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*Research article*

# Oil palm leaf ash's effect on the growth and yield of Chinese cabbage (*Brassica rapa* L.)

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**Abstract:** The production of Chinese cabbage (*Brassica rapa* L.) has not been able to keep up with consumers' demand. Appropriate application of fertilizers is a key element in boosting plant productivity. One of the problems faced when fertilizing is that plant nutrient uptake has low efficiency. The application of basic nitrogen–phosphorus–potassium (NPK) fertilizers is typically the main emphasis of traditional agriculture, whereas the need for micronutrients, including Si, receives less consideration. Organic and inorganic materials are sources of Si nutrients. Currently, organic materials include straw or rice husks. The use of oil leaf palm waste as a source of nutrients is relatively still rare. The oil palm leaf ash in the production of Chinese cabbage is still not yet been researched. This analysis aims to know the optimal of oil palm leaf ash for the growth and yield of Chinese cabbage. The growth parameters measured 40 days after planting: leaf number, plant height, crown diameter, and fresh weight were impacted by the usage of oil palm leaf ash. A combination of oil palm ash at a concentration of 3.75 kg/m$^2$ and manure at a concentration of 1500 kg/m$^2$ produced the greatest results. In general, the usage of oil palm leaf ash affected the growth of Chinese cabbage, but the results could not be statistically separated from the role of manure as a source of NPK for plants. It was also demonstrated that the use of oil palm leaf ash increased the resistance of Chinese cabbage to armyworms. Therefore, Si for agriculture it can be utilized from oil palm leaf ash as a natural source.

**Keywords:** Chinese cabbage; fertilizer application; oil palm leaf ash; silica

## 1. Introduction

The agricultural sector is divided into several sub-sectors, one of which is the horticulture sub-sector which has an important role and function and contribution to the development of the agricultural sector in the agricultural sector's economy. The horticulture sub-sector includes vegetables, fruits, and ornamental plants. One vegetable commodity that is often consumed by the public is Chinese cabbage. This vegetable commodity has commercial value and good potential for development. Based on data from the Central Agency on Statistics (Badan Pusat Statistik) [1] in 2021, the production of Chinese cabbage in Indonesia reached 727,467.00 tons. The amount increased by 8.99% compared to the previous year which amounted to 667,473 tons. However, the high public demand for Chinese cabbage is not matched by the high production capacity. Therefore an effort is needed to maintain consistency in increasing the production of chicory vegetables in Indonesia, namely by paying attention to and maintaining product quality, optimizing existing inputs, and optimizing the factors of each production to meet the increasing demand for Chinese cabbage vegetables for the community.

As a result, it is necessary to boost the productivity of Chinese cabbage by enhancing harvest quality, resistance to pests, and tolerance to acidic soils. Fertilizer application can boost plant productivity, but the low efficiency of nutrient uptake by plants remains a problem [2]. The addition of silicon (Si) with the right composition is one method to boost plant nutrient uptake [3–5]. Traditional farmers only focus on providing basic nitrogen–phosphorus–potassium (NPK) fertilizers, while the need for micronutrients, including Si, receives less consideration [4,6]. Si is assumed to be present in the soil; however, the majority of it is not accessible to plants for uptake and is lost as a result of the leaching process [4]. Therefore, it is crucial to maintain Si levels in plants to correctly sustain plant development potential.

The fourth most significant element for plant nutrition is silicon, which is also the second most abundant element in the Earth’s crust after oxygen [3,7]. Si is found in soil, mineral rocks, and 6biological materials. Generally, 1 kg of soil contains between 50 and 400 g of Si [8], but, despite this abundance, most of the silicon is unavailable to plants and is lost as a result of the desilication process [4]. Additionally, because silica is soluble and biogeochemically immobile, its availability in the soil is continuously declining [9,10]. The most common forms of silica (including biogenic silica), silicate minerals, and aluminosilicates, found in soil are silica and aluminosilicates, although none of these are available to plants for absorption. The absorption of nutrients by plants depends on the water potential and the solubility of elements in the soil. The pathway for nutrient uptake is from the soil solution with a higher solute concentration to the plant tissue with a lower solute concentration. Although Si is abundantly found in both silicate and oxidase forms in the soil, the only silicon molecule that is accessible to plants is mono silic acid, but its presence in soil is very low [11], and the amount available to plants is not guaranteed [12]. Solid silicon compounds have a poor conversion rate to mono silicic acid due to the complex soil environment [8,11]. Orthosilicic acid ormono silicicc acid ($H_4SiO_4$) is a form of Si that is absorbed by plant roots [13,14]. Consequently, Si will accumulate in the epidermal tissue, and the formation of a cellulose-Si membrane layer occurs when Ca and pectin ions are present [15], which will then create protection for plants [16]. The increase of Si in plants due to the polymerization of monosilicic acid into oligomeric and polymeric silicic acid has an impact on the soil's lack of monosilicic acid as well [3,9]. The addition of Si fertilizers to the soil is possible to overcome the deficiency of silicon resulting from the deficiency of monosilicic acid (such as rice husk ash), and diatomaceous earth products. Si is very important for avoiding soil nutrient imbalances and reducing the detrimental influence of Mn, Fe, and Al, which often arise in acidic and poorly drained soils [4]. Additionally, Si fertilizer helps plants be more resilient to biotic stresses such as bacteria, fungi, viruses, insects, and rodents [8,10,17–20], the addition of Si can make plants more resilient to abiotic conditions such as salinity and drought [6,21–24].

Both organic and inorganic materials can contain Si. Among the sources of inorganic Si in Indonesia's industrial waste such as coal fly ash and steel mill slag, a mixture of fly ash and potassium carbonate, magnesium hydroxide, liquid calcium silicate, and silica gel. Zeolite is a soil stabilizer that can improve the chemical properties of soil, and increase its ability to hold water and nutrients and release them slowly. Sources of organic Si can be rice husk and straw ash [25], rice straw bokashi [26], for example, hanjeli shell charcoal [27], and oil palm leaf ash [28,29]. Considering that Indonesia has the largest oil palm area in the world, there is tremendous potential for using oil palm trash as a source of silicon. Along with an expansion in palm oil mills, the area for oil palm production has been increasing annually by 2.45% [30]. In 2017, the number of palm oil companies was 1695, and this increased to 2165 in 2018 and 2019 [31]. Oil palm plantations expansion was also followed by an increase in palm oil waste including oil palm leaves.

Currently, oil palm leaves have not been widely used as a source of biogenic Si in the form of silica. Therefore, the opportunity to use oil palm leaf ash as a source of Si is considerable. As a source of biogenic silica, oil palm leaf ash is only just beginning to be used. Several studies on the use of oil palm leaves as a source of silica have been published in the field of advanced material synthesis [32–35]. To the best of our knowledge, no one has studied the impact of Si-containing oil palm leaf ash on the production of Chinese cabbage. Therefore, the impact of oil palm leaf ash on the quality of Chinese cabbage production should be examined. The purpose of this study was to determine the right ideal of oil palm leaf ash application dosage for growth and increased Chinese cabbage productivity.

## 2. Materials and methods

The study was carried out between June to September 2021. Ash from oil palm leaves was obtained by burning the leaves. The as-prepared oil palm leaf ash was characterized using scanning electron microscopy (SEM) coupled with Energy-Dispersive X-ray (EDX) analysis. In the Cipanas Botanic Gardens, Bogor experimental garden, mustard plants were treated with oil palm leaf ash. Seeds of hybrid chicory and *Brassica rapa* L. (Chinese cabbage, Sawita CR variety) was used (PT, Known-You Seed Indonesia, Magelang, Central Java). Mustard seeds were soaked in warm water for 2 h in a small bucket before being sown. Seedlings were prepared by planting Chinese cabbage seeds in beds with a width of 1.0–1.2 m. The nursery bed received two kilograms of organic materials such as compost, manure, and husks. In order to keep seedlings young and mobile, nurseries were kept on land adjacent to the experimental plots.

Experiments began with the preparation of the experimental land. Plots made by the experiment were created after clearing the land. Each experimental plot was closed off with plastic mulch before transplantation. Holes were made on the surface of the plastic mulch using special tools, and 15-day-old, healthy, and uniform seedlings were transplanted into the holes. According to the experimental dose and treatment of oil palm leaf ash, fertilizer was administered. A two-factorial Randomized Block

Design with 10 replications served as the basis for the experiment. The first factor was the dose of manure fertilizer (0, 375, 750, 1125, and 1500 kg/m$^2$), and the second factor was the dose of oil palm leaf ash (0, 1.20, 2.50, 3.75, and 5 kg/m$^2$). When ready, harvesting was performed. After 40 days of observing the morphoagronomic characterization of Chinese cabbage following oil palm leaf ash silica treatment, harvesting was carried out. The morphoagronomic observations of the mustard greens were leaf number (pieces/plant), leaf crown diameter (cm), height of the crown (cm), and fresh weight (g/plant). Analysis of variance (ANOVA) was used to assess the measurements with a 5% confidence level. The significance between treatments was examined using Duncan's multiple-range analysis.

## 3. Results

Grayish white palm leaf ash is produced when dried, dry palm leaves are burned directly using fire in an aluminum box. Oil palm leaf powder was characterized by SEM and revealed to have erratic granules (Figure 1a-b). As shown in Figure 1c, analysis using EDX shows the presence of several important elements contained in palm ash resulting from direct burning using fire, namely $SiO_2$ (71.27%), $K_2O$ (5.03%), MgO (3.27%), and CaO (3.08%) along with other minor compounds.

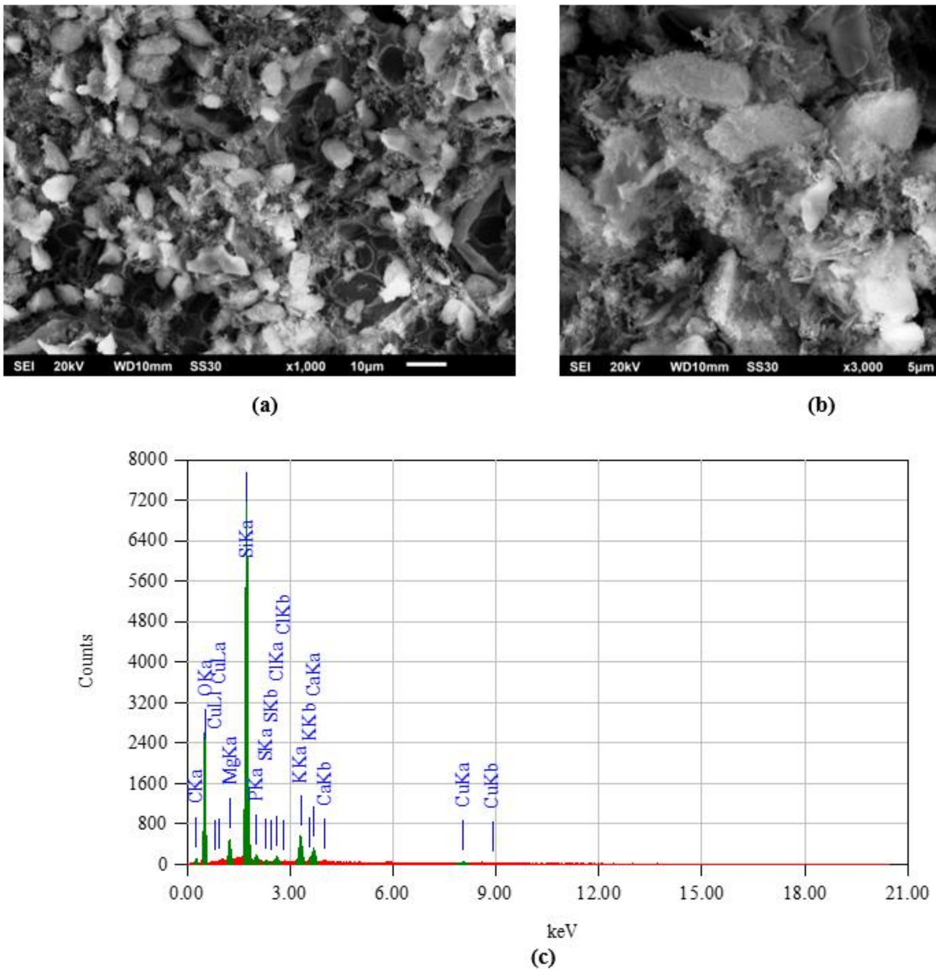

**Figure 1.** SEM pattern of oil palm leaf ash from burning using fire in an aluminum box (a) 1000×, (b) 3000×, and (c) EDX pattern of as-prepared oil palm leaf ash.

### 3.1. Leaf Number

According to the ANOVA results, applying oil palm ash had a significant effect on leaf number and interaction with the dose of manure. The treatment combination that produced the highest leaf number was oil palm leaf ash at 3.75 kg/m$^2$ and manure at 1500 kg/m$^2$ (Table 1), with a mean of 22.50 leaf strands.

**Table 1.** The response of the leaf number of Chinese cabbage aged 40 days after planting to the application of oil palm leaf ash and manure at various concentrations.

| Treatments | The concentration of Manure (kg/m$^2$) | | | | | Average |
|---|---|---|---|---|---|---|
| The concentration of Oil Palm Leaf Ash (kg/m$^2$) | 0 | 375 | 750 | 1125 | 1500 | |
| 0.00 | 12.50 a | 13.40 ab | 15.20 cd | 17.00 de | 18.00 e | 15.22 a |
| 1.25 | 13.70 b | 15.00 c | 17.00 d | 18.20 e | 19.44 f | 16.67 b |
| 2.50 | 14.40 b | 15.00 c | 16.50 d | 17.00 de | 19.57 f | 16.50 b |
| 3.75 | 15.50 cd | 17.50 de | 18.33 e | 20.80 g | 22.50 h | 18.93 c |
| 5.00 | 14.25 b | 15.00 c | 17.00 d | 17.50 de | 19.33 f | 16.62 b |
| Average | 14.07 a | 15.18 ab | 16.81 b | 18.10 bc | 19.77 c | |

Note: Numbers followed by the same letter are not significantly different based on Duncan's test, level 5%.

### 3.2. Plant Height

We measured the height of the plants 40 days after planting. Oil palm leaf ash and manure were applied, and the outcome was planted that were taller than those receiving control treatment (Table 2). The height of Chinese cabbage was statistically increased by using oil palm leaf ash as a source of silicon (Table 2).

**Table 2.** The response of plant height (cm) of Chinese cabbage aged 40 days after planting to the application of oil palm leaf ash and manure at various concentrations.

| Treatments | The concentration of Manure (kg/m$^2$) | | | | | Average |
|---|---|---|---|---|---|---|
| The concentration of Oil Palm Leaf Ash (kg/m$^2$) | 0 | 375 | 750 | 1125 | 1500 | |
| 0.00 | 13.13 a | 13.67 a | 17.00 c | 21.4 d | 22.50 d | 17.54 a |
| 1.25 | 15.25 ab | 17.14 c | 21.20 d | 23.12 e | 25.00 e | 20.34 b |
| 2.50 | 16.38 b | 17.00 c | 19.80 d | 25.75 e | 26.00 e | 20.99 b |
| 3.75 | 21.38 b | 21.50 d | 24.00 de | 28.00 f | 31.00 g | 24.18 c |
| 5.00 | 19.00 c | 21.00 d | 23.50 de | 25.17e | 26.00 e | 22.93 bc |
| Average | 16.03 a | 18.06 ab | 21.10 b | 24.69 c | 26.10 c | |

Note: Numbers followed by the same letter are not significantly different based on Duncan's test, level 5%.

### 3.3. Leaf Crown Diameter

Chinese cabbage's leaf crown diameter was affected 40 days after planting by the manure and oil palm leaf ash applications. The widest crown diameter, 49.14 cm, was obtained with concentrations of oil palm leaf ash and manure at 3.75 and 1500 kg/m$^2$, respectively (Table 3). Application of manure alone, at concentrations of 1125 and 1500 kg/m$^2$, also resulted in a larger crown diameter (Table 3).

**Table 3.** The response of leaf crown diameter (cm) of Chinese cabbage aged 40 days after planting to oil palm leaf ash and manure at various concentrations.

| Treatments | The concentration of Manure (kg/m$^2$) | | | | | Average |
|---|---|---|---|---|---|---|
| The concentration of Oil Palm Leaf Ash (kg/m$^2$) | 0 | 375 | 750 | 1125 | 1500 | |
| 0.00 | 30.88 a | 34.30 b | 35.39 b | 40.94 cd | 41.44 cd | 36.59 a |
| 1.25 | 35.25 b | 39.50 c | 40.63 cd | 41.55 d | 44.83 e | 40.35 b |
| 2.50 | 43.60 de | 41.38 cd | 45.50 e | 46.20 f | 47.07 f | 44.75 c |
| 3.75 | 40.14 c | 42.71 d | 44.13 de | 46.63 f | 49.14 g | 44.55 bc |
| 5.00 | 41.11 cd | 44.71 e | 45.13 e | 45.25 e | 47.25 f | 44.69 c |
| Average | 38.20 a | 40.52 b | 42.15 b | 44.11 c | 45.95 c | |

Note: Numbers followed by the same letter are not significantly different based on Duncan's test, level 5%.

### *3.4. Fresh Weight*

One of the metrics used to gauge plant growth is plant biomass in this study, plant biomass was measured by weighing the leaves of Chinese cabbage in their fresh form (Table 4). The fresh weight of Chinese cabbage was impacted by the use of manure and oil palm leaf ash. The heaviest fresh weight, 2633.33 g, resulted from the treatment of oil palm leaf ash at 3.75 kg/m$^2$ and manure at 1500 kg/m$^2$. A low fresh weight of 785.71 g was measured when no oil palm leaf ash and manure were added.

**Table 4.** The response of fresh weight (g) of Chinese cabbage aged 40 days after planting to the application of oil palm leaf ash and manure at various concentrations.

| Treatments | The concentration of Manure (kg/m$^2$) | | | | | Average |
|---|---|---|---|---|---|---|
| The concentration of Oil Palm Leaf Ash (kg/m$^2$) | 0 | 375 | 750 | 1125 | 1500 | |
| 0.00 | 785.71 a | 1000.00 c | 1200.00 d | 1420.00 e | 1725.00 g | 1226.14 a |
| 1.25 | 1180.00 d | 1350.00 e | 1425.00 e | 1541.67 f | 1600.00 g | 1419.33 b |
| 2.50 | 1110.00 d | 1200.00 d | 1433.33 e | 1562.50 f | 1725.00 g | 1406.17 b |
| 3.75 | 800.00 a | 1400.00 e | 1400.00 e | 1866.67 h | 2633.33 i | 1620.00 c |
| 5.00 | 950.00 b | 1250.00 d | 1400.00 e | 1650.00 f | 1950.00 h | 1440.00 b |
| Average | 965.14 a | 1240.00 ab | 1371.67 b | 1608.17 bc | 1926.67 c | |

Note: Numbers followed by the same letter are not significantly different based on Duncan's test, level 5%.

### *3.5. Resistance to Armyworms*

It was discovered that adding oil palm leaf ash to Chinese cabbage increased its defenses against pests, namely, armyworms (in this study, the area of the leaves affected by the armyworm was not calculated). Figure 2 depicts the look of pest-infested mustard plants that were cultivated with and without oil palm leaf ash. When oil palm leaf ash was added, Chinese cabbage leaves were less attacked by armyworms relative to when grown without oil palm ash.

**Figure 2.** Chinese cabbage tolerance to armyworm in response to oil palm leaf ash application. (a) Without the application of oil palm leaf ash; (b) application of oil palm leaf ash at 1.25 kg/m$^2$; (c) application of oil palm leaf ash at 2.5 kg/m$^2$; (d) application of oil palm leaf ash at 3.75 kg/m$^2$; and (e) application of oil leaf ash at 5 kg/m$^2$.

## 4. Discussion

At this time there is no data regarding the characteristics of oil palm leaf ash. Therefore, the characteristics of oil palm leaf ash were observed using SEM. The results show that the oil palm leaf ash has the form of erratic granules (Figure 1a-b). Analysis using EDX shows the presence of several important elements contained in palm ash resulting from direct burning using fire, namely $SiO_2$ (71.27%), $K_2O$ (5.03%), MgO (3.27%), and CaO (3.08%) along with other minor compounds. It is obvious that the powder of oil palm leaf ash contains a sizable amount of silica, which is useful for soil remediation in the current investigation. In general, plants absorb silicon (Si) in the form of monosilicic acid ($H_4SiO_4$) by diffusion and through the influence of transpiration which induces root uptake which is called mass flow. The presence of Si in the xylem in several plant species can generally be at concentrations many times higher than Si in the soil (F). This suggests that Si uptake may be metabolically driven (G). Different plants can also have different mechanisms of Si accumulation, this is influenced by the mechanisms involved in Si uptake (H). So far no one has discussed the detailed mechanism of silicon absorption in oil palm plants.

The growth of mustard plants was generally impacted by the application of oil palm leaf ash, but the results could not be statistically separated from the role of manure as a source of NPK for plants (Table 1). We measured the height of the plants 40 days after planting. The statistical study showed that the application of oil palm ash and manure had a significant effect on the height of Chinese cabbage. Oil palm leaf ash and manure were applied, and the outcome the plant that was planted was taller than those receiving control treatment (Table 2). Interaction between the application of oil palm leaf ash and manure on the height of Chinese cabbage was also shown to have an impact on the results. The height of Chinese cabbage was statistically increased by using oil palm leaf ash as a source of silicon (Table 2). The application of oil palm ash at high concentrations triggered plant height growth compared with the control treatment. This is connected to Si's involvement in improving plant erection. In addition, plant height also serves as a proxy for environmental influences. Additionally, standing plants can boost solar absorption. which plays a role in the process of photosynthesis. An example of an increase in cells as a result of increased assimilation is the observed increase in plant height.

Chinese cabbage produced with oil palm leaf ash added has better morphological traits than those without the addition of oil palm leaf ash. In particular, the addition of both oil palm leaf ash resulted in denser leaves compared to other treatments, demonstrating that the role of Si in physiology in plants is important. The important role of Si is related to increasing plant resistance to nutrient imbalances and increasing the availability of P nutrients in the soil [11,36–39]. Sican reduces the negative impact of Mn, Fe, and Al, which are frequently present in acidic and poorly drained soils [4,23], by increasing antioxidant enzyme activity and increasing osmolyte concentration, which can help abiotic stress resistance in plants [24]. Silica can also increase the strength of plant stems so that they do not collapse easily and has been shown to improve yield quality. This is due to the fact that Si settles on the epidermal cell wall after being absorbed by plants [40]. When compared to NPK treatment alone, the addition of Si as an extra fertilizer to rice plants increased rice production by 117% [37].

The application of oil palm leaf ash as a source of Si may improve the ability of plants to absorb available nutrients (N, P, and K) and thereby improve plant growth. This is suggested by the improved growth seen in all manure applications with the addition of oil palm ash relative to manure on its own (Table 4). In addition, increased growth in response to the application of oil palm leaf ash demonstrated that the silicon compounds in oil palm leaf ash can serve as a biostimulant [11]. Regardless of nutrient content, a biostimulant is a chemical that is used on plants to increase nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and plant quality, regardless of nutrient content [41]. The experimental evidence demonstrated that fresh weight was affected by both the treatment of oil palm leaf ash and the interaction with manure. In addition, environmental conditions, such as water availability, can have an impact on plant biomass, growth, and development.

Due to the associated advantages of silicon availability, including increased photosynthesis, water transport, nutrient absorption, and tolerance to abiotic influences, the usage of oil palm leaf ash boosted the harvest weight of Chinese cabbage. The cause of the decrease in transpiration rate is happening when silicon accumulates in leaves, the change in transpiration rate is due to the stomatal opening that reduces by the double layer of silica, it is reducing water loss [42]. Furthermore, lignin and silicon that enters the cell wall together will form a structural component that is resistant to stress. Plant leaves develop better architecture, resulting in greater sunlight penetration, increased $CO_2$ absorption and photosynthetic rate, and transpiration rate decreases [43,44].

It was discovered that adding oil palm leaf ash to Chinese cabbage increased its defenses against pests, namely, armyworms (in this study, the area of the leaves affected by the armyworm was not calculated). Figure 2 depicts the look of pest-infested mustard plants that were cultivated with and without oil palm leaf ash. When oil palm leaf ash was added, Chinese cabbage leaves were less attacked by armyworms relative to when grown without oil palm ash. This has to do with how Si contained in oil palm leaf ash serves a purpose. Si plays the main role in improving agricultural yields and disease resistance [17–19,45,46]. Si is associated with the ability increased tolerance for metal toxicity, and increased enzyme activity [12]. Silica is also called a "beneficial element" for certain plants, but this is sometimes not given attention [45]. In general, agriculture overlooks the addition of Si and only concentrates on macronutrient fertilizers $H_4SiO_4$ a monosilicate acid, is the type of silicon that plants absorb [47].

Si is an element involved in cellular processes, so the physiological and metabolic activities of plants can be affected by the application of Si. Si can boost growth and productivity in higher plants by increasing tolerance to various stress factors including disease [5]. This is because of the presence of 3-hydroxypropanoate groups and serine, which is classified as polar hydrophilic amino acid [5]. Serine is, therefore, an important component in biosilica metabolism and the development of plant metabolism. Plants, especially dicots, cannot readily absorb Si from the soil to maximize growth. Diffusion mediates the dicotyledonous plants, and absorption of monosilicic acid is mediated which produces monosilicic acid with lower concentrations than in monocotyledonous plants [48]. After absorption in the xylem, monosilicic acid follows the transpiration flow and is eventually deposited as silica (biogenic opal and phytolite) in all plant tissues, including the leaf epidermis, and spaces inside or between cells, in cell walls [49,50]. Plants that absorb monosilicic acid in sufficient quantities will provide benefits to plants [51–54]; and decreased damage from insects and rodents due to plant fortification, all of which are associated with increased plant resistance through triggering defense reaction mechanisms, by acting as a functional deterrent to herbivores. These advantages are evident from the study's findings, which showed that adding oil palm leaf ash produced plants that are stronger against pests, namely, and armyworms. Plants that did not receive any oil palm leaf ash, and hence did not get enough silicon had lower structural support than plants that did.

Si can deplete from the soil by ongoing, intensive plant agriculture. Therefore, the availability of Si should be taken into account. Silica fertilizer can be added using natural organic sources, such as oil palm leaf waste. Ash from oil palm waste naturally contains Si in the form of silica. Therefore, this ash can be used as a Si fertilizer. As an alternative natural fertilizer that can be used for agriculture the usage of oil palm waste ash has not yet drawn considerable attention. Further studies should be performed to test the addition of silica on the growth of Chinese cabbage under conditions of abiotic stress, e.g., acidic soil.

## 5. Conclusions

When oil palm leaf ash was applied, Chinese cabbage's growth and yield improved by increasing leaf number, plant height, leaf crown diameter, and fresh weight 40 days after planting. The best treatment was a combination of oil palm leaf ash at 3.75 $kg/m^2$ and manure at 1500 $kg/m^2$. The growth of mustard plants was generally impacted by the usage of oil palm leaf ash, but the impact could not be statistically separated from the contribution of manure as a source of NPK fertilizer. In addition, it was discovered that the use of oil palm leaf ash improved the resistance of mustard plants to armyworms.

Si has a major role not only as an essential element status but has a unique function in reducing the influence of biotic stresses that damage plants in this study, namely the effect on armyworm pests. In addition, as abiotic stress, it is necessary to evaluate Si's role. The research that has been carried out has not yet reached the point of seeking information regarding the characterization of Si uptake and transport in the root system of Chinese cabbage. This is an interesting topic for further studies, namely studying the mechanism of xylem Si uptake and loading in Chinese cabbage and regarding the role of Si in stress physiology.

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## Conflict of interest

The authors have no conflicts of interest to declare.

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