Effects of Silicon on Upland Rice under Drought Condition

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ABSTRACT

Effect of silicon on upland rice under drought condition were studied in four upland rice varieties which were different in silicon uptake ability. These upland rice varieties included Hao, IRAT 191, SMG 9037-2-1-1-2 and SMGC 90002-4. Results of the study indicated that silicon in leaf blade increased as silicon concentration was increased in culture solution. Hao variety showed the highest silicon concentration in leaf blade, followed by SMGC 90002-4, SMG 9037-2-1-1-2 and IRAT 191, respectively. Results of this study revealed further that upland rice varieties, when grown under high silicon culture solution, resulted in increasing relative water content and decreasing stomatal resistance of leaves when compared with non-silicon culture solution. In addition, stomatal resistance showed highly negative significant correlation with both relative water content (r = -0.58**) and silicon concentration in leaf blade (r = -0.82**) whereas silicon concentration in leaf blade had highly positive significant correlation with relative water content (r = 0.74**). Since silicon concentration in leaf blade of upland rice varieties showed predominant characters in connection with drought resistance, hence, high uptaking and accumulating ability of silicon in leaf blade could be possible and helpful as a selection criterion for breeding and improvement of drought resistance in upland rice crop.

Key words: Drought, Relative water content, Silicon, Stomatal resistance, Upland rice

INTRODUCTION

Although silicon (Si) is not considered as an essential element for growth and development, addition of this element can increase growth and yield of rice (Yoshida, 1981; Takahashi et al., 1990; Takahashi, 1995; Savant et al., 1997). The beneficial effects of Si on rice growth are mostly attributable to the characteristics of the silica gel accumulated on the epidermal tissues. This accumulation helps alleviate water stress by decreasing transpiration, improving light interception characteristics by keeping leaf blade erect, increasing resistance to diseases, pests and lodging, improving reproductive fertility and thus, final yield (Yoshida et al., 1969; Idris et al., 1975; Marwat and Baloch, 1985; Snyder et al., 1986; Takahashi, 1995; Savant et al., 1997; Ma and Takahashi, 2002). However, the effects of Si on upland rice under drought condition and informations regarding drought resistance are still lacking. Therefore, this study is focused on the effects of Si application on drought resistance, and the relationship between Si concentration in leaf blade and drought resistance in upland rice in order to verify whether silicon concentration in leaf blade could be useful to a selection criterion for breeding drought-resistant variety in upland rice.

MATERIALS AND METHODS

This experiment was conducted during September to October, 2006, at the nursery of Rajamangala University of Technology Lanna-Nan, Nan. Four upland rice vareities differing in Si uptake ability were used as plant materials for this study. They were Hao (high Si concentration in leaf), IRAT191 (low Si concentration in leaf), SMGC90002-4 (high Si concentration in stem) and SMG9037-2-1-1-2 (low Si concentration in stem). These differences in Si uptake ability among genotypes were reported by Surapornpiboon et al., (2004). The treatments were consisted of 0 and 200 ppm of Si application in culture solution. They were replicated three times and the experiment was laid out in Completely Randomized Design. Seeds of four upland rice varieties were soaked in water for overnight at 25°C in the dark after sterilizing the surface with 0.1% sodium hypochlorite for 2 min. The seeds were then transferred to a net floated on Yoshida et al., (1976) solution in a plastic container. The composition of this nutrient solution contained the macronutrients 1.4 mM NH_4NO_3, 0.3 mM $NaH_2PO_4.2H_2O$, 0.5 mM K_2SO_4, 1.0 mM $CaCl_2$ and 0.8 mM $MgSO_4.7H_2O$ and the micronutrients 11 µM $MnCl_2.4H_2O$, 0.1 µM $(NH_4)_6.Mo_7O_{24}.4H_2O$, 19 µM H_3BO_3, 0.2 µM $ZnSO_4.7H_2O$, 0.2 µM $CuSO_4.5H_2O$ and 36 µM $FeCl_3.6H_2O$. On day 7, three seedlings of uniform size were transferred to a 3.5-l plastic pot containing one-half-strength Yoshida et al., (1976) solution with applied 0 or 200 ppm of Si. The pH of this solution was 5 and the nutrient solution was renewed every 7 days. After one month, the culture solution with various Si concentrations were added PEG 6000, giving -0.3 MPa of drought stress. The required amount of PEG 6000 was computed according to Lawlor (1970). Solution of PEG 6000 was purified by mixing with ion-exchange resin prior to adding nutrients. The experiment was terminated after 10 days when different drought signs among genotypes were visible.

Data collection

The performance of four rice varieties under different treatments was recorded through dry weight, relative water content (RWC), stomatal resistance and Si concentration in leaf blade.

1) Dry weight: For each sample, rice plant samples were taken randomly from 5 plants of each variety. Then, these plant samples were separated into two parts:

first part was shoots and second part was roots. Each part of rice plant samples was then oven-dried for 72 hr at 80°C and the dry weight of each organ was measured after drying the samples.

2) RWC: For each sample, 5 pieces of the second-youngest fully-expanded leaf were weighed and cut into 5-cm segments and then allowed to rehydrate inside a refrigerator overnight. The following day, samples were blotted dry and turgid weight immediately determined. The leaves were then oven-dried for 2 days at 80°C. Leaf RWC was then calculated according to Basnayake et al., (1993).

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

when FW = Fresh weight of leaves
DW = Dry weight of leaves
and TW = Tugor weight of leaves

3) Stomatal resistance: For each sample, stomatal resistance was measured at the youngest fully-expanded leaf from 5 plants of each genotype between 11.00 to 12.00 am by polometer (model AP4 produced by Delta-T devices-Cambridge-UK).

4) Si concentration in leaf blade: For each sample, leaf blade of rice plant samples were taken randomly from 5 plants of each genotype. Silicon concentration in leaf blade was determined by the AID method (Elliott and Snyder, 1991) as described before.

Statistical analysis

Data were analysed statistically by analysis of variance (ANOVA), with subsequent comparison of means by the least significant difference test (LSD). All of statistical analyses were done by using commercial software (Statistix V. 7.1, Analytical Software, Inc.).

RESULTS

Dry weight

Table 1 shows dry weight of upland rice plant parts which included root and shoot dry weights which were significantly increased by Si application in culture solution under drought condition ($P < 0.01$). However, significant differences were not observed in root and shoot dry weights among the varieties ($P > 0.05$). In addition, significant interaction was not observed between the Si application and variety for the root and shoot dry weights.

Stomatal resistance

As shown in Table 2, the stomatal resistance of leaves was significantly decreased by Si application in culture solution under drought condition ($P < 0.01$). Applying 200 ppm of Si in culture solution decreased the stomatal resistance of leaves from 8.7667 to 4.2542 s cm^{-1}, compared with no Si application or decreased about 51.47%. While variation among varieties was significant for the stomatal resistance of leaves ($P < 0.01$), IRAT 191 variety showed the highest stomatal resistance of leaves, followed by SMG 9037-2-1-1-2, SMGC 90002-4 and Hao, respectively. However, SMG 9037-2-1-1-2, SMGC 90002-4 and Hao were not significantly different.

There was significant interaction between Si application and variety on the stomatal resistance of leaves ($P < 0.01$). When Si was applied in the culture solution, the stomatal resistance of leaves decreased in all varieties and was accounted for about 31.90 to 65.66% of the stomatal resistance of leaves. The strongest effect of Si application on the stomatal resistance of leaves was on SMG 9037-2-1-1-2 variety (65.66%) and the least effect was on SMGC 90002-4 (31.90%). Among the four upland rice varieties, IRAT 191 showed highest stomatal resistance when it was grown in culture solution without Si application.

Table 1. Effect of Si application on root dry weight and shoot dry weight of Hao, IRAT 191, SMG 9037-2-1-1-2 and SMGC 90002-4 variety grown under drought condition.

Variety	Si concentration in culture solution (ppm)	Root dry weight (g $plant^{-1}$)	Shoot dry weight (g $plant^{-1}$)
Hao	0 200	0.0904 0.0970	0.2114 0.2708
IRAT 191	0 200	0.0893 0.0930	0.2315 0.2686
SMG 9037-2-1-1-2	0 200	0.0910 0.1016	0.2341 0.2561
SMGC 90002-4	0 200	0.0748 0.1063	0.1712 0.2656
Means for Si conc.*	0 200	0.0864^x 0.0995^y	0.2121x 0.2652y
Means for variety*	Hao IRAT 191 SMG 9037-2-1-1-2 SMGC 90002-4	0.0937 0.0912 0.0963 0.0906	0.2411 0.2500 0.2451 0.2184
F-test (Si)		**	**
F-test (var.)		ns	ns
F-test (Si x var.)		ns	ns

* Data are the means of three replications. Different letters in the table indicate significant differences by LSD ($P < 0.01$).

** and ns = significant at the 0.01 probability level and not significant by ANOVA, respectively.

Table 2. Effect of Si application on leaf stomatal resistance, relative water content and Si concentration in leaf blade tissues of Hao, IRAT 191, SMG 9037-2-1-1-2 and SMGC 90002-4 variety grown under drought condition.

Variety	Si concentration in culture solution (ppm)	Leaf stomatal resistance (s cm^{-1})	Relative water content (%)	Si concentration in leaf blade tissues (mg g^{-1})
Hao	0 200	7.3333^{c} 3.6333^{e}	82.637 93.313	0.0038^{e} 38.433^{a}
IRAT 191	0 200	11.367^{a} 5.4000^{d}	80.027 81.620	0.0024^{e} $18{,}244^{d}$
SMG 9037-2-1-1-2	0 200	9.3667^{b} 3.2167^{e}	81.740 85.703	0.0031^{e} 24.367^{c}
SMGC 90002-4	0 200	7.0000^{c} 4.7667^{de}	79.253 89.907	0.0024^{e} 27.083^{b}
Means for Si conc.†	0 200	8.7667^{x} 4.2542^{y}	80.914^{x} 87.636^{y}	0.0029^{x} 27.032^{y}
Means for variety†	Hao IRAT 191 SMG 9037-2-1-1-2 SMGC 90002-4	5.4833^{p} 8.3833^{q} 6.2917^{p} 5.8833^{p}	87.975^{p} 80.823^{q} 83.722^{pq} 84.580^{pq}	19.219^{p} 9.1234^{s} 12.185^{r} 13.543^{q}
F-test (Si)		**	**	**
F-test (var.)		**	*	**
F-test (Si x var.)		**	ns	**

† Data are the means of three replications. Different letters in the table indicate significant differences by LSD ($P < 0.05$ or 0.01 followed to *F*-test).

**, * and ns = significant at the 0.01, 0.05 probability levels and not significant by ANOVA, respectively.

Relative water content

Under drought condition, RWC in leaves was significantly increased by Si application in culture solution ($P < 0.01$) (Table 2). It increased about 6.72% when compared with no Si application. For effect of variety, variations among varieties were significant for RWC in leaves ($P < 0.05$) and they were classified into three groups. First group, Hao variety showed highest RWC in leaves. Second group, varieties with the intermediate RWC in leaves were SMGC 90002-4 and SMG 9037-2-1-1-2. And third group, IRAT 191 showed least RWC in leaves. However, significant interaction was not observed between Si application and variety.

Si concentration in leaf blade

The results showed that Si concentration in leaf blade increased significantly by Si application in culture solution under drought condition (Table 2). There were highly significant differences in the Si concentration among the varieties for Si concentration in leaf blade. The highest Si concentration in leaf blade varieties were Hao, followed by SMGC 90002-4, SMG 9037-2-1-1-2 and IRAT 191.

There was significant interaction between Si application and variety on Si concentration in leaf blade ($P < 0.01$) (Table 2). Si concentrations increased in all varieties when applied Si in the culture solution, but the amounts of increase were different among the upland rice varieties. Hao and SMG 9031-2-1-1-2 showed higher Si concentration in no Si application than IRAT 191 and SMGC 9002-4. These discrepant responses of Si content among the Si, both 0 and 200 ppm, application rates resulted in Si x Var. interaction.

DISCUSSION AND CONCLUSION

The results showed that under drought condition, supplemental Si application in the rice culture solution would ameliorate the decrease of stomatal resistance, and lead to the increase of dry weight, relative water content and Si concentration in leaf blade tissues. These results demonstrated that under drought stress conditions, upland rice plants growing in Si-applied culture solution could reduce the transpiration loss of water in order to maintain higher RWC or water potential. As the stomatal resistance and relative water content were closely associated with the status of the plants, these identifications could be quantified and used as criteria for water stress evaluation. Under drought stress, the plant loses more water than it absorbs through its root. It suffers internal moisture stress, the stomata partially or entirely close, conserving water and, hence, preventing loss of internal plant moisture is therefore essential (Yoshida, 1975). The stomatal resistance is the resistance of the leaf to moisture loss through the stomata which can be used as a measurement of internal moisture stress and has negative relationship with the transpiration rate (Yoshida, 1975). Relative water content is the water content in proportion to that at full turgor and is commonly used as a measurement of water status in plant (Turner, 1986). As stomata act as regulators for CO_2 exchange as well as regulators of water loss, water deficit is sufficient to close stomata and must also depress photosynthetic activity (Begg and Turner, 1976). Based on these facts, Si application in culture solution could maintain the photosynthetic activity for the increase in dry weight under drought condition.

Table 3. Correlation among stomatal resistance, relative water content (RWC), root dry weight (RDW), shoot dry weight (SDW) and Si concentration in leaf blade (Si-L) of upland rice grown under drought condition.

Traits/Activity	Stomatal resistance	Relative water content	Root dry weight	Shoot dry weight
Relative water content	-0.58**			
Root dry weight	-0.41*	0.43*		
Shoot dry weight	-0.40	0.56**	0.58**	
Si concentration in leaf blade	-0.82**	0.74**	0.52**	0.67**

** and * = significant at the 0.01 and 0.05 probability levels, respectively.

However, statistical analysis indicated that under drought condition, Si concentration in leave blade showed negative correlation with stomatal resistance and positive correlation with relative water content (Table 3). These results suggested that the Si concentration in leaf blade would enhance the drought resistance in upland rice plant. As transpiration from the leaves occurs mainly through the stomata and partly through the cuticle and Si was deposited beneath the cuticle of the leaves forming a Si-cuticle double layer (Ma and Takahashi, 2002; Ma, 2004), there was a possibility that the Si concentration in leaf blade led to decrease in water loss from cuticle to maintain the high leaf water potential and would mask the increasing transpiration from the stomata. These results were similar to the reports of Ma et al., (2001), Ma and Takahashi (2002) and Hattori et al., (2005). These results clearly indicated that the water loss through transpiration at leaf stomata and the cuticle might be minimized by Si deposition in rice leaves.

In addition, the results showed that significant variations were observed among the varieties for stomatal resistance, relative water content and Si concentration in leaf blade (Tables 1 and 2), indicating that there were some varieties which had higher Si uptake ability than others or the ability of Si uptake depended on genetic variation of upland rice. These results agreed with Garrity et al., (1984), Winslow (1992) and Deren et al., (1992). As described earlier that the Si concentration in leaf blade will enhance the resistance to drought in upland rice plant, these results suggested that varieties possess different degrees of drought resistance (Ma and Takahashi, 2002). Hao variety could maintain higher water content than the other varieties under drought condition. However, there were no significant differences in dry weight among the varieties. Hence, it clearly indicated that varieties which were different in ability of growth and adaptation under drought condition (Fukai and Cooper, 1996) not only depended on Si uptake and accumulation in shoot but also Si could maintain the photosynthetic activity for increasing in dry weight (Ma and Takahashi, 2002; Hattori et al., 2005).

Moreover, there were significant interactions among the Si application and variety on stomatal resistance and Si concentration in leaf blade. Since Si x variety interactions are expressed as a change in the relative performance of varieties with applied Si in the culture solution, therefore, supplemental Si application which enhances the uptaking ability and accumulating Si in upland rice genotypes (Ma and Takahashi, 2002) can be used to improve the drought resistance.

Results of this study could be concluded that under drought stress condition, supplemental Si application in the rice culture solution may be useful as a criterion to improve the drought resistance of upland rice via the enhancement of water content in plant. However, the abilities of Si uptake in upland rice depend both on genetic variation and Si concentration in culture media. Since Si concentration in leaf blade of upland rice varieties showed predominant characters in connection with drought resistance, hence, high uptaking and accumulating ability of Si in leaf blade tissues could be possible and helpful as a selection criterion for breeding drought-resistant in upland rice.

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