Improving rice plant using Si materials on P and Si uptake, growth and production in Ultisols

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Abstract. Silica plays a role on nutrient uptake as increasing soil available P and increasing plant resistance on abiotic and biotic stresses. The purpose of this research was to find out the effect of silica material application on P, Si uptake, rice growth and production. A pot experiment was carried out under greenhouse condition. The experiment was set up in completely randomized design with six treatments and four replications. The treatments used five silica materials, including palm nutshell compost, volcanic ash, palm nut shell ash, coal fly ash, and waste media of mushroom. Urea (200 kg ha⁻¹), SP-36 (75 kg ha⁻¹) and KCl (50 kg ha⁻¹) were applied as basal fertilizer. The results showed that the application of silica material had a significant effect on P and Si uptake in rice plants. The highest P uptake was in the palm nut shell compost treatment compared to the control. Meanwhile, the highest Si uptake was in coal fly ash treatment compared to the control. Silica applications could increase the growth and yield of rice. The highest yield for the 1,000 grain weight and the straw yield were obtained in the palm nut shell compost and coal fly ash treatments compared to the control.

1. Introduction

Ultisols are a mineral soil that distributes widely in Indonesia about 45,759.00 ha of the total land area of Indonesia. Lampung’s Ultisol is a soil that develops in wet tropical climates with high rainfall and temperatures so that it experiences advanced weathering and leaching of basic cation [1]. Leaching of bases and silica ions in the soil causes the soil to react acidiy. Low Si content and high Al solubility, causing low available P [2]. These conditions made Ultisols soil in Lampung – Indonesia has limiting factors in the nutrients P and Si for plant growth.

Rice is one of the crops that suitable in Ultisol. However, the limiting factor possessed by Ultisol can be an obstacle in the process of cultivating rice. Iron toxicity occurs mostly in Ultisols, which is high in active iron and potential acidity. Those conditions, make the growth and development of roots become inhibited, low nutrient absorption, and can affect plant production. Besides, soils that have a pH <5.5 can cause rice yields decreasing by 12 to 100% [3].

Silica has a beneficial effect on the growth of rice plants when P was low or high [4]. This effect might be due to decreased Mn and Fe uptake, thus increased P availability within P deficient plants, or from reduced P uptake when P was high. Kopittke et al. [5] found that Si can reduce the toxicity of Al through the formation of Al-Si complexes.
Silica and P are nutrients needed by rice plants in large quantities [6]. The only Si absorbed is by plants in the form of monosilicic acid or orthosilicic acid ($H_4SiO_4$) [6–8]. While phosphorus is absorbed by plants in the form of $H_3PO_4$ on acid soils and $HPO_4^{2-}$ on alkaline soil [9] Sources that can be utilized but are often considered as waste include oil palm empty fruit bunch compost, Merapi ash, oil palm empty fruit bunch ash, coal fly ash, and waste media of mushroom. Each of these Si sources has various Si contents.

Silica increases phosphorus mobilization, by mobilizing Fe (II)-P phases from mineral surfaces [10]. Furthermore, Si is important for sustainable management of phosphorus availability in soils in general. The beneficial effects of Si on rice growth are increased photosynthesis, decreased susceptibility to disease and insect damage as well as prevent lodging for rice plants [11,12]. Thus, this research needs to be carried out to determine the effect of giving silica material on plant growth and production and its effect on P and Si uptake in rice plants.

2. Materials and methods
The study was conducted in greenhouse of the Indonesian Soil Research Institute from July to October 2018. The experimental design used was a completely randomized design consisting of 6 treatments and 4 replications.

2.1. Soil analyses
The soil sample was collected from Taman Bogo, Lampung. The soil sample was air-dried and crushed to pass through 2 mm sieve. The pH was measured in 1: 5 (soil: water) by using a pH meter. The soil texture was determined by the pipet method. Organic carbon content was determined using The Walkley-Black method. Exchangeable calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were analyzed using 1 M NH$_4$ acetate at pH 7.0, and Ca, Mg, K, and Na in the extracts were measured by flame AAS. Available P was measured using Bray 1 method. Total nitrogen (N) was determined by the Kjedahl method. Available Si was extracted by acetate buffer pH 4.0 with ratio of 1:10, kept in an incubator at 40°C for 5 h with intermittent shaking, and determined using molybdenum blue method [13].

2.2. Si sources materials
There are five silica materials, including control (without Si material), palm nutshell compost (palm nut SB), volcanic ash, palm nutshell ash (palm nut SA), coal fly ash, and waste media of mushroom (MM) (Figure 1).

Silicon was extracted from six materials by acetate buffer pH 4.0 with a modified in ratio 1:30 [13]. The concentration of Si in the supernatant was measured by colorimetric with Spectrophotometer UV at the wavelength of 810 nm.

Figure 1. Silica materials.
2.3. Greenhouse experiment
The soils used for the experiment were collected from Taman Bogo, Lampung. They were collected from in the field using hoe at the depth of 0 to 20 cm (topsoil). Eight kilograms of 2 mm dry soils were weighed into each pot. The soils were saturated with water and stirred by hand to form a slurry. The treatments included control, palm nutshell compost (T1), volcanic ash (T2), palm nutshell ash (T3), coal fly ash (T4), and waste media of mushroom (T5). Silica materials were applied a week before planting. Besides Si materials as treatments, each pot experiment was added with urea (200 kg ha\(^{-1}\)), SP-36 (75 kg ha\(^{-1}\)) and KCl (50 kg ha\(^{-1}\)).

Seeds of INPARI-3 variety were soaked in water for 24 hours before transferring into a seedling pot filled with 3 kg soil as a seedling growing media in the nursery.

| No. | Treatments | Doses Si materials | Doses of basal fertilizer (kg ha\(^{-1}\)) |
|-----|------------|---------------------|------------------------------------------|
|     |            | g pot\(^{-1}\) | kg ha\(^{-1}\) | Urea | SP-36 | KCl |
| 1.  | T0         | -                   | -                        | 200  | 75    | 50  |
| 2.  | T1         | 364.00              | 91 \times 10^3           | 200  | 75    | 50  |
| 3.  | T2         | 712.16              | 178 \times 10^3          | 200  | 75    | 50  |
| 4.  | T3         | 89.52               | 22.38 \times 10^3        | 200  | 75    | 50  |
| 5.  | T4         | 116.08              | 29.02 \times 10^3        | 200  | 75    | 50  |
| 6.  | T5         | 729.44              | 182.32 \times 10^3       | 200  | 75    | 50  |

2.4. Plant growth observation and sampling
Plant height is one indicator of rice plant growth which is used to measure the effectiveness of the treatment applied. After transplanting, the tiller number and plant height were recorded at 2, 4, and 8 weeks after transplanting (WAT). Plant height was measured from ground level to the tip of the topmost of the leaf. The tiller numbers were obtained by counting the number of tillers that grow from the main stem of rice plants. The rice plant was harvested at the maturity phase, separated into straw and grain. Then they were washed thoroughly with distilled water. The plants were dried in an oven at 60 to 70°C for 2 days.

Stem strength and lodging resistance were measured at 10 WAT. Lodging resistance was measured by using Force Gauge. The stem was bent at 15 cm from the soil surface to establish an angle 45° [14].

2.5. Statistical analysis
The effects of the treatment on plant height, tiller number, straw, grain, P and Si uptake were analyzed using analysis of variance (ANOVA) at p < 0.05. Variance analysis was performed using Genstat 4 Edition software. One-way ANOVA was carried out to analyse the effects of the treatment on stem strength and lodging resistance using the statistical package SPSS 22.

3. Results and discussions
3.1. Soil sample and Si materials
The type of soil was Ultisol with a textural class of silty clay and acidic (4.9). Exchangeable K and CEC were very low (0.04 cmol(+), kg\(^{-1}\)) and low (14.53 cmol(+), kg\(^{-1}\)). Organic carbon and total N were low and very low, respectively. The available P and Si were 7.3 ppm PbO\(_3\) and 223.92 ppm SiO\(_2\), respectively. SiO\(_2\) was classified to be below the critical level of available Si for rice (300 mg SiO\(_2\) kg\(^{-1}\)) [15]. The high rainfall in parts of Indonesia causes nutrient leaching rates high especially the bases, so the bases in the soil will be immediately leached out. So that what lives in the clay and humus adsorption complex are H and Al ions. As a result, the soil becomes acidic with low base saturation [1].

The material which has higher available Si concentration was palm nutshell ash (5364 mg SiO\(_2\) kg\(^{-1}\)) and the lower was waste media of mushroom (659 mg SiO\(_2\) kg\(^{-1}\)) (table 2). Based on these results, each
of the materials has a higher SiO$_2$ content compared to the Si available in this soil. Besides, each material also contains available of P, so that it can enrich the availability of phosphorus in Ultisols soil.

| No. | Treatments                      | SiO$_2$ (mg kg$^{-1}$) |
|-----|---------------------------------|------------------------|
| 1   | T0 Control                      | -                      |
| 2   | T1 Palm nutshell compost        | 1,319                  |
| 3   | T2 Volcanic ash                 | 674                    |
| 4   | T3 Palm nut shell ash           | 5,364                  |
| 5   | T4 Coal fly ash                 | 4,134                  |
| 6   | T5 Waste media of mushroom      | 659                    |

3.2. The effect of silica material application on the growth of rice plants

3.2.1. Plant height. Based on the analysis of the variety, it is known that the treatment has a significant effect on the observation of 4 WAT and 8 WAT. The effects and differences in the application of silica material between treatments on plant height are presented in Table 3.

| Treatments | Plant Height |
|------------|--------------|
|            | 2 WAT (cm)   | 4 WAT (cm) | Enhancement (%) | 8 WAT (cm) | Enhancement (%) |
| T0         | 37.02        | 60.05 a     | -                | 89.90 a     | -               |
| T1         | 39.80        | 81.78 b     | 36.18            | 98.90 b     | 10.01           |
| T2         | 38.45        | 78.78 b     | 31.19            | 93.60 ab    | 4.11            |
| T3         | 39.00        | 76.78 b     | 27.86            | 94.20 ab    | 4.78            |
| T4         | 39.50        | 79.10 b     | 31.72            | 94.85 ab    | 5.50            |
| T5         | 38.05        | 79.30 b     | 32.05            | 90.35 a     | 0.50            |

Notes: T0= control (soil); palm nutshell compost (T1), volcanic ash (T2), palm nut shell ash (T3), coal fly ash (T4), and waste media of mushroom (T5).

Table 2 shows that at 2 WAT, the application of silica material on plant height had no significant effect. This is probably because the roots of plant rice have not grown optimally. Also, the application of silica material does not have a direct effect on the growth phase. Silica has little effect on the vegetative phase [16]. At the age of 4 WAT, all treatments showed significant differences with T0. Meanwhile, at 8 WAT, only T1 was significantly different from T0. The highest average plant height was obtained in the T1 with an increase of 4 WAT (36.18%) and 8 WAT (10.01%) compared to that of the control treatment. This is because palm nutshell compost not only containing silica (0.13%) but also containing the highest levels of P$_2$O$_5$ (0.74%) compared to those of other treatments. In support of our findings, it has been reported that the addition of silica can increase uptake of nutrients by roots, especially P elements which affect plant height [17]. Apart from that, silica can also improve photosynthetic efficiency. Silica that accumulates in plant leaves will make the leaves straighter so that they can absorb sunlight more optimally for photosynthesis. The photosynthate produced from the photosynthesis process will be used for the process of plant height growth. The application of silica material from the compost of empty palm oil bunches had a significant effect on the growth of brown rice [18].
3.2.2. Number of tillers. Rice is a plant that can form tillers in each clump. The effect of silica material on the tiller number of rice plants are presented in table 4. The application of silica material significantly affected the tiller number at 4 WAT and 8 WAT observations. Meanwhile, at 2 WAT the treatment had no significant effect on the number of tillers.

Table 4. The effect of silica material application on tillers number.

| Treatments | 2 WAT (cm) | 4 WAT (cm) | Enhancement (%) | 8 WAT (cm) | Enhancement (%) |
|------------|------------|------------|-----------------|------------|-----------------|
| T0         | 3          | 9 a        | -               | 20 a       | -               |
| T1         | 3          | 27 c       | 200             | 38 c       | 90              |
| T2         | 3          | 17 b       | 89              | 36 c       | 80              |
| T3         | 3          | 13 ab      | 44              | 28 b       | 40              |
| T4         | 3          | 23 c       | 155             | 36 c       | 80              |
| T5         | 3          | 23 c       | 155             | 31 b       | 55              |

Note: T0= control (soil); palm nutshell compost (T1), volcanic ash (T2), palm nut shell ash (T3), coal fly ash (T4), and waste media of mushroom (T5). Values with different letter within same column show significant differences at p<0.05.

Figure 2. Effect of treatments on stem strength (A) and lodging resistance (B).

Note: Values with different letter show significant differences at p<0.05 level between treatments according to the Duncan’s multiple range test.

The new basic fertilization is given at 2 WAT, so that the new roots can absorb the available nutrients after 2 WAT. The growth of tillers was seen in the 4 WAT observation. The highest mean number of tillers at 4 WAT and 8 WAT was in the T1 treatment with an increase of 200% and 90%, respectively. At 4 WAT, all treatments showed significant differences from T0 (control) except T3. Meanwhile, at 8 WAT, all treatments were significantly different from T0 (control). This is because the provision of silica can increase the uptake of P nutrients which have a role in cell division and can stimulate shoot growth (tillers). In line with the statement of [11, 19] which stated that giving silica to rice plants would increase the number of tillers. The application of silica can control stomata activity, photosynthesis, the efficiency of water use, and increase P uptake, which in turn it can result in better vegetative growth so that the number of tillers can also increase to a greater number. The tiller number could increase with the increase in P uptake as a result of giving silica, because phosphorus is needed by rice plants in the growth process [20].
3.2.3. **Stem strength and lodging resistance.** The result of stem strength and lodging resistance at 10 WAT is shown in Figure 2. Stem strength in T1 (palm nutshell compost) significantly increased compared to those of other treatments. Meanwhile, in this research, the lodging resistance was not affected by Si materials. The physical strength of the culm is the important factor of lodging resistance [21]. Silica increased the stem strength which was positively correlated with the Si content of the stems [22]. Silica affects to reduce the risk of lodging for rice plants [23, 24]. Furthermore, Si application significantly increased the pushing resistance of rice plants (12.2 to 16.7%) compared to control plants [25].

3.3. **The effect of silica material application on rice yield**

3.3.1. **Dry straw weight**

The results show that the application of silica material had a significant effect on the dry straw weight (table 5). The application of silica material increased dry straw weight than control. The highest dry straw weight was in the P4 treatment followed by T1 treatment. This can be due to the provision of silica material in rice plants which can provide sufficient P nutrient for these plants. The sufficient amount of P nutrients accumulated in the tissue will increase the dry weight of the plant. On the other hand, coal fly ash and palm nutshell compost also contain nutrients Ca and Mg which can support the formation of rice straw [18, 26].

**Table 5. Effect of silica material application on dry straw weight.**

| Treatments | Dry straw weight (g clump<sup>1</sup>) | Enhancement (%) |
|------------|--------------------------------------|-----------------|
| T0         | 31.73 a                              | -               |
| T1         | 44.30 b                              | 39.62           |
| T2         | 40.35 ab                             | 27.17           |
| T3         | 40.88 ab                             | 28.84           |
| T4         | 45.52 b                              | 43.46           |
| T5         | 37.95 ab                             | 19.60           |

Note: T0= control (soil); palm nutshell compost (T1), volcanic ash (T2), palm nut shell ash (T3), coal fly ash (T4), and waste media of mushroom (T5). Values with different letter within same column show significant differences at p<0.05.

3.3.2. **The weight of 1000 grain.** The use of 1,000 grain weight is represented to determine the need for seeds in one hectare. The results show the silica materials application have a significant effect on the weight of 1,000 grain.

**Table 6. Effect of silica material application on 1,000 grain weight.**

| Treatments | 1,000 dry weight (g clump<sup>1</sup>) | Enhancement (%) |
|------------|---------------------------------------|-----------------|
| T0         | 38.25 a                               | -               |
| T1         | 61.58 c                               | 60.99           |
| T2         | 43.98 ab                              | 14.98           |
| T3         | 47.40 ab                              | 23.92           |
| T4         | 55.58 bc                              | 45.31           |
| T5         | 46.33 ab                              | 21.12           |

Note: T0= control (soil); palm nutshell compost (T1), volcanic ash (T2), palm nut shell ash (T3), coal fly ash (T4), and waste media of mushroom (T5). Values with different letter within same column show significant differences at p<0.05.

Table 6 shows that the application of silica material to 1,000 weight has a higher average weight compared to the control. The average weight of 1,000 kernels was obtained in the T1 treatment, followed by T4 treatment with a mean of 61.58 and 55.58 g clump<sup>-1</sup>, respectively. Silica addition improve plant
growth, which might be due to the increased photosynthetic efficiency, and it was exerted through the numbers of productive tillers, panicle length, and grain weight [27].

3.4. Plant nutrients uptake

3.4.1. P uptake by straw. Phosphor uptake was obtained by measuring the P content in dry straw. The results show that the application of Si materials had a significant effect on P uptake (table 7). The highest P uptake was obtained in treatment T1 (71.74 mg clump$^{-1}$). The palm nutshell compost contains higher P$_2$O$_5$ among all treatments. Therefore, T1 treatment provides higher P uptake than other treatments.

Table 7. The effect of silica material on P levels and uptake in rice straw at 15 WAT.

| Treatments | P uptake (mg clump$^{-1}$) |
|------------|----------------------------|
| T0         | 31.93 a                    |
| T1         | 71.74 c                    |
| T2         | 47.81 b                    |
| T3         | 49.17 b                    |
| T4         | 69.71 c                    |
| T5         | 43.12 ab                   |

Note: T0= control (soil); palm nutshell compost (T1), volcanic ash (T2), palm nut shell ash (T3), coal fly ash (T4), and waste media of mushroom (T5). Values with different letter within same column show significant differences at p<0.05.

The application of silica into the soil can increase the P content into a more available form. Si in the form of mono silicic acids resulting in the transformation of slightly soluble phosphates into plant-available P. This can be explained by the chemical reaction of silica on acid soil such as $2\text{FePO}_4 + \text{Si(OH)}_4 + 2\text{H}^+ = \text{Fe}_2\text{SiO}_4 + 2\text{H}_3\text{PO}_4$ [28]. Besides, P uptake has a positive correlation with 1000 grains weight with a value of $r = 0.67$. This indicates that an increase in P uptake will be followed by an increase in the yield. Meanwhile, application of silica material had no significant effect on P uptake in rice plants [29].

3.4.2. Si uptake by straw. Table 8 shows that Si application has a significant effect on Si uptake. Each application of materials resulted in higher Si absorption compared to that of T0 (control). The Si uptake of T0 treatment was significantly different from T1, T2, and T4 treatments. The highest average Si uptake was obtained in the T4 treatment (234.6 mg clump$^{-1}$), then followed by T1 treatment (215.8 mg clump$^{-1}$). Rice plant is Si accumulator as they require a large quantity of Si [7].

Table 8. The effect of silica material on Si levels and uptake in rice straw at 15 WAT.

| Treatments | Si Uptake (mg clump$^{-1}$) |
|------------|---------------------------|
| T0         | 131.0 a                   |
| T1         | 215.8 bc                  |
| T2         | 182.7 b                   |
| T3         | 155.9 a                   |
| T4         | 234.6 c                   |
| T5         | 156.8 a                   |

Note: T0= control (soil); palm nutshell compost (T1), volcanic ash (T2), palm nut shell ash (T3), coal fly ash (T4), and waste media of mushroom (T5). Values with different letter within same column show significant differences at p<0.05.
The high Si uptake in T4 and T1 treatments was the same as plant height and tiller number (table 3 and table 4) and plant production, namely dry straw weight (table 4) and the 1000 grain weight (table 6). Besides, Si uptake with P uptake and 1,000 grain weight has a positive correlation, which indicates that increasing Si uptake will be followed by an increase of P uptake ($r = 0.85$) and 1,000 grain weight ($r = 0.76$).

3.5. Relationship between parameters
Based on the results of the correlation test, it was found that Si uptake had a strong relationship with the weight of 1,000 grain, with $r = 0.76$ (data not shown). Regression test results between Si uptake with a weight of 1,000 grain $r = 0.58$ (Figure 3A) which indicates that 58% of the yield of 1,000 grain is influenced by Si uptake, while 42% is influenced by other factors. P uptake has a strong relationship with the weight of 1,000 grain, namely with a value of $r = 0.67$. The regression between P uptake and weight of 1,000 grain was $R^2 = 0.45$ (Figure 3B), which indicates that 45% of 1,000 grain was influenced by P absorption, while 55% was influenced by other factors. The relationship between Si and P uptake was strong with a value of $r = 0.85$. The regression test between Si uptake and P uptake obtained $R^2 = 0.76$ (data not shown).

![Figure 3](image-url)

**Figure 3.** Relationship between grain weight with Si (A) and P (B) uptake.

The positive results of correlation and regression tests indicate that each increase in nutrient uptake will be followed by an increase in crop production, such as the weight of 1000 kernels and the dry weight of the plant. The increase in Si uptake with P uptake is also positive, which indicates that every increase in Si uptake will be followed by an increase of P uptake in plants. This is because silica is a beneficial element in rice plants which has a function to increase the vegetative and generative phases of plants. This is supported by [11] which states that Si makes plants have an upright leaf shape so that the leaves are effective in capturing sunlight to increase photosynthesis. The photosynthetic results will then be translocated to all plant tissues and will make the plant grow more optimally.

4. Conclusions
The application of silica material has a significant effect on P uptake, except waste media of mushroom. Meanwhile, Si uptake significantly increased with the application of palm nutshell compost, volcanic ash, and fly ash compared to that of the control. The application of all silica material increases the tiller number. However, the application of palm nutshell compost produces rice plant with the highest plant height, tiller number, 1,000 grain weight and stem strength.

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