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RESEARCH ARTICLE

Influence of Silicon on Physiology and Yield of Rice under Drought Stress

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Abstract

A field experiment was conducted during *kharif* season of 2017 at the Department of Rice, Tamil Nadu Agricultural University, Coimbatore, to study the effect of drought on physiology and yield of rice genotypes and to assess the effect of silicon on physiology and yield of rice under drought stress. Seven genotypes of rice were used in study and they were imposed with various treatments *viz.,* control, drought at flowering stage and foliar spray of silicon [Silixol (0.6 %); orthosilicic acid] during drought. Among the various genotypes used for the study, CB13804 recorded the highest total dry matter production (TDMP) and specific leaf weight(SLW) in drought and foliar spray of silicon under drought. Concerning the yield parameters, the higher number of productive tillers was recorded in CB13805 under drought and foliar spray of silicon under drought. The highest grain yield under drought was recorded in CB13804. Based on the various parameters recorded, it has been found that the genotypes CB13804 and Sahbhagi Dhan are promising drought tolerant with minimum reduction in yield and hence can be suggested for drought prone areas, whose yield potential can be increased by the foliar spray of silicon under drought at the flowering stage.

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Introduction

Rice (*Oryza sativa* L.) is one of the most important crops of the world and forms the staple diet of about 2.7 billion people and the requirement will be increased by 50% in 2050 owing to the ever-increasing population and the shift in food habit. Rice, being a water-loving crop got the higher sensitivity to water deficit stress by innate.

Drought invariably affects rice severely in all aspects *viz.* morphological, physiological, biochemical, molecular aspects and in turn drastically influences the yield reduction (Pandey and Shukla, 2015). Reproductive stage is the most critical phase for drought susceptibility, which can delay flowering in rice, reduce pollen viability, stigma receptivity, alters anthesis resulting in poor fertility, leading infilled and reduced grain production (Kumar *et al*., 2014).

Silicon (Si) is the second most element in earth by its abundance next to oxygen. Silicon is beneficial for higher plants, especially under stressful environment wherein plants uptake silicon in the form of monosilicic acid (H_4SiO_4), which is soluble in nature (Chen *et al*., 2018). Silicon subsidizes stress tolerance by physical and mechanical protection (SiO_2 deposits) 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). Silicon can alleviate the drought stress by decreasing transpiration by forming silicon cuticle double layer (Tripathi *et al*., 2016). Therefore, in this research, the effects of foliar Si application on physiology and growth of rice under drought conditions were examined. The results could help us to achieve a better understanding of the physiological mechanisms of Silicon induced drought tolerance in rice plants.

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Material and Methods

A field experiment was carried out in the Department of Rice, Tamil Nadu Agricultural University, Coimbatore during *kharif* season of 2017. Experiment was carried out in factorial randomized block design with seven short duration rice genotypes *viz.,* CB06803, CB08702, CB12702, CB13804, CB13805, Sahbhagi Dhan and IR64, which were imposed with a control (well-watered) and drought, followed by drought along with foliar spray of silicon. Silicon used for spray was Silixol (0.6 %); stabilized orthosilicic acid, which is available form for plant uptake. Drought was imposed by withdrawing irrigation on treatments,drought and foliar spray of silicon (Silixol 0.6%) under drought, plots from 12 days before flowering to 10 days after flowering.Irrigation was checked by bund and the seepage was prevented by covering the bunds with plastic sheets. Buffer channels were made to drain out the water from drought imposed plots. Silicon as Silixol (6 ml L^{-1}) was given as foliar spray at 50 % flowering in middle of the drought.

The entire plant was pulled outat flowering stage and dried till constant dry weight was obtained for total dry matter production (TDMP) and expressed in g $plant^{-1}$. Specific leaf weight (SLW) wasobtained by calculating dry weight per unit leaf area and expressed in mg cm^{-2}. Chlorophyll content in leaves was estimated by Hiscox and Israelstam (1979) method and expressed in mg $g^{-1}$of fresh weight. Photosynthetic rate was measured using a portable photosynthesis system (LI-6400 XT; LI-COR Inc. Lincoln, Nebraska, USA) with defined light intensity of 1500 µmol m^{-2} s^{-1} PAR and ambient CO_2 concentration expressed finally in µmol CO_2 m^{-2} s^{-1}. chlorophyll fluorescence was measured using chlorophyll fluorescence meter (Opti-Sciences OS1p) with 20 minutes of dark adaptation. The key fluorescence parameters Fo (Initial fluorescence), Fm (Maximum fluorescence), Fv (Variable fluorescence) and the ratio of Fv / Fmwere obtained. Soluble protein content of the leaf was estimated by the method suggested by Lowry *et al*. (1951) and expressed as mg g^{-1} of fresh weight whereasmembrane stability index (MSI) was estimated as per Sairam *et al*. (1997), and expressed in percent. Number of productive tillers per plant was counted and expressed in numbers, whereas spikelet fertility per panicle was calculated andexpressed in percent. Grains from each plot were sun dried, weighed and adjusted to 14 per cent moisture content and the grain yield was expressed as kg ha^{-1}.

Results and Discussion

The total dry matter production (TDMP)is the overall efficiency of a plant in resource utilization of light, water and nutrient for the synthesis of photosynthates.In this experiment, the results revealed that drought significantly reduced TDMP with a mean reduction of 40% over control (Table.1).

Table 1. Effect of silicon on changes in total dry matter production (g plant $^{-1}$), specific leaf weight (mg cm^{-2}), total chlorophyll (mg g^{-1}), leaf soluble protein (mg g^{-1}) in rice genotypes under drought.

Genotypes	Total dry matter production (g plant $^{-1}$)			Specific leaf weight (mg cm^{-2})			Total chlorophyll (mg g^{-1})			Leaf soluble protein (mg g^{-1})		
	Control	Drought	Drought + Silicon	Control	Drought	Drought + Silicon	Control	Drought	Drought + Silicon	Control	Drought	Drought + Silicon
CB06803	68.1	45.9	51.7	5.67	5.03	5.18	2.5	1.6	1.8	16.5	11.2	14.7
CB08702	63.7	29.9	37.1	6.17	5.13	4.77	2.4	2.0	2.1	15.8	11.4	13.2
CB12702	57.4	27.4	36.7	7.17	4.97	5.77	2.6	1.3	2.3	16.0	13.9	14.3
CB13804	65.2	50.6	51.9	6.30	5.47	5.79	4.0	2.3	3.6	14.0	12.7	13.5
CB13805	70.7	36.3	44.1	5.37	4.70	5.03	2.8	1.9	2.5	18.4	12.6	16.0
IR 64	59.1	32.1	33.9	5.80	4.67	4.83	3.7	2.5	3.1	17.3	10.5	15.2
Sahbhagi Dhan	50.6	37.1	41.2	7.03	5.03	5.64	2.5	1.4	2.4	17.2	12.9	15.7
Mean	62.1	37.0	42.4	6.22	5.00	5.29	2.9	1.9	2.5	16.5	12.2	14.7

	SEd	CD (0.05)	SEd	CD (0.05)	SEd	CD (0.05)	SEd	CD (0.05)
G	1.64	3.31 **	0.18	0.36 **	0.036	0.072 **	0.186	0.375 **
T	1.07	2.17 **	0.12	0.24 **	0.023	0.047 **	0.122	0.246 **
G x T	2.84	5.74 **	0.31	0.62 **	0.062	0.125 **	0.321	0.650 **

Control = well-watered

Higher dry matter production under drought was observed in genotype CB13804 (50.6 g plant $^{-1}$) wherein lower the dry matter production (27.4 g plant $^{-1}$) was obtained in genotype CB12702. TDMP reduction under drought may be due to reduction in leaf number, leaf area which consequently affects the photosynthetic system, by the synthesis of ROS and inefficiency of generative tissues.Foliar spray of Silicon (Silixol 0.6%) under drought higher TDMP by 13%than drought, of which the highest was recorded in genotype CB13804

(51.9 g plant $^{-1}$) and the least was recorded in IR64 (33.9 g plant $^{-1}$). Improving the TDMP under drought by application of silicon may be due to enhancement of gas exchange parameters, photochemical efficiency, mineral nutrient absorption, thickness of leaves, silicification of cells and by deposition of silicon in plant tissues as reported by Chen *et al*., (2018).

Table 2. Effect of silicon on changes in membrane stability index, productive tillers plant^{-1}, spikelet fertility, grain yield (kg ha^{-1})in rice genotypes under drought

Genotypes	Membrane stability index			Productive tillers plant^{-1}			Spikelet fertility			Grain yield(kg ha^{-1})		
	Control	Drought	Drought + Silicon	Control	Drought	Drought + Silicon	Control	Drought	Drought + Silicon	Control	Drought	Drought + Silicon
CB06803	93.1	78.1	82.4	20.0	17.3	18.7	93.6	73.5	85.7	7043	5712	6528
CB08702	86.2	73.5	81.5	15.0	12.3	13.3	91.7	74.6	84.4	7616	5174	6582
CB12702	88.4	68.4	79.4	18.7	12.7	17.3	90.5	72.1	83.1	6653	4696	6482
CB13804	91.6	76.2	85.3	20.7	16.0	19.7	84.2	68.4	72.1	7309	6270	6983
CB13805	89.5	70.3	78.7	24.0	22.7	23.3	91.1	84.7	90.2	6997	4976	6505
IR 64	90.7	67.6	83.6	18.7	14.3	16.3	83.3	55.6	74.2	6523	5397	5904
Sahbhagi Dhan	91.2	79.8	88.4	18.7	14.3	15.7	87.2	76.1	82.0	7456	5545	6813
Mean	90.1	73.4	82.8	19.4	15.7	17.8	88.8	72.1	81.7	7085	5396	6543

	SEd	CD (0.05)	SEd	CD (0.05)	SEd	CD (0.05)	SEd	CD (0.05)
G	1.149	2.323 **	0.247	0.499 **	1.060	2.143 **	98.35	198.78
T	0.752	1.521 **	0.162	0.327 **	0.694	1.403 **	64.39	130.13
G x T	1.990	4.023 **	0.428	0.865 **	1.837	3.712 **	170.35	344.30

Control = well-watered

Specific leaf weight (SLW) confines directly to the thickness of the leaf, which observed at end of reproductive stage drought shown significant reduction over the control. Genotype CB13804 registered the highest SLW under drought (5.47 mg cm^{-2}) while the least SLW (4.67 mg cm^{-2}) was observed in IR64, with a mean reduction of 18% SLW over the control(Table.1). Upon Silicon (Silixol 0.6 %) spray under drought SLW had increased notably by 5% where the higher SLW was recorded in genotype CB13804 (5.79 mg cm^{-2}) closely followed by CB12702 (5.77 mg cm^{-2}) and lower SLW was recorded in CB08702 (4.77 mg cm^{-2}). Increase in the SLW under drought because of silicon spray may be due to induction of innate drought tolerant mechanism (thickening of leaves), silica deposition in the leaves, activity of the silicon transporters (Lavinsky *et al*., 2016) which helps in retention of leaf erect, trapping more light energy, reducing the sensitivity to leaf rolling. These results were found to be in consonance with the reports by Garg *et al*. (2017) and Wang *et al*. (2017) in rice.

Chlorophyll content decreased in drought stressed plants by17% in comparison to control(Table 1),with the highest chlorophyll content in IR64 (2.5 mg g^{-1}) and lowest was observed in CB12702 (1.3 mg g^{-1}). The reduction of chlorophyll content under drought stressed plants may be due to the fact that drought stress blemishes the chlorophyll content through causing internal modification in the thylakoid membrane. Foliar spray of silicon (Silixol 0.6 %) under drought increased the total chlorophyll content by 11 % over the plants imposed with drought with higher (3.6 mg g^{-1}) in CB13804 and as the lower value (1.8 mg g^{-1}) in CB06803. Similar result of silicon improved chlorophyll content under drought in wheat was reported by Maghsoudi *et al*. (2015) and it may be due to increased antioxidant enzyme activity.

Photosynthetic ability during and after drought stress was identified as important index of drought resistance.The ability of plants to continue relatively higher rate of photosynthetic activity under drought can contribute significantly to the yield. Photosynthetic rate observed in various rice genotypes shows a decrease of 15 % under drought over the control, with the higher photosynthetic rate (29 µmol CO_2 m^{-2} s^{-1}) was recorded in Sahbhagi Dhan and the lowest was observed in genotype CB13805 (16.4 µmol CO_2 m^{-2} s^{-1}) (Fig. 1). Reduction in photosynthetic rate under drought may be due to inhibition of photochemical efficiency, shift in chlorophyll fluorescence, reduced chlorophyll content, closure of stomata, decline in intercellular CO_2 concentration in leaves thereby, reduction in CO_2 assimilation, ROS production, membrane damage and rolling of leaf. Foliar spray of silicon (Silixol 0.6%) under drought increased the photosynthetic rate by 7% over the drought stressed plants, with maximum observed in Sahbhagi Dhan (29.1 µmol CO_2 m^{-2} s^{-1}) and the lowest one was observed in CB13805 (19 µmol CO_2 m^{-2} s^{-1}). Higher photosynthetic rate may be due to the improved efficiency in water uptake, stomatal conductance, water use efficiency and root hydraulic conductance, when drought stressed plants were supplied with silicon. Similar results were obtained previously under experiments of Chen *et al*. (2011) in rice.

Chlorophyll fluorescence parameters projects the statusof photosystem II (PSII) activity and changes in photosynthetic metabolism of stressed plants where in maximum/potential quantum efficiency of PS II (Fv/Fm) related with photosynthetic efficiency of plant leaves has been widely used to detect stress-induced perturbations in the photosynthetic apparatus. Fv/Fm ratio were found influenced by both genotype and treatments shows a mean decline of 15 % under drought with Sahbhagi Dhan recorded the highest efficiency (0.72) and the lowest efficiency was recorded in IR64 (0.61) (Fig. 2). Drought induced decline in chlorophyll fluorescence parameter may be due to decreased efficiency of energy transfer from the antennae to the reaction centers and inhibition of activity of PS (II) reaction centers. Foliar spray of silicon (Silixol 0.6 %) under drought increased Fv/Fm ratio significantly by 11% with 0.77 as the highest in genotype CB13805 followed by 0.76 in CB06803 and the lowest of 0.72 was recorded in CB12702. Similar reports were obtained in several experiments and it may be the ability of silicon to alleviate the drought induced damage to photosystems (Chen *et al*., 2011).

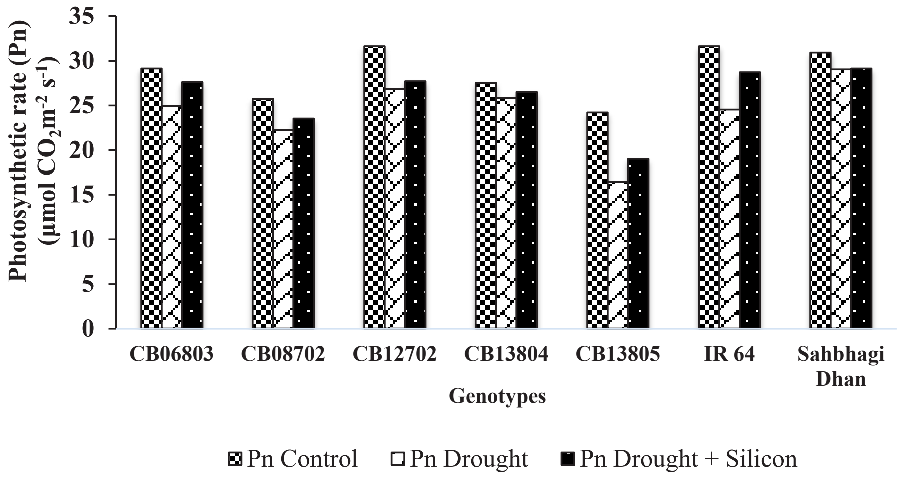

Fig. 1.Effect of silicon on changes in photosynthetic rate (μmol $CO_2m^{-2}s^{-1}$) in rice genotypes under drought

Leaf soluble protein is the indirect measure of RuBisCO enzyme, which is the primary element in carbon fixation cycle. RuBisCO enzyme forms nearly 50 per cent of soluble protein in leaves of many plants and it is severely affected by the severity and duration of moisture stress. Leaf soluble protein is the first nitrogenous compound to be lost under abiotic stress. Drought imposition considerably reduced the soluble protein content by 25% over control wherein genotype CB12702 registered the highest value of soluble protein (13.9 mg g^{-1}) and the lower soluble protein content was recorded in IR64 (10.5 mg g^{-1}) (Table.1). Silicon (Silixol 0.6 %) as foliar spray under drought increased the soluble protein content significantly by 16% over drought with higher content (16 mg g^{-1}) recorded in CB13805, while the lowest was observed in CB08702 (13.2 mg g^{-1}). Silicon might increase the tolerance by enhancing the membrane integrity and keeping the photosynthetic system and pigments undamaged by oxidative stress. Similar reports were evidenced in several experiments by Korres *et al*. (2017) and Hasanuzzaman *et al*. (2018).

Cell membrane remains the primary target of injury, when they are exposed to stress. Stress increases the membrane permeability, leading to greater electrolyte leakage. Drought had decreased the membrane stability index (MSI) over control by 18.5%, Sahbhagi Dhan retained the maximum MSI (79.8) and IR64 fetched the lowest (67.6) under drought (Table 2). Foliar spray of Silicon (Silixol 0.6 %) under drought increased the MSIby 11% over drought with maximum (88.4) in Sahbhagi Dhan, wherein minimum (78.7) was observed in CB13805. MSI was observed as an indicator of drought tolerance of rice genotypes. Silicon treated plants retained a higher MSI than drought stresses plants, by improved membrane integrity. Silicon may reduce the damage to membrane through reduced MDA formation (lipid peroxidation), by regulating the antioxidant defense in plants, maintaining the membrane integrity and decreasing membrane permeability (Etesami and Jeong, 2018).

Number of productive tillers retained under stress is an important yield component that has a significant impact on the grain yield of rice. Productive tillers observed at the physiological maturity with response to genotype and treatment showed a mean reduction of 19% under drought; among the seven genotypes, CB13805 had recorded the maximum productive tillers regardless of the treatment imposed (Table 2). The genotype had documented productive tillers of 24, 22.7 and 23.3 per plant in control, drought and foliar spray of Silicon (Silixol 0.6 %) under drought, respectively. Another genotype CB08702 recorded the lowest number of tillers per plant irrespective of the treatments, wherein tiller number of 15, 12.3 and 13.3 were observed in control, drought and foliar spray of Silicon (Silixol 0.6 %) under drought, respectively. Foliar spray of Silicon (Silixol 0.6 %) under drought increased the productive tillers by 11% over drought.

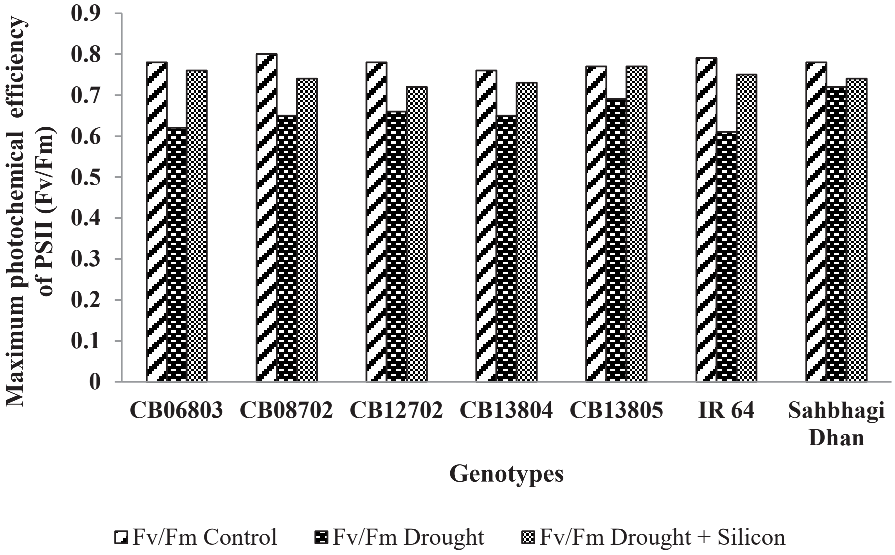

Fig. 2.Effect of silicon on changes in maximumphotochemical efficiency of PSII (Fv/Fm)in rice genotypes under drought

Spikelet fertility in relation to filled and unfilled grains per panicle was calculated. Spikelet fertility was declined by 18% under drought, in which genotype CB13805 had retained the higher spikelet fertility (84.7%) whereas, the lower was recorded in IR64 (55.6 %) under drought(Table 2). Foliar spray of Silicon (Silixol 0.6 %) under drought had increased spikelet fertility significantly by 11% with the highest (90.2%) in CB13805 while CB13804 retained the lower fertility (72.1%). Silicon deposited in the hull between the epidermal cell wall and the cuticle, forming a cuticle-Si double layer as in the leaf blades may reduce cuticular transpiration in hull as no stomata was found in hull. The rate of water loss from low Si spikelets was about 20% higher than that from spikelets containing higher Si at both the milky and maturity stages (Ma *et al*. 2001); this may be the reason for higher yield under drought on silicon supply.

Grain yield per hectare obtained at the harvest stage had influence on both treatment and genotypes. Among the treatments, maximum grain yield (7616 kg ha^{-1}) in CB08702 and lower grain yield (6523 kg ha^{-1}) in IR64 were recorded under control (Table 2). Drought had significantly reduced yield of all genotypes by 23%, with lower grain yield (4696 kg ha^{-1}) in CB12702 and maximum grain yield (6270 kg ha^{-1}) in CB13804 were recorded in drought. Significant increase in grain yield of all the genotypes were observed by 17%, of that maximum grain yield (6983 kg ha^{-1}) in CB13804 and minimum grain yield (5904 kg ha^{-1}) in IR64 were observed in foliar spray of Silicon (Silixol 0.6 %) under drought. Silicon improves the yield components by enhancing various physiological and biological processes contributing to the final yield of the plant. Silicon enhanced yield under drought may be due to decreased percentage of reduction in plant height, leaf area, chlorophyll content, gas exchange parameters under drought, improved photochemical efficiency, higher plant water status, which tend to increase several components of yield including panicle length, weight, spikelet number, spikelet fertility and 1000 grain weight (Cuong *et al*., 2017; Pati *et al*., 2016; Ullah *et al*., 2018).

Conclusion

From the above results, it may be concluded that growth, physiology, biochemical characters and yield of different rice genotypes were significantly influenced by drought and foliar spray of silicon (Silixol 0.6 %) during middle of the drought. Irrespective of the genotypes, foliar spray of silicon (Silixol 0.6 %) under drought enhanced better performance and drought tolerance over the drought treatment genotypes. CB13804 and Sahbhagi Dhan are promising drought tolerant lines and hence, can be suggested for drought prone areas, whose yield potential can be increased by the foliar spray of silicon under drought at the flowering stage.Thus, the identified rice genotypes, CB13804 and Sahbhagi Dhan can be effectively utilized donors for developing drought tolerant lines. Drought sensitive genotypes could resemble resistant genotypes upon foliar application of silicon.

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