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Research Article
Role of Boron and Silicon in Inducing Mechanical Resistance of Oil Palm Seedlings to Drought Stress

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Abstract

Objectives: The objectives of the study were to determine (1) The level of mechanical resistance of oil palm seedlings to drought stress in some application doses of boron (B) and silicon (Si) and (2) The mechanism of B and Si actions to induce the mechanical resistance of oil palm seedlings to drought stress. **Methodology:** Field trial was arranged in the Randomized Complete Block Design (RCBD) factorial. The first factor was the dose of B, namely 0.00, 0.17, 0.44, 0.87 and 1.31 g per plant. The second factor was the dose of Si, namely 0.00, 1.15, 2.31, 3.46 and 4.69 g per plant. The data were analysed using analysis of variance (ANOVA) and the means were separated using Duncan's Multiple Range Test (DMRT) at 5% level. Meanwhile, the optimum dose of B and Si were determined using regression analysis. **Results:** Results showed that the optimal dose of B which can induce mechanical resistance of oil palm seedlings to drought stress was ranges from 0.64-0.73 g per seedling. Indicators that can be used to detect a positive effect of B application were the increase of lignin and suberin scores in the root as well as plant height and stem diameter when they were applied using B in the range of 0.64-0.73 g per seedlings. Meanwhile, the indicator which was used to detect a positive impact of Si applications was the increase in root hardness. Scores of lignin and suberin in the root cannot be used as indicators of the resistance level, because they were not responsive to Si application. **Conclusion:** The optimal dose of Si to induce resistance of oil palm seedlings to drought stress could not be determined due to the regression relationship between the dose of Si application with the roots hardness has a linear trend, when the dose of Si application increase up to 4.65 g per seedlings.

Key words: Oil palm, B and Si, mechanical, resinstance, drought

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Drought stress is becoming more frequent in the tropics in the next few years. Indonesia as one of the countries in the region potentially affected by these negative effects[1-3]. The agricultural sector is an activity that allegedly most affected by the negative effects of drought stress[4-17]. Oil palm as the main crops also has the potential to receive the most severe impacts of such environmental stresses[18,19]. Moreover, oil palm is a commodity that is sensitive to drought stress[20]. Oil palm requires high rainfall and evenly throughout the year to be able to grow and produce maximum yield[19,21-25].

Several strategies can be undertaken to improve the tolerant level of oil palm to drought stress, namely genetic character improvement through plant breeding programs as well as the induction of the internal defense mechanisms of plants through agronomic manipulation. Agronomic manipulation can be done through the application of some nutrients that have the ability to strengthen the internal resistance of plants to abiotic stresses. The previous studies provide the information that silicon (Si) and boron (B) have these capabilities[19,26-29].

The role of B to reduce the negative impact of drought stress can be divided into three ways, namely mechanical, physiological and biochemical. Mechanically, application of B to the plant under drought stress has the positive impacts on the strength and stability of cells and tissues[19,30-35]. The powerful and stable of plant tissues are not susceptible to damage or deterioration due to by the exposure to oxidative stress. Application of B can increase the strength and stability of plant cells and tissues because of its ability to form complexes with other compounds, namely complex of boron-pectic polysaccharides. This complex accumulates at the cell wall and serves to strengthen the bond of organic fibers such as lignin and cellulose as the cell wall constituents[31,32,34,35] so that the osmotic and water potentials of cells are more stable than the plant with B deficiency[19,28,29,36]. This mechanism is an internal attempt to counter the negative influence of drought stress through mechanical modifications to the organs and tissues of plants.

The other element which allegedly has a positive impact to the tolerant level of plants under drought stress is Si[19,37,38]. The Si application helps the plant to maintain the balance of water potential, enhancing photosynthetic activity, supporting the establishment of leaves, maintaining the structure of xylem vessels under conditions of rapid transpiration rate, improving the balance of nutrients, minerals reduce toxicity and improve the mechanical strength of plant tissues under drought stress condition[19,26,35,38-40]. The Si application in plants experiencing drought stress stimulates an increase in the content of polysaccharides in the cell walls such as lignin, suberin, pectin and cellulose so that the cells become stronger and not easily damaged[31,32,34,35].

Explanations on some previous paragraphs provide an overview of the positive effect of B and Si application in improving the mechanical resistance of plants to drought stress. Even so, on the oil palm the information has yet to be found. The mechanism of B and Si in the mechanical resistance of plants to drought stress also remains unclear, especially on the oil palm. Given this situation, the study aimed to determine the level of mechanical resistance of oil palm seedlings to drought stress in some application doses of B and Si and mechanism of B and Si actions to induce the mechanical resistance of oil palm seedlings to drought stress which was important enough to get the priority.

MATERIALS AND METHODS

Planting materials used in the study were 5 months old of oil palm seedlings, ready to be moved from pre-nursery to the main-nursery, which were of the same size and healthy. The seedlings were planted in the polybags 40×40 cm and then filled up with the top soil. Polybags with the oil palm seedlings were arranged at $90\times90\times90$ cm, with a pattern of equilateral triangles.

The experiment was arranged in a Randomized Complete Block Design (RCBD) factorial with three blocks as replications. The factors were the doses of B and Si. In this study, the boric acid (H_3BO_3) was a source of B and sodium silicate (Na_2SiO_3) was a source of Si. The B factor consisted of 5 dose levels, namely 0.00, 0.17, 0.44, 0.87 and 1.31 g per seedling. While the Si factor consisted of 5 dose levels, namely 0.00, 1.15, 2.31, 3.46 and 4.69 g per seedling. The B and Si applications were done before drought stress treatment until four months after transplanting, once a month with the same dose every month depending on the treatment. Applications of B and Si were done by sowing in a circular array was about 10 cm from the base of the stem and then covered with soil.

The plants were also fertilized using NPK fertilizer (15:15:15), KCl and kieserit. The NPK fertilizer doses per month started from 1st, 2nd, 3rd and 4th month after transplanting were 24.00, 28.00, 32.00 and 40.00 g per seedling, respectively. The KCl doses at 1st, 2nd, 3rd and 4th month after transplanting were 2.50, 2.83, 3.25 and 4.17 g per seedling, respectively. While, the kieserit doses at 1st, 2nd, 3rd and 4th month were 10.81, 12.69, 13.07 and 3.85 g per seedling, respectively. In addition, the weeding and pest control activities were done in accordance with field conditions.

Before the oil palm seedlings got drought stress treatment, during the 1st-4th month after transplanting, the seedlings were watered regularly every day as much as 1-3 L per polybag.

Resistance Level's testing of oil palm seedlings to drought stress was done as soon as to the plants which were maintained in ideal conditions for 4 months. Drought stress treatment started at the beginning of the 5th month after transplanting. During the drought stress treatment, oil palm seedlings were not watering until the the soil's moisture content of seedling media reached permanent wilting point. To anticipate the possibility of the rain occurred during drought stress treatment, the seeds being tested were placed in a plastic house. Toruan-Mathius *et al.*[41] provide the information that the oil palm seedlings at 14th month after transplanting with the composition of planting medium soil:sand:compost (1:1:1) reached the permanent wilting point after 18 days of drought stress treated with a soil moisture content of approximately 10%.

Samples for B and Si concentration analysis were obtained from leaf organs. Leaf samples were taken from the 3rd leaf, especially at the midrib area. Sampling was carried out shortly before the oil palm seedlings applied with drought stress. The samples were oven-dried, granulated and weighed to achieve 0.25 g per sample. The samples were placed in a digestion flask, where 5 mL of H_2SO_4 was then added and the mixture was then heated on a hot plate at 450°C. This process was done in a fume chamber for 7 min. Subsequently, 10 mL of H_2O_2 (50%) was added into the digestion set using a small funnel. The digestion flask was removed from the hot plate using a glove when cool (i.e., ±4 min) and a clear concentrated solution was produced. Next, the solution was made up to 100 mL using deionised water. Then, the solution was analysed using the Inductively Couple Plama-Mass Spectrophotometer (ICP-MS) Perkin Elmer Model ELAN DRC-e to determine the concentrations of B and Si in the leaf samples.

The score of lignin in the root tissue was observed by the Santiago *et al.*[42] methods. The leaf samples were cut into 1 cm long. Samples were fixed using FAA solution (formalin alcohol acetic acid) for 24 h. Then, the thin transverse incision was made by using the aid of cork. The pieces were painted using solution of 0.1 g of phloroglucinol in 10 mL of 95% ethanol and covered with a glass cover. Rest of the solution was allowed to evaporate. One drop of 25% HCl was given on the side cover glass. After 15 min, samples were observed using a light microscope. Cells that contain large amounts of lignin became reddish purple.

The suberin in the root tissue was observed by preparing small pieces of leaves for lignifications way. The slices were stained with sudan black B solution in 80% ethanol for 5-30 min. The slices were washed in 80% ethanol and then glycerol was added. Samples were observed under light microscope. The existences of suberin in the cells were characterized with the presence of black, blue or brownish black colours.

Root hardness was observed using Pnetrometer type D-89610 oberdischingen BS 61 11. Part of the roots measured was the central side of primary roots. The roots measured were placed on pnetrometer, then pressed, so that the pnetrometer indicate the roots hardness in Newton's unit.

Height and diameter of oil palm seedling stem were observed once a week, beginning at the first week after transplanting. The instruments used were ruler and digital callipers. Plant height was measured from the base of the stem above the soil surface to the tip of the highest leaf. While, the trunk diameter was measured at a height of ±2 cm above the soil surface.

Data were analysed using the Analysis of Variance (ANOVA) at 5% level and they were continued with the Duncan Multiple Range Test (DMRT). Meanwhile, the relationship patterns between the parameters were determined using regression and correlation analysis. All the analyses were performed using the General Linear Model Procedure (PROC GLM)[43].

RESULTS AND DISCUSSION

Response of the oil palm seedlings to the application of B: Figure 1 and Table 1 give the information that the dose of B which was applied to the oil palm seedlings influence to the concentration of B in the leaf tissue. There was a relationship between the application doses of B with B concentration in the leaf tissue, with quadratic trend. The optimal dose of B

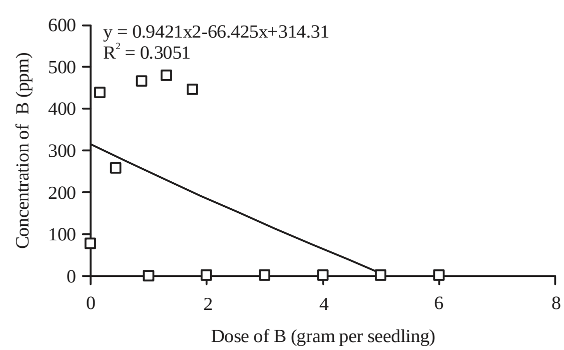

Fig. 1: Concentration of B in the leaf tissue of oil palm seedlings at several doses of B application

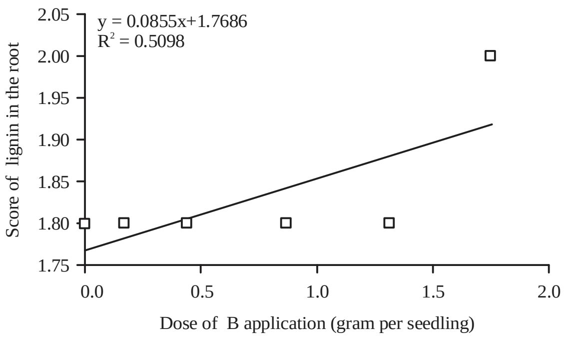

Fig. 2: Score of lignin in the root tissue of oil palm seedling in some dose of B application

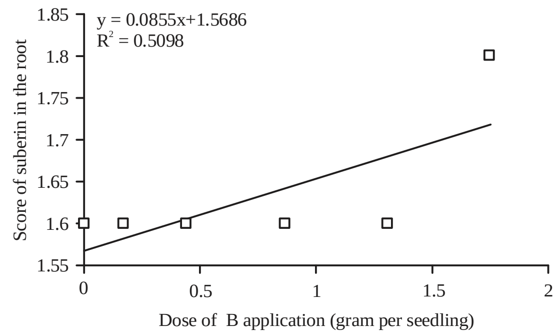

Fig. 3: Score of suberin in the root tissue under some dose of B application

Table 1: Regression between the dose of B application with B and Si levels in the leaf tissue

Variables	Regressions	Notes
Boron (B) (gram per seedling)	$y = -190.3x^2+485.1x+175.8$	*
Silicon (Si) (gram per seedling)	$y = 1.390x+357.0$	ns
	$y = -1.11x^2+6.50x+354.1$	ns

*Regression relationship and ns: No regression relationship

Table 2: Regression between the dose of B application with score of lignin and suberin in the root

Variables	Regression relationship	Notes
Lignin	$y = 0.0855x+1.7686$	*
Suberin	$y = 0.0855x+1.5686$	*

*Regression relationship and ns: No regression relationship

application that increases the concentration of B in the leaf tissue was 1.26 g per plant. The increasing dose of B up to 1.26 g per seedling was always followed by a rise in the concentration of B in the leaf tissue of oil palm seedlings. However, increasing doses of B application to exceed 1.26 g per seedling had lowered B concentration in leaf tissue as it begins to the effect of B toxicity in the oil palm seedlings. The toxicity effect of B application occured because the concentration of B in the soil solution was already exceeded the range of the ideal B for oil palm seedlings[28,44-46]. Tanaka and Fujiwara[47] suggested that the translocation of B from the roots to the leaves was following the transpiration stream which then accumulates in the leaves, especially at leaf tips and edges, so that have a potential to large display of B toxicity symptoms if the level of B in the soil exceeds the desired threshold of oil palm seedling. While, Nable *et al*.[48] provided information that in normal conditions the concentration of B in leaf tissue was range from 40-100 ppm. Plants began to experience of B toxicity if the level B in the leaf tissue was greater than 250 ppm.

It was a different look at concentration of Si variable in the leaf tissue. Table 1 provided information that B application did not have a regression relationship with the concentration of Si in the leaf tissue. There was no antagonistic or synergistic relationship between B and Si in the soil solution, so that regardless of the magnitude of the applied dose of B did not affect the rate of Si uptake. This was consistent with the results from Inal *et al*.[49] which showed that the concentration of Si in the shoot of barley was not influenced by the dose of B application, even the concentration of B already surpassed the toxicity level.

Lignin and suberin were the constituent components of boron-pectic polysaccharides polymer compound that accumulated in the cell wall. Synthesis of polymer compound dependent upon the presence of B in plant tissues, including the constituent components were lignin and suberin. The level of presence of lignin and suberin in plant tissues, especially the roots might be indicated by using the score. There was a linear regression relationship between the score and suberin lignin content in root tissue with the dose of B application (Fig. 2 and 3, Table 2). Increasing doses of B application up to 1.75 g per seedling were significantly always followed by an increase in lignin and suberin scores in the root tissues of oil palm seedlings. Therefore, the ability of plants to synthesize the polymer of boron-pectic polysaccharides also increased in accordance with the increasing in the dose of B up to 1.75 g per seedling. These conditions resulted that the opportunities of oil palm seedlings which more resistant to drought stress becomes larger.

Rate of lignin and suberin synthesis in the root tissue was directly influenced by the adequacy of B[35]. Oil palm seedlings experienced adequacy of B (Fig. 1 and Table 1) had higher ability to synthesize lignin and suberin (Fig. 2 and 3, Table 2). Nevertheless, the application of B>1.26 g per seedling led to decrease in the rate of B uptake by plant roots due to the effects of B toxicity. Different things found in the scores of lignin and suberin, which were both still up to the application of B until the dose of 1.75 g per seedling. This fact suggested

Table 3: Regression between application dose of B with root hardness

	Regression			
Variables	Before drought stress treatment	Notes	After drought stress treatment	Notes
Root hardness (N)	y = 0.36x+76.95	ns	y = 1.071x+86.01	ns
	y = 1.17x^2-1.65x+77.35	ns	y = 0.57x^2+0.09x+86.20	ns

*Regression relationship and ns: No regression relationship

Table 4: Regression between dose of B application with plant height and stem diameter

	Regression			
Variables	Before drought stress treatment	Notes	After drought stress treatment	Notes
Plant height (cm)	y = -11.69x^2+19.24x+53.12	*	y = -6.21x^2+7.96x+62.36	*
Stem diameter (cm)	y = -1.43x^2+2.02x+3.16	*	y = -1.51x^2+2.20x+3.29	*

*Regression relationship and ns: No regression relationship

that the ability of plants to absorb B was more sensitive to B toxicity[28,44-46] when compared to the synthesis of lignin and suberin. The dose of B application had begun to be toxic at 1.26 g per seedling (Fig. 1 and Table 1) but the ability of oil palm seedling to synthesize lignin and suberin had not decreased until the B application dose up to 1.75 g per seedling (Fig. 2 and 3, Table 2).

The application of B with an appropriate dose significantly improved the scores of lignin and suberin in the root tissues of oil palm seedlings (Fig. 2 and 3, Table 2). These conditions potentially increased the resilience of oil palm seedlings to drought stress. However, the increase in lignin and suberin scores in the root tissue did not necessarily caused of the plant roots to become harder, in the period after the oil palm seedlings were exposed to drought stress. Table 3 provided information that the applications of B up to 1.75 g per seedling did not have a regression relationship with the roots hardness. Any dose of B was applied, up to 1.75 g per seedling and it did not affect the level of root hardness of palm seedling.

Application of B increased the accumulation of lignin and suberin in the outer surface of root epidermal tissue in the period before and after the application of drought stress. However, after oil palm seedlings were exposed to drought stress conditions, the seedlings could not increase its roots hardness. Oil palm seedlings without or with B applications had the same level of root hardness. The condition was caused by the demolition of lignin and suberin deposit that was accumulated in the root tissue[31,32,34,35]. Lignin and suberin deposits that had been dismantled back then used to meet the needs of dry matter, especially the need of dry matter to the shoot of oil palm seedlings. The shoots of oil palm seedlings with the adequate level of dry matter had better shoot growth even in the drought stress condition[19,28,29,35]. Therefore, oil palm seedlings which with higher level of lignin and suberin reserved in the roots (Fig. 2 and 3, Table 2) had stronger growth of canopy under drought stress condition (Table 4) when compared to the oil palm seedlings with lower lignin and suberin stock.

Table 4 provided information that doses of B application had a quadratic regression relationship with plant height and stem diameter of oil palm seedlings, before the drought stress treatment. Plant height and stem diameter of oil palm seedlings reached the maximum at the dose of B application of 0.82 and 0.5 g per seedling, respectively. Application of B with the dose of >0.82 g per seedling caused of the delay in the increase of plant height, while the increase of stem diameter of oil palm seedlings began to decline if B dose application >0.50 g per seedlings. The same conditions encountered in the period after the oil palm seedlings were exposed to drought stress, where the application of B significantly increased the plant height and stem diameter (Table 4). After the drought stresses treatment, plant height and stem diameter of oil palm seedlings reached a maximum at the dose of B application of 0.64 and 0.73 g per seedling, respectively. The increase of plant height and stem diameter of oil palm seedlings started to decrease if the application of B was higher than 0.64 and 0.73 g per seedling, respectively.

Response of the oil palm seedlings to the application of Si: The concentration of Si in leaf tissue's oil palm seedlings was significantly affected by the dose of Si application. There was a linear regression relationship between doses of Si application with the concentration of Si in leaf tissues of oil palm seedlings, after a drought stress period (Fig. 4 and Table 5). Silicon concentration in leaf tissue continued to increase along with the increase in dose application of Si until 4.65 g per seedling (Fig. 4).

Different things were found in the variable of B concentrations in the leaf tissue. The concentrations of B in the leaf tissue's oil palm seedlings were not affected by Si dose applied (Table 5). Any dose of Si was applied to oil palm

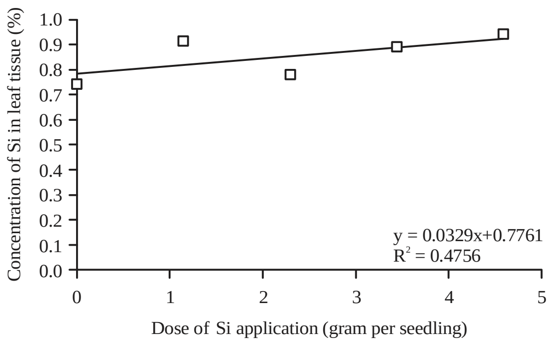

Fig. 4: Concentration of Si in the leaf tissue of oil palm seedlings under the treatment of Si application dose

Table 5: Regression between the dose of Si application with B and Si levels in the leaf tissue

Variables	Regression	Notes
Boron (B) (gram per seedling)	y = 1.5x+354.15	ns
	y = -0.06x²+1.5x+354.15	ns
Silicon (Si) (gram per seedling)	y = 0.03x+0.78	*

*Regression relationship and ns: No regression relationship

Table 6: Regression between the dose of Si application with the scores of lignin and suberin in the root tissue of oil palm seedlings

Variables	Regression	Notes
Lignin	y = -0.25x+1.81	ns
	y = 0.05x²-0.25x+1.81	ns
Suberin	y = 1.7	ns

*Regression relationship and ns: No regression relationship

seedlings did not cause any difference in the concentration of B in the leaf tissue of oil palm seedlings, in the period of drought stress. This fact suggested that in the soil solution B and Si did not interact with each other so that the increased in Si concentration in the soil solution did not suppress the ability of roots to absorb B[26,27,39,50-59]. It could be stated that B and Si were mutually independent in the soil solution.

Table 6 provided information that the dose of Si application did not influence the scores of lignin and suberin in the root tissues of oil palm seedlings after the drought stress period. The situation was not in line with the Si concentration in the leaf tissue that was constantly increasing in line with the increase of Si application dose (Fig. 3 and Table 5). Based on the data in Table 6, it can be stated that the scores of lignin and suberin in the root tissues of oil palm seedlings were not determined by the ability of seedlings to accumulate Si, so the contribution of Si in the synthesis of lignin and suberin in root tissue was remained unclear.

There was a distinct tendency between the root hardness of oil palm seedlings before and after the drought stress period. Before the drought stresses treatment, when the soil moisture levels were ideal, the root hardness of oil palm seedling had not been affected by Si application dose (Table 7). The root hardness of new oil palm seedlings were affected by Si application dose after the seedlings exposed to drought stress. In the period of drought stress treatment, application dose of Si has a linear relationship with the root hardness (Table 7). The increase in a dose of Si application was always followed by an increase in root hardness of oil palm seedling, when the application dose of Si was increased in the range of 0.00-4.65 g per seedling.

Several previous studies provided information that the positive effects of Si application were expressed after the oil palm seedlings were exposed to drought stress[26,27,39,50-59]. By the time the plants were exposed to ideal environmental conditions, one of which the adequacy of soil moisture, crop response as a result of the Si application has not been seen significantly (Table 7). The positive effects of Si application on oil palm seedlings were significantly different when the seedlings were exposed to drought stress (Table 7). The indication was an increase in root hardness, under drought stress condition. Oil palm seedlings with harder roots could penetrate the soil layer becomes better, so that the roots of oil palm seedlings grew so deep and wide. Plants with longer, wider and deeper roots tended to be more resistant to drought stress when were compared to other plants with shallower and narrower roots. In addition, harder roots were not easy to the damage when the planting medium was fairly limited. These conditions directly affected in improving the resilience of oil palm seedlings to drought stress.

Tables 6 and 7 provided information that scores of lignin and suberin had a different response with the root hardness, related to the application dose of Si. Score of lignin and suberin in the root tissues of oil palm seedlings did not respond to the doses of Si application, while the roots hardness were positively affected by the dose of Si application. Oil palm seedlings with harder roots were to be more resistant to drought stress when were compared to other seedlings with softer roots. The increase of roots hardness of oil palm seedlings after drought stress period as a result of the application of Si allegedly caused by the accumulation of other organic compounds outside of lignin and suberin. One of the complex organic compounds other than lignin and suberin which had the ability to harden the network was cellulose. However, the accumulations of cellulose in the root tissues of oil palm seedlings which were exposed to drought stress had not become one of the objects of observation in this study.

Based on the fact that the roots of oil palm seedlings become harder with the application of Si (Table 7) in terms of lignin and suberin scores did not change (Table 6). That was an indication that there were other compounds

Table 7: Regression between application dose of Si with root hardness

	Regression			
Variables	Before drought stress treatment	Notes	After drought stress treatment	Notes
Root hardness (N)	y = 0.08x+77.03	ns	y = 0.75x+85.08	*
	$y = 0.23x^2-0.98x+77.64$	ns		

*Regression relationship and ns: No regression relationship

Table 8: Regression between dose of Si application with plant height and stem diameter

	Regression			
Variables	Before drought stress treatment	Notes	After drought stress treatment	Notes
Plant height (cm)	y = 0.16x+59.24	ns	y = 0.09x+63.37	ns
	$y = 0.09x^2-0.27x+59.49$	ns	$y = 0.11x^2-0.41x+63.66$	ns
Stem diameter (cm)	y = -0.01x+3.68	ns	y = -0.003x+3.84	ns
	$y = 0.01x^2-0.07x+3.72$	ns	$y = 0.01x^2-0.06x+3.87$	ns

*Regression relationship and ns: No regression relationship

which took part in the process of hardening the roots. The compound was believed as cellulose. Therefore, the role of Si in the process of induction mechanical resistance's oil palm seedlings to drought stress was through an increase in the roots hardness, but the organic material was involved in hardening. It was cellulose. Allegedly, Si also took part in the process of cellulose synthesis and accumulation in root tissues of oil palm seedlings when exposed to drought stress.

The root hardness was one key indicator of the resilience of oil palm seedlings to drought stress[26,27,39,50-59]. However, the harder of root's oil palm seedlings were the more resistant to drought stress. But they were not guaranteed that the seedlings grow better. Table 8 suggested that the dose of Si application had no regression relationship with plant height and stem diameter of oil palm seedlings, before and after drought stress period. Any dose of Si applied was not affect to the plant height and stem diameter of oil palm seedlings. Oil palm seedlings with harder roots (Table 7) due to get more Si intake (Fig. 3 and Table 5) were more resistant to drought stress when were compared with others seedlings with softer roots due to getting fewer Si intakes, however, vegetative growths between the two oil palm seedlings were not significantly different. Oil palm seedlings with harder roots (Table 7) had the equal plant height and stem diameter when compared to others with softer roots (Table 8).

CONCLUSION

Application of B had the ability to induce a mechanical resistance of oil palm seedlings to drought stress. The optimal dose of B to induce mechanical resistance of oil palm seedlings to drought stress ranges from 0.64-0.73 g per seedling. The indicators that can be used to detect the positive effects of B application were the increase of lignin and suberin scores in the root tissues of oil palm seedlings when exposed to drought stress as well as the increase of growth activities of oil palm seedlings in the form of plant height and stem diameter when applied using B in the range of 0.64-0.73 g per seedlings. The application of Si also had the ability to induce resistance of oil palm seedlings to drought stress. The indicator used to detect the positive impact of Si applications to drought stress conditions was an increase in root hardness of oil palm seedlings. Scores of lignin and suberin in the root tissues of oil palm seedlings could not be used as indicators of the level of resistance of oil palm seedlings to drought stress because the two compounds were not responsive to Si application. The optimal dose of Si to induce resistance of oil palm seedlings to drought stress could not be determined due to the regression relationship between the dose of Si application with the roots hardness had a linear trend, when the dose of Si application increased up to 4.65 g per seedlings.

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REFERENCES

1. Al-Amin, W. Leal, J.M. de la Trinxeria, A.H. Jaafar and Z. Abdul Ghani, 2011. Assessing the impacts of climate change in the Malaysian agriculture sector and its influences in investment decision. Middle-East J. Scient. Res., 7: 225-234.

2. Ananthi, K. and H. Vijayaraghavan, 2012. Soluble protein, nitrate reductase activity and yield responses in cotton genotypes under water stress. Insight Biochem., 2: 1-4.
3. Abbas, S.R., S.D. Ahmad, S.M. Sabir and A.H. Shah, 2014. Detection of drought tolerant sugarcane genotypes (*Saccharum officinarum*) using lipid peroxidation, antioxidant activity, glycine-betaine and proline contents. J. Soil Sci. Plant Nutr., 14: 233-243.
4. Garkar, R.M., R.W. Bharud and S.N. Mate, 2011. Effect of water stress on chlorophyll, nitrate reductase activity and cane yield in sugarcane (*Saccharum officinarum* L.). J. Sugarcane Res., 1: 43-49.
5. Chakraborty, U. and B. Pradhan, 2012. Oxidative stress in five wheat varieties (*Triticum aestivum* L.) exposed to water stress and study of their antioxidant enzyme defense system, water stress responsive metabolites and H_2O_2 accumulation. Braz. J. Plant Physiol., 24: 117-130.
6. Chutia, J. and P. Borah, 2012. Water stress effects on leaf growth and chlorophyll content but not the grain yield in traditional rice (*Oryza sativa* Linn.) genotypes of Assam, India II. Protein and proline status in seedlings under PEG induced water stress. Am. J. Plant Sci., Am. J. Plant Sci.,: 971-980.
7. Khayatnezhad, M. and R. Gholamin, 2012. The effect of drought stress on leaf chlorophyll content and stress resistance in maize cultivars (*Zea mays*). Afr. J. Microbiol. Res., 6: 2844-2848.
8. Sepehr, M.F., M. Ghorbanli and F. Amini, 2012. The effect of water stress on nitrate reductase activity and nitrogen and phosphorus contents in *Cuminum cyminum* L. Pak. J. Bot., 44: 899-903.
9. Ashraf, M. and P.J.C. Harris, 2013. Photosynthesis under stressful environments: An overview. Photosynthetica, 51: 163-190.
10. Giuliani, R., N. Koteyeva, E. Voznesenskaya, M.A. Evans, A.B. Cousins and G.E. Edwards, 2013. Coordination of leaf photosynthesis, transpiration and structural traits in rice and wild relatives (*Genus oryza*). Plant Physiol., 162: 1632-1651.
11. De Assis Gomes, M.D.M., A.T. Netto, E. Campostrini, R. Bressan-Smith and M.A.T. Zullo et al., 2013. Brassinosteroid analogue affects the senescence in two papaya genotypes submitted to drought stress. Theor. Exp. Plant Physiol., 25: 186-195.
12. Silva, M.D.A., J.L. Jifon, C.M. dos Santos, C.J. Jadoski and J.A.G. da Silva, 2013. Photosynthetic capacity and water use efficiency in sugarcane genotypes subject to water deficit during early growth phase. Braz. Arch. Biol. Technol., 56: 735-748.
13. Ancu, S., E. Chitu, F.C. Marin, I. Ancu and C. Plopa, 2014. Correlation of stomatal conductance with photosynthetic capacity of six walnut cultivars from the national assortment. South West J. Hortic. Biol. Environ., 5: 1-10.
14. Beig, A.V.G., S.H. Neamati, A. Tehranifar and H. Emami, 2014. Evaluation of chlorophyll fluorescence and biochemical traits of lettuce under drought stress and super absorbent or bentonite application. J. Stress Physiol. Biochem., 10: 301-315.
15. Bouranis, D.L., A. Dionias, S.N. Chorianopoulou, G. Liakopoulos and D. Nikolopoulos, 2014. Distribution profiles and interrelations of stomatal conductance, transpiration rate and water dynamics in young maize laminas under nitrogen deprivation. Am. J. Plant Sci., 5: 659-670.
16. Chaukiyal, S.P. and P. Bhatia, 2014. Effect of water stress on nitrate reductase activity and growth parameters of some *Dalbergia sissoo* Roxb. clones under glass house condition. Octa J. Environ. Res., 2: 112-120.
17. Fahramand, M., M. Mahmoody, A. Keykha, M. Noori and K. Rigi, 2014. Influence of abiotic stress on proline, photosynthetic enzymes and growth. Int. Res. J. Applied Basic Sci., 8: 257-265.
18. Jaleel, C.A., M. Paramasivam, A. Wahid, M. Farooq, H.J. Al-Juburi, F. Somasundaram and R. Panneerselvam, 2009. Drought stress in plants: A review on morphological characteristics and pigments composition. Int. J. Agric. Biol., 11: 100-105.
19. Putra, E.T.S., Issukindarsyah, Taryono and B.H. Purwanto, 2015. Physiological responses of oil palm seedlings to the drought stress using boron and silicon applications. J. Agron., 14: 49-61.
20. Cha-Um, S., T. Takabe and C. Kirdmanee, 2010. Osmotic potential, photosynthetic abilities and growth characters of oil palm (*Elaeis guineensis* Jacq.) seedlings in responses to polyethylene glycol-induced water deficit. Afr. J. Biotechnol., 9: 6509-6516.
21. Henson, I.E. and M.H. Harun, 2007. Short-term responses of oil palm to an interrupted dry season in North Kedah, Malaysia. J. Oil Palm Res., 19: 364-372.
22. Legros, S., I. Mialet-Serra, J.P. Caliman, F.A. Siregar, A. Clement-Vidal and M. Dingkuhn, 2009. Phenology and growth adjustments of oil palm (*Elaeis guineensis*) to photoperiod and climate variability. Ann. Bot., 104: 1171-1182.
23. Cao, H.X., C.X. Sun, H.B. Shao and X.T. Lei, 2011. Effects of low temperature and drought on the physiological and growth changes in oil palm seedlings. Afr. J. Biotechnol., 10: 2630-2637.
24. Sun, C.X., H.X. Cao, H.B. Shao, X.T. Lei and Y. Xiao, 2011. Growth and physiological responses to water and nutrient stress in oil palm. Afr. J. Biotech., 10: 10465-10471.
25. Zlatev, Z. and F.C. Lindon, 2012. An overview on drought induced changes in plant growth, water relations and photosynthesis. Emir. J. Food Agric., 24: 57-72.
26. Ahmad, S.T. and R. Haddad, 2011. Study of silicon effects on antioxidant enzyme activities and osmotic adjustment of wheat under drought stress. Czech J. Genet. Plant Breed., 47: 17-27.

27. Biglary, F., R. Haddad, R. Hosseini and A. Sotudehniya, 2011. Roles of silicon in improving oxidative stress resistance by increase of chlorophyll content and relative water content of rice (*Oryza sativa* L.) genotypes. Proceedings of the 5th International Conference on Silicon in Agriculture, September 13-18, 2011, Beijing, China, pp: 1-9.
28. Metwally, A., R. El-Shazoly and A. M. Hamada, 2012. Effect of boron on growth criteria of some wheat cultivars. J. Biol. Earth Sci., 2: B1-B9.
29. Putra, E.T.S., W. Zakaria, N.A.P. Abdullah and G.B. Saleh, 2012. Stomatal morphology, conductance and transpiration of *Musa* sp. cv. rastali in relation to magnesium, boron and silicon availability. Am. J. Plant Physiol., 7: 84-96.
30. Han, S., L.S. Chen, H.X. Jiang, B.R. Smith, L.T. Yang and C.Y. Xie, 2008. Boron deficiency decreases growth and photosynthesis and increases starch and hexoses in leaves of citrus seedlings. J. Plant Physiol., 165: 1331-1341.
31. Putra, E.T.S., W. Zakaria, N.A.P. Abdullah and G. Saleh, 2010. Cell ultrastructure and peel nutrient content of neck zone in six cultivars of *Musa* sp. fruit during ripening. Int. J. Bot., 6: 47-52.
32. Putra, E.T.S., W. Zakaria, N.A.P. Abdullah and G. Saleh, 2010. Weak neck of *Musa* sp. cv. Rastali: A review on it's genetic, crop nutrition and post harvest. J. Agron., 9: 45-51.
33. Bellaloui, N., 2011. Effect of water stress and foliar boron application on seed protein, oil, fatty acids and nitrogen metabolism in soybean. Am. J. Plant Sci., 2: 692-701.
34. Putra, E.T.S., 2010. Weak neck problem in *Musa* sp. cv. rastali populations in relation to magnesium, boron and silicon availability. Master's Thesis, Universiti Putra Malaysia, Malaysia.
35. Putra, E.T.S., W. Zakaria, N.A.P. Abdullah and G. Saleh, 2011. Cell development of *Musa* sp. cv. *Rastali* fruit in relation to magnesium, boron and silicon availability. Malays. J. Microsc., 7: 103-108.
36. Hajiboland, R. and F. Farhanghi, 2011. Effect of low boron supply in turnip plants under drought stress. Biologia Plantarum, 55: 775-778.
37. Henriet, C., X. Draye, I. Oppitz, R. Swennen and B. Delvaux, 2006. Effects, distribution and uptake of silicon in banana (*Musa* spp.) under controlled conditions. Plant Soil, 287: 359-374.
38. Henriet, C., L. Bodarwe, M. Dorel, X. Draye and B. Delvaux, 2008. Leaf silicon content in banana (*Musa* spp.) reveals the weathering stage of volcanic ash soils in Guadeloupe. Plant Soil, 313: 71-82.
39. Hattori, T., K. Sonobe, S. Inanaga, P. An and S. Morita, 2008. Effects of silicon on photosynthesis of young cucumber seedlings under osmotic stress. J. Plant Nut., 31: 1046-1058.
40. Ahmed, S., L.H. Akhtar, S. Ahmad, N. Iqbal and M. Nasim, 2009. Cotton (*Gossypium hirsutum* L.) varieties responded differently to foliar applied boron in terms of quality and yield. Soil Environ., 28: 88-92.
41. Toruan-Mathius, T., T.L. Wang, M. Ibrahim-Danuwikarsa, G. Suryatmana, H. Djajasukanta, D. Saodah and I.G.P.W. Astika, 2004. [Biochemical responses of several oil palm (*Elaeis guineensis* Jacq.) progenies to drought stress in field condition]. Menara Perkebunan, 72: 38-56, (In Indonesian).
42. Santiago, R., J. Quintana, S. Rodriguez, E.M. Diaz, M.E. Legaz and C. Vicente, 2010. An elicitor isolated from smut teliospores (*Sporisorium scitamineum*) enhances lignin deposition on the cell wall of both sclerenchyma and xylem in sugarcane leaves. Pak. J. Bot., 42: 2867-2881.
43. SAS., 1990. SAS/STAT Users Guide. 4th Edn., SAS Institute Inc., Cary, NC., USA.
44. Hajiboland, R., F. Farhanghi and M. Aliasgharpour, 2012. Morphological and anatomical modifications in leaf, stem and roots of four plant species under boron deficiency conditions. Anales Biologia, 34: 15-29.
45. Demiray, H. and A.E. Dereboylu, 2013. Effects of excess and deficient boron and niacin on the ultrastructure of root cells in *Daucus carota* cv. Nantes. Turk. J. Bot., 37: 160-166.
46. Gupta, U. and H. Solanki, 2013. Impact of boron deficiency on plant growth. Int. J. Bioassays, 2: 1048-1050.
47. Tanaka, M. and T. Fujiwara, 2008. Physiological roles and transport mechanisms of boron: Perspectives from plants. Pflugers Archiv-Eur. J. Physiol., 456: 671-677.
48. Nable, R.O., G.S. Banuelos and J.G. Paull, 1997. Boron toxicity. Plant Soil, 193: 181-198.
49. Inal, A., D.J. Pilbeam and A. Gunes, 2009. Silicon increases tolerance to boron toxicity and reduces oxidative damage in barley. J. Plant Nutr., 32: 112-128.
50. Gong, H., X. Zhu, K. Chen, S. Wang and C. Zhang, 2005. Silicon alleviates oxidative damage of wheat plants in pots under drought. Plant Sci., 169: 313-321.
51. Hou, L., E. Szwonek and S. Xing, 2006. Advances in Silicon research of horticultural crops. Vegetable Crops Res. Bull., 64: 5-17.
52. Gorecki, R.S. and W. Danielski-Busch, 2009. Effect of silicate fertilizers on yielding of greenhouse cucumber (*Cucumis sativus* L.) in container cultivation. J. Elementol., 14: 71-78.
53. Sacala, E., 2009. Role of silicon in plant resistance to water stress. J. Elementol., 14: 619-630.
54. Bocharnikova, E.A. and S. Benes, 2011. Effect of Si on Barley and Corn under simulated drought condition. Proceedings of the 5th International Conference on Silicon in Agriculture, September 13-18, 2011, Beijing, China, pp: 1-10.
55. Dastan, S., A.G. Malidarreh and H.R. Mobasser, 2011. Effects of water stress and silicon application on agronomical indices, quantity yield and harvest index in rice (*Oryza sativa* L.). Proceedings of the 5th International Conference on Silicon in Agriculture, September 13-18, 2011, Beijing, China, pp: 30-31.

56. Gong, H.J., 2011. Regulation of silicon on photosynthetic gas exchange of *Triticum aestivum* L. in field drought conditions. Proceedings of the 5th International Conference on Silicon in Agriculture, September 13-18, 2011, Beijing, China, pp: 1-54.
57. Son, M.S., J.Y. Song, M.Y. Lim, I. Sivanesan and B.R. Jeong, 2011. Effect of silicon on tolerance to high temperatures and drought stress in euphorbia pulcherrima willd. Ichiban. Proceedings of the 5th International Conference on Silicon in Agriculture, September 13-18, 2011, Beijing, China, pp: 1-188.
58. Rahimi, R., A. Mohammakhani, V. Roohi and N. Armand, 2012. Effects of salt stress and silicon nutrition on chlorophyll content, yield and yield components in fennel (*Foeniculum vulgar* Mill). Int. J. Agric. Crop Sci., 4: 1591-2012.
59. Bharwana, S.A., S. Ali, M.A. Farooq, N. Iqbal, F. Abbas and M.S.A. Ahmad, 2013. Alleviation of lead toxicity by silicon is related to elevated photosynthesis, antioxidant enzymes suppressed lead uptake and oxidative stress in cotton. J. Bioremed. Biodegrad., Vol. 4. 10.4172/2155-6199.1000187