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The Effect of Candlenut Shell Ash and Biochar and NPK Fertilization on Corn (Zea mays L.) Growth and Production

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Abstract

Corn (*Zea mays* L.) is a strategic food crop that requires an adequate supply of essential nutrients, particularly nitrogen, phosphorus, and potassium, to support optimal growth and yield. The increasing accumulation of candlenut shells, which are difficult to decompose due to their high lignin content, has contributed to environmental pollution. Processing candlenut shells into ash or biochar can enhance their value. Both candlenut shell ash and biochar can serve as soil ameliorants, improving soil fertility by increasing soil pH, organic carbon, and cation exchange capacity (CEC), especially in ultisol soils characterized by low fertility. Ultisol soils are typically acidic, have high aluminum saturation, and low CEC. Ash, an inorganic material rich in calcium, is produced through complete combustion, whereas biochar is a carbon-rich material generated via pyrolysis. This study aimed to evaluate the effects of candlenut shell ash and biochar on the availability of N, P, and K nutrients in corn (Zea mays L.) cultivated in Samosir Regency. The research was conducted in Pangururan, Samosir Regency, from June to November 2024. The results demonstrated that applying candlenut shell ash and biochar as ameliorants enhanced corn growth. Candlenut shell ash was more effective than biochar at improving NPK fertilizer efficiency. Specifically, the application of candlenut shell ash at 10 tons per hectare, combined with a single NPK fertilizer dose (treatment A12), yielded the best corn growth. Based on these findings, the use of candlenut shell ash is recommended for corn cultivation on ultisol soils, as it more effectively increases nutrient availability and plant growth, thereby potentially enhancing corn productivity sustainably.

Keywords: Ash, Ameliorant, Biochar, Maize, Ultisol Soil

1. Introduction

Samosir Regency is recognized as one of the key regions producing candlenuts, which are widely used as a primary cooking spice. In 2023, candlenut production in Samosir Regency reached 1,916 tons per hectare (Badan Pusat Statistik Kabupaten Samosir, 2023). This increase in production has led to a corresponding rise in candlenut shell waste, necessitating proper management to prevent environmental pollution. Currently, the common practice is to burn candlenut shell waste to produce ash containing inorganic elements. Additionally, candlenut shells can be processed into biochar through pyrolysis, offering added value and opportunities for more sustainable utilization.

On the other hand, the low fertility of Ultisol soil in Samosir Regency is a major obstacle to increasing agricultural productivity, particularly for corn (*Zea mays* L.) (Central Statistics Agency of Samosir Regency, 2023). Corn is an important food commodity that plays a significant role in food security and the economy, but infertile soil conditions often hamper its productivity. Ultisol soils are generally acidic, have low organic matter content, and limited nutrient availability, making conventional fertilization often ineffective. This condition is exacerbated by land degradation and soil nutrient imbalances.

Candlenut seed processing also produces shell waste with a lignin content of approximately 60.1% and hemicellulose of approximately 30.4%, which is difficult to decompose naturally and has the potential to pollute the environment if not managed properly. Therefore, the use of candlenut shells as a soil ameliorant, processed into ash or biochar, is a promising alternative. Candlenut shell ash contains alkaline minerals, such as calcium and magnesium, which help raise soil pH, improve soil physical

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structure, and increase soil water-holding capacity (Nguyen et al., 2017). Meanwhile, biochar resulting from candlenut shell pyrolysis has high stability and the ability to increase water retention, cation exchange capacity, and reduce nutrient loss due to leaching and erosion (Gani, 2009).

Thus, the utilization of candlenut shell waste in the form of ash and biochar not only contributes to environmentally friendly agricultural waste management but also has the potential to improve the chemical and physical properties of Ultisol soil, thereby supporting the growth and productivity of corn plants (Siruru et al., 2018).

Several previous studies have examined the use of biomass waste as a soil fertility ameliorant. Siruru et al. (2018) and Nguyen et al. (2017) showed that biochar can increase cation exchange capacity, retain water, and support plant growth, but these studies did not specifically use candlenut shells or were conducted under laboratory conditions. Hale et al. (2020) studied the effects of biomass ash on pH and mineral content, but its effects on corn have not been widely studied. Research by Cornelisen et al. (2018) on Ultisol soil showed that biochar and ash can improve soil properties, but the raw materials used were not candlenut shell waste.

This study explores the use of local candlenut shell waste from Samosir Regency, in the form of biochar and ash, to enhance the fertility of Ultisol soil and promote corn growth. The novelty of this research lies in the simultaneous evaluation of both waste forms, a comprehensive assessment of the soil's physical, chemical, and biological properties, and the application of dosages specifically tailored to field conditions. This approach not only boosts corn productivity but also maximizes the economic value of the waste and supports sustainable agricultural practices.

Therefore, this research was motivated by the need to evaluate the effectiveness of candlenut shell ash and biochar as soil amendments to improve Ultisol soil quality and enhance corn growth, while simultaneously promoting the sustainable use of agricultural waste. The results of this study are expected to provide a scientific basis for land management strategies, optimize fertilization practices, and mitigate the environmental impacts of candlenut shell waste.

2. Material and Methods

The research was conducted in the Pangururan area of Samosir Regency, North Sumatra, located at coordinates ±2.61° North Latitude and 98.70° East Longitude. The altitude of the area above sea level ranges from 900 to 1,100 meters to 2,157 meters. The climate of Pangururan, Samosir Regency, is humid tropical, with cool air temperatures ranging from 17–26°C and quite high rainfall, around 2,200–2,300 mm per year. This condition causes rain almost year-round. Environmentally, Pangururan is located in a highland area surrounded by Lake Toba. Soil analysis was conducted at the Research and Technology Laboratory and the Plant Pest and Disease Laboratory, Faculty of Agriculture, University of North Sumatra, and PT. Socfin Indonesia. This research was conducted from June to November 2024.

The materials used in this study include Pioneer 32 corn seeds as planting material, Urea fertilizer (46% N), SP-36 (36% P_2O_5), and KCl (60% K_2O) as nutrient sources, and candlenut shell ash and biochar as ameliorants. Seeds and fertilizers were obtained from agricultural stores in Pangururan. 500 kg of candlenut shells were obtained from farmers in Pangururan, Samosir Regency. Biochar was produced by pyrolysis at 350–500°C for 5–8 hours, until a uniform black charcoal formed; it was then cooled for 24 hours and ground to 10 mesh. Candlenut shell ash was obtained by burning the shells in a drum until a gray ash was formed, then cooled naturally.

The recommended dosage of NPK fertilizer is 300 kg/ha of Urea, 75 kg/ha of SP-36, and 50 kg/ha of KCL. The half dosage of NPK fertilizer is: Urea 100 kg/ha (32.5 g/plot), SP-36 37.5 kg/ha (12.1875 g/plot), and KCL 25 kg/ha (8.125 g/plot). The single dosage of NPK fertilizer is: Urea 200 kg/ha (65 g/plot), SP-36 75 kg/ha (24.375 g/plot), and KCL 50 kg/ha (16.25 g/plot).

The tools used in this research are a hoe to manage the soil, a plastic rope, a pyrolysis tube for making biochar, scales for weighing materials and fertilizers, meters, label paper as markers for each treatment, a hand sprayer as a tool for spraying pesticides to control HPT, and other laboratory tools for soil analysis purposes. The research used a non-factorial randomized block design (RAK) with 9 treatments:

K : Control)
A11 : Shell ash) 10 tons/ha of candlenut and ½ dose of NPK fertilizer
A21 : Shell ash) 20 tons/ha of candlenut and ½ dose of NPK fertilizer
A12 : Shell ash) 10 tons/ha of candlenut and 1 dose of NPK fertilizer
A22 : Shell ash) 20 tons/ha of candlenut and 1 dose of NPK fertilizer
B11 : Candlenut shell biochar 10 tons/ha and NPK fertilizer ½ dose
B21 : Candlenut shell biochar 20 tons/ha and NPK fertilizer ½ dose
B12 : Candlenut shell biochar 10 tons/ha and 1 dose of NPK fertilizer
B12 : Candlenut shell biochar 20 tons/ha and 1 dose of NPK fertilizer

Each treatment was repeated 3 times, yielding 27 experimental units. The data were processed using the Statistical Package for the Social Sciences (SPSS) V.25 trial. The data were analyzed using Analysis of Variance (ANOVA) followed by an orthogonal contrast test at a 5% level. The observed variables were pH, organic carbon, CEC, plant height, shoot dry weight, and root dry weight.

The study began with an analysis of initial soil chemical properties, including pH, total N, available P, exchangeable K, organic C, and cation exchange capacity (CEC), from soil samples collected at a depth of 0–20 cm and randomly distributed across the research site in Pangururan, Samosir Regency. The research land measuring 11.15 m x 10.1 m, or 112,615 m², was cultivated and divided into 27 plots, each planted with corn, with ash and biochar applications at the treatment dose 14 days before planting. Corn planting was carried out using a dipstick, followed by NPK fertilization according to the treatment level, and plant maintenance, including thinning, watering, weeding, and pest and disease control. Final soil analysis was conducted at the end of the vegetative phase (60 days after planting) to assess changes in pH (electrometric method), organic C (Walkley-Black method), and CEC (NH4OAc pH 7 extraction method). The observed plant variables included plant height and the dry weight of the crown and roots.

2.1. Research Flowchart

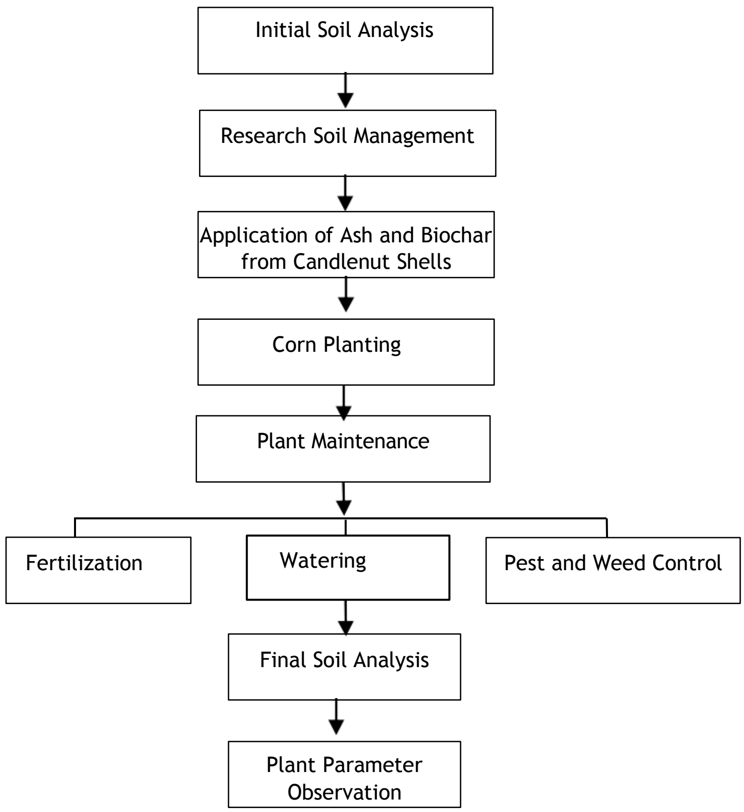

Figure 1. Research Flowchart

3. Results and Discussion

3.1. Soil Properties

Observational data show that the application of candlenut shell ash and biochar, and NPK fertilizer has no significant effect on soil properties (soil pH, organic C, and CEC (Cation Exchange Capacity)). The average data on soil properties resulting from the application of candlenut shell ash and biochar are presented in Table 1.

Table 1. Soil properties due to application of candlenut shell ash, biochar, and NPK fertilizer dosage

Treatment	Soil pH	C-organic (%)	KTK
K (Control)	4.90 M	1.43 R	18.91 S
A11 (Shell ash) 10 tons/ha of candlenut and ½ dose of NPK fertilizer)	4.91 M	1.30 R	17.15 S
A21 (Shell ash) 20 tons/ha of candlenut and ½ dose of NPK fertilizer)	4.95 M	1.50 R	17.43 S
A12 (Shell ash) 10 tons/ha of candlenut and 1 dose of NPK fertilizer)	4.86 M	1.19 R	17.55 S
A22 (Shell ash) 20 tons/ha of candlenut and 1 dose of NPK fertilizer)	5.00 M	1.52 R	16.15 R
B11 (Candlenut shell biochar 10 tons/ha and NPK fertilizer ½ dose)	4.96 M	1.37 R	17.59 S
B21 (Candlenut shell biochar 20 tons/ha and NPK fertilizer ½ dose)	4.94 M	1.42 R	18.33 S
B12 (Candlenut shell biochar 10 tons/ha and 1 dose of NPK fertilizer)	4.91 M	1.40 R	18.69 S
B22 (Candlenut shell biochar 20 tons/ha and 1 dose of NPK fertilizer)	4.86 M	1.35 R	18.02 S

Note: M = Sour (4.5 – 5.5), R = Low (1.00 – 2.00), S = Medium (2.01 – 3.00)

Based on Table 1, the application of candlenut shell ash and biochar, as well as NPK fertilizer, did not increase soil pH, as it remained acidic. It did not affect the increase in soil organic carbon (C) because all criteria were still low. There was a decrease in soil CEC (Central Crucible) values after the application of candlenut shell ash and biochar. This finding was due to insufficient application rates of candlenut shell ash and biochar, and to the timing of soil sampling, which prevented the ash and biochar from affecting soil properties.

Rapid changes in soil pH after ash application are primarily influenced by the presence of carbonates, oxides, hydroxides, and bicarbonates. During biomass combustion, the formation of various oxides and high aeration conditions promote the formation of carbonates in the ash, making it alkaline (Hossain et al., 2020). Candlenut shell ash contains alkaline compounds such as calcium carbonate ($CaCO_3$) and magnesium oxide (MgO), which can neutralize hydrogen ions (H^+) and reduce soil acidity (Gani, 2009). However, in Ultisol soils with low buffering capacity and high rainfall, alkaline cations are easily leached, making the increase in soil pH temporary and less effective in the long term.

In line with this, the cation exchange capacity (CEC) value of the soil after the administration of candlenut shell ash was in the range of 16.15–18.91 cmol(+) kg^- 1, which did not show a significant increase compared to the control (18.91 cmol(+) kg^- 1), even in some treatments it decreased by around 5–15 %. This result is consistent with Gani's (2009) research, which found that ash from biomass combustion at high temperatures has a very low organic carbon content (<1%), limiting its contribution to increasing soil CEC. On the other hand, the increase in organic matter in land material by 1 % was reported to increase soil KTK by 1.5–3.0 cmol (+) kg^{-1} (Sari et al., 2019). In this study, the organic C content of land post-application ash ranges from 1.19–1.52%, which is relatively the same as the control (1.43%), suggesting that the quantitative increase in soil KTK is not yet sufficient.

Combustion process temperature and height also change the structure and properties of the surface ash, which is next lower in its ability to tie Cations. Soil organic matter provides important exchange sites for base cations such as K, Ca, and Mg. Therefore, the low organic matter content of candlenut shell ash limits its effectiveness as a soil ameliorant to increase CEC.

The application of candlenut shell biochar did not significantly affect soil organic carbon levels. This observation relates to the highly stable (recalcitrant) nature of biochar carbon and its predominantly aromatic structure, which makes it difficult to decompose biologically and contributes little to the soil's active organic carbon fraction (Gani, 2009). Biochar produced at high pyrolysis temperatures (>500 °C) generally contains approximately 97% stable carbon and only ±3% labile carbon, resulting in very low availability to soil microorganisms (Biswal et al., 2025).

Although several studies have reported significant increases in soil organic carbon (SOC) after biochar application, this effect is strongly influenced by biochar type, pyrolysis temperature, application rate, soil characteristics, and incubation time. Stabilization of soil carbon through aggregate formation and changes in microbial activity is generally only observed after a relatively long period (>1–2 years) (Singh et al., 2014). Therefore, the insignificant effect of biochar on soil organic C in this study is consistent with the persistent nature of biochar and the relatively short observation period.

3.2. Plant Growth

Observational data showed that applying candlenut shell ash and biochar, along with NPK fertilizer, significantly affected plant height, shoot dry weight, and root dry weight. Average plant growth data with candlenut shell ash and biochar applications are presented in Table 2 as follows.

Based on Table 2, the application of candlenut shell ash and biochar significantly increased corn plant height compared to the control. The highest plant height was obtained in the A22 candlenut shell ash treatment (6.5 kg/plot + 1 dose of NPK fertilizer) at 222.52 cm, while in the B21 biochar treatment, the highest was 196.89 cm. Compared with the control (155.33 cm), both ameliorants significantly increased plant height, but candlenut shell ash was more effective than biochar.

The superiority of candlenut shell ash in increasing plant height is thought to be related to its ability as an ameliorant and nutrient source. Candlenut shell ash not only improves soil chemical properties but also provides essential nutrients that are more readily available to plants. Hamidi et al. (2021) reported that plant ash is hydrophilic, increasing soil water retention, microbial activity, and the availability of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), thereby supporting plant growth and yield.

These results are also in line with the findings of Hasnia (2017), which stated that administering rice husk ash at various concentrations resulted in better plant growth responses. Chemically, ash functions to reduce soil acidity by releasing acid bonds, so that nutrients become more available. Physically, ash also improves soil aeration, which in turn supports optimal plant growth and development.

Based on Table 2, the application of candlenut shell ash and biochar had a highly significant effect on corn shoot dry weight compared to the control. The highest shoot dry weight was observed in the candlenut shell ash treatment, with A22 averaging 244.89 g, while in the biochar treatment, the highest value was observed in B12 at 184.38 g. The results of the contrast test showed that the application of ash and biochar significantly increased shoot dry weight compared to the control (113.51 g), with the increase from candlenut shell ash being higher than that from biochar.

Table 2. Plant growth due to the application of candlenut shell ash, biochar, and NPK fertilizer dosage

Treatment	Plant Height (cm)	Dry Weight of Head (g)	Root Dry Weight (g)
K (Control)	155.33 ± 2.67	113.51 ± 15.33	39.40 ± 6.36
A11 (Shell ash) 10 tons/ha of candlenut and ½ dose of NPK fertilizer)	212.67 ± 8.66	193.49 ± 18.07	96.68 ± 20.26
A21 (Shell ash) 20 tons/ha of candlenut and ½ dose of NPK fertilizer)	218.44 ± 6.29	204.77 ± 39.50	72.87 ± 17.59
A12 (Shell ash) 10 tons/ha of candlenut and 1 dose of NPK fertilizer)	210.33 ± 4.36	244.14 ± 21.46	85.08 ± 11.75
A22 (Shell ash) 20 tons/ha of candlenut and 1 dose of NPK fertilizer)	222.52 ± 11.43	244.89 ± 11.55	75.36 ± 13.17
B11 (Candlenut shell biochar 10 tons/ha and NPK fertilizer ½ dose)	191.67 ± 6.34	133.54 ± 39.41	62.56 ± 3.00
B21 (Candlenut shell biochar 20 tons/ha and NPK fertilizer ½ dose)	196.89 ± 6.87	176.11 ± 41.68	64.61 ± 19.66
B12 (Candlenut shell biochar 10 tons/ha and 1 dose of NPK fertilizer)	195.00 ± 6.08	184.38 ± 16.07	60.32 ± 16.55
B12 (Candlenut shell biochar 20 tons/ha and 1 dose of NPK fertilizer)	191.89 ± 4.76	146.57 ± 46.79	62.07 ± 16.30
Contrast Test			
C1: K Vs A11 A21 A12 A22 B11 B21 B12 B22	**	**	**
C2: A11 A21 A12 A22 vs B11 B12 B12 B22	**	**	**
C3: A11 vs A21 A12 A22	tn.	tn.	tn.
C4: A21 VS A12 A22	tn.	tn.	tn.
C5: A12 vs A22	tn.	tn.	tn.
C6: B11 vs B21 B12 B22	tn.	tn.	tn.
C7: B21 vs B12 B22	tn.	tn.	tn.
C8: B12 vs B22	tn.	**	tn.

Note: tn = not real, ** = very real, * = real

The increase in dry crown weight following the application of candlenut shell ash is thought to be related to increased availability of essential nutrients, which support cell division and enlargement, resulting in optimal plant growth. This result is consistent with the findings of Kuvaini and Surbakti (2019), who reported that applying boiler ash increased leaf number, plant height, and dry weight. Furthermore, candlenut shell ash contains essential nutrients such as calcium (Ca), potassium (K), and phosphorus (P), and is alkaline, thus increasing the pH of acidic soils and improving nutrient availability and root condition (Lehmann and Kleber, 2015).

Based on Table 2, the application of candlenut shell ash and biochar had a highly significant effect on corn root dry weight compared to the control. The highest dry root weight was observed in the candlenut shell ash treatment (A11; 96.68 g), while in the biochar treatment the highest value was observed in B21 (64.61 g). The results of the contrast test showed that the application of ash and biochar significantly increased dry root weight compared to the control (39.40 g), but the increase from candlenut shell ash was higher than that from biochar. Quantitatively, candlenut shell ash increased root dry weight by 96.68 g, while biochar only achieved 64.61 g.

Figure 2. Comparison of the application of candlenut shell ash and biochar to corn plants.

The effectiveness of candlenut shell ash is thought to be related to its role as an ameliorant, which not only improves soil chemical properties by releasing bound acids but also provides essential minerals and increases aeration and water-holding capacity, thereby supporting root system development. This result is consistent with Hamidi et al. (2021), who reported that plant ash is hydrophilic and can enhance water retention, microbial activity, nutrient availability, and plant growth.

Meanwhile, the application of candlenut shell biochar also resulted in a significant increase in root dry weight, although lower than that of ash. This result relates to biochar's ability to increase soil water retention and nutrient-use efficiency. However, the lower response in the early growth phase is likely due to biochar's relatively stable nature, which requires a longer time to decompose and release nutrients. This finding aligns with Winie and Hidayat (2023), who stated that biochar has a positive effect on plant growth and dry weight, but its optimal effect tends to occur over a longer period.

4. Conclusion

The research results demonstrated that candlenut shell ash was more effective than biochar, particularly at a 10-ton-per-hectare dose combined with the recommended NPK fertilizer dose. This combination led to optimal growth and increased corn yield. Therefore, candlenut shell ash is recommended as an effective and practical soil amendment for enhancing corn productivity on Ultisol soils.

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