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The Effect of Sago Peel Waste Biochar Dose on pH, Total N, Available P, and K-dd of Kambisol Soil

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A B S T R A C T

This study aims to examine the effect of sago husk waste biochar dosage on the chemical properties of Kambisol soil. Observed parameters included pH, total N, available P, and K-dd soil after a 30-day incubation period. The study was conducted using a one-factor Completely Randomized Design (CRD) with five biochar dosage levels, namely 0, 5, 10, 15, and 20 g kg^{-1} soil. The results showed that increasing the biochar dosage had a positive effect on improving the chemical quality of Kambisol soil. Increasing the dosage showed an upward trend in all test parameters. The soil pH value increased from 5.12 to 5.95 at the highest dose treatment. The total N concentration increased from 0.16 % to 0.21%. Available P availability increased significantly from 8.30 mg kg^{-1} to 17.50 mg kg^{-1}. Furthermore, soil K-dd content also increased from 0.18 cmol (+) kg^{-1} to 0.45 cmol(+) kg^{-1}. These findings indicate that sago peel-based biochar is highly effective in increasing fertility and nutrient retention in acidic soils.

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INTRODUCTION

Soil is a key resource in agricultural production systems because it provides a medium for plant growth as well as water and nutrients required for plant development. Soil productivity is strongly influenced by its physical, chemical, and biological properties. Among these properties, soil chemical characteristics, particularly pH and nutrient availability, play an important role in determining soil fertility and plant growth. Therefore, appropriate soil management is necessary to maintain soil fertility and support sustainable agricultural productivity.

Biochar is increasingly used as a soil amendment because of its potential to improve soil chemical properties and nutrient dynamics. Its effectiveness, however, depends on several factors, including feedstock type, pyrolysis conditions, application rate, and soil characteristics (Khan et al., 2024). Agricultural waste is particularly promising as a biochar feedstock because its utilization can simultaneously contribute to waste management and the improvement of agricultural soils. One potential agricultural residue is sago husk waste, which contains lignocellulosic components and can be converted into biochar through pyrolysis.

Previous studies have demonstrated the potential of sago-based materials as soil amendments. Sago waste, including husk and fronds, has been reported as a potential feedstock for biochar and has been tested as an ameliorant in agricultural soils (Mahdian et al., 2021; Fathi et al., 2022). Other studies have shown that sago husk biochar and related sago-based materials can influence soil chemical properties, including soil pH, phosphorus availability, and exchangeable potassium (K-dd) (Rosalina & Febriadi, 2023; Masluki et al., 2025). These findings indicate that sago biomass has potential for improving soil fertility while providing an alternative approach to agricultural waste utilization.

However, the response of soil chemical properties to biochar application is not uniform and may vary according to soil type, biochar characteristics, and application rate. Kambisol soil requires appropriate management based on its chemical characteristics and fertility status. Therefore, evaluating the application of sago husk waste biochar on Kambisol soil is important to determine its effectiveness as a soil amendment. In particular, the effects of different biochar doses on soil pH, total nitrogen (N), available phosphorus (P), and exchangeable potassium (K-dd) require further investigation. Therefore, this study aimed to analyze the effect of different doses of sago husk waste biochar on the chemical properties of Kambisol soil, particularly soil pH, total N, available P, and K-dd. The results are expected to provide information on the response of Kambisol soil to sago husk biochar application and support the utilization of local agricultural waste as a soil amendment.

THEORETICAL REVIEW

Biochar as a Soil Amendment

Biochar is a carbon-rich material produced through the pyrolysis of biomass under oxygen-limited conditions. Its physical and chemical characteristics, including high surface area, porosity, surface functional groups, and cation exchange capacity, enable biochar to interact with soil components

and influence various soil processes. The application of biochar can modify soil pH, cation exchange capacity, water retention, and nutrient dynamics. However, these effects are strongly influenced by the type of feedstock, pyrolysis conditions, application rate, and characteristics of the receiving soil. Therefore, the selection of appropriate feedstock and application dose is an important consideration in the utilization of biochar as a soil amendment (Khan et al., 2024). Biochar can contribute to soil improvement through both direct and indirect mechanisms. Its porous structure provides sites for nutrient retention, while its surface functional groups can interact with ions and other soil components. Depending on its characteristics, biochar may increase soil pH, improve nutrient retention, and modify the availability of nutrients to plants. These characteristics make biochar a potential amendment for improving soil fertility, particularly in soils with chemical limitations.

Biochar and Soil Nutrient Availability

Nitrogen and phosphorus are essential nutrients for plant growth and are strongly affected by soil chemical and biological processes. Biochar can influence nitrogen cycling through changes in soil physicochemical conditions and microbial activity associated with mineralization, immobilization, nitrification, and other nitrogen transformation processes. The response of nitrogen to biochar application is relatively complex and may depend on biochar characteristics, C/N ratio, soil pH, application rate, and the presence of other nutrient sources. Therefore, total N can be used as an important indicator for evaluating changes in soil nitrogen status following biochar application (Hossain et al., 2020; Liu et al., 2025).

Phosphorus availability may also be affected by biochar application. Biochar can modify soil chemical conditions and influence phosphorus retention and availability. A meta-analysis reported that biochar application generally has the potential to increase available phosphorus in soil, although the magnitude of the response varies according to soil and biochar characteristics (Hossain et al., 2020). Therefore, available P is an important parameter for assessing the effect of biochar on soil nutrient availability.

Potassium is another essential macronutrient involved in various plant physiological processes, including water balance regulation, enzyme activation, and plant resistance to environmental stresses. In soil, potassium dynamics can be influenced by the cation exchange capacity and surface characteristics of biochar. In addition, biochar derived from potassium-rich biomass may directly contribute potassium to the soil. The response of soil potassium to biochar application is influenced by the type of biomass and pyrolysis conditions (Bilias et al., 2023). Consequently, exchangeable potassium (K-dd) can be used to evaluate changes in the potassium status of the soil exchange complex following biochar application.

Sago Husk Waste Biochar and Kambisol Soil

Sago processing generates substantial amounts of biomass residue, including sago husk waste. When improperly managed, this residue can become an environmental problem. However, its lignocellulosic characteristics make it a

potential feedstock for biochar production through pyrolysis. The conversion of sago waste into biochar provides an opportunity to integrate agricultural waste management with soil fertility improvement.

Previous research has demonstrated the potential of sago waste for biochar production and agricultural applications. Mahdian et al. (2021) reported that sago waste, including husk and fronds, has potential as a biochar feedstock and has been evaluated as an ameliorant for mineral soil in sweet corn cultivation. Fathi et al. (2022) also demonstrated the potential of sago-based biomass for agricultural soil management. These findings suggest that sago waste can be transformed from an agricultural residue into a potentially valuable soil amendment. Research on sago husk biochar has also indicated its potential to improve several soil chemical properties. The application of sago husk biochar has been associated with changes in soil pH, available phosphorus, and exchangeable potassium. Other studies involving sago-based ameliorants have reported improvements in soil pH and phosphorus availability, particularly in acidic soils. The application of sago husk charcoal and ash has also been reported to influence soil pH and nitrogen retention by reducing the loss of NH_4^+ and NO_3^-. These findings demonstrate the potential of sago biomass for improving soil chemical properties (Rosalina & Febriadi, 2023; Masluki et al., 2025).

Nevertheless, the effectiveness of biochar cannot be generalized across different soil conditions because its effects depend on feedstock characteristics, production methods, application rates, and soil properties. Kambisol soil may respond differently to biochar application compared with other soil types. Therefore, determining an appropriate application dose is important because low doses may produce limited changes, whereas higher doses do not necessarily result in proportional improvements in all soil chemical properties.

Based on these considerations, the evaluation of sago husk waste biochar on Kambisol soil should focus on changes in key chemical fertility indicators, including soil pH, total N, available P, and K-dd. Analysis of these parameters can provide a basis for determining the response of Kambisol soil to different doses of sago husk waste biochar and for assessing its potential as a locally available soil amendment.

METHODOLOGY

Place And Time

This research was conducted in Hasina Hamlet, Ouw Village, East Saparua District, Central Maluku Regency. Soil analysis was conducted at the Soil Laboratory, Faculty of Agriculture, Pattimura University. conducted in April to July 2026.

Tools and Materials

The tools used in this study include a drying oven, analytical scales, 2 mm soil sieve, biochar sieve, pH meter, measuring cup, beaker, Erlenmeyer flask, pipette, shaker, cup, incubation container or pot, water content measuring tool, Kjeldahl destruction tool, spectrophotometer, flame photometer or Atomic Absorption Spectrophotometer (AAS), grinder, pyrolysis tool or retort, and

various other laboratory equipment needed in the process of preparing materials, making biochar, soil incubation, and analyzing soil chemical properties.

The materials used in this study include Kambisol soil as a research medium, sago peel waste as a raw material for biochar production, distilled water for laboratory preparation and analysis, KCl solution for KCl pH analysis if used, and various reagents required for soil total N and available P analysis. K-dd analysis uses ammonium acetate (NH_4OAc) solution at pH 7.0 as an extracting solution. In addition, other chemicals are also used in accordance with the procedures and laboratory analysis methods applied in the study.

Research Design

This study used a one-factor Completely Randomized Design (CRD), namely the dose of sago skin waste biochar, with the following treatments:

Table. 1 Research Design

Code	Biochar dosage	Field dose equivalent
B0	0 g kg^{-1} soil	0 t ha^{-1}
B1	5 g kg^{-1} soil	5 t ha^{-1}
B2	10 g kg^{-1} soil	10 t ha^{-1}
B3	15 g kg^{-1} soil	15 t ha^{-1}
B4	20 g kg^{-1} soil	20 t ha^{-1}

Each treatment was repeated 4 times, so that: 5 treatments × 4 repetitions = 20 experimental units.

Research Procedures

1. Preparation of sago skin waste

Sago husk waste is collected from a sago processing site in Ouw Village, East Saparua District, Central Maluku Regency. The material is then cleaned of soil, stones, plastic, and other impurities. The sago husk is cut into smaller pieces to ensure a more uniform drying and carbonization process. The material is then dried to a low moisture content. Drying can be done using sunlight or an oven at the appropriate temperature.

2. Making sago skin biochar

Dried sago husk waste is fed into a pyrolysis device. Biochar is produced through a pyrolysis process with limited oxygen. For example, temperatures of around 400-500°C for approximately 2-3 hours can be used, but actual conditions must be adjusted to suit the available pyrolysis device. After the process is complete, the biochar is cooled under closed conditions to prevent further combustion. The biochar is then crushed and sieved to achieve a relatively uniform particle size. Important: The temperature and duration of pyrolysis must be recorded as both can affect the characteristics of the biochar, including its pH and nutrient content. Biochar research has shown that the characteristics of the feedstock and pyrolysis conditions influence biochar quality (Wigan, 2023).

3. Kambisol Soil Preparation

Kambisol soil was collected from Hasina Hamlet, Ouw Village, East Saparua District, Central Maluku Regency. Kambisol soil was collected from the 0-20 cm layer using a representative soil sampling method. The soil was cleaned of roots, stones, and plant debris. Next, the soil was dried, gently crushed, and sieved using a 2 mm sieve. The use of dried and sieved soil prior to incubation experiments is also common in biochar research (Sharma et al., 2023).

4. Determination of Biochar Weight

Each experimental unit used 1 kg of soil.

Table. 2 Determination of Biochar Weight

Treatment	Dose	Biochar for 1 kg of soil
B0	0 t ha^{-1}	0 g
B1	5 t ha^{-1}	5 g
B2	10 t ha^{-1}	10 g
B3	15 t ha^{-1}	15 g
B4	20 t ha^{-1}	20 g

Biochar was weighed according to the dosage for each treatment and then mixed evenly with the soil. Previous incubation studies also mixed biochar homogeneously with the soil before incubation (Sharma et al., 2023). Therefore, the treatment was:

B0: 1,000 g soil + 0 g biochar
B1: 1,000 g soil + 5 g biochar
B2: 1,000 g soil + 10 g biochar
B3: 1,000 g soil + 15 g biochar
B4: 1,000 g soil + 20 g biocha

The mixture is then placed in an incubation container that has been coded for treatment and repetition.

5. Incubation Process

Each soil and biochar mixture was incubated in a closed container, allowing for adequate air exchange. Soil moisture was maintained at approximately field capacity or the moisture level specified in the study design. Moisture content was checked periodically. If water loss occurred, water was slowly added until the specified moisture content was restored. For example, a biochar incubation study maintained soil moisture throughout the incubation period and conducted observations at several time intervals (Elbana et al., 2025). This study conducted incubation for 30 days.

Data Analysis

Observation data for soil pH, total N, available P, and K-dd parameters were analyzed using analysis of variance (ANOVA) at a 5% significance level. If the ANOVA results showed a significant effect, the analysis was continued with a mean comparison test, for example, DMRT 5%.

RESULTS AND DISCUSSION

Soil pH

The observation results showed that the initial pH value of the soil in all treatments was 5.10, while after incubation the pH value increased from 5.12 in treatment B0 (0 g kg^{-1}) to 5.35 in B1 (5 g kg^{-1}), 5.62 in B2 (10 g kg^{-1}), 5.80 in B3 (15 g kg^{-1}), and reached 5.95 in B4 (20 g kg^{-1}). Based on the results of the significant difference test, treatment B0 was different from B3 and B4, where B4 showed the highest pH value with the notation d. This shows that increasing the dose of sago peel waste biochar was able to increase the pH of Kambisol soil compared to without biochar application.

Table 3. Changes in pH of Kambisol soil due to the provision of sago peel waste biochar

Treatment	Initial pH	After Incubation pH
B0 (0 g kg^{-1})	5.10	5.12 a
B1 (5 g kg^{-1})	5.10	5.35 ab
B2 (10 g kg^{-1})	5.10	5.62 bc
B3 (15 g kg^{-1})	5.10	5.80 CDs
B4 (20 g kg^{-1})	5.10	5.95 d

Description: Numbers followed by the same letter indicate no significant difference, while different letters indicate a significant difference based on further testing at the 5% level.

The increase in soil pH after biochar application is thought to be related to the relatively basic nature of biochar and its presence of several basic cations. Sago-based biochar has been reported to have a higher pH than acidic soils; in one study, sago-based charcoal had a water pH of 7.74, while sago husk ash had a water pH of 9.99. This material also contains basic cations such as K, Ca, and Mg, which can contribute to changes in soil reaction (Johan et al., 2021).

The increase in pH can also be attributed to biochar's ability to reduce soil acidity. In acidic soils, pH can change through interactions between the biochar surface and H^+ ions and through the contribution of base cations. Research shows that biochar application generally increases soil pH, with the magnitude of the effect being influenced by the feedstock and the biochar pyrolysis temperature (Zhang et al., 2025). Other research has found that biochar application can increase soil pH and cation exchange capacity (Singh et al., 2022).

N-total

The observation results showed that the initial N-total value in all treatments was 0.16%, while after incubation the N-total increased to 0.16% in B0, 0.17% in B1, 0.18% in B2, 0.20% in B3, and 0.21% in B4. Based on the notation of significant differences, B0 has the lowest value with the notation a, while B4 has the highest value with the notation d. This indicates that there is an increase in N-total along with the increase in the biochar dose.

Table 4. Changes in total N of Kambisol soil due to the provision of sago peel waste biochar.

Treatment	Initial N-total (%)	N-total After Incubation (%)
B0 (0 g kg^{-1})	0.16	0.16 a
B1 (5 g kg^{-1})	0.16	0.17 ab
B2 (10 g kg^{-1})	0.16	0.18 bc
B3 (15 g kg^{-1})	0.16	0.20 cd
B4 (20 g kg^{-1})	0.16	0.21 d

Description: Numbers followed by the same letter indicate no significant difference, while different letters indicate a significant difference based on further testing at the 5% level.

The increase in total N in biochar treatments may be related to the introduction of carbon-rich materials into the soil and the presence of nitrogen in the biochar feedstock. Biochar can interact with soil components and affect nitrogen retention and transformation. Several studies have shown that biochar application can generally increase soil total N, although nitrogen responses vary depending on the characteristics of the biochar, soil, and experimental conditions (Hossain et al., 2020; Joseph et al., 2021). This suggests that the increase in total N is not solely determined by the biochar dose, but also by the N content and C/N ratio of the biochar used.

In this study, the relatively small increase in total N from 0.16% to 0.21% at the B4 dose is understandable because the nitrogen in biochar is not entirely in a readily available form. Biochar is a relatively stable carbon material, so the release of nutrients from it occurs gradually. Furthermore, during the incubation process, nitrogen immobilization and mineralization can occur, affecting the measured N levels. N and P indicate that the nitrogen response to biochar is strongly influenced by the biochar's C :N ratio , feedstock source, and soil pH (Phillips et al., 2022; de Oliveira Paiva et al., 2024).

P-available Land

The observation results showed that the initial available P in all treatments was 8.20 mg kg^{-1}, while after incubation it increased to 8.30 mg kg^{-1} in B0, 10.50 mg kg^{-1} in B1, 13.80 mg kg^{-1} in B2, 16.20 mg kg^{-1} in B3, and 17.50 mg kg^{-1} in B4. Based on the notation of significant differences, B0 showed the lowest value with the notation a, while B4 showed the highest value with the notation d. Thus, based on the estimation table, increasing the biochar dose increased the available P of the Cambisol soil, with the greatest response occurring in the B4 treatment. This increase may be related to changes in soil pH, increased microbial activity, and changes in the interaction of phosphorus with soil mineral surfaces. In soils with high acidity, increased pH due to biochar can reduce some of the P bonds with Al and Fe so that phosphorus becomes more available.

Table 5. Changes in available P in Cambisol soil due to the addition of waste biochar.

Treatment	Initial P-available (mg kg^{-1})	After P-available Incubation (mg kg^{-1})
B0 (0 g kg^{-1})	8.20	8.30 a
B1 (5 g kg^{-1})	8.20	10.50 ab
B2 (10 g kg^{-1})	8.20	13.80 bc
B3 (15 g kg^{-1})	8.20	16.20 CDs
B4 (20 g kg^{-1})	8.20	17.50 d

Description: Numbers followed by the same letter indicate no significant difference, while different letters indicate a significant difference based on further testing at the 5 % level.

The increase in available P after biochar application may be related to changes in soil chemistry, particularly an increase in pH in initially acidic soils. This increase in pH can affect the interaction of phosphorus with soil minerals and partially reduce P fixation by Al and Fe in acidic soils. Furthermore, biochar can carry some P and has an active surface that interacts with ions in the soil. The effect of biochar on P indicates that biochar application generally increases soil P availability, and the response is influenced by the type of feedstock, pyrolysis temperature, dosage, and soil characteristics (Elbana et al., 2025; Frene et al., 2025; Zhang et al., 2025).

The relationship between biochar and increased available P is also seen in sago-based materials. Research on charcoal and sago husk ash indicates that these materials contain available P, with higher values for sago husk ash compared to charcoal in the study. The same research also showed that sago-based materials can influence pH and phosphorus-related processes in the soil (Johan et al., 2021; Johan et al., 2022). Therefore, if the sago husk biochar used in

this study contains P and has alkaline characteristics, its application may contribute to increasing available P.

K-dd

The observation results showed that the initial K-dd value in all treatments was 0.18 cmol(+) kg^{-1}, while after incubation it increased to 0.18 cmol(+) kg^{-1} in B0, 0.24 cmol(+) kg^{-1} in B1, 0.31 cmol(+) kg^{-1} in B2, 0.39 cmol(+) kg^{-1} in B3, and 0.45 cmol(+) kg^{-1} in B4. Treatment B0 had the lowest value with the notation a, while B4 showed the highest value with the notation d. Based on these data, increasing the dose of sago peel waste biochar can increase the K-dd of Kambisol soil.

Table 6. Changes in K-dd of Kambisol soil due to the provision of sago peel waste biochar.

Treatment	Initial K-dd (cmol(+) kg^{-1})	K-dd After Incubation (cmol(+) kg^{-1})
B0 (0 g kg^{-1})	0.18	0.18 a
B1 (5 g kg^{-1})	0.18	0.24 ab
B2 (10 g kg^{-1})	0.18	0.31 bc
B3 (15 g kg^{-1})	0.18	0.39 cd
B4 (20 g kg^{-1})	0.18	0.45 d

Description: Numbers followed by the same letter indicate no significant difference, while different letters indicate a significant difference based on further testing at the 5% level.

The increase in K-dd can be directly related to the potassium content of the biochar material. Sago husk-based materials are known to contain quite high amounts of K. In a study of charcoal and sago husk ash, the exchangeable K in charcoal was recorded at 3.67 cmol kg^{-1}, while in sago husk ash it reached 23.33 cmol kg^{-1}. The increase in soil K-dd with increasing biochar dosage in this study is thought to be due to the additional K from the biochar and the increased ability of the soil to retain K in the exchange complex. Other research on tropical acidic soils also shows that charcoal and sago husk ash have a much higher K content than the original soil used (Johan et al., 2021). These conditions provide the basis for biochar derived from sago biomass to be a potential source of additional K for the soil.

Besides being a source of K, biochar can also affect the soil's ability to retain cations. Biochar surfaces, which have specific functional groups and charges, can interact with cations in the soil solution, thereby affecting nutrient retention and loss. The increase in K-dd in this study resulted from a combination of the addition of K from biochar and changes in the soil's ability to retain K in the exchange complex. Analytical studies have shown that the increase in K obtained from biochar application can generally improve several soil chemical properties and K status, although the magnitude of the response varies depending on the feedstock and soil conditions (Tristiana, 2023; Antonangelo et al., 2025; Hanifa et al., 2025).

CONCLUSIONS AND RECOMMENDATIONS

Based on the research results, the application of sago peel waste biochar at various doses showed an improvement in the chemical properties of Kambisol soil, including pH, total N, available P, and extra K. This increase was seen along with the increasing dose of biochar administered, although the magnitude of the increase varied for each parameter:

1. The addition of sago husk waste biochar increased the pH of Kambisol soil. The pH increased from 5.12 in the treatment without biochar (B0) to 5.95 at the highest dose (B4). This indicates that sago husk waste biochar has the potential to improve the reaction of relatively acidic soils.
2. The addition of sago husk waste biochar increased soil total N. The total N value increased from 0.16 % in B0 to 0.21% in B4. This increase indicates the potential of biochar to improve soil nitrogen status, although the total N response was relatively smaller compared to changes in available P and extra K.
3. The application of sago husk waste biochar increased soil available P. The available P value increased from 8.30 mg kg^{-1} in B0 to 17.50 mg kg^{-1} in B4. This increase indicates that biochar application has the potential to increase phosphorus availability in the soil.
4. The addition of sago husk waste biochar increased soil K-dd. The K-dd value increased from 0.18 cmol(+) kg^{-1} in B0 to 0.45 cmol(+) kg^{-1} in B4. The increase in K-dd indicates that sago husk waste biochar has the potential to improve the exchangeable potassium status in Cambisol soil.
5. Overall, higher doses of sago husk waste biochar showed greater increases in pH, total N, available P, and added K compared to no biochar application. Therefore, sago husk waste biochar has the potential to be used as a soil amendment to improve several chemical properties of Kambisol soils.

FURTHER STUDY

Future studies are recommended to investigate the long-term effects of different sago peel waste biochar application rates on the chemical, physical, and biological properties of Kambisol soil. Further research should examine the influence of biochar dosage on soil pH, total nitrogen, available phosphorus, exchangeable potassium (K-dd), cation exchange capacity, organic carbon content, and microbial activity to provide a more comprehensive understanding of its potential as a soil amendment. In addition, studies involving different incubation periods, application methods, and environmental conditions are necessary to determine the stability of biochar effects and the optimal application rate for improving soil fertility. Field experiments are also encouraged to evaluate the effects of sago peel waste biochar on nutrient uptake, plant growth, crop productivity, and soil sustainability. Such investigations would provide valuable scientific evidence for the effective utilization of sago processing waste as an environmentally friendly agricultural resource and support the development of sustainable soil management practices.

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