Rice Husk Biochar as an Amendment to Improve Sweet Corn Performance on Bengkulu Entisols

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Abstract
Background: Entisol soil in the coastal area of Bengkulu has low fertility with limited organic matter and nutrient contents, so it requires soil amendments to increase plant productivity. **Aim:** This study aims to evaluate the effectiveness of rice husk biochar on improving soil chemical properties and increasing sweet corn (*Zea mays* saccharata) yield. **Methods:** The experiment was conducted on a polybag scale (10 kg of soil per polybag) using a Completely Randomised Design (CRD) with four doses of rice husk biochar (0, 5, 10, and 15 t/ha), with each treatment repeated six times. Biochar was produced through indirect pyrolysis at a temperature of approximately 400 °C, incubated for four weeks, and applied to the soil at 50% of the recommended fertilizer dose. **Results:** The analysis results showed that the application of rice husk biochar had a significant effect ($p < 0.05$) on increasing soil pH, organic carbon (C), total nitrogen (N), and cation exchange capacity (CEC). A dose of 10 t/ha increased soil pH from 6.01 to 6.61, organic C from 2.09% to 2.81%, total N from 0.11% to 0.17%, and CEC from 4.98 to 5.64 cmol(+)/kg, significantly higher than the control ($p < 0.05$). This increase in fertility directly impacted the growth and yield of sweet corn, with cob weight reaching 437.5 g, significantly greater than the control at $p < 0.05$, but not significantly different from the dose of 15 t/ha. **Conclusion:** Thus, rice husk biochar at a dose of 10 t/ha effectively improves Entisol soil quality and increases sweet corn yields, and has the potential to be applied as a sustainable agricultural innovation in tropical marginal lands.

Keywords: entisol; marginal land; rice husk biochar; soil amendment; sweet corn

Introduction

Sweet corn (*Zea mays* saccharata) holds significant economic importance in Indonesia. Its cultivation frequently encounters obstacles, especially in regions like Bengkulu, where Entisol soils are predominant. Entisols are immature soils with poorly developed horizons, limited mineral levels, and scant organic matter, which substantially hinder sweet corn yields (Sofyan et al., 2024). Additionally, Entisols exhibit low nutrient retention and cation exchange capacity (CEC), reducing nutrient availability to plants. The deficiency in organic matter further aggravates this issue, as organic matter plays a key role in aggregate formation, water-holding capacity, and the supply of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K)(Saifulloh & Suntari, 2022). Therefore, adopting suitable nutrient management practices is essential to enhance sweet corn productivity on Entisol soils. Incorporating organic materials can elevate soil organic carbon and nitrogen levels, for instance, through manure or liquid fertilizers derived from vegetable waste. This indirectly facilitates nutrient uptake and sweet corn growth (Sianturi et al., 2019). Nonetheless, the impact of these organics depends on soil type and material, necessitating customized nutrient strategies based on land traits. Improving Entisol fertility can also involve soil amendments that boost carbon levels, stimulate microbial activity, and improve access to vital nutrients (Rumbang et al., 2024).

Rice husks can be transformed into biochar, a type of charcoal created through the pyrolysis of agricultural waste, offering significant potential as a soil enhancer. Biochar has been shown to improve the physical, chemical, and biological characteristics of soil. Its porous nature allows it to hold onto water and nutrients, boosting the soil's ability to retain moisture, improve aeration, and aid plant roots during drought (Manickam et al., 2015). Applying rice husk biochar is recognized for raising soil pH and cation exchange capacity, lowering acidity, and enhancing the accessibility of essential nutrients (Zhang et al., 2022; Adekiya et al., 2019). A higher cation exchange capacity (CEC) helps the soil hold onto more nutrients and minimizes losses from leaching (Ding et al., 2016; Adebajo et al., 2020).Additionally, biochar promotes the activity of soil microbes, which are vital for breaking down organic matter and recycling nutrients, leading to improved plant development and productivity (Mahindru et al., 2024). Utilizing rice husk biochar also represents an eco-friendly farming approach by repurposing agricultural waste into valuable resources (Ariningsih et al., 2024).

Despite numerous studies reporting the benefits of biochar on acidic soils, limited data are available on the use of rice husk biochar in Bengkulu's Entisol, particularly when combined with reduced fertilizer doses. This study addresses that gap by evaluating the effects of rice husk biochar on soil chemical properties and sweet corn performance under low-input fertilization. The tested biochar rates (5–15 t/ha) were chosen to reflect practical and affordable applications for smallholder farmers in Bengkulu, where rice husk is abundantly available as a by-product of local rice milling. This locally sourced material can be utilised at minimal cost, reducing dependence on chemical fertilizers and supporting more sustainable, low-input farming systems (Mahmud et al., 2025; Mosharrof et al., 2021).

Previous studies have demonstrated that moderate biochar doses can significantly enhance soil pH, organic matter, and nutrient retention, while increasing maize yields even with reduced fertilizer input. These findings highlight the potential of rice husk biochar to maintain productivity under fertilizer constraints while promoting cost-effective and sustainable farming practices. Therefore, determining an optimal and economically feasible biochar rate is crucial for developing practical soil fertility recommendations for sustainable sweet corn production on Bengkulu's Entisol soils.

Methods

Place and Time

This study was carried out in Beringin Raya Village, located in Muara Bangkahulu District, Bengkulu City, Indonesia at coordinates roughly 3°44′45.600″ South Latitude and 102°15′50.400″ East Longitude. The fieldwork spanned from July to November 2022. Soil chemical property analyses were performed at the Soil Science Laboratory within the Faculty of Agriculture at the University of Bengkulu.

Research Design and Data Analysis

The experiment employed a Completely Randomized Design (CRD) featuring four levels of rice husk biochar application: 0, 5, 10, and 15 t/ha. Each treatment was replicated six times, yielding a total of 24 experimental plots. Each treatment consisted of six replications, resulting in a total of 24 experimental units. Polybags (35 × 50 cm, filled with 10 kg of Entisol soil) were arranged randomly within a 2 × 3 m plot area, spaced 30 cm apart to prevent shading and competition. Randomisation was conducted using a random number generator, and the polybag positions were re-randomised mid-experiment to minimise spatial autocorrelation from micro-environmental gradients (light, moisture, and airflow). Because environmental variation across the site was relatively uniform, blocking was not required.

Data were subjected to Analysis of Variance (ANOVA), followed by a Least Significant Difference (LSD) test at a 5% significance level if differences were found. All statistical processing was done using Costat software version 6.400.

Rice Husk Biochar Production

Biochar was manufactured via indirect pyrolysis in a basic perforated metal reactor, which provides partial control over air intake during burning. This method was selected for its efficiency, cost-effectiveness, and ability to yield high-quality biochar on-site. Initially, the rice husks were cleaned of impurities and sun-dried for 2–3 days to lower their moisture levels. The cylindrical reactor has small openings on its sides and base to manage restricted airflow. Rice husks were arranged around the reactor's core, with the center loaded with solid fuel like dry wood or coconut fiber to start the fire.

Pyrolysis starts at the center and gradually extends to the husks. Signs of carbonization include a shift to a grayish-black hue and the emission of faint smoke. The process typically lasts 2–3 hours, varying with material volume and heat. After full carbonization, the furnace top is sealed to block oxygen. The resulting biochar cools naturally for about 12 hours before removal, then passes through a 2 mm sieve for consistent particle size. Well-carbonized biochar appears deep black, feels lightweight and porous, and leaves no ash when crushed.

Sweet Corn Planting Procedure

The experiment utilized 35 x 50 cm polybags filled with 10 kg of Entisol soil sourced from a 0–20 cm depth. The soil was air-dried and sieved through a 2 mm mesh to remove coarse fragments and sizable organic debris prior to serving as the growing medium. It was then uniformly blended with biochar based on the assigned treatments and allowed to incubate for four weeks before sowing. The sweet corn cultivar selected was Bonanza F1. Seeds were planted by creating holes about 3 cm deep, which were treated with a small amount of granular insecticide to deter soil-borne pests, followed by placing three seeds per hole and covering them with fine soil.

Maintenance activities encompassed daily watering (twice if no rainfall occurred), thinning to retain a single vigorous plant per polybag, and routine soil mounding and weed removal. Pest and disease management was implemented as needed, incorporating both preventive and corrective measures based on field observations. Initial fertilization occurred at sowing, using half the standard recommendation: 150 kg/ha Urea (0.63 g/polybag), 100 kg/ha SP-36 (0.42 g/polybag), and 50 kg/ha KCl (0.21 g/polybag). Harvesting took place once the plants achieved physiological maturity, evidenced by alterations in husk color, cob silks, and seeds signaling full seed maturation (Kartina et al., 2023; Nazirah et al., 2022).

Parameters and Analysis

The study evaluated the properties of biochar, alterations in soil chemical attributes, and the development and productivity of plants. Soil testing occurred following a four-week incubation period, assessing: pH via a 1:5 soil-to-extractant ratio; organic carbon through the Walkey & Black technique; total nitrogen via the Kjeldahl approach; available phosphorus using the Bray-1 method; and cation exchange capacity (CEC) along with exchangeable potassium (K-exchangeable) employing 1 N NH_4OAc extraction at pH 7. Plant measurements encompassed height, leaf count, leaf dimensions (length and width), cob length, cob diameter, and cob weight.

Study Limitation and Recommendation

This experiment was conducted entirely in polybags under controlled conditions, which allowed precise control of variables but limited environmental realism. Therefore, the results should be interpreted as indicative of potential responses under field conditions, rather than as direct outcomes in the field. Future studies are recommended to validate these findings in field-scale trials, incorporating environmental variability and farmer management practices to ensure applicability under real farming conditions in Bengkulu's Entisols.

Results and Discussion

Characteristics of Rice Husk Biochar

Before being applied to the soil, rice husk biochar was analysed to determine its chemical characteristics, providing a basis for assessing its potential to enhance soil quality (Table 1).

Table 1. Chemical properties of rice husk biochar

Parameters	Unit	Value
pH	-	6.05
Nitrogen	%	0.53
Phosphorus	%	0.21
Potassium	%	1.71
C-Organic	%	31.17
C/N Ratio	-	39.94

The biochar exhibited a moderately neutral pH (6.05), indicating its potential to buffer soil acidity through the incorporation of mineral ash and stable aromatic carbon compounds (Niu et al., 2022). The organic carbon content of 31.17% indicates high carbon sequestration potential and the capacity to improve soil structure and water retention (Hossin et al., 2020). A C/N ratio of 39.94 implies chemical stability and a slow decomposition rate beneficial for long-term soil amendment, although there may be a short-term risk of N immobilisation if applied in large quantities (Jusoh et al., 2021; Sharkawi et al., 2016).

Compared to similar rice husk biochars used on acid soils, the values fall within the reported range of 30–35% C and pH 6–7 (Zhang et al., 2019), indicating that the material used in this study is typical of well pyrolysed feedstock.

Chemical Characteristics of Entisol Soil After Incubation

Incorporating rice husk biochar markedly altered several chemical aspects of Entisol soil. The mean values for each treatment are detailed in Table 2.

Table 2. Chemical properties of entisols with rice husk biochar application

Parameter	Unit	Dose Rice Husk Biochar			
		0 t/ha	5 t/ha	10 t/ha	15 t/ha
pH	-	6.01	6.06	6.06	6.07
C-organik	%	2.09	2.41	2.47	2.47
N-total	%	0.11	0.13	0.14	0.17
P-available	ppm	5.47	5.78	6.56	6.57
K-exchangeable	cmol(+)/kg	0.24	0.24	0.29	0.33
CEC	cmol(+)/kg	4.98	4.98	5.37	5.64

Using rice husk biochar has proven effective in enhancing key chemical attributes of Entisol soils. As biochar application rates rose, there were corresponding boosts in soil pH, organic carbon levels, total nitrogen, available phosphorus, exchangeable potassium, and cation exchange capacity (CEC), all pointing to better soil fertility. For instance, soil pH climbed from 6.01 in the untreated control to 6.07 with the 15 t/ha dose, showcasing biochar's alkalizing impact. The carbonate and hydroxide components in biochar help counteract soil acidity and restore chemical equilibrium (Wigan, 2023; Bhat et al., 2022). However, while the change was statistically significant, the absolute difference (6.01-6.07) remains small, suggesting limited agronomic relevance but confirming biochar's potential to buffer alkalinity.

Organic carbon content rose from 2.09% to 2.47%, showing biochar's role as a durable carbon reservoir that boosts soil organic matter, improves structure, and aids nutrient holding. Biochar's high carbon content endures in soil, stimulates microbial life, and boosts nutrient uptake efficiency. Nevertheless, microbial processes were not directly measured in this study, so claims regarding microbial stimulation are inferred from previous literature. Total nitrogen increased from 0.11% to 0.17%, highlighting biochar's capacity to curb nitrogen leaching and foster habitats for nitrogen-fixing microbes, thus raising plant-accessibility (Wigan, 2023; Wang & Li, 2018).

Available phosphorus increased from 5.47 ppm to 6.57 ppm due to biochar, as the pH rise reduced phosphorus binding by iron and aluminium, making more phosphorus available to plants (Fidel et al., 2017). Exchangeable potassium also increased from 0.24 to 0.33 cmol(+)/kg, underscoring biochar as a vital supplier of potassium for plant health (Wigan, 2023; Bhat et al., 2022). CEC improved from 4.98 cmol(+)/kg in the control to 5.64 cmol(+)/kg at the top dose, enhancing the soil's ability to retain nutrients via biochar's increased negative surface charge. This enables the better absorption of key cations, such as Ca^{2+}, Mg^{2+}, and K^{+}, thereby elevating nutrient availability and overall soil productivity (Fidel et al., 2017).

Such magnitude of change although moderate suggests meaningful improvement in soil fertility, particularly given that fertilizer was applied at only 50% of the recommended rate. In summary, these findings highlight rice husk biochar's strong promise as a soil enhancer for Entisols, which typically suffer from poor fertility and elevated acidity. Because the experiment was limited to a short (four-week) incubation under polybag conditions, further validation in multi-season field trials is recommended to confirm these improvements under variable environmental conditions.

Sweet Corn Growth and Yield

The use of rice husk biochar significantly enhanced the vegetative development of sweet corn and improved nutrient availability in the soil. A dose of 10 t/ha resulted in taller plants, more leaves, and longer leaves than the 0 t/ha and 5 t/ha options (Table 3).

Lant height, leaf number, and leaf length improved significantly up to 10 t/ha, after which the response plateaued. The LSD test was retained for pairwise comparison to identify the most responsive dose. However, future analyses should apply Tukey's HSD or orthogonal polynomial contrasts to test linear or quadratic dose trends more robustly. The nutrient composition of rice husk biochar plays a critical role in meeting sweet corn's nutritional requirements during development. Biochar has been widely recognised for its potential to improve soil fertility by increasing cation exchange capacity (CEC) and reducing nutrient leaching both essential for crops like corn that require a steady nutrient supply for optimal growth.

Table 3. Sweet corn growth response to rice husk biochar application

Dose Rice Husk Biochar	Plant Height (cm)	Number of Leaves (blades)	Leaf Length (cm)	Leaf Width (cm)
0 t/ha	173.25[c]	11.00[b]	81.33[b]	9.35
5 t/ha	177.33[bc]	11.17[b]	83.67[ab]	8.99
10 t/ha	187.08[a]	13.33[a]	90.17[a]	9.73
15 t/ha	184.50[ab]	12.33[a]	90.58[a]	9.53

Note: Values with the same lowercase letter in the same column are not significantly different according to the LSD test at the 5 percent significance level.

Studies have shown that biochar derived from agricultural residues, such as corn cobs and rice husks, can improve soil physical and chemical properties, enhance nutrient availability, and reduce the loss of key nutrients, including potassium and nitrogen (Masria et al., 2021; Kurniah et al., 2024). Additionally, biochar has been reported to mitigate soil acidity and improve texture, which enhances microbial activity and moisture retention (Maydayana et al., 2023; Frimpong et al., 2021; Mahmud et al., 2025). This microbial stimulation supports the decomposition of organic matter and the release of essential nutrients, including calcium, magnesium, phosphorus, and potassium.

However, in the present study, microbial activity and enzymatic dynamics were not measured, so these mechanisms are presented as plausible explanations based on prior findings rather than direct evidence. Empirical evidence also supports the positive impact of rice husk biochar on sweet corn growth indicators, including root length, cob length, and cob weight. Optimal application rates, particularly 10 t/ha, have been linked to significant improvements in physiological performance and yield (Maharani et al., 2025; Abdu et al., 2025; Umam et al., 2025). Furthermore, the benefits of biochar can be enhanced when combined with organic amendments, such as compost, which further increase soil fertility and promote sustainable agricultural practices.

Such benefits align with the observed vegetative improvements under the 10 t/ha treatment, confirming that this rate is agronomically effective yet economically practical for smallholders in Bengkulu. In summary, biochar application at 10 t/ha significantly promoted vegetative growth and improved soil chemical characteristics, synergistically enhancing nutrient uptake and sweet corn productivity. These outcomes reinforce the potential of rice husk biochar as an eco-friendly strategy for optimising sweet corn production efficiency while supporting sustainable soil management.

Applying biochar at a rate of 10 t/ha yielded the most favorable outcomes for root development and cob production in sweet corn (Table 4).

Table 4. Evaluation results of sweet corn with rice husk biochar application

Dose Rice Husk Biochar	Plant Height (cm)	Number of Leaves (blades)	Leaf Length (cm)	Leaf Width (cm)
0 t/ha	85,33[a]	5,96	29,83[ab]	340,83[b]
5 t/ha	68,33[b]	6,15	28,75[b]	406,67[ab]
10 t/ha	85,67[a]	6,29	31,42[a]	437,50[a]
15 t/ha	70,67[b]	6,14	29,92[ab]	478,33[a]

Note: Values with the same lowercase letter in the same column are not significantly different according to the LSD test at the 5 percent significance level.

This result aligns with earlier findings indicating that approximately 9–10 t ha^{-1} of biochar is sufficient to improve the physical and chemical properties of soil, enabling optimal nutrient uptake and plant development (Suryani et al., 2023). According to Table 4, the greatest cob weights occurred with the 15 t ha^{-1} dose. However, this was not statistically different from the 10 t ha^{-1} treatment, indicating a possible saturation point in biochar effectiveness. Although elevated rates may enhance nutrient supply, the 10 t ha^{-1} application appears to be the agronomically optimal threshold, beyond which further increases provide diminishing yield returns. Biochar boosts the supply and retention of essential nutrients, thereby enhancing crop productivity.

High-quality biochar enhances soil health by refining texture, improving water retention, and increasing nutrient-holding capacity (Sulakhudin et al., 2022). The 10 t/ha treatment also produced longer cobs and greater overall plant vigour. Its presence stimulates biomass accumulation, resulting in improved growth performance (Jahromi et al., 2020). However, the potential for nutrient immobilisation at higher application rates (e.g., 15 t/ha) should be considered, as excessive carbon input can temporarily restrict nitrogen availability to plants.

These findings align with prior studies that attribute biochar's advantages to both its nutrient enrichment and its facilitation of soil microbial interactions, which enhance nutrient assimilation (Abed, 2022). Nonetheless, microbial activity and soil enzyme dynamics were not directly measured in this study; thus, these explanations are theoretical and should be verified in future work. From a practical perspective, 10 t/ha represents an effective balance between agronomic benefit and cost-efficiency, especially for smallholder farmers in Bengkulu who can readily access rice husk residues as a low-cost biochar source. Overall, the yield response confirms that moderate biochar inputs can substantially improve sweet corn performance without excessive material use, highlighting its value as a sustainable soil amendment for low-fertility Entisols.

Conclusion

Rice husk biochar improved the chemical properties of Entisol soil and enhanced sweet corn growth and yield under controlled conditions. The 10 t/ha rate produced the best results, increasing soil pH, nutrient availability, and cob weight compared to the control. Although the effects were statistically significant, the absolute changes were moderate and based on a short-term polybag experiment. Field-scale and multi-season studies are needed to validate long-term impacts. Locally produced rice husk biochar provides a practical and low-cost soil amendment for smallholders, provided that production safety and efficiency are ensured.

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