Utilization of Coal Ash as an Ameliorant to Enhance Growth and Nutrient Availability for Chili Plants (Capsicum annuum L.) on Peat Soil

Farrah Fadhillah hanum [a,1*], Budi Setya Wardhana [a,2], Imran [a,3], Annisa Vada Febriani [a,4]

[a] Department Master of Chemical Engineering, Faculty of Industrial Technology, Ahmad Dahlan University Yogyakarta 55191, Indonesia
[1]farrah.hanum@che.uad.ac.id*; [2]2308054013@webmail.uad.ac.id; [3]2208054008@webmail.uad.ac.id; [4]2307054003@webmail.uad.ac.id

* corresponding author

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ABSTRACT

Peat soil has limitations in nutrient content and low pH, thus requiring improvement efforts to support optimal plant growth.This study aims to examine the effect of adding coal ash (fly ash and bottom ash) on the growth of chili plants in peat soil media.The research design uses a combination of peat soil, manure, and coal ash from the power plant, which are tested under several treatments.The main parameters observed were plant height and nutrient analysis in the growing medium.The results show that the combination of peat soil, manure, and bottom ash from PLTU 2 (GA-B2B) produced the highest plant growth (26.3 cm).The addition of coal ash increases the CaO content in the growing medium, which plays a role in improving the chemical properties of the soil.However, nitrogen levels tend to decrease with the increase in coal ash dosage.Thus, coal ash has the potential to act as an ameliorant to improve the productivity of peat soil, especially when combined with organic fertilizers.

1. Introduction

Indonesia is known as a country rich in natural resources, one of which is abundant coal, making it one of the largest producers in the world. Most of this coal is used as fuel for Steam Power Plants (PLTU).As the national electricity demand increases, the utilization of coal by steam power plants (PLTU) is expected to continue to rise [1], [2].

The conversion of coal into electrical energy is carried out through a combustion process, which produces solid waste in the form of fly ash and bottom ash. As the national electricity demand increases, the amount of coal ash waste produced continues to rise [3], [4]. If not properly managed, this waste can have a negative impact on the environment [5]. Nevertheless, coal ash holds beneficial potential because it contains various essential nutrients for plants, such as potassium (K), calcium (Ca), magnesium (Mg), silica (Si), and phosphorus (P), and can be utilized as an ameliorant to improve soil fertility, especially in peat soil [6]. Peat soil is one of the types of soil widely distributed in various regions of Indonesia with distinctive characteristics such as high moisture content and porosity [7]. Generally, peat soil has a low pH, low base saturation, and relatively low macro-nutrient content such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). In addition, the micro-nutrient content in peat soil is also relatively limited, although its cation exchange capacity is considered high [8]. Based on these characteristics, peat soil presents a unique challenge in its use as a planting medium in the agricultural sector. This is especially true in the cultivation of horticultural plants such as chili peppers (Capsicum annuum L.) which require the availability of nutrients and soil pH within a certain range to grow optimally [9].

Several studies that have been conducted show that the addition of coal ash to the soil can affect the characteristics of the soil. The research conducted by Imran et al. (2024) [6] shows that the addition of coal ash to peat soil increases soil pH and enhances the availability of certain nutrients such as potassium (K) and silica (Si), although on the other hand, it can reduce nitrogen (N) and phosphorus (P) levels due to leaching processes and binding by heavy metal ions. In the study by Elawati et al., (2023) [10] , the application of a mixture of coal bottom ash with compost media showed a significant effect on the height of chili plants, root length, and total biomass, although the effect on the number of roots was not significant.

This research aims to evaluate the effect of adding coal ash from different power plants on the height growth of chili plants (Capsicum annuum L.) in peat soil media. Through this approach, it is hoped that a deeper understanding of the potential of coal ash as an ameliorant capable of improving the chemical properties of peat soil can be obtained. In addition to aiming to improve soil fertility and the productivity of horticultural crops, particularly chili peppers, this research also represents an effort to optimize the utilization of coal ash waste in a more environmentally friendly and sustainable manner. Thus, the results of this research are expected to contribute to the development of agriculture on peatlands and provide more efficient solutions for managing energy industry waste.

2. Research Methodology

2.1. Materials

This research uses several types of materials, namely peat soil, fly ash, bottom ash, and manure. All materials were obtained from the East Kalimantan region. Peat soil serves as the main medium, while coal ash and manure are added as ameliorants in various combinations and proportions.

In this study, fourteen variations of planting media treatments were used. The first treatment was a control, namely pure peat soil (GA). The second treatment is a combination of peat soil and manure (GA-PK). Next, there are three treatments that combine peat soil, manure, and bottom ash from PLTU 1, coded GA-B1A, GA-B1B, and GA-B1C. The next three treatments are combinations of peat soil, manure, and bottom ash from Power Plant 2, coded GA-B2A, GA-B2B, and GA-B2C. In addition, there are three treatments that combine peat soil, manure, and fly ash from Power Plant 1, namely GA-F1A, GA-F1B, and GA-F1C. Finally, three other treatments use a mixture of peat soil, manure, and fly ash from Power Plant 2, each coded GA-F2A, GA-F2B, and GA-F2C.

Each treatment was prepared in a total media weight of 500 grams per polybag. The addition of approximately ±100 ml of water is done to help homogenize the mixture before the media is transferred into the planting container.

2.2. Procedures

2.2.1 Sampel Preparation

The initial process begins with drying peat soil, fly ash, and bottom ash under sunlight, then grinding them to an 80 mesh size. The peat soil is then dried using an oven, mixed with coal ash in a 1:10 ratio, and ±100 ml of water is added to achieve homogeneity. This mixture is sun-dried again, ground to 200 mesh, and prepared for XRF testing. For nutrient element analysis (Nitrogen), the sample is ground to 0.5–2 mm and dried naturally without an oven.

2.2.2 Preparation of Planting Media

The initial stage of preparing the planting medium begins with drying the peat soil to reduce excess moisture, thereby improving aeration and preventing the medium from becoming too dense. Next, fly ash and bottom ash are ground to make them easier to distribute evenly in the media mixture. The selection of the ratio of peat soil (100, 200, or 300 grams), manure (100 grams), and coal ash (100, 200, or 300 grams) is based on a combination test to balance the physical and chemical properties of the medium. Peat soil serves as the main organic material but is acidic in nature, so the addition of coal ash aims to neutralize the pH while also providing micronutrients such as calcium and magnesium. Meanwhile, manure serves as a source of nitrogen, phosphorus, and potassium, which are essential for the early growth of plants. Meanwhile, manure serves as a source of nitrogen, phosphorus, and potassium essential for the early growth of plants. After all the materials are weighed, they are mixed in a plastic container with the addition of water (±100 ml) to achieve optimal moisture—the media clumps when squeezed but does not release water.

After all the materials were weighed, they were mixed in a plastic container with the addition of water (±100 ml) to achieve optimal moisture—the sign is that the medium clumps when squeezed but does not release water. The media is then placed into 500-gram capacity polybags to ensure sufficient growing space for the chili roots. Before planting, the media is allowed to sit for 3-5 days to stabilize the pH and initiate the initial decomposition of organic materials.

2.2.3 Maintenance and Observation Plants

Watering is done sufficiently to maintain the moisture of the media without causing waterlogging.No additional fertilization was carried out during the observation period to purely evaluate the influence of the initial planting media.Plant height measurements were taken every 3 days for 30 days to monitor the rate of vegetative growth.The obtained data were analyzed to determine the best media composition based on the optimal growth of chili plants.With this approach, the research focuses on the influence of variations in growing media composition on chili growth without further fertilization intervention.

2.2.4 Analysis of Results

The samples that have undergone the preparation process are then taken to the Yogyakarta Radiation Laboratory for chemical composition analysis using the X-Ray Fluorescence (XRF) method. This method is applied to identify and measure the content of various oxides such as calcium oxide (CaO) as well as the chemical elements present in the mixture of peat soil and coal ash. In addition to the XRF test, further analysis of the sample quality was conducted using specific methods. Nitrogen (N) content was analyzed using the Kjeldahl method, which is the standard method for measuring total nitrogen content in soil samples. This analysis aims to determine the contribution of the mixture to the availability of essential nutrients for chili plant growth.

3. Results and Discussion

3.1. The effect of adding fly ash and bottom ash on Growth Height of Chili Plants

The measurement of plant height is conducted every three days for one month using a ruler, with the measurement taken from the ground level to the top of the plant. The measurement results are systematically recorded for each observation period.

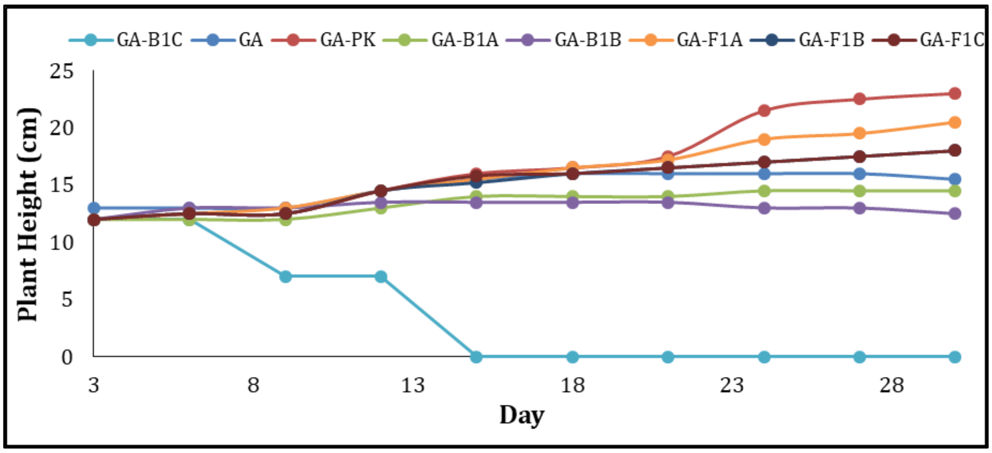

Fig. 1 Analysis Results of Chili Plant Stem Height at Various Compositions of PLTU 1 Coal Ash

In **Fig.1**, differences in the height of chili plants are observed due to variations in the composition of the planting media used. The initial height of the chili plants when planted ranged from 12 to 13 cm. After 30 days after planting (DAP), the final height of the chili plants was measured, resulting in heights ranging from 0 to 23 cm.

Based on the measurement results, the planting medium with the addition of PLTU 1 coal ash with code GA-F1A showed the best results, with the chili plant height reaching 20.5 cm. However, these results are still lower compared to the planting medium with the code GA-PK, which produced a chili plant height of 23 cm. On the contrary, the planting medium with the code GA-B1C showed the worst results, with a chili plant height of 0 cm, caused by the plants starting to wilt after 7 days after transplanting (HST) and eventually dying by 15 HST.

In **Figure 2**, differences in the height of chili plants resulting from various media composition variations can be observed. In general, all plants showed an increase in height that was directly proportional to the planting time. The height of the chili plants at the beginning of planting ranged from 12 to 15 cm. After 30 days since planting (HST), the final height of the chili plants was measured and the results ranged from 15.5 to 26.3 cm.

Based on the observation results, the planting media variation with the code GA-B2B that uses PLTU 2 coal ash shows the best growth, with the chili plant height reaching 26.3 cm. This result is much higher compared to the planting media variations that do not use coal ash, indicating that the addition of PLTU 2 coal ash to the planting media has a significantly positive impact on chili plant growth

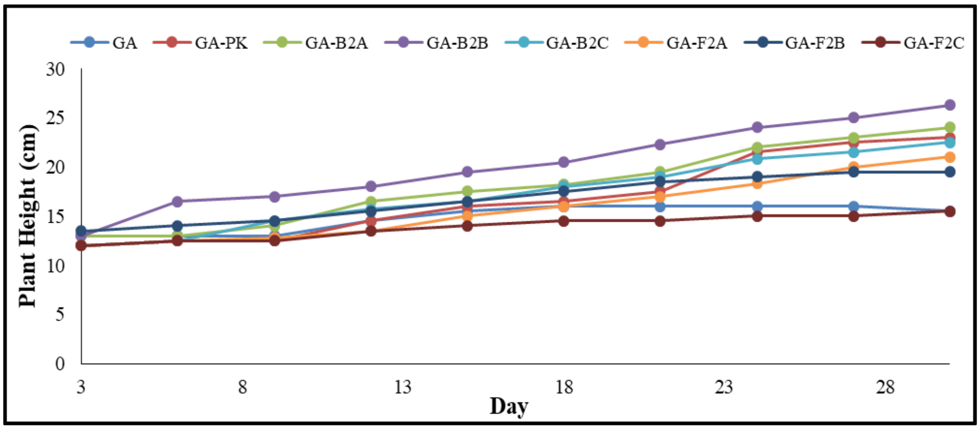

Fig. 2 Analysis Results of Chili Plant Stem Height at Various Compositions of PLTU 2 Coal Ash

Conversely, the worst results were found in the planting media variations with the codes GA-F2C and GA, with plant heights of 15.5 cm each. However, between GA-F2C and GA, the increase in height in the GA-F2C variation was greater, at 3.5 cm, compared to GA which was only 2.5 cm. This shows that although both variations have low results, the GA-F2C variation shows a slightly better improvement compared to GA.

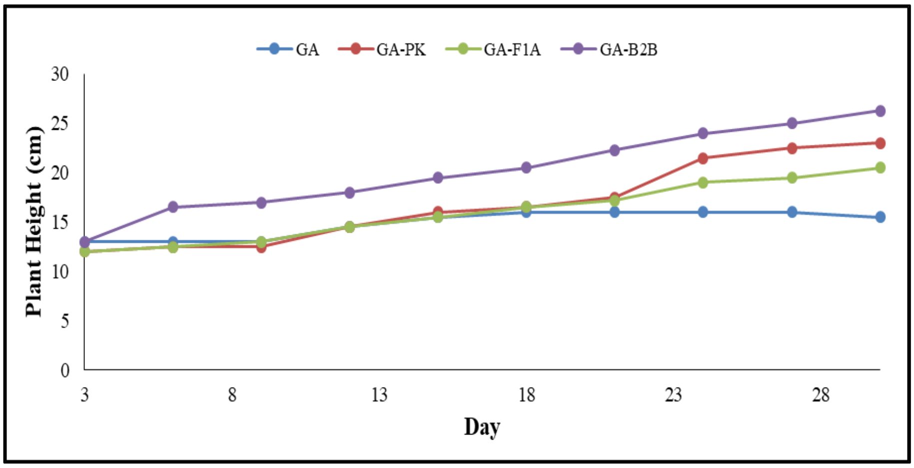

Fig. 3 Comparison of the Best Results in Plant Height of Chili Plants Using Growing Media from PLTU 1 and PLTU 2

Based on **Figure 3**, the height of the chili plants increased over the duration of the observation period. The best results were obtained with the planting media variation coded GA-B2B, which used coal ash from PLTU 2, manure, and peat soil, with a plant height reaching 26.3 cm.

If compared to other best planting media variations that use PLTU 1 coal ash, peat soil, and manure, the GA-B2B combination shows more optimal results. The difference in the height of the chili plants is influenced by the variation in the composition of nitrogen (N) and calcium oxide (CaO) from the growing media produced by each combination of coal ash, peat soil, and manure [11], [12].

3.2. The Effect of Adding Coal Ash on Nitrogen (N) Content and the Growth Height of Chili Plants

Nitrogen (N) is an essential nutrient component for plant growth. Nitrogen is absorbed by plants through the roots and leaf stomata, with the help of soil microorganisms, both free-living and symbiotic with plants [13]. Nitrogen absorption usually increases during humid conditions, such as during rain or after the application of foliar fertilizer. In addition, the availability of nitrogen in the soil is greatly influenced by the acidity level (pH). An increase in soil pH can enhance the mineralization of nitrogen from organic matter, thereby increasing the organic nitrogen content in the soil. However, disturbances to the nitrogen cycle can lead to a decrease in the amount of organic nitrogen available in the ecosystem [14].

Nitrogen plays an important role in the formation of chlorophyll, which functions in the process of photosynthesis and gives green color to plant leaves. The availability of sufficient nitrogen can increase the growth rate of plants, increase the number of tillers, enlarge leaf size, and enhance the protein and fat content in plant tissues [15].

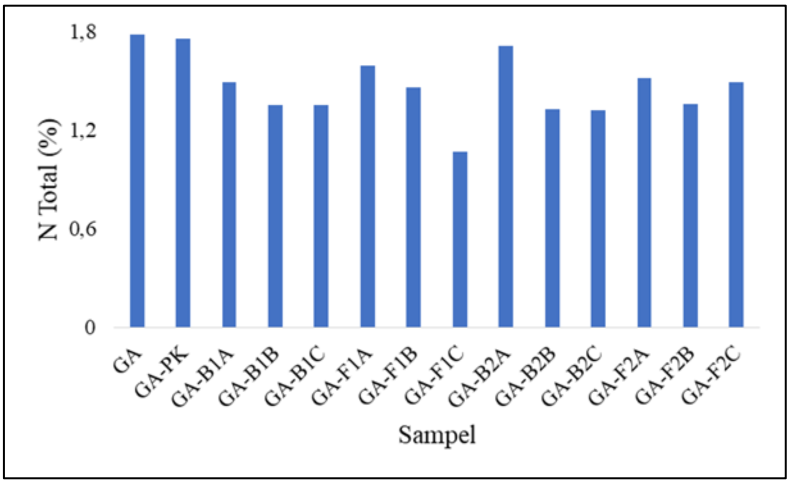

Fig. 4 Results of Nitrogen (N) Content Analysis in Various Planting Media Compositions

Based on Figure 4, it is known that the two samples, namely peat soil (GA) and peat soil with manure (GA + PK), have relatively the same nitrogen content.This indicates that the addition of manure to peat soil does not have a significant effect on increasing nitrogen levels.On the contrary, in the variations of the planting media containing bottom ash from PLTU 1 (GA + B1A, GA + B1B, GA + B1C) and bottom ash from PLTU 2 (GA + B2A, GA + B2B, GA + B2C), there was a decrease in nitrogen content.A similar decrease also occurred in the growing media supplemented with fly ash from PLTU 1 and PLTU 2.

A similar decrease also occurred in the growing media supplemented with fly ash from PLTU 1 and PLTU 2. This decrease in nitrogen content can be explained by the nature of nitrogen, which is easily leached (dissolved into water) and volatilized, especially in chemically unstable growing media.This decrease in nitrogen levels can be explained by the nature of nitrogen, which is easily leached (dissolved into water) and volatilized, especially in chemically unstable growing media conditions.This can cause nitrogen deficiency in plants growing in that medium [16].

3.3. The Effect of Adding Coal Ash on Calcium (Ca) Content and the Height Growth of Chili Plants

Calcium (Ca), in the form of calcium oxide (CaO), is a secondary macronutrient that plays an important role in strengthening plant cell structures, regulating membrane permeability, and supporting enzymatic activity [17]. Calcium also contributes to the neutralization of soil acidity and increases cation exchange capacity (CEC), which affects the availability of other nutrients. The CaO content in the growing medium is greatly influenced by the type of constituent materials, including coal ash, which is known to have a high metal oxide content, especially from the high-temperature combustion of coal.

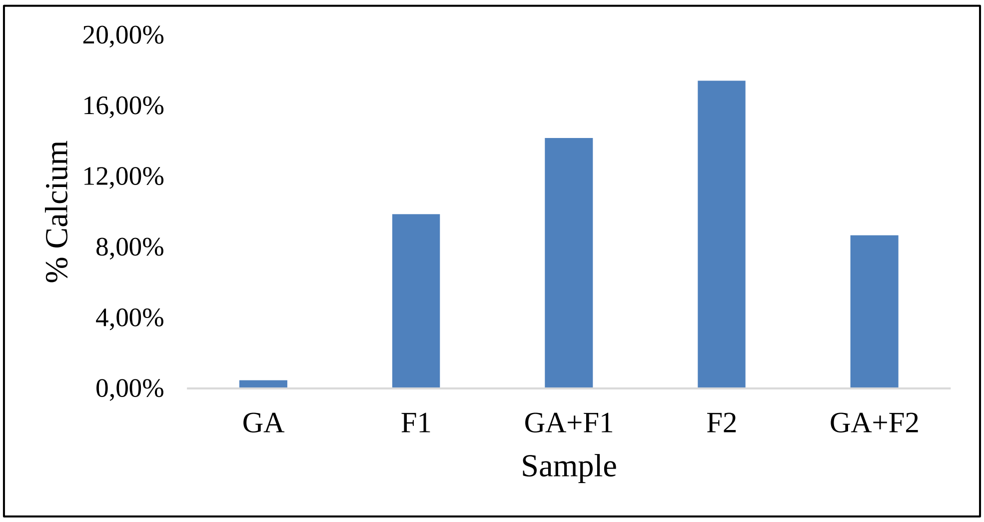

Fig. 5 Variation of calcium content with the addition of fly ash

Based on **Figure 5**, it can be seen that the calcium content (in the form of oxide, CaO) significantly increased in the samples with added fly ash compared to the control sample (peat soil/GA).The calcium content in the GA sample is very low, at less than 1%, indicating that peat soil naturally has a limited calcium content. The calcium content in the GA sample is very low, less than 1%, indicating that peat soil naturally has limited calcium content. The addition of fly ash from PLTU 1 (sample F1) increases the calcium content to around 9%, while the combination of peat soil with fly ash from PLTU 1 (GA+F1) results in an even higher calcium content, reaching around 13%.The addition of fly ash from PLTU 1 (sample F1) resulted in an increase in calcium content to around 9%, while the combination of peat soil with fly ash from PLTU 1 (GA+F1) produced a higher calcium content, reaching around 13%.This indicates that fly ash from PLTU 1 contributes significantly to the calcium content in the growing medium, especially when combined with peat soil.

This indicates that the fly ash from Power Plant Unit 1 contributes significantly to the calcium content in the growing medium, especially when combined with peat soil. The highest calcium content was obtained from the fly ash of Power Plant Unit 2 (F2), which is around 17%, indicating that the fly ash from Power Plant Unit 2 has a higher calcium oxide content compared to Unit 1.The highest calcium content was obtained from the fly ash of PLTU 2 (F2), which is around 17%, indicating that the fly ash from PLTU 2 has a higher calcium oxide content compared to PLTU 1.However, when fly ash from PLTU 2 is combined with peat soil (GA+F2), the calcium content actually decreases to around 8%, which is likely due to the influence of chemical reactions between the organic materials in the peat soil and the inorganic components in the fly ash, or due to mixing in a certain ratio that reduces the proportion of calcium.

However, when the fly ash from PLTU 2 is combined with peat soil (GA+F2), the calcium content actually decreases to around 8%, which is likely due to the influence of chemical reactions between the organic materials in the peat soil and the inorganic components in the fly ash, or due to mixing in a certain ratio that reduces the proportion of calcium. The increase in CaO content obtained from the addition of fly ash has important implications for plant growth.The increase in CaO content obtained from the addition of fly ash has significant implications for plant growth.CaO plays a role in improving soil structure, neutralizing acidity, and enhancing the absorption of other nutrients.Therefore, the addition of fly ash—especially from PLTU 2—has the potential to positively impact the growth of chili plants, as reflected in the increased plant height in the GA+B2B sample as previously explained.

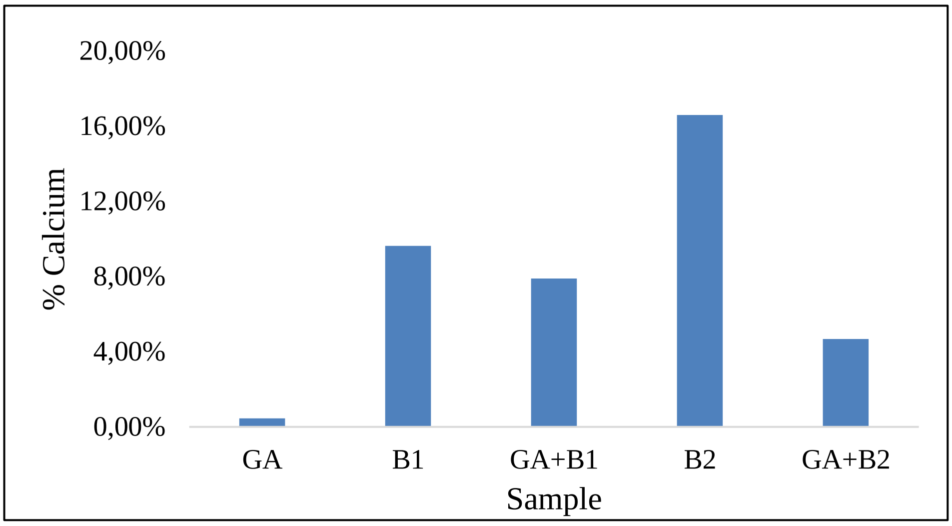

Fig. 6 Variation in calcium content with the addition of bottom ash

Based on **Figure 6**, it can be seen that the calcium (CaO) content significantly increased in the planting medium with added bottom ash compared to pure peat soil (GA).The GA sample only has a very low calcium content, less than 1%, indicating that peat soil is naturally poor in calcium. The addition of bottom ash from PLTU 1 (B1) resulted in a calcium content of about 9%, while the combination of peat soil and bottom ash from PLTU 1 (GA+B1) reduced the calcium content to about 8%.Although there is a slight decrease compared to pure B1, this level is still much higher than peat soil without the addition of bottom ash.

Sample B2 (bottom ash from Power Plant 2) shows the highest calcium content, which is around 17%, consistent with the previous results of fly ash from Power Plant 2.The high CaO content indicates that the bottom ash from PLTU 2 has better potential in enriching the calcium content in the growing medium.However, like fly ash, the mixing of PLTU 2 bottom ash with peat soil (GA+B2) actually results in a lower calcium content, around 5%, compared to pure bottom ash.

The decrease in calcium content in the mixtures (GA+B1 and GA+B2) can be caused by several factors, including the chemical interaction between organic compounds in peat soil and metal elements in bottom ash, which leads to the precipitation or immobilization of calcium, as well as the mixing ratio that causes the concentration of bottom ash to be lower in the total sample volume.

In general, the addition of bottom ash, especially from PLTU 2, has the potential to increase the calcium content in the growing medium.The high calcium content in bottom ash can help increase soil pH, strengthen plant cell structure, and support the vegetative growth of chili plants.However, its effectiveness depends on the mixing proportions and the chemical properties of each component of the growing medium

4. Conclusion

The addition of coal ash, both fly ash and bottom ash, to peat soil affects the height growth of chili plants.The best treatment was obtained from the combination of peat soil, manure, and bottom ash from PLTU 2 (GA-B2B), with plant height reaching 26.3 cm.Fly ash and bottom ash have been proven to increase the calcium (CaO) content in the growing medium, which contributes to the improvement of soil chemical properties and plant growth.However, the addition of fly ash also tends to reduce nitrogen (N) levels, so it needs to be balanced with proper nutrient management.Overall, coal ash has the potential to be a peat soil ameliorant in horticultural plant cultivation.

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