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Soil Drenching with Silicon Improves the Adaptive Response of Tobacco Cultivation under Excess Water Condition

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Abstract

Tobacco variety H382 was a cigar type tobacco that has a high economic value and potential as export trade commodity in Indonesia. The development stage of tobacco was very sensitive to water stress, like the water excess. Silicon was one of the most abundant elements in earth crust and has a role in water stress reduction to the plant. The objective of this study was to determine the response of tobacco crop variety H382 with the application of silicon fertilizer to adapt in waterlogging stress condition. This study used a factorial randomized block design with first factor was silicon fertilizer (0, 0.15, 0.30 and 0.45 ml) and second factor was excess water stress treatments (50% to 70%, 70% to 90%, 90% to 110% and 110% to 130% of field capacity). All treatments were replicated three times. The results showed that the addition of 0.45 ml silicon fertilizer to waterlogged tobacco crop could escalate the adaptive response of plant to cope with stress; seen from the increasing of the opened stomata, aerenchyma formation and the chlorophyll content of tobacco crop under excess water stress compared to control. Silicon supplementation improves the water availability in root surroundings and repairs the root architecture; thus, lead to a better hydraulic conductivity of the root for water and nutrient intake. Furthermore, authors found that the application of silicon fertilizer helped tobacco crop variety H382 improve plant adaptability to deal with excess water stress.

Keywords: abiotic stress; chlorophyll content; H382; stomatal density; waterlogging

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INTRODUCTION

Indonesia is a big country with vast agricultural field along its cities and regencies and the plantation industry was one of a sub-sector that leads the agricultural production. Tobacco (*Nicotiana tabacum* L.) was one of commercial crops associated with a large industry in Indonesia. Tobacco industry contributed to regional revenue as it has a high selling value in the global market and one of the sectors that absorb million workers (Wardhono et al., 2019). Tobacco plant itself has been also used in medicinal and agricultural item production such as pesticides (Nurhidayati et al., 2017a). Tobacco crop variety H382 was a type of cigar tobacco which has a high potential as an export commodity. Jember Regency was known as tobacco city because of its region is mainly tobacco cultivation (Muktianto and Diartho, 2018).

The growth of tobacco crops are affected by several factors; including soil condition, microclimate, pest and disease management,

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and rainfall (Wardhono et al., 2021). According to Setyoningrum et al. (2021) from 2007 to 2021, Jember Regency has a fluctuated rainfall with average rainfall is around 1,906 mm per year. Growing healthy crops under stressful condition has always been a big challenge for agricultural sector. Tobacco crop was very sensitive to water stress. As it grew the plants require specific amount of water for each developmental stage (Peng et al., 2015). A high rainfall could lead the plant to face a waterlogging condition in the cultivation land and served a water saturated condition in the root surrounding environment. This condition would rise up several mechanism of plant to adapt the undesirable water stress (Biswas and Kalra, 2018).

Excess water from a high rainfall could lead to a waterlogging condition in crop cultivation. This would create a water saturated level in soil and root environment. A water saturated condition in the root of plant tends to promote a hypoxia or anoxia condition, which are the condition where there was limited or none oxygen (J. Pan et al., 2021). The excess water condition would eventually result in several adverse conditions to plant growth and development. The most affected was the decrease of oxygen level in root surrounding. Thereby, the plant would be loaded with reactive oxygen species (ROS) during abiotic stress that also affect the plant growth. The ROS is very impactful and damaging to plant cells (Kumar et al., 2018). In addition, there was a change in soil chemical element like pH and redox potential change in the soil of low oxygen availability (Nurhidayati et al., 2017b). The excess water condition occurred in the sowing period would result in a fatal damage. The seedling would have a non-seed germination. The seeds and seedlings radical and roots was still vulnerable, and still had low adaptability into the environment (Erhenhi et al., 2019).

Silicon (Si) is the second most abundant element after oxygen in the earth's crust (Shi et al., 2016). Plant absorbed Si in the form named PAF (plant-available form), which is even when Si is abundant in soil but the PAF of Si is a limiting factor. Si in the form of silicic acid and mono-silicic acid could cross the root plasma membrane at physiological pH. The accumulation of Si led to phenolic compound production that provide tolerance against plant pathogens (Zargar et al., 2019). The Si supplementation enhanced water stress tolerance by improving the root hydraulic conductance in tomato (Shi et al., 2016) and sorghum under salinity stress (Liu et al., 2015). Si was also reported to increase plant growth and density of stomata, which promote a better balance in water use and improve photosynthesis process; thus, would increase the corn grain production (Marques et al., 2022). Another role of Si was increasing antioxidant production against the damaging effect of ROS due to abiotic stress. The advantage of Si on plant under stress condition has been observed in a range of crop plant species. The response of Si application under stress condition was varied according to the genus of plants and the type of stress (Cooke and Leishman, 2016). Soil drenching with Si fertilizer allowed easy dilution of nutrient into the soil and easier to absorb by the roots (Schaller et al., 2020).

Si fertilizer has been experimented with various type of plant like rice (Siregar et al., 2020), corn (Marques et al., 2022), eggplant (Hartman et al., 2020) and tomato (Shi et al., 2016) in various place of study in Asia, Europe, Australia, Africa and America (Cooke and Leishman, 2016; Artyszak, 2018; Siregar et al., 2020). Si fertilizer is widely known to help plant to cope with stress, it has the potential to contribute to agricultural sustainability through crop quality improvement. But there was lack of study about the effect of liquid Si application in tobacco crops in Indonesia, especially in a cigar type tobacco like variety H382. This study aimed to determine the adaptive response of Si fertilizer application to tobacco crops variety H382 under several waterlogging conditions in a range field capacity.

MATERIALS AND METHOD

Study location and growth condition

This study was conducted from November 2021 to January 2022 in the greenhouse of the Research and Development Department, Agronomy Center, Universal PT. Tempu Rejo Indonesia. The latitude is 8°17'9.04" S and longitude is 113°32'27.16" E in 24 m above sea level. The study was carried out under greenhouse conditions 6 m wide, 15 m long and 3.5 m height. Film was used for covering 200 µ in thickness and it is characterized by being resistant to UV rays.

Plants and soil

The plant used in this study was cigar type tobacco variety H382 from private collection of Universal PT. Tempu Rejo Indonesia. The seed germination was conducted for 30 days in a pot tray with a soil and compost media in 1:1 comparison. The compost consisted of 30% vermiculite and 70% cocopeat. The optimum watering condition of 73 ml water per pot tray was given for the first 10 days to ensure the well-germinated seed.

Soil type for planting was Inceptisols contains SiO_2 80.08 ppm, N 0.11%, K 1.05% and P_2O_5 29.6 ppm. Soil volume used was 15 kg per 30 x 30 cm sized polybag. The planting media was prepared 7 days before the germination period was over. The tobacco plants were planted for 45 days after transfer (DAT) to harvest period.

Experimental design

A factorial randomized block design was used in this study. The first factor was the Si fertilizer doses which consisted of 4 levels 0 ml (D0), 0.15 ml (D1), 0.30 ml (D2) and 0.45 ml (D3). The second factor was waterlogging or excess water condition due to percentage of field capacity which consisted of 4 levels 50% to 70% (W1), 70% to 90% (W2), 90% to 110% (W3) and 110% to 130% (W4) field capacity. There were 16 combination treatments and 3 replications, thus in total there were 48 trial units.

Si fertilizer was implicated twice in 14 and 28 DAT. The form of Si was liquid SiO_2 and the application was conducted by a drenching method direct to the soil (Kowalska et al., 2021). Each treatment level of Si dose (0, 0.15, 0.30 and 0.45 ml) was diluted in 50 ml water before drenched. The Si content of Si fertilizer was SiO_2 26.29%.

Excess water treatment was conducted in 29 DAT for 48 hours. The excess water treatment was determined based on the percentage of field capacity. The field capacity was established by weighing the 15 kg soil in polybag for growing media, named first weight. The 15 kg of soil then immersed for 24 hours until saturated in a big chamber contains water. The growing media was allowed to stand until there was no water drip and weighed again as end weight (Nurhidayati et al., 2017a). The weight difference was assumed as 100% field capacity.

Data analysis

The plant height and number of leaves was measured every 7 days. The measurement of plant height was assigned from the basal part of the stem to the top of the shoot. The number of leaves was defined by counting the total leaves in each plant in a polybag.

The stomata were specified by smeared the polish to the underside leaf. After the polish dried, the leaf was then affixed to the clear tape and stacked to prep glass (Gago et al., 2019). Result was observed under light microscope Leica EZ4HD. Measurement was carried on the fully developed leaf after a day of excess water treatment was finished.

The histology of tobacco root was conducted 7 days after the excess water stress was over. The root sample was 10% formalin buffer solution fixed and dehydrated with alcohol (graded percentage 70%, 80% and 90%). It was then rinsed by xylol and colored with eosin, followed by embedding with paraffin and the embedded root section was thinly transverse sliced using microtome (Feldman and Wolfe, 2014). The observation was run with light microscope Leica EZ4HD.

The chlorophyll content was measured at 1 day after excess water stress was finished, by SPAD meter (Konica Minola SPAD-502Plus) which conducted in 5 spots in different leaves. The value occurred in SPAD meter was identified as SPAD Value (SV) and would be inputted in regression formula: Chlorophyll (mg g^{-1}) = 1.034 + 0.308 x SV + 0.11 x SV^2. The analysis of chlorophyll A and chlorophyll B content was conducted by extracting 0.05 g fresh leaf and added with ethanol 90% and the results were analyzed in 665 nm and 649 nm wavelength with a spectrophotometer from Amersham Bioscience (Li et al., 2018).

Data were statistically analyzed using ANOVA at $\alpha < 0.05$ and differences in each treatment were inspected with DMRT test at $\alpha < 0.05$. Microsoft excel was used to all statistical analysis and DMRT test.

RESULTS AND DISCUSSION

Plants have several mechanisms to overcome the stress condition whether biotic or abiotic stress. This study was conducted with excess water stress on tobacco crops variety H382. Figure 1 showed the plant height of tobacco variety H382 under several excess water and optimum watering condition.

As presented in Figure 1, the tobacco variety H382 plants were getting taller from 7 to 42 DAT in all field capacity treatment. In optimum watering condition with 50% to 70% field capacity, the D3W1 treatment has the highest plant height at the end of observation time (42 DAT). Almost all of D3 treatment with addition of 0.45 ml Si fertilizer, which was the highest level of Si fertilizer in this study, reached the highest plant height at the end of observation time (D3W1, D3W2 and D3W4) except for W3 condition with 90% to 110% field capacity (D3W3). The waterlogging treatment in this study was conducted in 29 DAT for 48 hours. Tobacco is one of the crops that sensitive to waterlogging. It affects the yield only with 6 hours waterlogged condition. Nurhidayati et al. (2017b) claimed that waterlogging suppressed the tobacco plant height up to 50% in waterlogging condition at 150% field capacity. In this case, the tobacco crops still had normal plant height even when the stress occurred for excess water 110% to 130% field capacity for 48 hours. The plant height of waterlogging plants had no significant difference compared to control for 48 hours waterlogging condition. But according to the results, the addition of Si fertilizer also has a big role in promoting the adaptive response of tobacco crops to overcome the waterlogging stress. The plants with Si fertilization had a better plant height performance compared to the treatments without Si fertilizer. Similar trend occurred to the number of leaves parameter that shown in Figure 2.

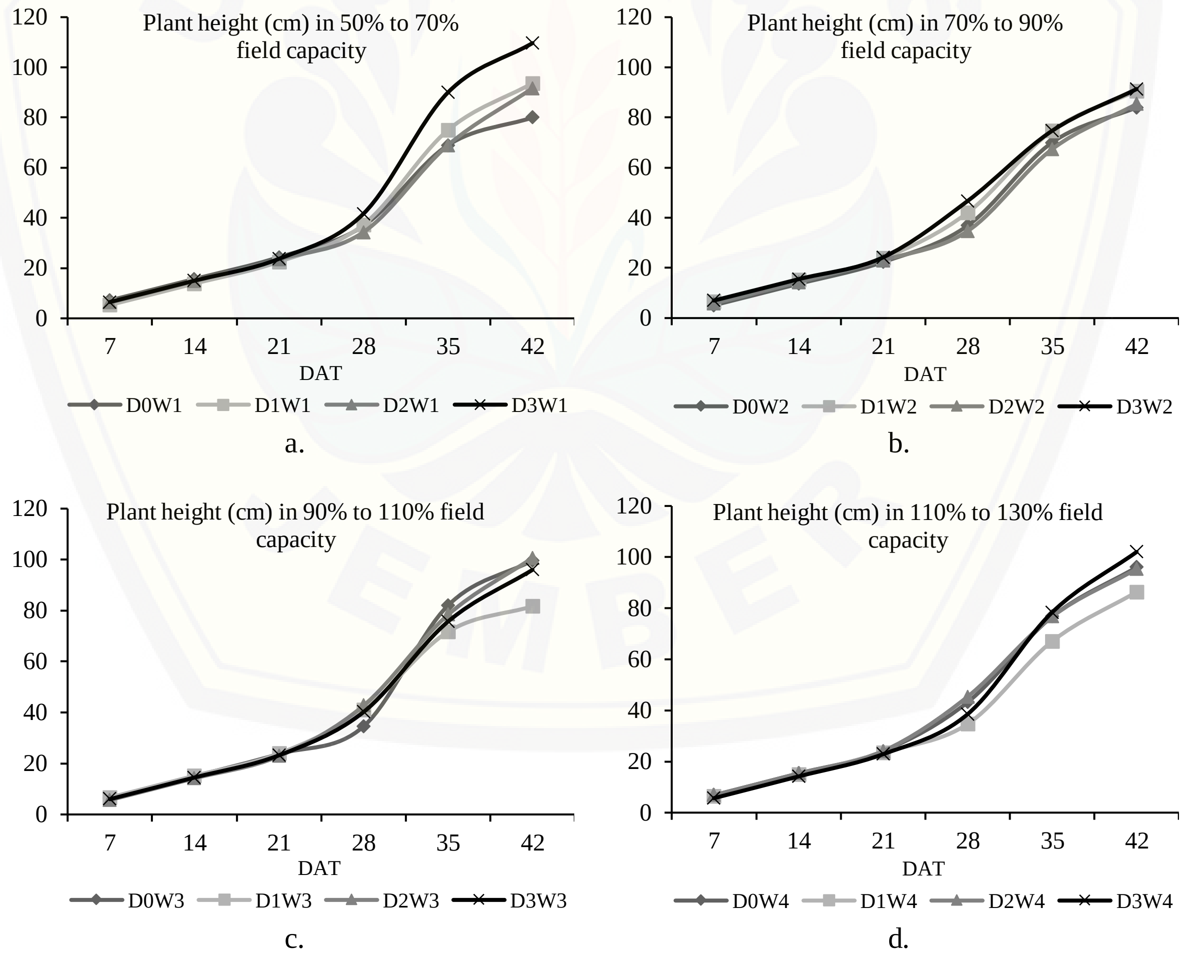


Figure 1. Plant height of tobacco variety H382 at 7 to 42 DAT. (Note: D represented application of Si fertilizer with D0: 0 ml, D1: 0.15 ml, D2: 0.30 ml and D3: 0.45 ml)

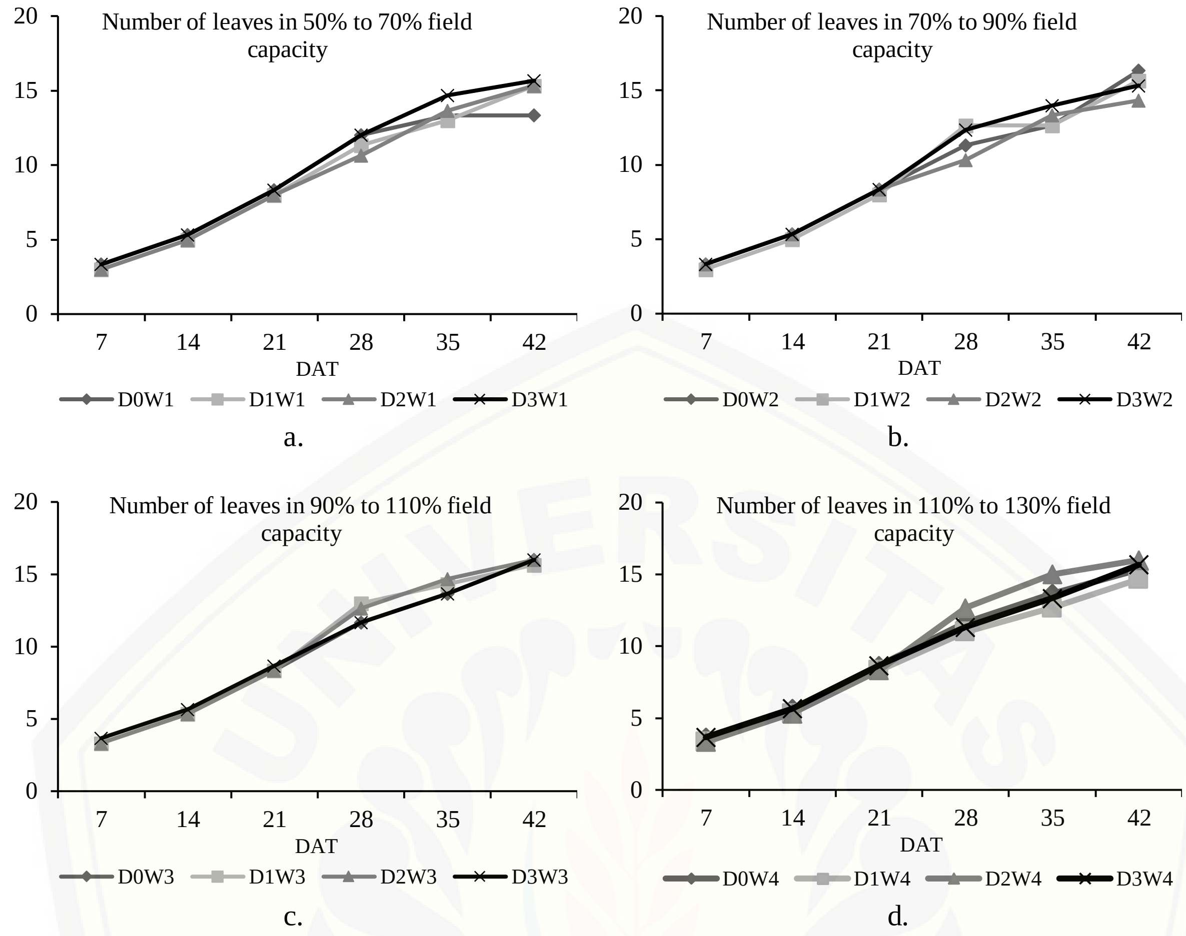


Figure 2. Number of leaves of tobacco variety H382 at 7 to 42 DAT. (Note: D represented application of Si fertilizer with D0: 0 ml, D1: 0.15 ml, D2: 0.30 ml and D3: 0.45 ml)

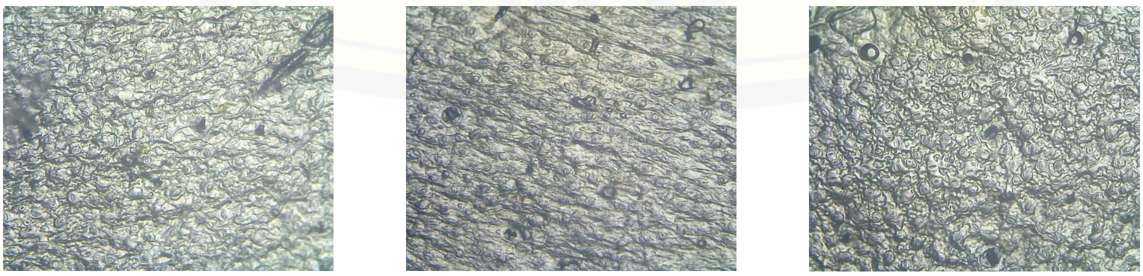
Similar to the plant height, the number of leaves was also increased from 7 to 42 DAT in the end of observation period. At 42 DAT, the results of total leaves seemed to had no significant difference among all treatments. The treatment of W1 with 50% to 70% field capacity, D0W1 (control or no addition of Si under optimum watering condition), had the lowest number of leaves with an average of 13 leaves per plant. Whereas D3W1 with addition of 0.45 ml Si, had the highest number of leaves with an average of 16 leaves per plant. In addition, the number of leaves of W2 treatment with 70% to 90% field capacity, W3 treatment with 90% to 110% field capacity and W4 treatment with 110% to 130% field capacity did not gave a significant different with average 15 to 16 leaves per plant. The waterlogging stress happened at 29 DAT for 48 hours did not affect the number of tobacco leaves mostly. And supplementation of Si fertilizer in waterlogging condition had a slow impact to the number of leaves. It could be happened because the waterlogging treatment was not conducted in critical phase of tobacco development stage. Study from Nurhidayati et al. (2017c) reported that waterlogging for 10 days or 240 hours with 150% field capacity decreased plant height and other morphological responses in tobacco.

Kurniawan et al. (2014) characterized the developmental stage of tobacco plant in two main groups. The first was the slow growing stage at 4 to 20 DAT, where the plant did not need abundant of nutrient. The next was the fast-growing stage at 20 to 50 DAT where high intake of water and nutrient was a necessity. Water requirement for each growth phase of tobacco crop is different. Peng et al. (2015) classified tobacco crops into three different phase which were elongation, vigorous growth and mature phase. The elongation phase required 60% to 70%, the vigorous growth phase required 75% to 85% and the mature phase required 70% to 80% of soil water content of field capacity.

Stomatal conductance and net photosynthetic rate of tobacco crops would improve as those water requirements were fulfilled. The waterlogging stress near to flowering stage could lead to stagnation plant development and the worst that plant lost its capability to recover from stress that would lead to plant death. The first stage of cultivation (germination) was also crucial stage where water deficit or excess in tobacco cultivation were not acceptable (Biglouei et al., 2010; Zambrano Nájera and Ortega, 2021). The critical stage of development may be different according to how the plants' tolerance with stress which depends on the genus and the ability of individual plant (Wang et al., 2017). The waterlogging stress conducted in this study was in the early of fast-growing stage which need high intake of water and nutrient. The waterlogging condition caused water availability decreased which led to the reduction of water and nutrient intake. But the plant height and number of leaves were not affected significantly because the waterlogging stress was not conducted in critical stage of plant height and number of leaves development which is germination stage.

Waterlogging condition limited water transport by suppressing the root hydraulic conductance as an important process represented the water uptake. The aquaporin which handled the amount and activity of water channels in cellular membrane plays the important role in regulating the root water uptake, mainly under stress condition. The aquaporin's activities are controlled by *Lsi1* gene that encodes a protein in influx and efflux transport. The expression of Si influx and efflux are elevated due to Si supplementation under stress condition and stress level elevates Si uptake (Mundada et al., 2021). The addition of Si fertilizer improved plant's morphology by helping plant to absorb water through the roots. Si also provides more water availability around the root environment. The mechanism of Si influenced plant height and number of leaves are by providing more water availability to be transported to the shoot and upper organ of plant. The water stress in plant whether waterlogging or drought would have an impact in stomata condition. In this study, the stomatal conductance was observed and the results are presented in Figure 3.

The opening-closing process of stomata or stomatal conductance was one of the general plant mechanisms to cope with water stress. Stomatal conductance was very affected by plant metabolism process. An inhibition of metabolism would inhibit the opening stomata. Figure 3a showed stomata in tobacco leaf under normal conditions. The normal condition represented the optimum watering condition of tobacco, which is around 50% to 70% of field capacity. The excess of water tends to induce stress condition and decrease the opening of stomata (Figure 3b). A higher field capacity of 70% could lead a waterlogging stress in tobacco plants. But the addition of Si to tobacco plants under waterlogging stress could increase the stomata opening (Figure 3c). It indicates that Si application promotes the stomata opening in the leaf of the tobacco plant. This study is in accordance with those observed in tomato, that Si addition ameliorate the stomatal conductance and significantly decrease the transpiration rate by deposition of Si on the leaf surface of plant (Shi et al., 2016). Addition of Si fertilizer was very closely related to the aquaporin gene activated by Si supplementation. The aquaporin which has role of Si transport to the cell, also has a contribution in enhancing antioxidant activity to tackle oxidative damage caused by waterlogging stress (Arif et al., 2021).



a. b. c.

Figure 3. Stomata in leaf part of tobacco variety H382 after being waterlogged for 48 hours. a) control, b) waterlogging plant without Si fertilizer application, c) waterlogging plant with Si fertilizer application

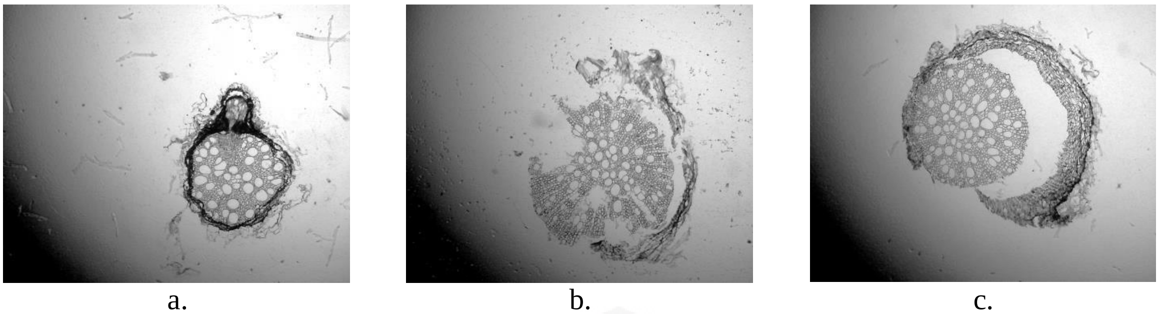


Figure 4. Histology of root transverse section of tobacco variety H382 after being waterlogged for 48 hours. a) control, b) waterlogging root without Si fertilizer, c) waterlogging root with Si fertilizer

Stomata consist of a pair of guard cells and regulate the transpiration and assimilation of CO_2. The transpiration in the leaf was affected by water availability within. When waterlogging stress occurs, the root were damaged, which provoked the inhibition of water intake because the root loses its hydraulic conductivity (Kumar et al., 2018). Stomata closure was the response to the decline of the transpiration rate. Stomata closure reduces transpiration but inhibits the photosynthetic process. The addition of Si increased the water intake availability, possibility of microbial activities and diffusion of nutrients to the plants. Si fertilization is associated with the upkeep of plant photosynthetic rate and stomatal conductance in the plant. It is caused by water potential affecting the turgidity of cells that compose stomata. It can be associated with the study of Marques et al. (2022) which contributes the Si application to the precipitation of Si in the cell walls, which reduces water loss. An increase in water availability will increase stomatal conductance and lead to enhance the photosynthetic rate, thereby consequently increasing growth and productivity. The replenishment of gas exchange in leaves related to higher nutrients absorbed by the roots indicated greater stomatal cell densities. The histology of root transverse section was also observed to observe the response of root to overcome waterlogging condition, it is shown in Figure 4.

Root was the first organs that face the stress in soil environment. Figure 4 showed the histology of tobacco root in both normal and waterlogged condition. A well-structure of root epidermis was shown in Figure 4a for the root in optimum watering condition. Meanwhile Figure 4b showed a critical damage in the tobacco root under highest waterlogging condition. This study was performed in 110% to 130% field capacity. Figure 4c was also taken from the root of the waterlogged plant, but with Si fertilizer supplementation. The addition of Si fertilizer with drenching method helped the root of tobacco plant to survive better under water stress. Moreover, the entire roots from excess water condition (Figure 4b and 4c) have formed the unique space called aerenchyma. This finding align with Nurhidayati et al. (2017c) study which found the aerenchyma development in the root part of tobacco under waterlogging stress.

Aerenchyma is an air cavity that formed in the root cortex during the development of root plant under waterlogging stress. It is formed because there was a damage of cell and degradation of cell wall in saturated root environment condition (Nurhidayati et al., 2017b). That phenomenon led to inhibition of water and nutrient supply from the bottom to the top of plant. Plant ran a survival mechanism by forming and developing cave-like structures that could improve transport processes. The oxygen supply within the plant could be restored and the oxygen supply was partially transferred to the soil enabling the condition of available oxygen in root surrounding. Saturated water conditions in root surrounding promotes cell death to sensitive plants regarding to the lack of oxygen (T. Pan et al., 2021). Adventitious root may be formed during the waterlogging condition. The adventitious root was emerged in the basal zone, which is the meeting point of shoot and root. As the environment was water saturated and the root was damaged, the auxin transport was inhibited and there was accumulation of auxin in the basal part of plant. This auxin accumulation would provoke the formation of adventitious root. In the water saturated condition, the adventitious root helped plant to get better water intake and dissolved nutrient in water; it also avoid the accumulation of alcohol in the plant body (Nurhidayati et al., 2017b; Purnobasuki et al., 2018).

In this study, waterlogging stress caused the damage on the root part of plants. It caused by limited oxygen condition by water saturated environment, which induce the increase of ROS and lead to plant cell damage even plant cell death. As the main gate of water and nutrient uptake, root plays an important role to bridge water and nutrient from soil to the leaves as the main production place. The damaged root inhibits the absorption process. Si supplementation is not only protecting root by maintaining the water hydraulic potential in root surrounding, it also improves root function by developing better aerenchyma structure and neutralize ROS by involving production of enzymatic and non-enzymatic antioxidants, thus root still have the ability to supply the water and nutrient to the upper part of plant.

The water saturated condition tends to change the aerobic to anaerobic respiration because of lack of air. The anaerobic respiration in waterlogged soil leads to fermentation in root surrounding. The ROS that mount up in this condition was so harmful to plant cell. It could led to a damage in plasma membrane and endomembrane system because it's oxidizing compound (Khan et al., 2019). Si fertilizer was promoted the plant ability in increasing the enzyme production to against stress. The reduction of oxidative damage could escalate the tolerance of plants to cope with stress. Ranjan et al. (2021) reported that oxidative stress protection of Si addition was also occurred in some plant species like sorghum, tomato and wheat. Supplementation of Si fertilizer was also reported to improve soil aeration that led to advance well-functioning root.

Si could be preserved in soils for a long time as phytoliths. The nutrients absorbed by the plant for surviving life will leave a residue long after the plant has no longer existed and it is absorbed back into the ground as nutrients for the next plant cultivated. Si was permeated mostly into the plant walls and specialized cells. According to Schaller et al. (2020) a high concentration of dissolved Si can lead to the formation of clay minerals, which were known for their high water holding capacity. Plants have been categorized as low (< 0.5%), intermediate (0.5% to 1.5%) and high (> 1.5%) Si accumulator based on leaf Si content levels. The Si permeability to each plant species was categorized based on their genotype (Coskun et al., 2019).

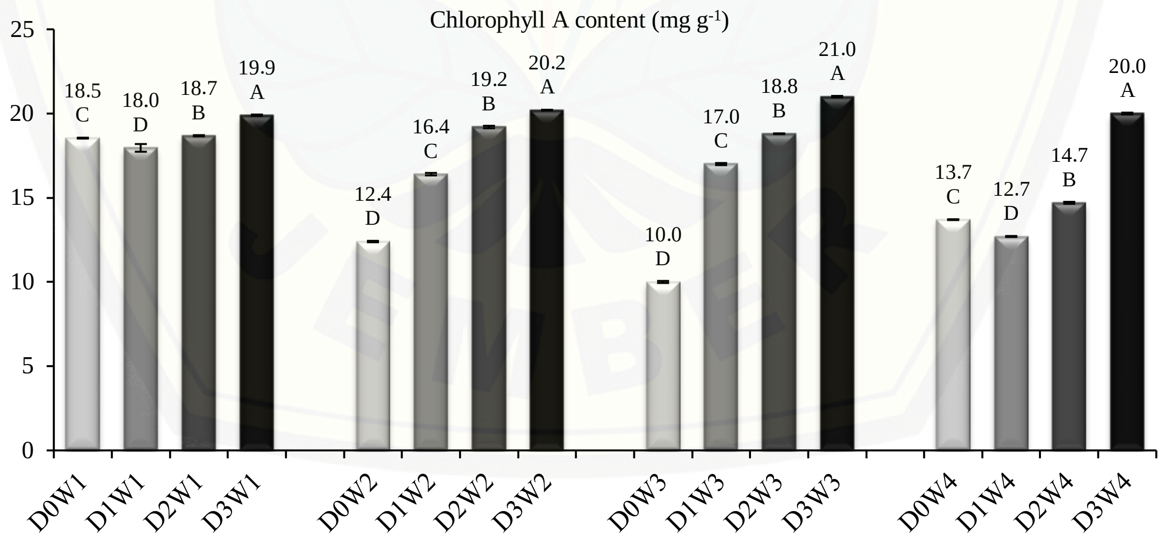


Figure 5. Chlorophyll A content in leaf of tobacco variety H382 after being waterlogged for 48 hours. Different letter means there is significantly different among the same W group according to DMRT test 5% (Note: D is represented for application of Si fertilizer with D0: 0 ml, D1: 0.15 ml, D2: 0.30 ml and D3: 0.45 ml, whereas W is represented for field capacity with W1: 50% to 70%, W2: 70% to 90%, W3: 90% to 110% and W4: 110% to 130%)

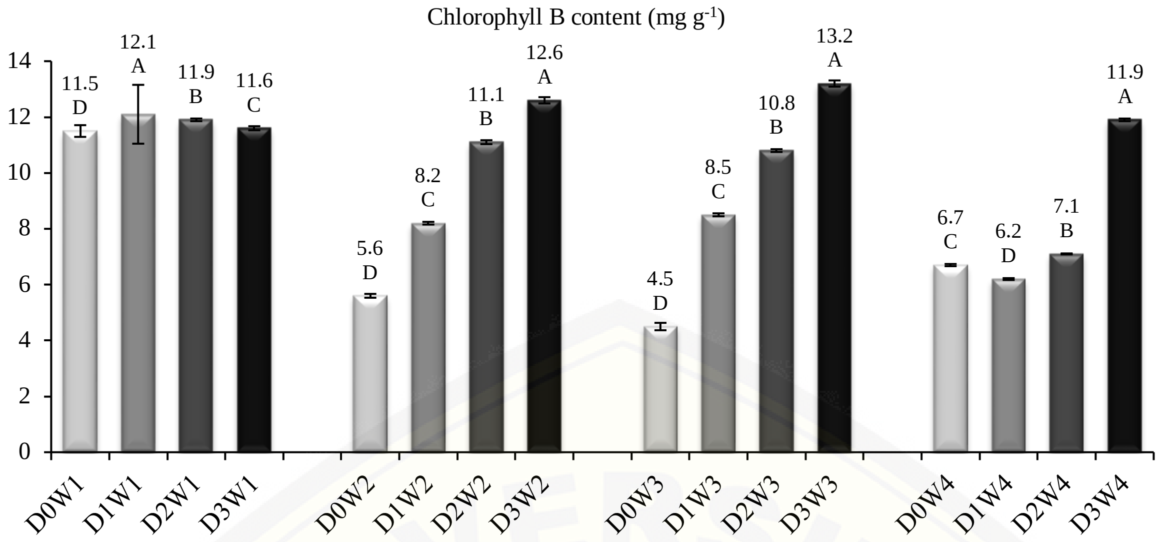


Figure 6. Chlorophyll B content in leaf of tobacco variety H382 after being waterlogged for 48 hours. Different letter means there is significantly different among the same W group according to DMRT test 5%. (Note: D is represented for application of Si fertilizer with D0: 0 ml, D1: 0.15 ml, D2: 0.30 ml and D3: 0.45 ml, whereas W is represented for field capacity with W1: 50% to 70%, W2: 70% to 90%, W3: 90% to 110% and W4: 110% to 130%)

The level of chlorophyll A content decreased as waterlogging stress treatment increased (Figure 5). The application of Si fertilizer gave a significant effect on the chlorophyll A content in the tobacco plant. In the optimum watering condition, the highest dose of Si application which was 0.45 ml (D3) had the highest level of chlorophyll A content in the W1 condition (50% to 70% field capacity). Meanwhile, as waterlogging stress got more intense, the level of chlorophyll A content was altered. In D0W3 with waterlogging stress 90% to 110% of field capacity and no addition of Si, the chlorophyll A content was only 10.0 mg g^{-1}. The application of Si fertilizer promotes the chlorophyll A content in W3 treatments: D1W3 was 17.0 mg g^{-1}, D2W3 was 18.8 mg g^{-1} and D3W3, the highest dose of Si, was 21.0 mg g^{-1}. The highest dose of Si application in this study was 0.45 ml, which could increase the chlorophyll A content in all waterlogging stress treatments a little bit higher compared to the control treatment in W1. This is similar to Kovács et al. (2022) that claimed Si supplementation alleviated the environmental stress by improving photosynthetic pigment which lead to better photosynthesis process.

Similar to chlorophyll A content, the chlorophyll B content was decreased with regard to waterlogging stress in the tobacco plants (Figure 6). In this study, the lowest chlorophyll B content was in W3 treatment, which was 90% to 110% waterlogging stress without the addition of Si fertilizer. As Si was added, the level of chlorophyll B content in waterlogging stressed plants increased. All of the D3 treatments (Si fertilizer application of 0.45 ml) in waterlogging stress (D3W2, D3W3 and D3W4) have a higher level of chlorophyll B content compared to optimum watering condition (D3W1). But in the optimum watering condition (W1), applications of Si tend to have a similar chlorophyll B level compared to the plant without the addition of Si fertilizer. This indicates that Si application to tobacco plants could help the plant to reach normal chlorophyll B content when abiotic stress like waterlogging occurred. Rangwala et al. (2019) found that Si application also increase the total chlorophyll concentration in drought and salinity stress. The improvement of chlorophyll A and B level was also accompanied by the improvement of carotenoid, another pigment of plant (Semenova et al., 2021).

The changes in chlorophyll content were the mechanisms to help to protect the plants from environmental stresses. It was in line with Barickman et al. (2019) which has reported that there was a decline in chlorophyll B content due to waterlogging compared to control plant.

The altered chlorophyll B content was resulted in yellowing in leaves plant. That chlorosis event was increased along with the level of waterlogging treatment. Another study showed an association of reduction in photosynthetic pigment concentration due to flooding stress in the plant. Excess watering condition, that held for a certain period of time, would change the respiration pathway from aerobic to anaerobic or fermentation. The fermentation pathway was less efficient in converting energy from ADP to ATP. This limitless metabolic available energy led to inhibition of biological processes, one of them was photosynthesis. Si improves the adaptive response of plants by increasing antioxidant production, binding to metal ions and deposition of toxic element in plant (Khan et al., 2019).

In this study, the waterlogging had caused an increase of ROS which was very damaging to the plant cell because of its powerful oxidizing ability. It marked by a chlorosis in the leaves of tobacco as ROS had a harmful effect to thylakoid membrane and chlorophyll molecules. Addition of Si fertilizer could suppress the oxidative damage by improving the antioxidant protection and decrease the ROS production. Si supplementation also improve the accumulation of N, P, K and Zn in leaves and ameliorate the chlorophyll content in leaves (Iqbal et al., 2021). As Si fertilizer helped the tobacco plant to improve the root growth and its architecture under water stress, it also increased the chlorophyll content in the leaves to run a better photosynthesis and other metabolism process related.

CONCLUSIONS

Si fertilization improves the adaptive response of tobacco crops variety H382 under various waterlogging conditions which ranged from 50% to 130% field capacity. The adaptive responses are including a better stomatal conductance and formation of root aerenchyma, increase in chlorophyll content in the leaves and maintaining the plant height and the number of leaves. The optimal application of 0.45 ml liquid Si fertilizer under waterlogging escalated the adaptive response of plants to survive. Therefore, it is imperative to identify the specific pathway of Si in which it could increase the quality of tobacco crops under water stress.

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