 hours at room temperature and their turgid weights (TW) were recorded. The leaves were then oven dried for two days at 65-70 °C before being weighed. The RWC was determined by the application of a given formula.

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

Membrane Stability Index (MSI)

Rice flag leaf membrane stability index was measured at the anthesis stage, according to Sariam *et al.*, 1997. 100 mg leaf discs were placed in test tubes containing 10 ml double distilled water in two different sets. One set was kept at 40 °C for 30 minutes in a boiling water bath, and the solution's electrical conductivity was measured on a conductivity bridge (C1). The other sample was boiled for ten minutes at 100 degrees Celsius. The electrical conductivity of the bridge was then measured using its conductivity (C2). To compute, MSI employs a formula.

$$\text{MSI}\ (\%) = 1 - \frac{\text{C1}}{\text{C2}} \times 100$$

Results and Discussion

Plant Height

The randomly selected plants of individual plot at maximum tillering and panicle initiation, the plant height were recorded for all genotypes in Figuer 1a, 1b. When compare to control, the highest plant height at tillering was recorded in silicon treated plants in both years. In 2020 the maximum plant height at tillering was obtained in IIRRH-143 (53.68 cm) under control (T1) treatment and under silicon treated plants T2 the maximum was attained by IIRRH-148 (58.48 cm) respectively. The maximum plant height was obtained by IIRRH-143 (58.11cm) for silicon supplemented plants (T3) and the highest value was attained in HRI-174 (51.03cm) respectively under control (T4) treatment. During the kharif season in 2021, for under control (T1) the maximum plant height was attained by HRI-174 (54.38 cm) and for silicon (0.6%) treated plant (T2) was showed maximum IIRRH-148 (61.14 cm) respectively. In case of silicon fertilized plant (T3) the maximum height was attained by US-312 (60.10 cm) and IIRRH-143 (53.72 cm) for control (T4) treatment. Statistically analysis showed that the interaction between treatment and genotypes was observed to be highly significant for all genotypes in 2020 and 2021.A significant increment in plant height at tillering was reported in US-312 (22.33%) and IRRH-314 (20.98%) respectively under T2 over T1 in 2020 and 2021. The minimum percent rise for 27P63 (1.96% and 3.99%) respectively for T2 over T1 in 2020 and 2021. A significant increment was recorded for US-312 (26.4% and 26.15%) respectively for T3 over T4 in 2020 and 2021.

In Figure 2.a, b, for kharif season 2020, under control (T1) the maximum plant height at panicle initiation was recorded by IIRRH-143 (85.00 cm) and for silicon 0.6% fertilized plant (T2) the height attained by IIRRH-143 (89.18 cm) respectively. In case of (T3) the highest value was obtained in IIRRH-143 (89.23 cm). In case of control (T4) treatment, the maximum was recorded in IIRRH-143 (85.28 cm) respectively. During the kharif season in 2021, for under control (T1) the maximum plant height at panicle initiation was attained by IIRRH-143 (82.38 cm) and IIRRH-143 (88.36 cm) for silicon (0.6%) treated plant (T2) treatment. In case of silicon fertilized plant (T3) the maximum height was attained by IIRRH-143 (88.42 cm) IIRRH-143 (80.35 cm) respectively for control (T4) treatment. The plant height at panicle initiation was observed significantly increase in both the year for silicon treated plants when compared to the control plants. Statistically analysis showed that the interaction between treatment and genotypes was observed to be highly significant for all genotypes in 2020 and 2021. A significant plant height at panicle initiation for T2 over T1was recorded in IIRRH-148 (14.42%) and US-314 (14.91%) respectively in 2020 and 2021. The minimum percent increment was obtained in HRI-174 (3.4% and 4.15%) respectively. The highest percent increment for T3 over T4 was recorded in 27P63 (14.33%) and IIRRH-148 (15.02%) respectively in 2020 and 2021. The minimum percent rise was for HRI-174 (3.61%) and DRR-Dhan- 148 (3.32%) respectively for T3 over T4 in 2020 and 2021.

Our results revealed that normal water irrigation with silicon (0.6%) supplemented plants was noted to improve significantly in term of plant height as compared to without silicon fertilized plants in 2020 and 2021. The possible reason for plant height in Si supplemented plants could be raised as a result of increased metabolic activity (Afzal *et al.* 2005) [1], increased cell division (Fageria *et al.* 2013) [15], elongation, expansion and photosynthesis (Singh *et al.* 2003) [38]. It has been stated that increasing rice plant height is dependent on silicon application rate, but only to a certain and appropriate level (Ali *et al.* 2013) [5]. The rapid elongation of the stem and roots caused by the application of Si may be the cause of the increased plant height (Ghouse *et al.* 2015) [18]. Rice plant height can be increased by increasing the erectness of the leaves and stems due to Si deposition in the cell wall, as a result of the reduced mutual shadowing induced by the high plant density, the photosynthetic rate of the plant increases as a result of improved light interception (Yoshida *et al.* 1969; Coung *et al.* 2017) [45, 13]. Si treatment improved plant height in both drought and non-drought environments (paddy conditions, or less than 120 percent soil moisture content) (Ibrahim *et al.* 2018) [21]. In the current study maximum plant height at tillering and panicle initiation was observed in silicon fertilized with water stress (T3) as compare to water stress only (T4). Plant height was also observed to increase with silicon treatment under drought conditions by other researcher in case of tomato (Cao *et al*. 2015) [10], rice (Torres and Henry, 2016) [42] and maize (Amin *et al.* 20216; 2018) [6, 7]. Numerous studies have highlighted the improvement in plant growth and development with Si addition under different abiotic stress in many crop species i.e. rice, wheat, soybean and sorghum due to positive impact of Si on plant mechanical strength and minerals nutrition, ultimately plants resistance to abiotic stress (Mustafa, 2021) [25]. The aforementioned results for increased plant height with silicon fertilization under ideal water supply circumstances are in agreement with Pati *et al*. 2016; Das, 2019; Ramadhani *et al.* 2021) [32, 35].

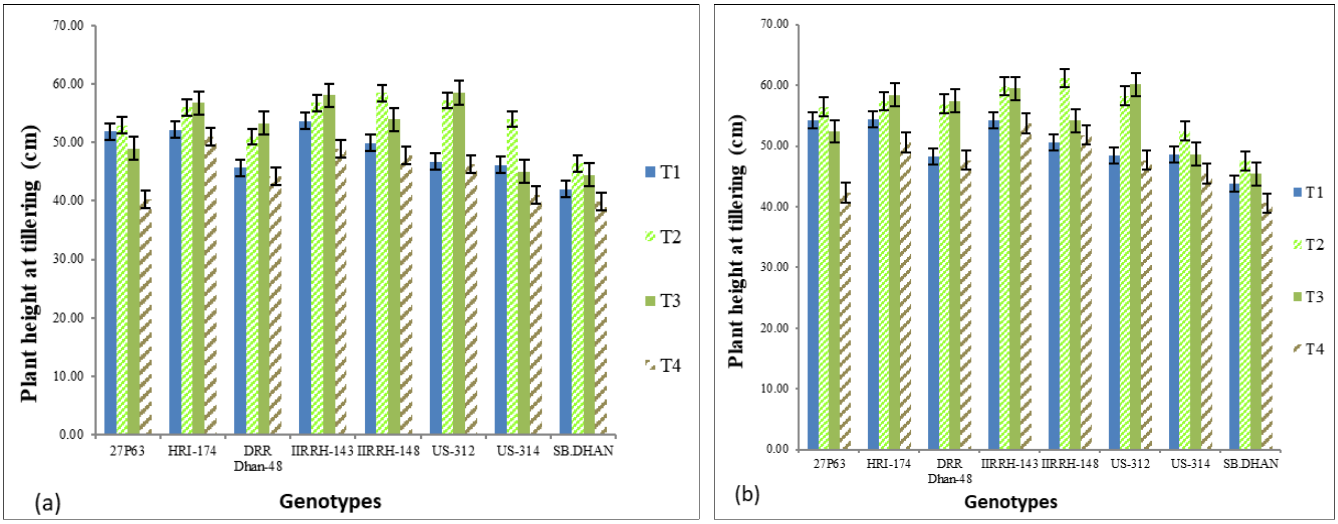

Fig 1a, b: Influence of silicon solubilizers on plant height (cm) at tillering in different rice genotypes during *kharif* season of 2020-2021 and vertical bars indicate ± standard error of mean.

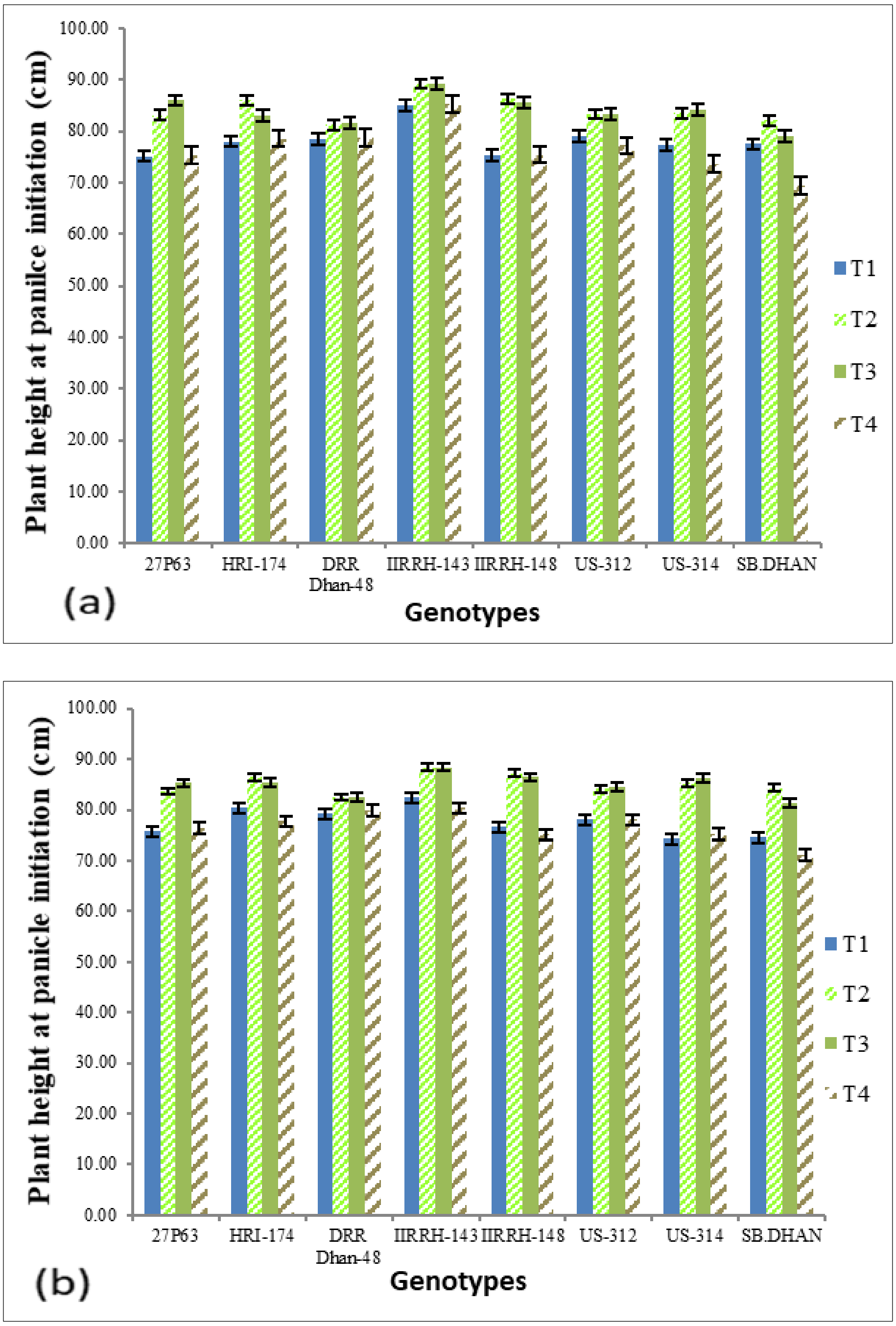

Fig 2a, b: Influence of silicon solubilizers on plant height (cm) at tillering in different rice genotypes during *kharif* season of 2020-2021 and vertical bars indicate ± standard error of mean.

Membrane Stability Index (MSI)

Membrane stability index at flowering in different rice genotypes under normal and silicon solubilized conditions exhibited in Figure 3.a, b exhibited. Membrane stability index in 2020 and 2021 under normal water irrigation and water-deficit conditions demonstrated that in case of silicon treated plants an enhancement when compared to the non-silicon supplemented plants was observed and was statistically significant. Under normal irrigation along with silicon treated plant, membrane stability index at flowering showed a significant improvement when compare to normal irrigation alone for both years. In 2020, the maximum MSI was recorded in 27P63 (73.40%) for (T1) and DRR Dhan-48 (79.27%) for silicon treated plants (T2). In case of water-stressed plants (T4) the highest MSI at flowering was attained in DRR Dhan-48 (50.62%) and under silicon treated water stressed plants (T3) the maximum MSI was recorded by 27P63 (68.42%) respectively. For kharif season 2021, the maximum MSI at flowering was observed in case of 27P63 (72.06%) for control (T1) and US-314 (78.76%) for silicon fertilized plants(T2). The highest MSI was observed by 27P63 (67.42%) for (T3) treatment and DRR Dhan48 (49.95%)for T4treatment. A significant percent increment of MSI was for US-312 (32.18% and 28.85%) respectively for T2 over T1 in 2020 and 2021. The minimum percent increment rise for T2 over T1 was for IIRRH-148 (7.18%) and SD. DHAN (6.82%) respectively in 2020 and 2021. The highest increase was for HRI-174 (45.44%) and US-314 (43.94%) respectively whereas the lowest increase was for DRR Dhan-48 (21.51%) and IIRRH-143 (20.31%) respectively for T3 over T4 in 2020 and 2021. Statistical analysis proves that the interaction between treatment and genotypes was recorded significantly with respect to all the treatments and all the rice genotypes in both 2020 and 2021. The current study reveal that MSI was significantly increase in silicon fertilized plants (T2) as compare to silicon treated and water stress (T3).

In this investigation, maximum MSI was observed in Si (0.6%) supplemented plants under normal and water deficit conditions in both years. Si-treated plants may contribute to increase MSI by improving osmotic adjustment, as well as lower lipid peroxidation, electrolytic, and hydrogen peroxide levels. Silicon may protect membranes by reducing MDA production (lipid peroxidation), modulating antioxidant defence in plants, preserving membrane integrity, and lowering membrane permeability (Etesami and Jeong, 2018) [14]. In the current study, maximum MSI was attained in silicon fertilized plants along with water stress as compared to water stress only. Drought stress reduced MSI significantly, while spraying solutions containing Se-, SiO2-, and especially Se/SiO2-NPs enhanced their contents (Zahedi *et al.* 2020) [47]. Many abiotic stressors target biological membranes as their initial target. The ability of plants to maintain membrane integrity and stability under water stress is widely recognized as a key component of drought resistance (Bajji *et al.* 2002) [8]. Drought interaction with nano silica treatment resulted in a significantly lower loss in membrane stability index of rice (Raja *et al*. 2021) [34]. As a result, Si treatment increased MSI considerably in wheat plants exposed to Cd stress. In wheat plants exposed to Cd stress, Si treatment greatly improved MSI. Si improved the membrane stability index to reduce wheat membrane injury and logging, which could be another way for Si to reduce Cd toxicity by improving stability, permeability, and integrity (Rahman *et al.* 2021) [33]. Enhancement of MSI under Si induced drought stress has also been ported in sorghum (Ahmed *et al*., 2011) [2], wheat (Maghsoudi *et al.* 2016), rice (Gokulraj *et al.* 2018) [19] and maize (Younas *et al*. 2022; Bijanzadeh *et al*. 2022) [46, 9].

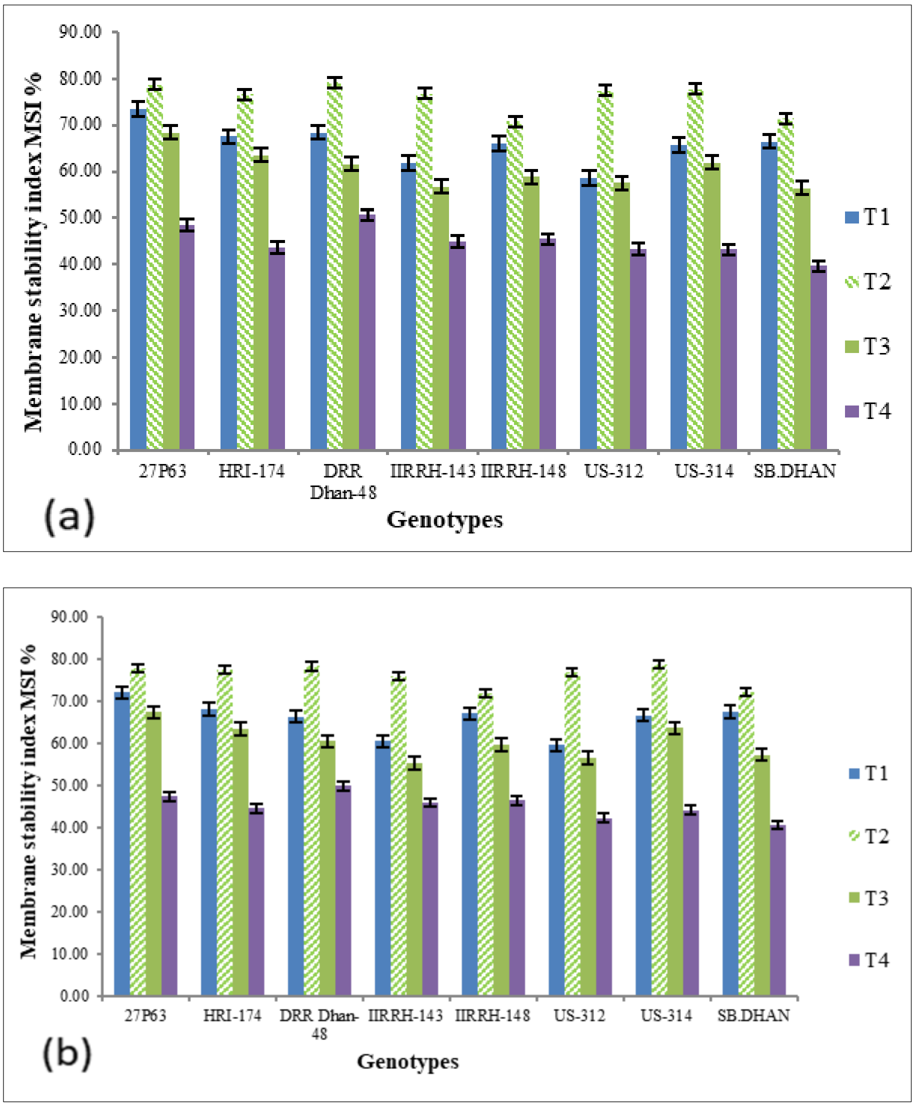

Fig 3a, b: Influence of silicon solubilizers on membrane stability index (MSI) (%) in different rice genotypes during kharif season of 2020-2021 and vertical bars indicate ± standard error of mean

Relative Water Content (RWC)

The data in Figure 4.a,b shows the relative water content at flowering for different genotypes of rice under control and silicon treatment. RWC is statistically significant for the silicon fertilized plants when compared to the control plant under normal water as well as water stressed conditions. For kharif season 2020, under control (T1) the maximum RWC at flowering was recorded by 27P63 (87.13%) and (89.23%) for (T2) treatment. In case of silicon fertilized plant (T3) was recorded by (82.52%) and (72.11%) for (T4) treatment. In

2021 under control treatment (T1) the maximum RWC was obtained for 27P63 (88.13%) and (90.23%) for silicon treated plant (T2). In case of silicon and water stress fertilized plant (T3) the highest RWC was for (83.52%) and 27P63 (71.45%) for (T4). RWC at flowering was observed significantly increased in both the year for silicon treated plants when compared to the control plants. Statistically analysis showed that the interaction between treatment and genotypes was observed to be significant for all genotypes in 2020 and 2021.A significant percent RWC at flowering for T2 over T1was recorded in DRR Dhan (8.43% and 8.33%) respectively whereas the minimum percent increment was obtained in SD. DHAN (1.38%) and US-312 (1.50%) respectively in 2020 and 2021. The highest percent increment of RWC for T3 over T4 was recorded in 27P63 (14.44% and 16.90%) respectively in 2020 and 2021. The minimum percent rise was for US-312 (8.73% and 8.60%) respectively for T3 over T4 in 2020 and 2021.

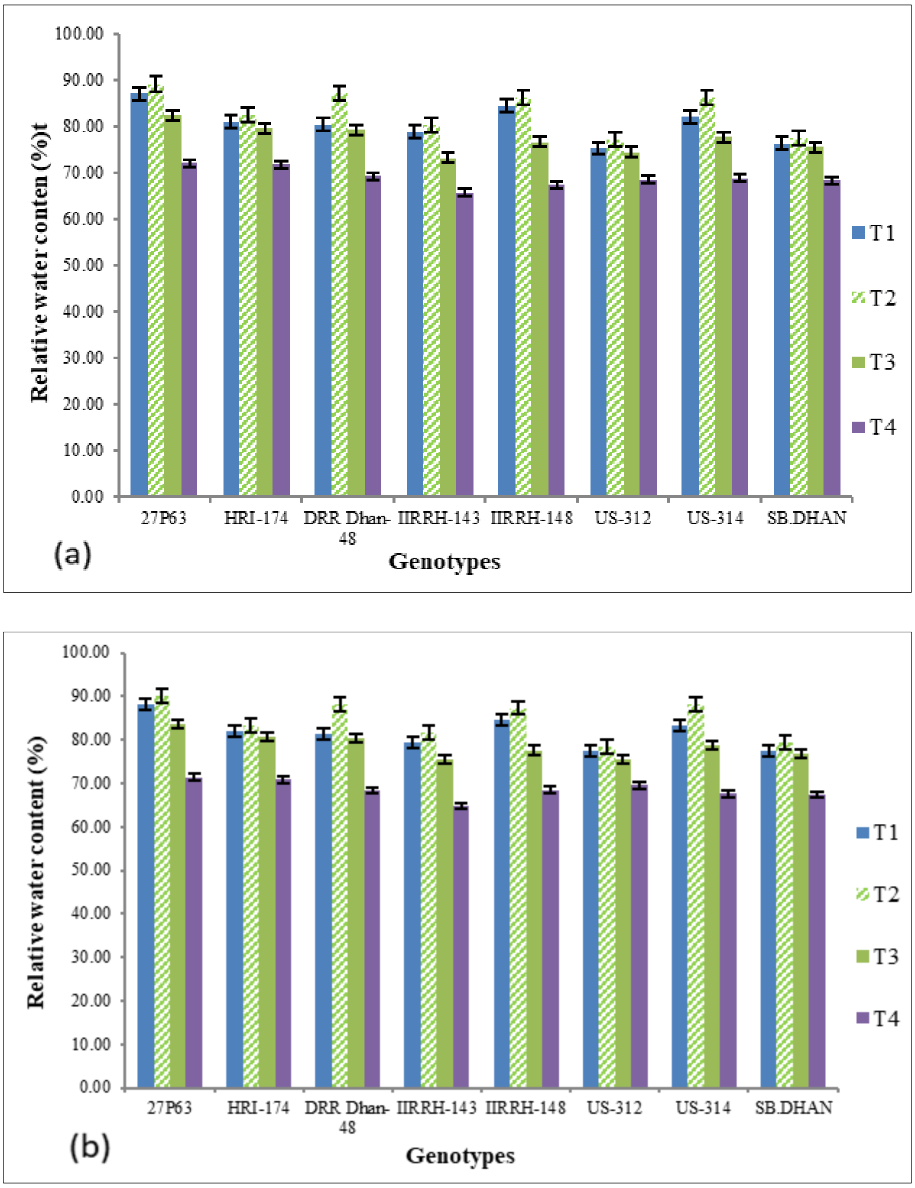

Fig 4a, b: Influence of silicon solubilizers on relative water content (RWC) (%) in different rice genotypes during kharif season of 2020-2021 and vertical bars indicate ± standard error of mean.

In both the years, application of silicon (0.6%) was significantly higher in RWC content of rice under both normal and water stress conditions. Si enhances relative water content by silicifying cell walls, resulting in decreased water loss through transpiration (Gong *et al*. 2003) [20]. The use of Si has also shown to enhance the water status of stressed plants (Shen *et al*. 2010) [37]. In the current study, maximum RWC content was recorded in silicon treated plants along with water stress as compared to water stress only. These finding suggest that applying Si to rice in a field during a water stress can help it retain more water. A previous experiment conducted with silica fertilizer has a favourable influence on relative water content during drought stress (Othmani *et al*. 2020; Nabizadeh *et al*. 2010) [28, 26]. 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 (Ghouri *et al*. 2021) [17]. The foliar silica nano formulation application is improved the RWC of rice (CO54 and CO53) under drought (Raja *et al.* 2021) [34].

Conclusion

We can draw conclusions based on the findings presented here; the foliar application of silicon (0.6%) was able to significantly ($p>0.05$) increase on plant height, MSI and RWC content in different rice genotypes under normal and water deficit conditions. Thus, silicon foliar application may be used to decrease the effects of drought for sustainable rice production under climate change condition. It also appears to be a long-term solution for biological and non-biological agricultural stress alleviation. More emphasis on the cellular processes of Si-induced stress tolerance, as well as their links with various stress resistance mechanisms in agricultural plants may help to boost yield under a range of stress conditions in the future.

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