Research on building a biochar production model from agricultural by-products in Gia Lai province

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Nghiên cứu xây dựng mô hình sản xuất than sinh học từ phụ phẩm nông nghiệp tại tỉnh Gia Lai

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https://doi.org/10.55250/jo.vnuf.9.2.2024.003-010

Article info:
Received: 29/08/2024
Revised: 07/10/2024
Accepted: 05/11/2024

Keywords:
Agricultural by-products, biochar, coffee trees, Gia Lai province, kilns.

ABSTRACT

The impact of climate change on ecosystems and agricultural systems, particularly in key agricultural areas like the Central Highlands of Vietnam, has caused severe soil degradation, water depletion, and desertification, directly affecting productivity and livelihoods. Sustainable agricultural solutions, especially biochar, have gained attention due to their ability to improve soil fertility, retain moisture, and reduce greenhouse gas emissions. This research focuses on developing a biochar production model from agricultural by-products in Gia Lai to meet both domestic and export needs. Biochar was produced through the pyrolysis of coffee by-products, including stems, branches, and fruit husks. The study employs 10 brick kilns (90 m^3 capacity) for stems and branches, and 15 steel kilns (300 kg/batch capacity) for fruit husks and leaves. The biochar produced meets export quality standards, with a fixed carbon content ≥70.0%, ash content ≤3.0%, and calorific value ≥7,000 Kcal/kg. Additionally, biochar is combined with the biological agent Trichoderma to produce 1,000 tons of organic microbial fertilizer, surpassing national standards for organic matter content (≥15%) and Trichoderma density (≥1.0x10^6 CFU/g). Biochar production from agricultural waste not only reduces waste but also contributes to sustainable agriculture in the Central Highlands. The research results show great potential for expanding biochar production models, improving soil health, reducing farming costs, and increasing farmers' income.

***Từ khóa**:*
Cây cà phê, lò đốt, phụ phẩm nông nghiệp, than sinh học, tỉnh Gia Lai.

TÓM TẮT

Tác động của biến đổi khí hậu đối với hệ sinh thái và hệ thống nông nghiệp, đặc biệt tại các khu vực nông nghiệp trọng điểm như Tây Nguyên của Việt Nam, gây ra sự suy thoái đất nghiêm trọng, cạn kiệt nguồn nước và hiện tượng sa mạc hóa, ảnh hưởng trực tiếp đến năng suất và sinh kế của người dân. Để ứng phó, các giải pháp nông nghiệp bền vững, đặc biệt là than sinh học (biochar), đã thu hút sự quan tâm nhờ khả năng cải thiện độ phì nhiêu của đất, giữ ẩm và giảm phát thải khí nhà kính. Nghiên cứu này tập trung vào xây dựng mô hình sản xuất than sinh học từ phụ phẩm nông nghiệp tại Gia Lai, nhằm vừa đáp ứng nhu cầu nội địa, vừa hướng đến tiềm năng xuất khẩu. Than sinh học được sản xuất thông qua quá trình nhiệt phân các phụ phẩm từ cây cà phê, bao gồm thân, cành, vỏ quả. Nghiên cứu sử dụng 10 lò đốt gạch (công suất 90 m^3) cho thân, cành cây và 15 lò thép (công suất 300 kg/mẻ) cho *vỏ quả và lá. Sản phẩm than sinh học đạt tiêu chuẩn chất lượng xuất khẩu với hàm lượng carbon cố định ≥70%, hàm lượng tro ≤3%, và nhiệt lượng ≥7.000 Kcal/kg. Ngoài ra, than sinh học được kết hợp với chế phẩm sinh học Trichoderma để sản xuất phân bón hữu cơ vi sinh, vượt tiêu chuẩn quốc gia về hàm lượng chất hữu cơ (≥15%) và mật độ nấm Trichoderma (≥1,0x10^6 CFU/g). Sản xuất than sinh học từ phế phẩm nông nghiệp không chỉ giúp giảm thiểu lượng chất thải mà còn góp phần phát triển nông nghiệp bền vững tại Tây Nguyên. Kết quả nghiên cứu cho thấy tiềm năng lớn trong việc mở rộng mô hình sản xuất than sinh học, cải thiện sức khỏe đất, giảm chi phí canh tác và tăng thu nhập cho nông dân.*

1. INTRODUCTION

Climate change and its impacts have significantly changed ecosystems and agricultural systems worldwide. In particular, key agricultural regions like Vietnam's Central Highlands are facing soil quality degradation, water depletion, and desertification, which seriously affect farmers' productivity and livelihoods [1, 2]. In this context, studies on the application of organic fertilizers and biological products, especially biochar, have garnered attention as sustainable agricultural solutions.

Biochar is produced through the pyrolysis of agricultural by-products, including stems, branches, leaves, and fruit husks, under high temperatures and low oxygen conditions. The superior properties of biochar, such as moisture retention, soil fertility enhancement, and greenhouse gas emission reduction, demonstrate the material's great potential in improving soil environments [3, 4]. Moreover, producing biochar from agricultural by-products not only minimizes waste and pollution but also contributes to environmental protection by reducing carbon emissions [1].

Gia Lai, a province in the Central Highlands, is well-known for its agricultural production, particularly key crops such as coffee, pepper, and cashew. Annually, thousands of tons of agricultural by-products from these crops are generated but often not utilized effectively, causing environmental issues if not properly managed. Utilizing these by-products to produce biochar can bring significant economic and environmental value, turning waste into resources for sustainable agricultural production [5].

Therefore, this study aims to develop a biochar production model from agricultural by-products in Gia Lai province to serve both domestic needs and export potential. By combining biochar with other nutrients to produce organic microbial fertilizers, the study expects to provide solutions to the region's agricultural problems, create opportunities to increase farmers' income and reduce farming costs. The project also promises to contribute to promoting a circular economy and reducing the impacts of climate change on agriculture in the Central Highlands [2, 3].

2. MATERIALS AND METHODS

2.1. Materials

The study used agricultural by-products from coffee, including stems, branches, fruit husks, and leaves. The raw materials were collected from major growing areas in Gia Lai province. The criteria for selecting households according to the approved project description, specifically:

+ For coffee in the construction period: selected farming households with a coffee growing area of 2 hectares or more to participate in the model. Each household with a minimum of 0.5 hectares was chosen to use organic microbial fertilizers from biochar;

+ For coffee in the business period, selected farming households with a minimum coffee growing area of 1 hectare or more to participate in the model. Each household with a minimum of 0.5 hectares was chosen to use organic microbial fertilizers from biochar.

Before production, the materials were pre-processed to ensure moisture content below 25%, with stem sizes of 10-30 cm and lengths of 60-100 cm. Afterward, the materials were carefully sorted before being loaded into the kilns.

Figure 1. Coffee tree trunks and branches are cut and prepared to be put into the biochar production kilns in Dak Doa district, Gia Lai province

(Photo by Nguyen Duc Hanh, 2020)

2.2. Methods

2.2.1. Site description and data sources:

The research models were implemented in Gia Lai province following specific timelines to ensure efficiency and consistency in the application of the technology.

First, the biochar production technology from stems and branches of coffee trees was implemented from April 2020 to December 2020. The raw materials were collected from coffee trees being grown in selected households of Ia Bang communes, Dak Doa district of Gia Lai province, including pre-treated stems and branches (with moisture content below 25%). To produce biochar, two types of kilns were used: (1) Brick kilns: 10 kilns with a capacity of 90 m^3, producing 10-15 tons of biochar per batch from coffee tree stems and branches; (2) Steel kilns: 15 kilns with a capacity of 300 kg/batch, used for fruit husks and coffee tree leaves. Additionally, the biological product Trichoderma was used in the production of organic microbial fertilizers. The production process was designed to meet export biochar production requirements.

Second, the biochar production model from coffee fruit husks and leaves was implemented from April 2020 to December 2022. The steel kilns, with a capacity of 300 kg/batch, were used for this production process, with 15 steel kilns built in Gia Lai. The production process and kiln operation were transferred by the Agricultural Environment Institute, along with technical guidance on smoke treatment procedures, biochar quality checks, ensuring the product to meet the standards for organic microbial fertilizer production.

Third, the organic microbial fertilizer production model from biochar was implemented from January 2021 to December 2022. This process included biochar pre-treatment, mixing with microbial agents, and activation composting for 10-15 days. The organic microbial fertilizer was tested and evaluated based on criteria such as organic matter content ≥15%, moisture content ≤30%, and Trichoderma fungus density $\geq 1.0 \times 10^6$ CFU/g. The final product was 1,000 tons of Bio-Trico organic microbial fertilizer that met current national standards.

2.2.2. Data analysis and evaluation

The technology transfer was conducted by the Agricultural Environment Institute - Vietnam Academy of Agricultural Sciences, in cooperation with An Hung Gia Lai Agricultural Engineering and Trade Service Company, which trained and instructed the operation of the kilns. The expected result of this process is the production of 2,000 tons of export-standard biochar with specifications such as carbon content ≥70.0%, calorific value ≥7,000 Kcal/kg, and ash content ≤3.0%.

These research models were carried out in close coordination between the technology transfer and receiving units to ensure that the implementation process was on schedule and met the technical standards set forth. Through specific steps and clear implementation timelines, the study successfully applied advanced technologies into agricultural production practices, contributing to the effective and sustainable reuse of agricultural by-products.

3. RESULTS AND DISCUSSION

3.1. Selection of locations for the biochar production model

A survey of the current state of agricultural production in project areas of Gia Lai province has been conducted to select suitable locations for building the biochar production model (Table 1). The survey results showed that Dak Doa district has the largest coffee-growing area, with 28,047 hectares, accounting for 28.02% of the total coffee area in the province. Based on this, the biochar production model from coffee tree stems and branches was chosen for implementing in Ia Bang commune, Dak Doa district. This selection was based on the availability and abundant supply of coffee tree stems and branches from large planting areas.

Table 1. Coffee cultivation area in districts/towns/cities in Gia Lai province

No.	Location	Area (ha)	No.	Location	Area (ha)
1	Pleiku City	3,418	10	Duc Co District	9,151
2	An Khe Town	-	11	Dak Po District	-
3	Ayun Pa Town	-	12	Chu Se District	11,394
4	K'bang District	3,595	13	Ia Pa District	-
5	Dak Doa District	28,047	14	Chu Pah District	8,478
6	Phu Thien District	-	15	Chu Puh District	2,506
7	Kong Chro District	-	16	Krong Pa District	-
8	Mang Yang District	5,151	17	Chu Prong District	13,514
9	Ia Grai District	14,856	**TOTAL**		**100,108**

Source: Gia Lai Provincial Statistics Office, 2022 [6]

Similarly, the biochar production model from coffee fruit husks and leaves was also implemented at the same location, Ia Bang commune. This area has a rich supply of coffee by-products, ensuring sufficient materials for production.

3.2. Improvement of biochar production from coffee stems and branches

The biochar production model from coffee stems and branches was implemented by using a system of 10 brick kilns, each with a capacity of 90 m^3. These kilns were placed on an area of 4,000 m^2 and operated continuously from June 2020 to May 2024, producing 2,000 tons of biochar for potential export.

The quality of biochar from coffee stems and branches was evaluated based on the criteria outlined in Circular 56/2013/TT-BTC (Ministry of Finance of Vietnam) [7], including (Table 2):

(1) Ash content: Biochar produced had an ash content ranging from 2.85% to 3.0%,

meeting the required standard of ≤3.0%. Low ash content helps reduce waste and improve utilization efficiency;

(2) Fixed carbon content: Biochar from stems and branches had a carbon content ranging from 70.26% to 74.09%, exceeding the required standard of ≥70.0%. This shows great potential for energy storage and soil quality improvement when using biochar;

(3) Calorific value (Kcal/kg): The calorific value of biochar ranged from 7,051 to 7,354 Kcal/kg, surpassing the standard of ≥7,000 Kcal/kg. High calorific value ensures efficient energy supply during combustion;

(4) Volatile matter: The volatile matter content of biochar ranged from 7.25% to 8.08%, higher than the required standard of ≥4.0%, indicating fast and efficient combustion for energy applications;

(5) Sulfur content: The sulfur content of biochar was ≤ 0.20%, meeting the standard for reducing harmful emissions during combustion.

The quality indicators of biochar from coffee stems and branches, including ash content, carbon content, calorific value, and volatile matter, all met export standards according to Circular 56/2013/TT-BTC of Ministry of Finance of Vietnam (Table 2) [7].

Table 2. Quality of biochar produced from coffee stems and branches

Sample £	Indicator				
	Ash content (%)	Carbon content (%)	Volatile matter (%)	Sulfur content (%)	Calorific value (Kcal/kg)
1	2.97	71.30	8.08	0.072	7,059
2	2.91	71.22	7.41	0.075	7,130
3	2.93	73.09	7.80	0.090	7,122
4	2.98	70.54	7.81	0.090	7,181
5	3.00	70.26	7.95	0.092	7,164
6	2.96	71.82	7.37	0.088	7,051
7	3.00	71.90	8.01	0.073	7,055
8	2.87	70.26	7.59	0.082	7,057
9	2.99	72.63	7.77	0.085	7,133
10	2.88	71.34	7.87	0.081	7,128
11	2.91	73.26	7.81	0.095	7,108
12	2.95	72.11	7.66	0.081	7,067
13	3.00	70.36	7.93	0.089	7,188
14	2.86	73.72	7.45	0.077	7,132
15	3.00	71.25	7.91	0.089	7,099
16	2.93	72.37	7.57	0.075	7,144
17	2.90	71.24	7.47	0.071	7,133
18	2.86	72.17	7.25	0.073	7,182
19	2.89	74.09	7.37	0.084	7,099
20	2.85	71.26	7.29	0.080	7,354
Requirements	≤ 3.00%	≥ 70.00%	≥ 4.00%	≤ 0.20%	≥ 7,000Kcal/kg

3.3. Improvement for biochar production from coffee fruit husks and leaves

The biochar production model from coffee fruit husks and leaves was implemented using

15 steel kilns, each with a capacity of 300 kg/batch. By May 2024, this model had produced 1,000 tons of biochar.

The quality of biochar from coffee fruit husks and leaves was evaluated based on the following criteria (Table 3):

(1) Organic carbon content: Organic carbon content ranged from 24.72% to 27.22%, exceeding the minimum requirement of >15%. High organic carbon content improves soil quality and supports plant growth;

(2) Moisture content: Moisture content ranged from 13.15% to 14.98%, meeting the requirement of < 15%. Low moisture content helps preserve biochar longer and reduces natural decomposition;

(3) Ash content: Ash content ranged from 9.10% to 9.31%. While no specific standard is set for ash content, low ash content improves energy efficiency and environmental protection.

The quality indicators of biochar from coffee fruit husks and leaves, including organic carbon content, moisture content, and ash content, all met the standards of Circular 56/2013/TT-BTC of Ministry of Finance of Vietnam [7]. Biochar from coffee fruit husks and leaves is of high quality and suitable for use in organic microbial fertilizers, supporting nutrient absorption in plants and improving soil health.

Table 3. Quality of biochar produced from coffee fruit husks and leaves

Sample	Organic Carbon Content (%)	Moisture Content (%)	Ash Content (%)
1	24.72	14.98	9.28
2	26.75	14.51	9.31
3	27.22	14.55	9.28
4	26.58	14.45	9.23
5	26.07	13.55	9.19
6	26.34	13.15	9.25
7	26.22	13.25	9.15
8	27.09	13.78	9.31
9	26.88	14.52	9.20
10	26.51	14.57	9.31
11	26.95	13.98	9.10
12	26.29	13.76	9.15
13	26.12	13.75	9.09
14	26.19	14.95	9.22
15	26.27	14.73	9.11
Requirements	> 15%	< 15%	N/A

3.4. Improvement for production of organic microbial fertilizer from biochar

The production model of organic microbial fertilizer from biochar was implemented at the An Hung Gia Lai Agricultural Engineering and Trade Service Company Branch, with full infrastructure and modern equipment for production. The main raw materials included biochar from the burning of coffee stems, branches, and coffee fruit husks, combined with the biological agent Trichoderma. The mixing and activation composting process lasted for 10-15 days to ensure the quality of the fertilizer.

The production of microbial fertilizers was evaluated according to the quality criteria of QCVN 01-189:2019/BNNPTNT (Ministry of Agriculture and Rural Development of Vietnam) [8]:

(1) Organic matter content: The produced fertilizer had an organic matter content ranging from 30.61% to 54.20%, far exceeding the

requirement of ≥15%. High organic matter content helps improve the soil structure, and provides abundant nutrients for crops; (2

(2) Trichoderma density (CFU/g): Trichoderma density ranged from 1.1 x 10^6 to 1.3 x 10^6 CFU/g, much higher than the standard of ≥1.0x10^6 CFU/g. Trichoderma fungi help protect plant roots from diseases and promote growth;

(3) Moisture content: Moisture content ranged from 24.46% to 28.00%, meeting the requirement of ≤30%. Low moisture content helps extend the shelf life of the fertilizer;

(4) pH: The pH ranged from 6.78 to 8.14, within the standard range of ≥5.00, suitable for maintaining an ideal environment for plant growth (Table 4).

The results showed that this model produced 1,000 tons of organic microbial fertilizer, meeting the quality criteria set by QCVN 01-189:2019/BNNPTNT [8]. These indicators ensure that the organic microbial fertilizer is of high quality, suitable for crops such as coffee and pepper, contributing to improving soil quality and increasing productivity.

Table 4. Quality of organic microbial fertilizer of the project

Indicator	Sample #										Quality Requirement
	01	02	03	04	05	06	07	08	09	10	
Organic matter content (%)	54.2	53.2	52.2	30.62	30.61	31.12	32.01	29.99	31.05	31.01	≥ 15
Trichoderma (CFU/g)	1.2x10^6	1.1x10^6	1.3x10^6	1.3x10^6	1.1x10^6	1.5x10^6	1.2x10^6	1.1x10^6	1.4x10^6	1.1x10^6	≥ 1.0x10^6
Moisture content (%)	27	28	26	26.35	25.52	26.09	26.82	24.46	25.13	26.3	≤ 30.0
pH	6.78	7.15	7.25	7.27	7.79	7.91	8.12	8.08	8.14	8.12	≥ 5
Lead content (mg/kg)	11.9	2.6	2.3	KPH	KPH	KPH	KPH	KPH	KPH	KPH	≤ 200.0
Mercury content (mg/kg)	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	≤ 2,0
Cadmium content (mg/kg)	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	≤ 5,0
Arsenic content (mg/kg)	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	≤ 10,0
Samonella spp (MPN/25g)	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	KPH	Not detected/ Negative
E.Coli (MPN/g)	1.5x10^6	1.1x10^2	1.1x10^2	1.5x10^1	KPH	KPH	KPH	KPH	KPH	KPH	≤ 1.1 x 10^3

4. CONCLUSION

The biochar and organic microbial fertilizer production model from agricultural by-products in Gia Lai province has achieved positive results and affirmed its feasibility in terms of economics, technology, and environmental sustainability. The biochar production models from coffee stems and coffee fruit husks have produced high-quality products that meet all technical standards for export. Both types of biochar have high carbon content, high calorific value, and low ash content, confirming their great potential for use in energy industries and sustainable agriculture.

The organic microbial fertilizer produced from biochar has proven to be effective in improving soil fertility and providing nutrients to plants, while also contributing to soil ecosystem protection due to its high content of beneficial microorganisms, particularly Trichoderma fungi. The quality indicators of the organic microbial fertilizer far exceed the requirements of national standards, affirming its high value for agricultural applications.

With these initial results, this model has significantly contributed to reducing agricultural waste, increasing the economic value of crop by-products, and supporting the development of sustainable agriculture in large coffee-growing areas. The implementation of these models not only brings economic benefits to local farmers but also opens up sustainable development pathways for the agricultural sector by minimizing negative environmental impacts. In the future, the expansion and replication of biochar and organic microbial fertilizer production models in other localities is entirely feasible [9]. The above results demonstrate that the application of production technologies from agricultural by-products not only has economic value but also contributes to green and sustainable development for Vietnam's agriculture.

Acknowledgment: Authors are thankful to the families in Dak Doa districts for providing by-products from coffee trees for the experiment of the research. We thank Ministry of Science and Technology of Vietnam for providing fund for achieving results presented in this paper, and Institute of Agricultural Environment, Vietnam Academy of Agricultural Sciences for its supports to transfer the results of the research.

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