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The Effectiveness of Cocoa Pod Husk Activated Carbon as an Ethylene Adsorbent for Extending the Shelf Life of Cavendish Bananas

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Abstract

One of the abundant agricultural wastes in Indonesia that has not been optimally utilized is cocoa pod husk (Theobroma cacao L.). Cocoa pod husk is the main by-product of the cocoa bean processing. Cocoa pod husk has a high cellulose content, making it a suitable precursor for activated carbon production. Activated carbon can adsorb ethylene from climacteric fruits, extending fruit shelf life. This research aims to test the effectiveness of activated carbon derived from cocoa pod husk as an ethylene adsorbent to extend the shelf life of fruits, specifically Cavendish bananas. The research procedure consists of preliminary research and primary research. The initial research involved measuring ethylene production, synthesizing activated carbon from cocoa pod husk, testing the characteristics of the cocoa pod husk activated carbon, calculating the activated carbon's capacity for ethylene adsorption, and determining the optimal amount of cocoa pod husk activated carbon. The primary research involved testing Cavendish bananas' storage and display life by applying an ethylene adsorber bag (EAB) using perforated LDPE packaging until spoilage. The Cavendish banana samples originated from Klaten, Central Java, with a maturity level of 1. The test parameters included moisture content, weight loss, firmness, color, total soluble solids (TSS), and Total Titratable Acidity (TTA). The treatments in this study consisted of samples treated with EAB from cocoa pod husk and a control group without EAB. All treatments were performed in triplicate. The experimental design used was a Completely Randomized Design (CRD). The results showed that a well-defined porous structure, a rough surface, and numerous cavities characterize the cocoa pod husk activated carbon. It has an ethylene absorption capacity of 363 ppm/g. The ethylene production rate of Cavendish bananas observed during storage was 1,280 ± 227.5 ppm. The results showed that bananas treated with cocoa pod husk-activated carbon were still green on the 10th day compared to the control treatment, which had already spoiled. During the display period, Cavendish bananas could last up to 5 days before spoilage. Therefore, cocoa pod husk-activated carbon can delay ripening and spoilage, thus extending the shelf life of Cavendish bananas.

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1. Introduction

The continuously increasing global population is directly proportional to the rise in biomass waste production, particularly in the agricultural and food processing industries. One abundant agricultural waste product that is not optimally utilized in Indonesia is cocoa pod husk (Theobroma cacao L.). Cocoa pod husks are the primary byproducts of cocoa bean processing. The volume of cocoa pod husks can reach approximately 60% of the total weight of the cocoa fruit (Tadda et al., 2016). Currently, cocoa pod husks are mostly discarded as solid waste or used as compost with a relatively low added value. When cocoa pod husk waste is piled up in plantations, it can lead to attacks by cocoa pod borers (CPB) (Saleh et al., 2019). This highlights the potential for converting it into a high-value material through a sustainable approach.

In waste utilization and functional material development, cocoa pod husks show promising prospects as a precursor for activated carbon production. Activated carbon is a carbonaceous material known for its high porosity, large specific surface area, and excellent adsorptive properties for various types of molecules in the gas and liquid phases. The production of activated carbon from biomass, including cocoa pod husks, involves carbonization and activation stages, either physical or chemical. This process is essential for developing complex pore structures (micropores, mesopores, and macropores), which are key to adsorption efficiency (Tadda et al., 2016).

One application of activated carbon is its role as an ethylene (C2H4) adsorbent. Ethylene is a gaseous plant hormone that is naturally produced by fruits, especially climacteric fruits, during ripening. Ethylene triggers biochemical changes essential for developing mature fruit organoleptic characteristics, including sweetness, distinct aroma, and texture softening (Pott et al., 2020). However, high ethylene concentrations in the storage environment are a primary trigger for accelerating fruit ripening and spoilage. This phenomenon causes significant post-harvest losses, both economically and nutritionally (Amirah et al., 2017).

One climacteric fruit is the Cavendish banana, which is popular and widely consumed worldwide. Cavendish bananas have a high international market potential as an export commodity among other banana varieties (Jamaluddin et al., 2019). Cavendish bananas produce high levels of ethylene, leading to a relatively short shelf life after harvest (Amirah et al., 2017). Efficient ethylene control in Cavendish bananas is key to maintaining their quality and extending their shelf life.

Considering the challenges in managing cocoa pod husk biomass waste and the need for innovation in effective post-harvest technology, this study aimed to test the effectiveness of activated carbon derived from cocoa pod husks as an ethylene adsorbent to extend the shelf life of Cavendish bananas. Furthermore, it can reduce post-harvest fruit losses and increase the value of agricultural products.

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2. Material and Methods

2.1 Material and Tools

The equipment utilized in this research included a Cosmos XP – 3160 ethylene meter, oven, digital balance, petri dishes, beaker glass, measuring cylinders, magnetic stirrer, furnace, stopwatch, 5-liter jars, plastic tubing, desiccator, Quantek O2/CO2 analyzer, sun rheometer CR-500DX, Atago Hand-held refractometer, single aperture spectrophotometer chromameter, Scanning Electron Microscope (SEM), and Hitachi type 350 gas chromatograph.

2.2 Research Procedure

This research was conducted in two phases. The first phase is preliminary research, and the second is primary research. The preliminary research involved several key steps: measuring ethylene production, synthesizing the ethylene adsorbent material, characterizing the cocoa pod husk activated carbon, calculating the ethylene adsorption capacity of the activated carbon, determining the optimal quantity of cocoa pod husk activated carbon, and fabricating the Ethylene Adsorber Bag (EAB) using Tyvek paper as the packaging material. The primary research evaluated the storage and display life of Cavendish bananas. This evaluation measured several parameters, including moisture content, weight loss, firmness, color, total soluble solids (TSS), and total titratable acidity (TTA).

2.3 Preliminary Research

The preliminary research focused on quantifying the accumulated ethylene production. This measurement of ethylene production was crucial for determining the optimal amount of cocoa pod husk activated carbon needed. The precise determination of the quantity of Ethylene Adsorber Bag (EAB) material ensured efficient ethylene adsorption.

2.4 Ethylene Production Measurenment

The initial step for measuring ethylene production involved preparing a sample of Cavendish bananas, specifically one comb weighing approximately ±1 kg. A 5-liter jar was used to place the bananas, and the ethylene meter was used for measurement. The jar lid was fitted with two holes to accommodate the hoses leading to the measurement apparatus. The lids of these hoses were sealed with plasticine to prevent gas from leaking out or entering, which would lead to erroneous measurements. Similarly, after placing the bananas, the edges of the jar lid were sealed with plasticine to ensure airtightness. During the measurement period, the jar remained sealed, with openings occurring every 3 h for ethylene gas measurement. There were three replicates for each experimental unit. Measurements were continued until the Cavendish banana sample showed signs of spoilage. The resulting concentration data were used for calculations. The ethylene production rate over time was calculated using Equation (1).

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$$RC_2H_4 = \frac{yC_2H_4\,ti - yC_2H_4\,tf}{100\ x\ m\ x\ (t_f - t_i)} \quad (1)$$

Where RC_2H_4 is the ethylene production rate (ppm kg^{-1}hours $^{-1}$), m is the mass (kg), t is the time (h), y is the volumetric concentration of ethylene gas (ppm), t_i is the initial, and t_f is the final.

2.5 Preparation of Cocoa Pod Husk Activated Carbon

Cocoa pod husk activated carbon was prepared following the method described by Khotimah et al. (2024). First, the cocoa pod husks were cut into small pieces and washed with running water. Next, the pieces were soaked in distilled water for 12 h. After soaking, the cleaned cocoa pod husks were blended into smaller fragments. The blended husks were filtered using filter paper to isolate the solid cocoa pod portion from the liquid. This liquid was cocoa pod husk extract, which was dried at an oven temperature of 100°C for 20 h. Subsequently, a 5-gram cocoa pod husk powder sample was taken and subjected to pyrolysis at 400°C for 4 h and 20 min in a pyrolysis reactor. Each pyrolyzed sample was then treated with 300 mL of 1.5 M sodium hydroxide solution to remove silica, which was kept on a magnetic stirrer at 100°C for 1 h. After dissolving the sample in sodium hydroxide, filter paper was used to separate the sample from the silica. Subsequently, the samples were washed with distilled water. The final step involved drying the cocoa pod husk activated carbon, which was carried out in an oven at 80°C for 20 h. The carbonized residue was then activated, dried, and passed through an 80-mesh sieve to obtain the catalyst.

2.6 Characterization of Cocoa Pod Husk Activated Carbon

The ash content, iodine adsorption capacity, and surface area were measured. Compliance testing for moisture content, ash content, and iodine adsorption met the SNI 06-3730-1995 standard for activated carbon. The surface area of the cocoa pod husk activated carbon material was analyzed using Scanning Electron Microscopy (SEM).

Moisture Content analysis began by drying 1 g of activated carbon in an oven at 105°C for 3 h. After drying, the sample was cooled in a desiccator and weighed. The drying, cooling, and weighing processes were repeated hourly until a constant weight was achieved. For Ash Content analysis, 2 g of activated carbon was placed in a furnace at 700°C for 6 h. This process was performed to completely ash the activated carbon. Iodine Adsorption Capacity Analysis was commenced by mixing 0.5 g of activated carbon with 50 mL of a 0.1 N iodine solution. The mixture was then thoroughly stirred using a magnetic stirrer for 15 min, followed by filtration. A 10 mL aliquot of the resulting filtrate was titrated with a 0.1 N sodium thiosulfate ($Na_2S_2O_3$) solution until the solution turned yellow. Subsequently, a few drops of 1% starch solution were added until a blue color appeared, and titration was continued until the blue color disappeared.

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2.7 Calculation of Activated Carbon's Ethylene Adsorption Capacity

The ethylene adsorption capacity of the activated carbon was determined using gas chromatography. The initial step involved the preparation of the necessary equipment and materials. Subsequently, 5 g of cocoa pod husk activated carbon was placed in a jar. The edges of the jar lid were sealed with plasticine to ensure an airtight seal.

Next, ethylene gas was injected into the jar using a gas chromatograph. The ethylene concentration within the jar was measured at intervals of several minutes until saturation was reached. Finally, the amount of ethylene adsorbed by the activated carbon was calculated by subtracting the remaining ethylene from the initial amount.

2.8 Calculation of Required Ethylene Adsorber Quantity

Based on the calculated ethylene oxidation capacity, we determined the required amount of cocoa pod husk activated carbon ethylene adsorber for one bunch of Cavendish bananas. The calculation for the necessary ethylene adsorber within the Cavendish banana packaging is presented in Equation 2:

$$EO = \frac{AE}{KO} \quad (2)$$

Where EO is required amount of ethylene oxidant (g kg^{-1}), AE; Ethylene accumulation (ppm kg^{-1}), KO; Oxidation capacity of the ethylene oxidant (ppm g^{-1}).

2.9 Primary Research

The primary research comprised two observational phases: during storage and display. Ethylene adsorber bags, packaged in Tyvek paper, were applied to Cavendish bananas stored at 27±2°C until the fruit spoiled or became unsuitable for consumption. The primary research process conducted on Cavendish bananas is illustrated in Figure 1.

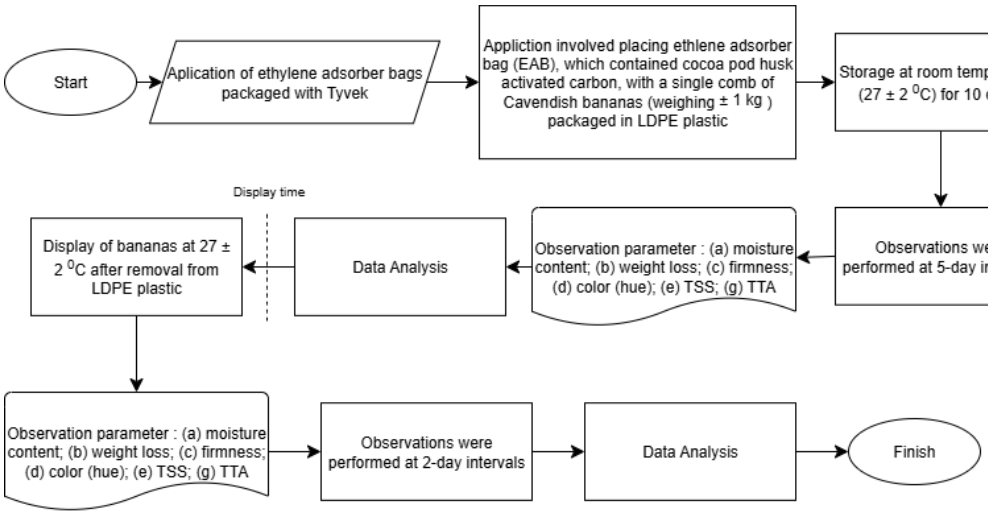

Figure 1. Flowchart Primary Research.

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2.10 The Observation Parameter

Parameter analysis was conducted during packaging with and without LDPE plastic. The parameters evaluated included moisture content, weight loss, firmness, color (hue), total soluble solids (TSS), and titratable acidity (TTA).

2.11 Moisture Content

We determined moisture content using the AOAC (2005) procedure, which employs an oven for measurement. Equation 3 shows the calculation for moisture content.

$$\text{Moisture Content (\%)} = \frac{W_{s0}-W_{s1}}{W_{s0}-W_w}\ x\ 100\% \quad (3)$$

Where W_w; Weight of container (g), W_{s0}; Weight of container and sample before drying (g), W_{s1}; Weight of container and sample after drying (g).

2.12 Weight Loss

Weight loss was measured using a digital balance based on the initial and final weights of the Cavendish bananas throughout the storage period. The weight loss was calculated using Equation 4:

$$\text{Weight Loss (\%)} = 1 - \frac{W_x}{W_o}\ x\ 100\% \quad (4)$$

Where Wx; Weight at the end of storage period 'n' (g), Wo; initial weight (g)

2.13 Firmness

We measured the firmness of Cavendish bananas using a rheometer. The first step involved selecting an appropriate plunger for the material. Subsequently, a banana sample was placed beneath the plunger on the rheometer. The diameter of the plunger is 5 mm. The speed of the probe's movement was 20 mm/min. The plunger was then operated constantly, pressing it into the sample until it ruptured. The firmness value was subsequently displayed on the rheometer screen. We measured the firmness at three points on each sample to ensure that the results accurately represented the actual condition of the material.

2.14 Color

We measured the color of the Cavendish bananas using a chromameter. First, we calibrated the instruments. The sensor was then placed on the fruit surface. This system employs the Hunter Lab color space notation to measure lightness (L), a∗, and b∗ values. The a∗ and b∗ values obtained from the chromameter were then converted into chromatic hue (H) using Equation 5, where The H value indicates the dominant color of the sample.

$$H = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (5)$$

Where a^*; The color parameter ranges from green to red, b^*; The color parameter ranges from blue to yellow.

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2.15 Total Soluble Solids (TSS)

A refractometer was used to measure the total soluble solids (TSS) of the Cavendish bananas. This measurement allowed us to determine the sweetness level of the fruit. The TSS results were displayed on the refractometer screen in °Brix.

2.16 Total Titratable Acidity

Total Titratable acidity (TTA) measurement determines the acid content in Cavendish bananas. TTA measurement is based on the neutralization of fruit extract by a strong base, such as NaOH. First, 25 grams of banana pulp were crushed. This was followed by filtration with the addition of distilled water. The resulting solution was then transferred into a 100 mL volumetric flask. A 25 mL aliquot was taken from this, and three drops of phenolphthalein indicator were added. Subsequently, the solution was titrated with 0.1 N NaOH until it turned light pink. Equation 6 shows the calculation for TTA.

$$\text{TAT (\%)} = \frac{volume\ NaOH\ (ml) x\ fp\ x\ 0.1\ N\ x\ BE}{Sample\ weight\ (g) x\ 1000}\ x\ 100\% \quad (6)$$

Where fp; Dilution factor, BE; Equivalent weight of malic acid

3. Results and Discussion

3.1 Ethylene Production During Storage of Cavendish Banana

Ethylene production in Cavendish bananas was measured over 6 days or until spoilage occurred. The total ethylene produced during storage was approximately 1,280 ± 227.5 ppm. The graph illustrating ethylene production over the storage period is shown in Figure 2.

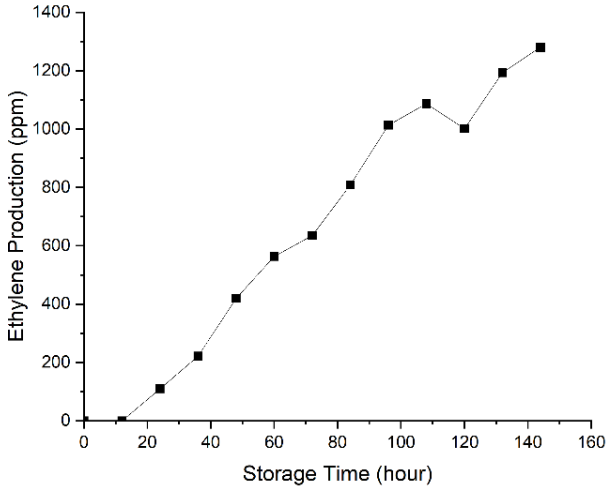

Figure 2. Graph of Ethylene Production During Storage.

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This indicates that the longer the storage duration, the higher the rate of ethylene production. Harvesting bananas triggers an increase in ethylene gas due to bananas being climacteric fruits, which, in turn, boosts their respiration rate (Yani et al., 2022). Ethylene is crucial in growth and development processes, particularly fruit ripening. However, ethylene accelerates fruit ripening and speeds up the spoilage process (Zhu et al., 2015).

3.2 Characterization of Cocoa Pod Husk Activated Carbon

The cocoa pod husk activated carbon was characterized based on its moisture content, ash content, and iodine adsorption capacity. Table 1 compares the cocoa pod husk activated carbon values against the Indonesian National Standard (SNI).

Table 1. Comparison of Cocoa Pod Husk Activated Carbon Characterization with SNI

No	Parameter	Value	SNI
1.	Moisture Content (%)	5.47	Max. 15
2.	Ash Content (%)	12.01	Max. 10
3.	Iodine Adsorption Capacity (mg/g)	478.91	Min. 750

Based on Table 1, the moisture content of the cocoa pod husk activated carbon aligns with the SNI. However, the ash content and iodine adsorption capacity are still below the SNI standards. This discrepancy could be attributed to several factors, such as suboptimal activation processes or the incomplete removal of impurities (Muhajir et al., 2021). The material's average pore diameter was between 25 - 40 nm, as determined by Image-J software analysis. The morphological characteristics of the cocoa pod husk activated carbon are illustrated in Figure 3 at 10,000x magnification.

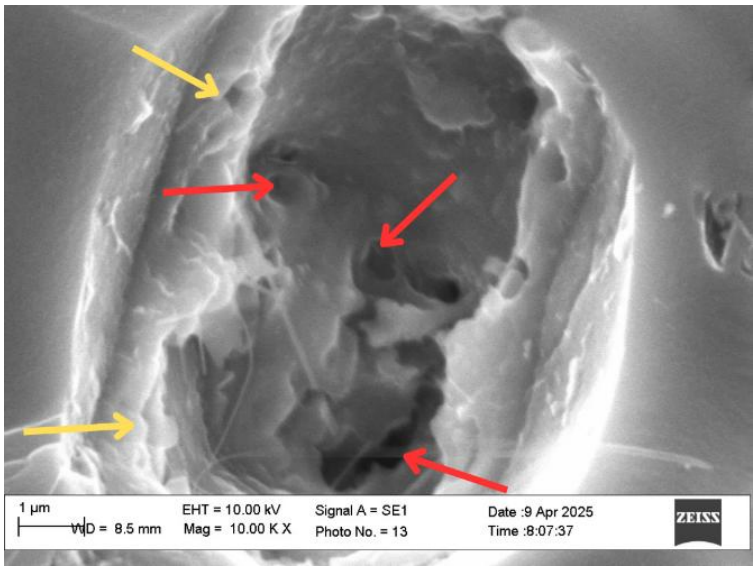

Figure 3. Scanning Electron Microscopy (SEM) of Cocoa Pod Husk Activated Carbon.

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The tested cocoa pod husk activated carbon exhibits excellent morphological characteristics for an adsorbent. Figure 3 clearly shows a distinct porous structure (indicated by red arrows), a rough surface (indicated by yellow arrows), and numerous voids. These features suggest that the activation process successfully created a material with a high surface area. Despite the low iodine number adsorption, which typically mandates a microporous structure, the resulting morphology demonstrates a significant pore distribution within the mesoporous range. This characteristic allows for broader applications, such as the adsorption of various substances, including ethylene (Khotimah et al., 2024). Consequently, the mesopores' substantial surface area facilitates a significant amount of adsorbed ethylene**.**

3.3 Adsorption Capacity and Determination of Cocoa Pod Husk Activated Carbon Weight

Cocoa pod husk activated carbon was utilized for ethylene adsorption over 105 minutes using a 3-gram sample. The initial ethylene concentration was set at 1,280 ± 227.5 ppm, derived from the ethylene production data shown in Figure 2. At time 0, the ethylene concentration was 1,280 ppm, which decreased to 88 ppm by the 105th minute, as illustrated in Figure 4. This indicates that the cocoa pod husk activated carbon effectively adsorbed 363 ppm/g of ethylene.

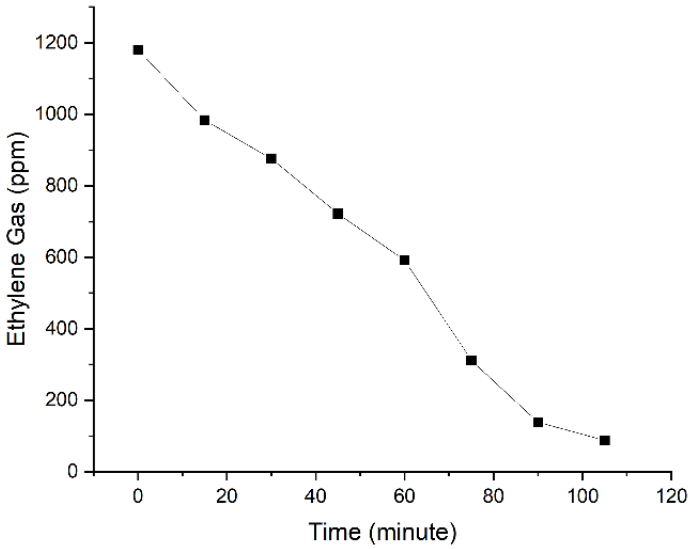

Figure 4. Graph of Ethylene Adsorption by Cocoa Pod Husk Activated Carbon.

These results led to a calculated requirement of 3.5 grams of activated carbon for inclusion in the ethylene adsorber bag (EAB). For comparison, research by Aprilia et al. (2023) used approximately 3.9 grams of ethylene adsorbent for 1 kg of Mas Kirana bananas, which had an ethylene accumulation of ± 1,400 ppm/kg. Conversely, 1 kg Barangan bananas required 2.5-3 grams of ethylene adsorbent (Agustiningrum et al., 2018). The variation in the required amount of ethylene adsorbent can be attributed to differences in the adsorption capabilities of the activated carbon materials.

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3.4 Observation Results

3.4.1 Moisture Content

The moisture content of banana fruit is vital in determining its quality after harvesting and longevity. On day 0, both control bananas and bananas treated with EAB had a low moisture content of around 75%. However, by day 10, control bananas had lost more moisture, reaching around 69% while EAB-treated bananas had around 74%. Throughout the display period, the moisture content of the bananas continued to decrease, and by day 15, had reached 70.5%. This trend is illustrated in Figure 5.

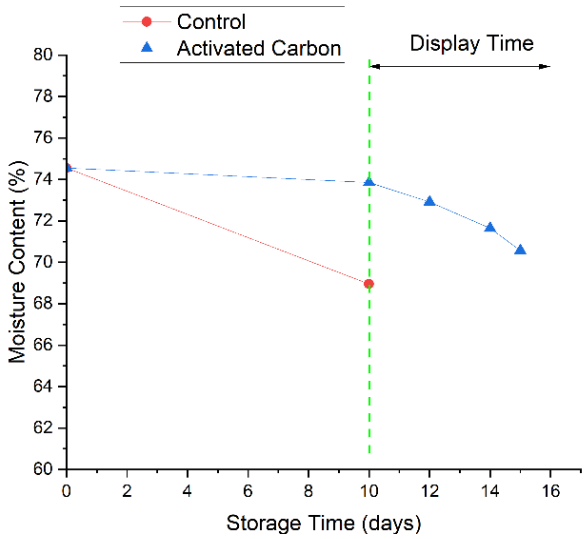

Figure 5. Changes in Moisture Content of Cavendish Banana Pulp During Storage.

This finding aligns with research by Wahhab et al. (2023), which reported that the moisture content of ripe bananas is approximately 70%. According to Amer et al. (2023), fresh bananas typically have a wet basis moisture content ranging from 75% to 82%. A prolonged storage period leads to a decrease in moisture content. This reduction is attributed to the transpiration process from the banana fruit to the atmosphere. Transpiration is driven by the vapor pressure difference between the moist interior of the fruit and the generally drier surrounding environment. A lower environmental relative humidity and a higher temperature accelerate the transpiration rate (Kumari et al., 2023).

3.4.2 Weight Loss

On day 0, the weight loss for control bananas and those treated with EAB remained low at 0%. However, by day 10, the weight loss in control bananas had increased significantly to approximately 14%, whereas EAB-treated bananas showed a lower weight loss of about 9%, as depicted in Figure 6.

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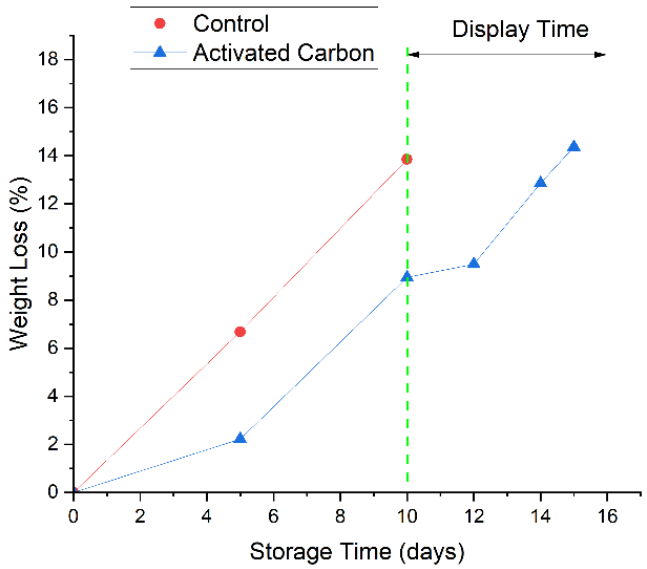

Figure 6. Changes in Whole Cavendish Banana Fruit Weight Loss During Storage.

Throughout the display period, the bananas experienced a continuous increase in weight loss. By day 15, the weight loss reached 14.3%. This observation is consistent with prior studies, which show that weight loss in stored bananas increases with the length of the storage period (Hutauruk et al., 2024). The increase in weight loss is mainly a result of the bananas losing moisture through transpiration. Water can evaporate through small pores (lenticels) on the banana peel. The difference in water vapor pressure between the fruit's interior, which is typically saturated with water vapor, and the surrounding environment, which has lower relative humidity, drives this transpiration process (Saraya et al., 2017). Also, while respiring, some of the dry mass of the fruit, including elements like carbon, hydrogen, and oxygen that constitute sugars and starches, is transformed into carbon dioxide and released into the atmosphere. The carbon dioxide released drives further reduction of the fruit's mass, but the effect is much smaller than that of transpiration. The agreement with the loss in moisture content results in greater weight loss of bananas.

3.4.3 Firmness

On day 0, the firmness of both control bananas and bananas treated with EAB remained high, measuring 4.6 kgf. However, by day 10, the firmness of control bananas significantly decreased to approximately 0.3 kgf, whereas EAB-treated bananas maintained a higher firmness of about 4.2 kgf. The firmness trend for Cavendish bananas is illustrated in Figure 7.

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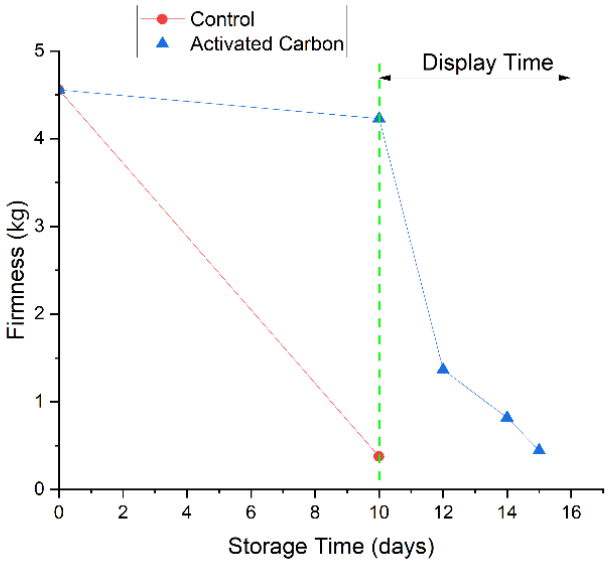

Figure 7. Changes in Cavendish Banana Firmness During Storage.

Throughout the display period, the bananas experienced a continuous reduction in firmness. By day 15, the firmness value was only about 0.4 kgf. This observation aligns with research by Zhu et al. (2015), which reported that while banana firmness starts high, it declines by day 12. The softening of bananas during storage results from a series of enzymatic processes that actively break down complex structural components within the cell walls, particularly pectin, and the conversion of starch into sugars, primarily driven by ethylene gas (Crismas et al., 2018). Therefore, prolonged banana storage leads to a greater decrease in firmness.

3.4.4 Color (Hue)

On day 0, both control and EAB-treated bananas were green, with a hue value of 112°, as shown in Figure 8. By day 10, the control bananas had turned yellow, whereas the EAB-treated bananas retained a yellowish-green color.

Throughout the display period, the bananas' color transitioned to a complete yellow, progressing to decay by day 15, with a hue value of approximately 80°. Bananas with a low ripening stage typically exhibit hue values between 120° and 90°, while fully ripe or mature bananas have values ranging from 85° to 80° (Ringer & Blanke, 2021). Figure 9 shows that the control banana samples on day 10 appeared brownish-yellow (decaying), while the bananas with EAB remained green.

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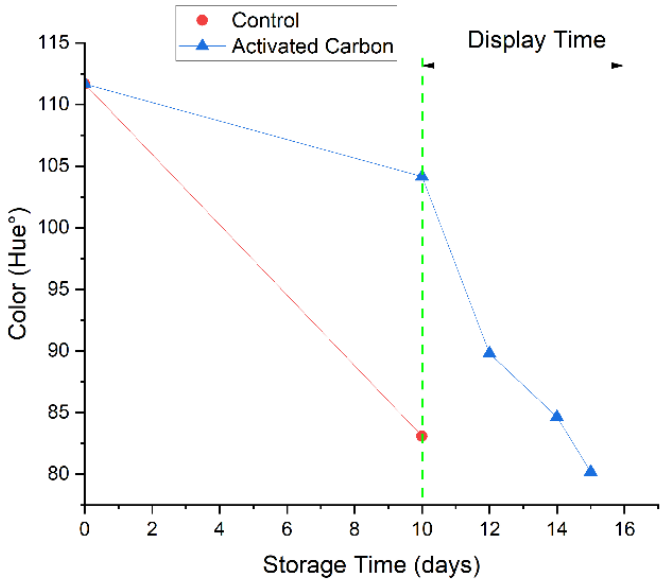

Figure 8. Changes in Color (Hue) During Cavendish Banana Storage.

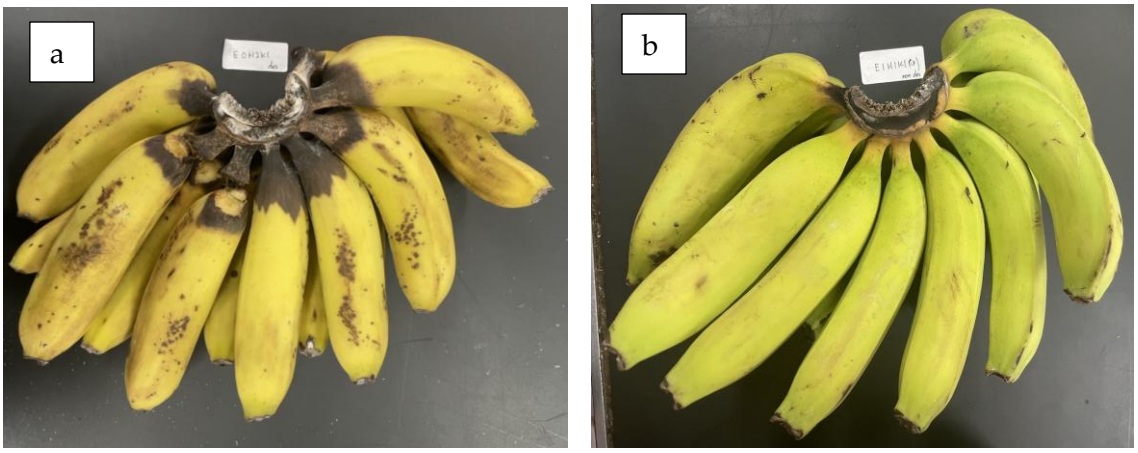

Figure 9. Comparison of Cavendish Bananas on Day 10 of Storage: (a) Control (b) Cocoa Pod Husk Activated Carbon.

The observed color change signifies a decline in quality post-ripening due to chlorophyll degradation. Ethylene, produced during the banana ripening process, activates enzymes such as chlorophyllase and magnesium dechelatase, which are responsible for degrading chlorophyll. Consequently, the initially dominant green color fades (Wiranata et al., 2019).

3.4.5 Total Solube Solids (TSS)

On day 0, the Total Soluble Solids (TSS) of both control and EAB-treated bananas remained low, at approximately 4.4°Brix. However, by day 10, the TSS of control bananas had significantly increased

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to around 19°Brix, whereas EAB-treated bananas still had a lower TSS of approximately 13°Brix. The changes in TSS during Cavendish banana storage are presented in Figure 10.

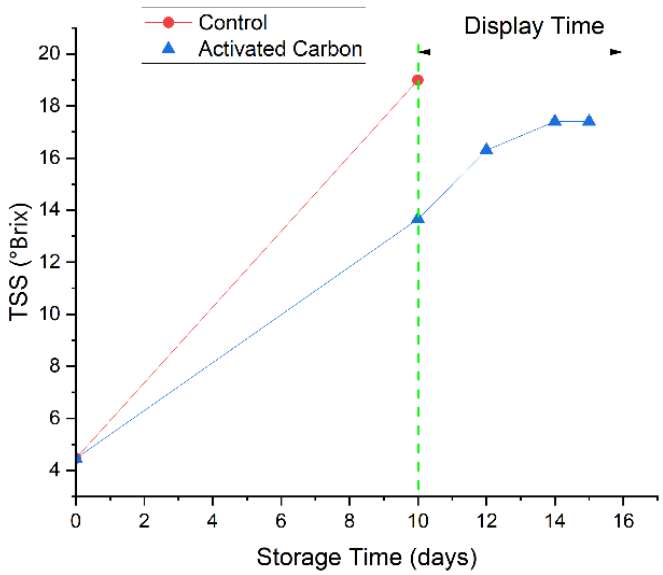

Figure 10. Changes in TSS During Cavendish Banana Storage

The bananas' TSS continued to increase throughout the display period, indicating a progressive fruit sweetening. By day 15, the TSS reached approximately 17°Brix. This accumulation of organic acids, carbohydrates, and amino acids constitutes the total soluble solids. These components increase during the fruit ripening process. Monosaccharides such as glucose, fructose, and sucrose contribute to the high TSS values observed during ripening. A higher TSS level in bananas is directly proportional to the duration of storage (Hutauruk et al., 2024).

3.4.6 Total Titratable Acidity (TTA)

At day 0, Total Titratable Acidity (TTA) for both control and EAB-treated bananas was low, approximately 0.15%. However, by day 10, control bananas' TTA had risen to about 0.32%, while EAB-treated bananas had a slightly elevated TTA of 0.34%. Figure 11 illustrates the changes in total titratable acidity.

During the display period, the TTA for the bananas continued to rise. By 15 days, bananas had a TTA of 0.36%. The increase in total titratable acidity is a function of the ripening of the fruit, which occurs, in this case, during storage. In bananas, the ripening process is characterized by a higher metabolic rate during the initial phases. This includes the breakdown of starch to sugars and a rise in the concentration of specific organic acids like malic and citric acids (Rahman et al., 2014).

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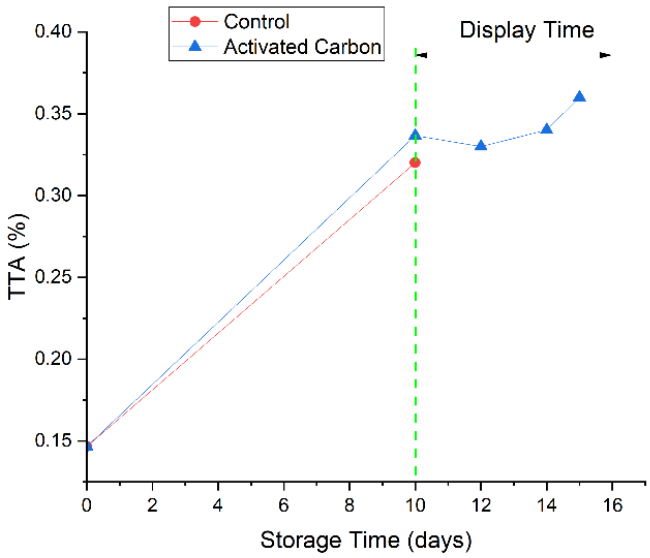

Figure 11. Changes in TTA During Cavendish Banana Storage.

3.4.7 Statistical Analysis of Quality Data Changes in Cavendish Banana

The statistical analysis for Cavendish banana quality data changes comprised two treatments: a control and the application of cacao pod husk activated carbon on Day 10. Each treatment was performed with three replications. The primary statistical methods employed were standard deviation and the t-test.

Table 2. Statistical Data Analysis of Cavendish Banana Quality Changes at Day 10.

No	Parameter	Control		Cocoa Pod Husk Activated Carbon		t-test
		Mean	SD	Mean	SD	Sig (2-tailed)
1	Color (Hue)	83.09	6.66	104.15	0.18	0.001
2	TSS	19.07	0.90	13.67	3.14	0.001
3	Firmness	0.38	0.73	4.23	0.48	0.07
4	Moisture Content	68.96	1.20	73.85	0.91	0.001
5	Weight Loss	13.85	0.002	8.95	0.39	0.001
6	TTA	0.32	0.09	0.34	0.02	0.001

The statistical analysis of the color parameter, based on standard deviation (SD), revealed that the control group (83.09±6.66) and the cacao pod husk activated carbon treatment group (104.15±0.18) showed non-overlapping values. This indicates a significant difference in the Cavendish banana's color parameter on the 10th day of storage. Other parameters, including Total Soluble Solids (TSS), firmness, moisture content, weight loss, and Titratable Acidity (TAA), also significantly differed from the control treatment. This finding aligns with the t-test result, which showed a p-value of 0.001<0.05,

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confirming a significant difference between the two samples. Conversely, the firmness parameter showed no significant difference, as its p-value (0.07>0.05) exceeded the significance level. This lack of difference may be attributed to high data variability, potentially resulting from the measurement of overly ripe samples, leading to inaccuracies in firmness assessment (Laryea et al., 2025).

4. Conclusion

This study effectively demonstrates the potential of cocoa pod husks as a viable source for activated carbon. The research shows that ethylene's impact on banana ripening during storage can be significantly suppressed by utilizing 3.5 grams of cocoa pod husk activated carbon (EAB) as an ethylene scavenger. The total ethylene produced by Cavendish bananas during storage until spoilage was determined to be 1280 ± 227.5 ppm. The activated carbon from cocoa pod husk has an ethylene absorption capacity of 363 ppm/g. The results indicate that the application of this activated carbon extended the shelf life of Cavendish bananas to 14 days, which is 5 days longer than the control group. The efficacy of cocoa pod husk-activated carbon successfully extended the shelf life of Cavendish bananas by an additional 5 days, lasting up to day 14, compared to the control group. Therefore, applying cocoa pod husk-activated carbon as an ethylene scavenger holds promise in reducing post-harvest losses during the distribution and marketing of Cavendish bananas.

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