

Effects of Biochar on Germination and Growth of Bok Choy at Varying Application Rates

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Abstract

Biochar is increasingly recognized as a climate-smart soil amendment due to its ability to improve soil fertility, enhance water and nutrient retention, and support sustainable crop production. Bok choy (Brassica rapa) is a fast-growing, nutrient-dense leafy vegetable commonly used as an indicator crop for evaluating early growth responses to soil amendments. This study evaluated the effects of three biochar types (coconut, soursop, and teak) applied at 1%, 3%, and 5% (w/w) on the germination and early growth of bok choy, using commercial peat moss as a control. Soursop biochar at 3% significantly improved germination rates, while teak biochar at 1% and 3% produced shoot and leaf growth comparable to peat moss. Higher biochar concentrations (5%), particularly soursop and teak, tended to suppress growth. These results indicate that biochar can enhance bok choy germination and early growth when applied at moderate rates, highlighting the importance of appropriate feedstock selection and application levels for sustainable vegetable production.

Keywords: Biochar, bok choy, germination, sustainable agriculture, soil amendment

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Introduction

Biochar, a carbon-rich material produced through the pyrolysis of biomass, has gained considerable attention in recent years due to its potential applications in agriculture. Known for enhancing soil fertility, improving water retention, and facilitating nutrient availability, biochar offers promising avenues for sustainable agricultural practices (Lehmann & Joseph, 2015). Among these practices, the use of biochar as a germination medium has become an emerging area of interest, particularly for vegetable crops such as bok choy (*Brassica rapa* subsp. *chinensis*), a widely consumed leafy vegetable in Asian cuisine. Bok choy is valued for its rapid growth and high nutritional content, making it an important crop in both subsistence and commercial agriculture.

Previous studies have highlighted biochar's beneficial effects on plant growth, particularly in germination and early seedling development. Zhang et al. (2017) demonstrated that bok choy seeds germinated more rapidly and achieved higher germination rates when grown in a biochar-based medium compared to traditional peat-based substrates. Similarly, Li et al. (2019) observed improved chlorophyll content, biomass accumulation, and nutrient uptake in bok choy seedlings cultivated with biochar, attributing these results to biochar's porosity and water-holding capacity, which enhance nutrient availability. Moreover, biochar's high cation exchange capacity (CEC) plays a vital role in the retention and release of essential nutrients, promoting healthier seedling growth (Glaser et al., 2002; Lehmann & Joseph, 2015).

In addition to its agronomic benefits, biochar contributes to environmental sustainability. It can be produced from agricultural waste, providing a cost-effective and resource-efficient alternative to commercial germinating mixes (Novak et al., 2009). The porous structure of biochar also fosters microbial activity in the rhizosphere, enhancing nutrient cycling and root proliferation, which are crucial for successful seedling establishment (Biederman & Harpole, 2013). Despite these promising findings, some studies report inconsistent results regarding the effects of biochar on Brassica species. Atkinson et al. (2010) and Lehmann et al. (2011) found minimal impacts on germination and growth in bok choy and other Brassica crops, highlighting the need for further research to clarify biochar's role in plant development.

The aim of this study is to investigate the effects of different biochar types and application rates on the germination and early growth of bok choy. Specifically, this research examines how biochar influences germination rates, shoot length, radicle length, and leaf development. By identifying the optimal biochar conditions for promoting bok choy growth, this study seeks to provide valuable insights into the potential of biochar as a sustainable medium for enhancing vegetable crop production.

Methodology

Production and Characterization of Biochar

Biochar was produced from three different feedstocks: coconut shells, soursop residues, and teak wood, using a basic recycled biochar kiln at the University of Belize, Central Farm Campus. The feedstocks were air-dried prior to pyrolysis, which was carried out at a temperature of 400°C for 4 hours. This temperature and duration were chosen based on the need to ensure sufficient carbonization while preserving the structural integrity of the biochar. Although the specific properties of the biochars were not analyzed in this study, their likely characteristics can be inferred from similar studies.

Coconut Shell Biochar

Coconut shell biochar, produced under pyrolysis conditions at 400°C, typically contains a high fixed carbon content of 70% to 80% (Jindo et al., 2014). Its surface area is often reported between 100–300 m²/g, contributing to its high porosity and water retention capacity (Ahmad et al., 2014). The pH of coconut biochar is generally alkaline, ranging from 8.5 to 9.5, which makes it an effective soil amendment for neutralizing acidic soils. This biochar is expected to improve soil aeration and nutrient retention, particularly in tropical agricultural systems.

Soursop Residue Biochar

Soursop biochar, produced under the same conditions, is expected to exhibit moderate fixed carbon content, typically in the range of 50% to 65% (Yuan et al., 2011). Biochar from fruit tree residues like soursop generally has moderate porosity and moisture retention capacity, along with a neutral to slightly acidic pH

(6.5–7.5), which could enhance microbial activity in the soil. The nutrient content of soursop biochar, although not measured in this study, is expected to support soil fertility and organic matter decomposition.

Teak Wood Biochar

Teak biochar, produced from hardwood, likely contains high fixed carbon, typically ranging between 70% and 90%, due to the lignin-rich structure of hardwoods (Major et al., 2010). The stable structure of teak biochar ensures long-term persistence in soil, contributing to improved soil structure and increased cation exchange capacity (CEC). The pH of teak biochar is typically neutral to slightly alkaline (7.0 to 8.5), making it effective for adjusting soil pH and enhancing nutrient retention.

Potential Characteristics Based on Literature

The expected characteristics of these biochars—high carbon content, moderate to high porosity, and varying pH ranges—are likely to influence their effects on soil properties and plant growth. Future studies should focus on detailed characterization of the produced biochars, including elemental analysis, surface area, porosity, and nutrient content, to better optimize biochar use in agricultural systems.

Experimental Design

The experiment was arranged in a two-way factorial design with complete randomization, featuring three replicates for each treatment. Two factors were examined:

Factor 1: Biochar Type

Three types of biochars were produced and tested from softwood and hardwood feedstocks:

- B-C: Coconut
- B-S: Soursop
- B-T: Teak

Factor 2: Biochar Rate

Three biochar concentrations were applied:

- 1%
- 3%
- 5%

Treatments were randomly assigned to 72-cell germination trays. Each tray was divided in half, with each half receiving one of two treatments. The control (C) treatment consisted of 100% commercial peat moss without biochar. The experimental setup consisted of the following 10 treatments:

Table 1. Biochar Experimental Treatments and Replications for Bok Choy Germination Study

Treatment	Number of Repetitions	Description
T1	3	Commercial peat moss (Control)
T2	3	B-C @ 1%
T3	3	B-S @ 1%
T4	3	B-T @ 1%
T5	3	B-C @ 3%
T6	3	B-S @ 3%
T7	3	B-T @ 3%
T8	3	B-C @ 5%
T9	3	B-S @ 5%
T10	3	B-T @ 5%

Application and Distribution of Treatments

Each 72-cell germination tray was divided into two halves, with six rows and six cells in each half. Two treatments were randomly assigned to each half of the tray. This ensured that each tray had two treatments, and one seed was placed per germination cell.

Establishment and Management

Before the trial, a germination test was conducted to assess the viability of the seeds. Thirty seeds were placed on damp germination paper in three replicates, with germination monitored on the fifth day. Only seeds with a minimum germination rate of 85% were used in the study. During the seedling phase, pest and disease management was conducted following standard protocols. A foliar fertilizer was applied to all plants to ensure uniform nutrient availability.

Variables Measured

The following parameters were measured to evaluate the effect of biochar type and rate on seedling growth and development:

1. **Germination Rate:** The number of germinated seeds was counted, and the germination rate was calculated as follows:

$$\text{Germination Rate} = \frac{\text{Number of Germinated Seeds}}{\text{Total Number of Seeds}} \times 100$$

2. **Shoot Length:** The length of the shoot was measured in centimeters (cm) from the base of the plant to the apex of the youngest leaf at 21 days after sowing.
3. **Number of True Leaves:** The number of true leaves was counted at 7, 14, and 21 days after sowing.
4. **Radicle Length:** The length of the main root was measured in centimeters from the root tip to the base of the plant at 21 days.

Data Analysis

Data were analyzed using a two-way analysis of variance (ANOVA) to evaluate the effects of biochar type and application rate on germination, shoot length, radicle length, and the number of true leaves. Tukey's HSD post hoc test was used to determine significant differences between treatment means, with a significance threshold of $p < 0.05$. IBM SPSS Statistics was used to analyze data and Microsoft Excel was used to organize data.

Results

Biochar Effects on Germination of *Brassica rapa* (Bok Choy)

The germination rates of *Brassica rapa* (bok choy) seeds as influenced by different types and concentrations of biochar are presented in Figure 1 below. Three biochar types—coconut, soursop, and teak—at rates of 1%, 3%, and 5% (w/w) were mixed with peat moss, and their effects on germination were compared to a peat moss control. The peat moss control consisted of 100% peat moss and no biochar addition. The germination rate of the peat moss (represented by the dashed line) was approximately 89%. At the 3% rate, soursop biochar significantly outperformed the other treatments, achieving a germination rate of 94.4%, while coconut and teak biochars and peat moss showed lower germination rates of 66.7%, 83.3% and 89%, respectively. At the 1% biochar rate, coconut biochar exhibited the highest germination rate (88.9%), amongst both soursop and teak biochars at 77.8%. At the 5% rate, coconut biochar achieved a germination rate of 88.9%, while soursop and teak biochars resulted in a lower germination rate of 77.8% and 72.2%, respectively. These results suggest that the type and concentration of biochar can have variable effects on the germination of bok choy, with soursop biochar at 3% promoting the highest rate of germination.

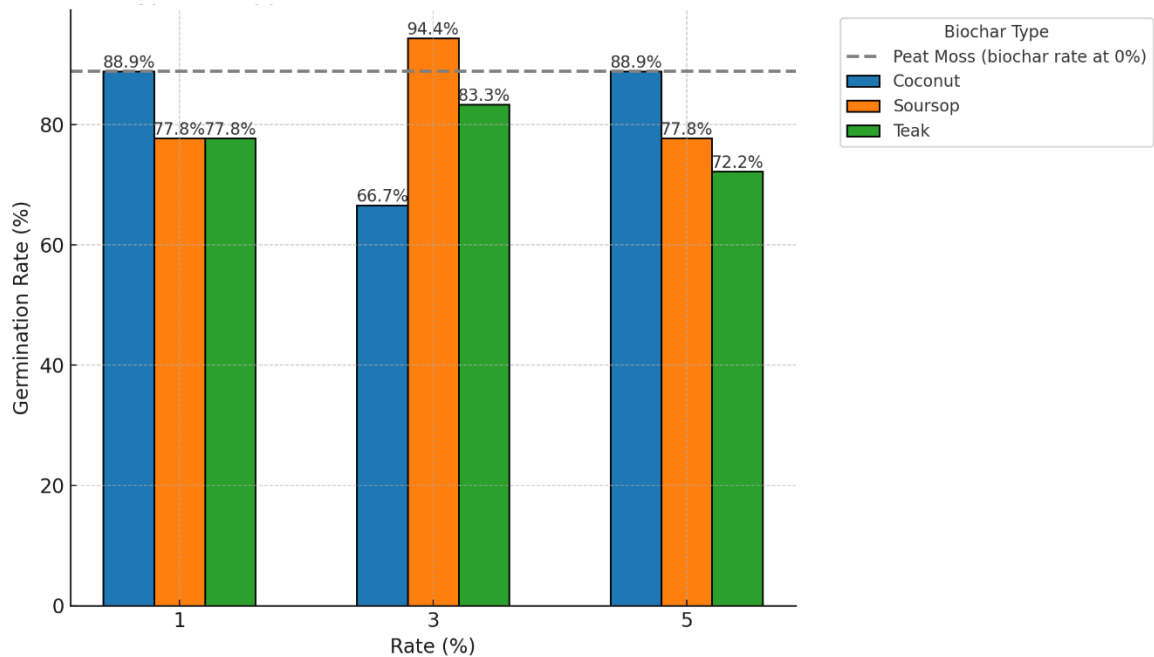


Figure 1. Effect of Different Biochar Types and Application Rates on the Germination Rate of *Brassica rapa* (Bok Choy)

Effect of Biochar Type on Shoot Length

Figure 2 presents shoot length at 21 days. The influence of different biochar types—coconut, teak, and soursop—as well as peat moss (used as a control without the addition of biochar) on shoot length at 21 days was evaluated. A one-way analysis of variance (ANOVA) was performed to determine whether biochar type had a significant effect on shoot length, with the results indicating a highly significant impact ($p < 0.0001$). Post hoc analysis using Tukey's multiple comparison test further revealed that certain biochar treatments had a statistically significant difference from each other and from the peat moss control, as denoted by the red asterisks. Peat moss produced the greatest mean shoot length (~3.5 cm), significantly outperforming the biochar treatments, followed closely by teak. In contrast, coconut and soursop exhibited lower mean shoot lengths, with no significant difference between them. These findings suggest that biochar type does not exert a substantial influence on shoot growth when compared to peat moss, since peat moss provided the most favorable conditions for enhancing shoot length under the conditions of this study.

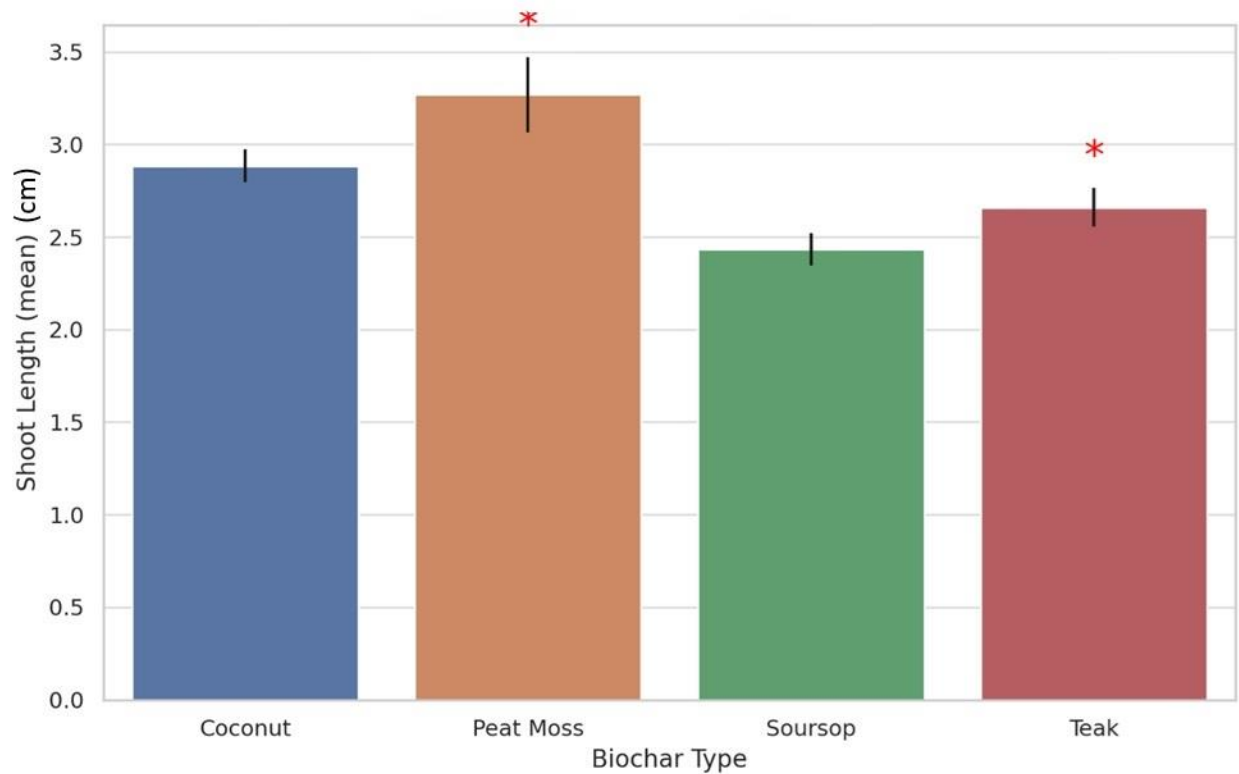


Figure 2. Effect of Different Biochar Types and Peat Moss on Plant Shoot Length at 21 Days. N.B. The graph shows mean shoot length (cm) across four treatments: Coconut, Teak, Soursop, and Peat Moss (control without biochar). Asterisks (*) indicate significant differences between treatments based on Tukey's post hoc test ($p < 0.05$). Error bars represent standard error.

Effect of Biochar Type on Radicle Length

Biochar type on radicle length at 21 days was evaluated (Figure 3). ANOVA analysis yielded a statistically significant effect of biochar type on root growth ($p = 0.0058$). Post hoc comparisons using the Tukey HSD test revealed a statistically significant difference between teak and all other treatments, as indicated by the red asterisk. Teak biochar produced significantly shorter radicle lengths compared to the control (peat moss), which had the greatest mean radicle length (~12 cm). Coconut and soursop biochars, while resulting in slightly shorter radicles, did not show significant differences from peat moss or each other. These findings also suggest that biochar type does not exert a substantial influence on radicle length.

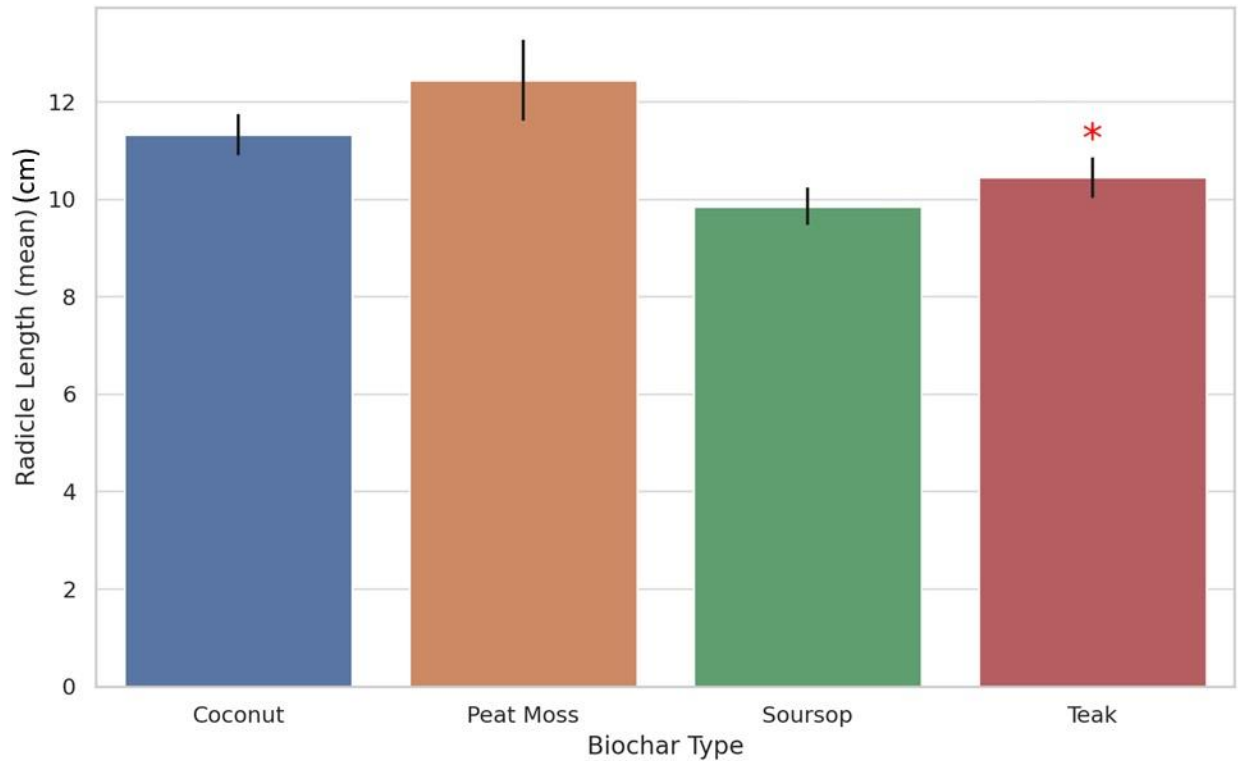


Figure 3. Effect of Different Biochar Types and Peat Moss on Radicle Length at 21 Days. N.B. Mean radicle lengths (cm) are shown for each biochar type: Coconut, Soursop, Teak, and Peat Moss (control without biochar). Error bars represent the standard error of the mean. Asterisks (*) denote significant differences between groups as determined by Tukey HSD test ($p < 0.05$).

Effect of Biochar Type on Number of Leaves

Figure 4 shows the effect of biochar type on the number of true leaves produced by bok choy seedlings at 21 days after sowing. Analysis of variance indicated a significant treatment effect on leaf development ($p = 0.0111$). Teak biochar resulted in a statistically significant difference in leaf number when compared with the other biochar treatments, as indicated by the post hoc test. However, the peat moss control produced the highest mean number of leaves overall. Despite this numerical difference, peat moss did not differ significantly from teak biochar, indicating comparable performance between these two treatments. Coconut and soursop biochars produced slightly fewer leaves and did not differ significantly from peat moss. These results suggest that while teak biochar influenced leaf development relative to other biochar types, it did not consistently outperform the peat moss control in promoting leaf production.

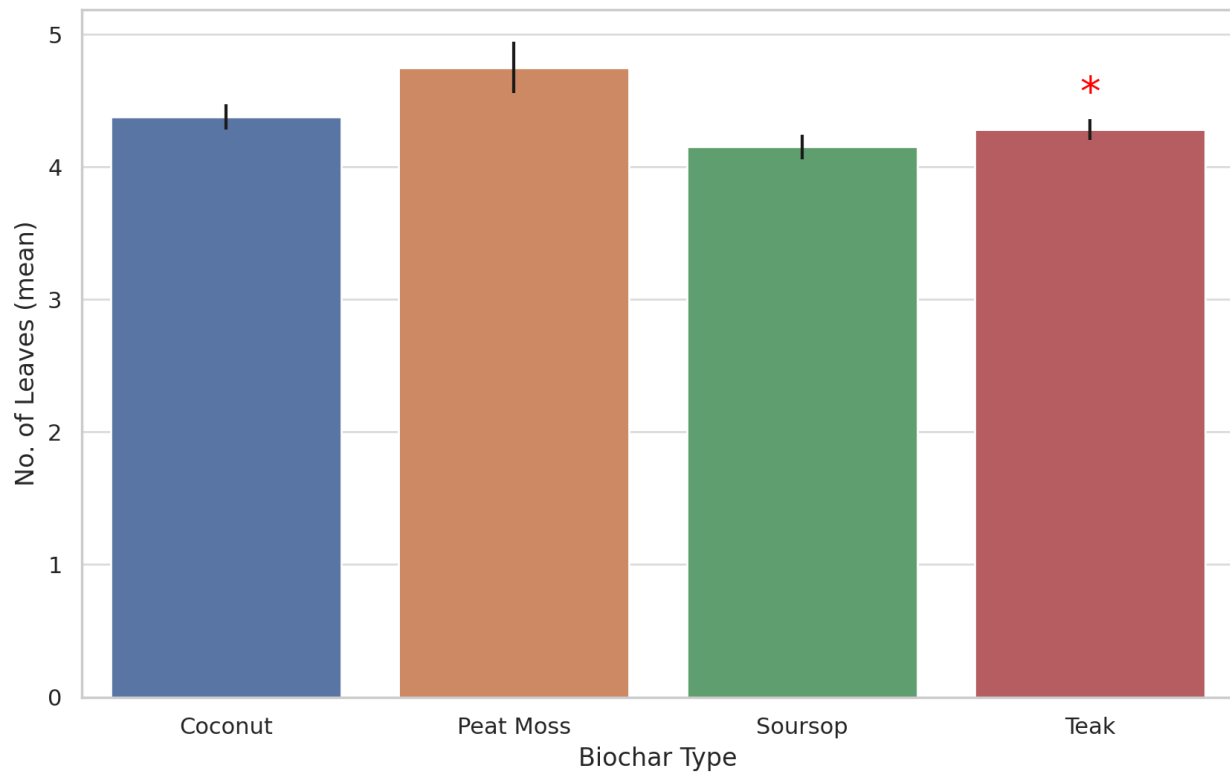


Figure 4. Effect of Different Biochar Types and Peat Moss on the Number of True Leaves at 21 Days. N.B. The bars represent the mean number of true leaves, with error bars showing the standard error. Asterisks (*) denote statistically significant differences between biochar types, as determined by the Tukey HSD test ($p < 0.05$). ANOVA analysis ($p = 0.0111$) confirms a significant effect of biochar type on leaf development.

Impact of Biochar Type and Rate on Bok Choy Shoot Growth Over Time

Bok choy shoot length growth over 21 days under various biochar treatments, including coconut, soursop, teak, and peat moss (control), applied at different rates (1%, 3%, 5%) are shown in Figure 5 below. The vertical axis represents shoot length (cm), and the horizontal axis marks days after planting. Peat moss consistently produced the highest shoot lengths, reaching 3.25 cm by day 21, closely followed by teak at 1% and 3% rates (~3 cm). In contrast, soursop and teak biochars, particularly at rates (3% and 5%), resulted in slower growth, with shoot lengths remaining below 2.25 cm.

Asterisks (*) indicate significant differences between treatments, as determined by Tukey's post-hoc test, especially at days 7, 14, and 21. Biochar type and application rate directly influenced plant shoot length, with lower rates of teak biochar and peat moss leading to the greatest growth, while higher rates of soursop and teak were less effective in promoting shoot development.

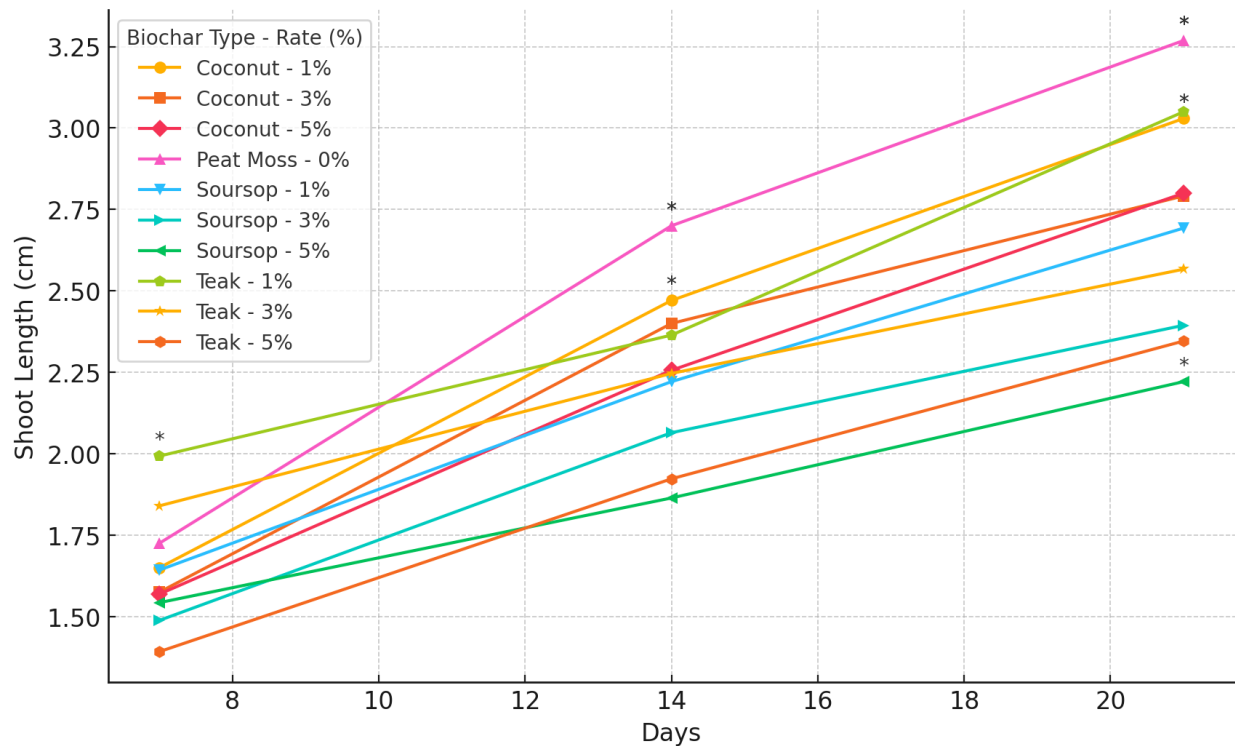


Figure 5. Impact of Biochar Type and Application Rate on Bok Choy Shoot Length Over Time. N.B. The graph shows shoot length (cm) over 21 days for bok choy treated with different biochar types (Coconut, Soursop, Teak, and Peat Moss) at various application rates (1%, 3%, 5%). Asterisks (*) indicate significant differences between treatments based on Tukey's post-hoc test ($p < 0.05$).

Discussion

Biochar Effects on Germination of *Brassica rapa* (Bok Choy)

The enhancement of germination rates with soursop biochar at 3% highlights biochar's role in improving seedling emergence, which is supported by research showing biochar's capacity to improve soil moisture retention and nutrient availability (Zhang et al., 2017). In many tropical soils, the porous structure of biochar helps maintain moisture levels, which is critical for seed germination, especially in fast-growing crops like bok choy. Furthermore, studies by Steiner et al. (2017) indicated that biochar can create favorable microclimates for seeds, potentially reducing stress conditions like temperature fluctuations and desiccation.

Interestingly, the decline in germination rates at 5% biochar concentrations, across all types, suggests that while biochar enhances germination at moderate levels, excessive amounts may lead to suboptimal conditions, potentially due to reduced oxygen availability in the seedbed (Bruun et al., 2014). This effect could also be linked to the feedstock of the biochar. According to Kammann et al. (2011), certain biochars might contain compounds that, at high concentrations, inhibit seedling growth, potentially due to altered microbial activity or the presence of phytotoxic substances.

Effect of Biochar Type on Shoot Length

The observed reduction in shoot length at higher biochar concentrations, particularly with soursop and teak biochar, is consistent with the theory that while biochar can improve certain soil properties, its benefits are highly concentration-dependent. Studies by Glaser et al. (2002) and Liu et al. (2017) confirm that biochar applied at high rates can cause an imbalance in nutrient availability, especially nitrogen, leading to reduced plant growth. Biochar's nutrient retention capacity, while beneficial at lower concentrations, might restrict nutrient uptake when applied in excess, as seen in the reduced shoot length observed in the present study.

In contrast, the performance of teak biochar at lower concentrations aligns with findings by Major et al. (2010), who demonstrated that biochar derived from woody materials can improve soil fertility and structure when applied in moderation. This improvement is likely due to teak biochar's ability to enhance cation exchange capacity (CEC), thus facilitating nutrient uptake. The positive effects of teak biochar at 1% and 3% may be due to its contribution to microbial activity and organic matter decomposition, as biochar has been shown to serve as a habitat for beneficial microorganisms (Thies et al., 2015).

Effect of Biochar Type on Radicle Length

Peat moss, which produced the longest radicle lengths, provided superior aeration and water retention compared to biochar treatments, which may have resulted in better root penetration and growth. Biochar's performance, particularly at higher concentrations, may have been affected by its interaction with soil moisture levels. As noted by Głab et al. (2016), biochar can retain water, but excessive amounts can lead to waterlogging or reduced oxygen availability, which hinders root development.

Additionally, the shorter radicle lengths observed with higher concentrations of biochar suggest that biochar application rates need to be carefully managed to avoid disrupting soil structure. High rates of biochar, particularly soursop and teak biochar, might impede root elongation due to physical barriers created by soil compaction or the reduced availability of certain nutrients, such as phosphorus (Bruun et al., 2014). Furthermore, the impact of biochar on soil pH could play a role, as biochar application has been shown to increase soil pH, potentially affecting root development, particularly in crops that prefer slightly acidic conditions (Kammann et al., 2011).

Effect of Biochar Type on Number of True Leaves

The increased number of true leaves observed with teak biochar at 3% highlights the role of biochar in enhancing vegetative growth. This effect can be attributed to biochar's influence on soil nutrient dynamics, particularly nitrogen availability. Major et al. (2010) showed that biochar-amended soils tend to have higher nitrogen-use efficiency, which can promote leaf growth, especially in fast-growing crops like bok choy. Furthermore, biochar's ability to increase microbial activity and promote symbiotic relationships in the rhizosphere may also contribute to the observed improvement in leaf production (Thies et al., 2015).

However, the lack of significant improvement in leaf development with coconut and soursop biochars suggests that biochar's effectiveness is highly dependent on the feedstock used. Research by Lehmann et al. (2011) found that biochar's impact on plant growth varies significantly depending on the type of biomass used to produce the biochar. Biochar derived from woody materials, such as teak, tends to have a higher cation exchange capacity, making it more effective in nutrient retention and plant growth promotion. Conversely, biochars produced from other sources, such as agricultural residues, may have different nutrient profiles, resulting in varied effects on plant growth.

Impact of Biochar Type and Rate on Bok Choy Shoot Growth Over Time

The shoot growth data over 21 days further underscore the concentration-dependent effects of biochar. The similar performance of peat moss and teak biochar at low concentrations (1% and 3%) is likely due to teak biochar's contribution to soil structure and fertility. As highlighted by Liu et al. (2017), biochar's porous structure allows for better water infiltration and retention, supporting plant growth during critical early stages of development.

However, the diminished growth at higher biochar concentrations, particularly with soursop and teak biochars at 5%, indicates that excessive biochar can create imbalances in soil properties, such as water retention and nutrient availability. Głab et al. (2016) found that high biochar concentrations could reduce soil aeration, leading to slower root and shoot development. Moreover, studies by Biederman & Harpole (2013) suggest that biochar's effects on crop growth depend on the specific soil and environmental conditions, meaning that its application rate must be tailored to the crop and growing medium to achieve optimal results.

The variability in biochar's impact on shoot growth over time points to the need for a more nuanced approach to biochar application. As Steiner et al. (2017) pointed out, biochar may have different effects at various stages of plant growth, with its benefits being more pronounced during early development and

tapering off as the plant matures. This may explain the more pronounced effects of biochar on shoot length during the first 14 days of the trial, followed by reduced growth rates in later stages.

Conclusion

This study explored the effects of different biochar types and application rates on the germination and early growth of *Brassica rapa* (bok choy) to identify optimal conditions for sustainable vegetable production. The results showed that soursop biochar at 3% significantly enhanced germination rates, demonstrating biochar's potential as a germination medium. However, its effects on shoot length, radicle length, and leaf development varied depending on biochar type and concentration. Teak biochar, when applied at 1% and 3%, promoted shoot and leaf growth, suggesting its ability to improve soil nutrient retention and microbial activity. On the other hand, higher concentrations of biochar (5%) had negative effects on plant growth, likely due to soil imbalances such as poor aeration or nutrient overload. The findings indicate that biochar can be beneficial for enhancing germination and early growth in bok choy, but its application must be carefully managed. Excessive biochar can hinder growth, emphasizing the need for appropriate application rates. Future research should focus on the long-term effects of biochar on crop yield and soil health, ensuring its effective use as a tool for sustainable agriculture.

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