From Peel to Paper: Nutritional Characterization and Biodegradable Paper Production from *Musa Paradisiaca* Banana Peels

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Abstract

Musa Paradisiaca is a variety of bananas used mainly for cooking instead of being consumed fresh. The peel of bananas, which is frequently seen as a byproduct, holds valuable nutritional and industrial potential. The nutritional banana peel can be applied and transformed into a beneficial product. This research aimed to characterise the nutritional content of the banana peel of Musa Paradisiaca and produce paper from it. The banana peel was analysed for its nutritional content across different ripening stages. The results showed that the nutritional content in the banana peel varies depending on the maturity stages, with unripe peels having the highest dry matter and fat content, ripe peels having the highest moisture, crude fibre, and protein content, and overripe peels having the highest ash content. Moreover, the total sugar content increases during the ripe stage due to enzymatic conversion to starch, and the total phenolic content of the ripe peel is at 7.93 mg GAE/g, indicating strong antioxidant properties in the peel. The paper made from the ripe peel is pale yellow with a rough texture and moderate flexibility compared to regular paper. Furthermore, ATR-FTIR analysis of the derived paper indicates that the presence of functional groups contributes to the paper's structural integrity. Additionally, the tensile strength of the paper exhibited moderate tensile strength and rigidity. The study indicated a 36.9% weight loss after 10 days in a soil burial experiment, indicating rapid biodegradation of derived paper from ripe Musa Paradisiaca peel.

Keywords: *Musa Paradisiaca; phenolic content; ripening stages; Gallic Acid; banana peel*

1. Introduction

Banana is a tropical fruit crop that is widely farmed and consumed. The average consumption of bananas per person is 12 kg, thus making it the world's fourth most important food crop after rice, wheat, and maise. Bananas are well-known as a primary food source of energy. Consuming bananas is good for our health because they contain a lot of resistant starch, which our body will use as fibre sources, as well as polyphenols, protein, essential amino acids, polyunsaturated fatty acids, natural antioxidants, carotenoids, and other bioactive compounds that have a variety of positive effects on one's wellbeing [1,2]. Over the past 20 years, the production of bananas has continuously grown. In 2019, the production of bananas was about 117 million tonnes, a 50% increase compared to 1999, which was only 70 million tonnes. In 2021, about 125 million tonnes of bananas were produced globally worldwide [3]. Bananas are one of the valuable resources that lasts for a short period, are simple to grow, and can be gathered

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throughout the year. The banana fruit's flesh is the part that is used the most, while the outer skin or peel is solely used as organic fertiliser and animal feed. It shows that the banana peel waste is still not fully optimised. The banana peel makes up about a third of the weight of a banana. Another study also stated that the banana peel is a waste that makes up 35% to 40% of the weight of fresh bananas. The chemical compounds in the banana peel are rich in antioxidant and antimicrobial activities, such as phenolic compounds, alkaloids, flavonoids, tannins, saponins, glycosides, and carotenoids [4]. These peels contain polyunsaturated fatty acids, amino acids, dietary fibre, carbs, proteins, and minerals [5]. According to Karne et al. (2023) [6], for every 100 g of banana peels, there are 18.50 g of carbohydrates, 2.11 g of fat, 0.3 g of protein, 1.60 mg of iron, 715 mg of calcium, 117 mg of phosphorus, 0.12 mg of B vitamins, and 17.50 mg of C vitamins. The banana peel's composition is dominated by water and carbohydrate compounds. The starch is also present in banana peels. Besides, the banana peel is rich in phenolic compounds, steroids, triterpenes, and amines [6]. In another study by Islam et al., (2023) [7], banana peel powder has high nutritional value, containing 1.337% moisture, 0.984% ash, 0.12% fat, 0.757% protein, 4.85% total carbohydrate, and 1.945% total fibre. *Musa Paradisiaca* is one of the species of banana that is a hybrid of *Musa Acuminata* and *Musa Balbisiana*. It is an edible and tasty yellow banana with ripe fruit that is sweet, juicy, and full of seeds [5]. However, the peel waste of *Musa Paradisiaca* is abundantly found and discarded near banana fritter stalls or banana chip factories in Malaysia. The purpose of this research is to fill the existing gap in our understanding by analysing the nutritional content (protein content, crude fibre, moisture content) of discarded banana peels of *Musa Paradisiaca* and potential products such as paper that can be used as starting material to fabricate other products such as facial tissue, sanitary pads or filler in textile to improve the properties of the fabric produced. Therefore, three specific objectives have been narrowed down and initiated to achieve the purpose of the research. The objectives were to determine the nutritional content in *Musa Paradisiaca* peel across different ripening stages, to investigate the total phenolic compounds (Gallic Acid) in the *Musa Paradisiaca* peel and to produce paper as the potential product that can be fabricated from the *Musa Paradisiaca* peel.

2. Materials and methods

2.1. Chemicals and instruments

Unripe, ripe, and overripe banana peel of *Musa Paradisiaca* was collected from a local vendor and seller of banana fritter in Arau, Perlis. 80% methanol, 80% ethanol, Folin-Ciocalteu reagent, 4% sodium hydroxide (NaOH), 0.25 M sulphuric acid (H_2SO_4), 0.3 M sodium hydroxide (NaOH), acetone, ammonia solution, ethanol, diethyl ether-petroleum ether solution, concentrated sulfuric acid, copper (II) sulfate ($CuSO_4$), selenium powder, boric acid indicator, 0.1 M hydrochloric acid (HCl), iodine reagent, hydrogen peroxide (H_2O_2) solution, nitric acid, and acetic acid were used in this research. Fourier-Transform Infrared Spectroscopy (FTIR), Ultraviolet-visible (UV/Vis) Spectrophotometer, and Texture analyser (TA-XT2i) were instruments used to characterise all samples.

2.2. Analysis of nutritional content in *Musa Paradisiaca* banana peel

Nutritional content (total fat content, protein content, moisture content, ash content, crude fibre content, cellulose content, dry matter, and total sugar analysis) was analysed using various methods with slight modifications [8–12]. For total fat content, the sample was weighed 5 g, and 5 mL of distilled water was used to dissolve the sample. Then, the mixture was transferred to a separating funnel. Next, 10 mL ethanol and 2 mL ammonia solution were introduced into the separating funnel to break down the protein. Following this, 25 mL of a diethyl ether-petroleum ether solution (1:1) was added as the extracting solvent. The funnel was shaken vigorously for 5 minutes, and two layers were formed - the upper and bottom layers. The upper layer was then poured into another flask (repeated thrice and

combined) and heated in a water bath at 100°C for a few minutes. After that, the sample was dried in an oven at 60°C until the solvent had dried [11]. The recorded value of the final dried sample was then used to calculate the percentage of total fat content using equation (1).

$$Total\ fat\ content\ (\%) = weight\ of\ residue/weight\ of\ sample\ x\ 100 \quad (1)$$

According to Sojinu et al., 2021 [11], the Kjeldahl method determined the protein content. A digestion flask combined 1.5 g of oven-dried banana peel sample, 20 mL of concentrated sulfuric acid, 1.0 g of $CuSO_4$, and 0.1 g of selenium powder. The mixture was heated until it transformed into a greenish-clear solution. After approximately 30 minutes of cooling, the digested sample was transferred into a 100 mL volumetric flask and diluted with distilled water. A boric acid indicator solution (10 mL) was placed beneath a condenser, and the tip of the condenser was submerged in the solution. The digested sample was added to the steam jacket's funnel stopcock into the chamber, followed by 20 mL of NaOH. The funnel and stopcock on the steam trap outlet were closed, allowing steam to flow through the decomposition chamber and pushing the liberated ammonia into the collection flask. After a short time, the receiving flask was lowered, positioning the condenser tip just above the liquid, which was then rinsed with distilled water. Approximately 10 mL of the distillate (ammonia borate solution) was titrated with a 0.1 M HCl solution. The recorded value of the titrate solution was then used to calculate the percentage of protein using equation (2).

$$Protein\ Content\ (\%) = Nitrogen\ content/Conversion\ factor\ x\ 100 \quad (2)$$

Where the conversion factor is equal to 6.25 [11].

For the moisture content analysis, the oven-dry method is based on SNI ISO 287: 2010 [8]. 1 g of the sample was placed in the crucible previously weighed. The sample was oven-dried at a temperature of 105°C for 4 hours. Then, the sample was reweighed after being cooled. The moisture content in the sample was calculated by the weight difference of the sample based on equation (3) [11].

$$Moisture\ content\ (g) = wet\ weight\ (before\ drying) - dry\ weight\ (after\ drying) \quad (3)$$

Ash content can be determined according to the method by Sojinu et al., 2021 [11]. 1 g of the sample was weighed and put into a pre-weighed crucible. Then, the sample was heated to 300°C in the muffle furnace for 30 minutes to pre-ash. After that, the temperature was increased to 500°C for four hours. After cooling, the crucible was weighed again, and the percentage of ash content was determined using equation (4) below.

$$\text{Ash content (\%)} = \text{Ash weight/Wet weight x 100} \quad (4)$$

For crude fibre content analysis, about 1.0 g of sample was added into 50 mL 0.25 M H_2SO_4. The mixture was heated in a water bath for an hour and filtered using a sieve. The remaining residue was transferred to another container containing 50 mL of 0.3 M NaOH and was heated in a water bath for an additional hour. The mixture was filtered again, and 5 mL of acetone was added to dissolve any leftover organic compound. Next, the residue was washed with about 25 mL of hot water and transferred to a crucible. The crucible and contents were then heated in an oven at 105°C overnight, cooled, and weighed. The crucible was ignited in a muffle furnace at 400°C for 6 hours, cooled, and weighed again. The difference in weight was recorded as the crude fibre content, and the content of crude fibre was determined using equation (5) below [11].

$$Crude\ fiber\ content\ (\%) = W_1 - W_2 / W_S\ x\ 100 \quad (5)$$

Where W_1 is the weight of the sample after oven drying, W_2 is the weight of the sample after the furnace, and W_s is the initial weight of the sample.

Kurschner's and Hanack's methods were used to determine the amount of cellulose in fibre [9]. This method relies on the fact that cellulose is insoluble in water and is resistant to dilute acids and bases. A few grams of treated *Musa Paradisiaca* peels were soaked in water for about 4 days to undergo microbial degradation. Then, the fibre was extracted from the wet peel, and the extracted fibre was washed to remove unwanted particles and let dry. After that, the fibre sample was crushed and degraded using a mixture of nitric acid and acetic acid. The resulting solution was boiled and filtered through a Büchner funnel. The insoluble residue on the filter paper was dried in an oven, and the cellulose content was measured directly. The cellulose percentage in the *Musa Paradisiaca* peel was determined using equation (6) below with slight modification [8].

$$Cellulose\ (\%) = Weight\ of\ the\ oven\text{-}dry\ cellulose\ residue/Weight\ of\ the\ original\ fibre\ x\ 100 \quad (6)$$

The samples were dried in an oven at 150°C for about 3 hours for dry matter analysis. After cooling down, they were weighed as dry weight. The percentage of dry matter was calculated using equation (7).

$$Dry\ matter\ (\%) = Dry\ weight/Fresh\ weight\ x\ 100 \quad (7)$$

2.3. Colour analysis of raw *Musa Paradisiaca* banana peel with different ripening stages

The banana peel's colour was determined using a standard colour chart. Seven indices of colour were used to classify colour changes: 1 is hard green, 2 is green with a trace of yellow, 3 is more green than yellow, 4 is more yellow than green, 5 is yellow with green traces, 6 is entirely yellow, and seven is yellow with brown speckles [10].

2.4. Total phenolic content in ripe *Musa Paradisiaca* peel

The total phenolic content was determined based on the Folin-Ciocalteu method. The phenolic compound in the ripe banana peel was extracted by soaking the banana peel powder in 80% methanol for 24 hours. Then, the extract was centrifuged to obtain a clear supernatant. Next, 0.5 mL of the sample extract was mixed with 0.5 mL of Folin-Ciocalteu reagent. 1 mL of 7.5% $NaHCO_3$ solution was added to the mixture, and the volume was adjusted to 10 mL with distilled water. The solution was vortexed for 30 seconds and left in a dark area for 35 minutes before being centrifuged at 4000rpm for 10 minutes. After that, the absorbance was measured at 760 nm using a UV-Vis spectrophotometer. The amount of TPC (mg GAE/g DM) was calculated based on the Gallic acid (0–200 μM) calibration curve (R^2 = 0.9976) [7].

2.5. ATR-FTIR analysis of *Musa Paradisiaca* peel across different ripening stages

The sugar content across different ripening stages (unripe, ripe, overripe) and other functional groups were analysed in *Musa Paradisiaca* peel via ATR-FTIR analysis. The sample was placed onto the ATR crystal of the ATR-FTIR spectrometer. The sample spectrum was examined at the wavelength between 4000 and 600 cm^{-1} with a resolution of 4 cm^{-1} [8,13].

2.6. Preparation of paper from ripe *Musa Paradisiaca* peel

Paper from the ripe banana peel of *Musa Paradisiaca* was fabricated based on the method by Alasalvar et al., 2023 [14] with few modifications. Firstly, the pulp was extracted from ripe banana peel

by alkalisation with a 4% NaOH solution in a 6:1 ratio. Next, the mixture was cooked at 100°C for 1.5 hours and filtered and cleaned with distilled water. Then, the pulp was bleached with 10% H_2O_2. 10% of tapioca starch was added to the bleached pulp. After bleaching, the pulp was placed on parchment paper and flattened into an even layer. The pulp was dried in the oven at 40-50°C for 24 hours [8].

2.7. Characterisation of ripe *Musa Paradisiaca* peel paper

The tests involved ATR-FTIR analysis and tensile instruments to determine the functional groups in paper and the mechanical properties, including Young's Modulus, tensile strength and elongation at break [14-15]. A texture analyser (TA-XT2i) equipped with tensile test grips was used to measure the paper's Tensile Strength (TS) according to the standard method D882-10. Using a scalpel, the paper was cut into rectangular specimens with 10 mm × 80 mm dimensions. The texture analyser was operated with an initial grip of 60 mm and a cross-head speed of 1.0 mm/min. Tensile strength, Young's Modulus and elongation at break were determined through this method [14]. The derived paper's physical properties, such as appearance, smell, texture, pH, and biodegradability were analysed via sensory evaluation, pH, and soil burial tests [11,16].

3. Results and discussion

3.1. Proximate analysis of raw *Musa Paradisiaca* peel across different ripening stages

The proximate compositions of the banana peel of *Musa Paradisiaca* across different ripening stages are presented in Table 1. The dry matter of the ripe peel is 13.64%, which is lower than that of the unripe peel (26.48%) and the overripe peel (23.45%). The dry matter content of a banana peel is directly related to its nutritional value since it represents the concentration of nutrients and other components that remain when water is removed. The nutritional value of peels varies based on the maturation stage, with plantain peels containing less fibre than dessert banana peels, and lignin content increases as they ripen (from 7 to 15% dry matter) [17]. Moreover, banana peels are also rich in polyunsaturated fatty acids and essential amino acids such as leucine, valine, starch, and pectin, which contain glucose, galactose, cellulose, and hemicellulose [18]. The ripe peel holds the most moisture content compared to the unripe and overripe peel. The ripe peel has a 0.8919-gram moisture content compared to the unripe and overripe peel, with 0.894 grams and 0.851 grams, respectively. Suresh Kumar et al., 2023 [19] stated that the increase in the pulp-to-peel ratio can be attributed to the accumulation of moisture in the fruit pulp due to the breakdown of complex carbohydrates into simple sugars. The rise in sugar content causes water to move from the peel to the pulp, resulting in a higher moisture content and an increased pulp-to-peel ratio. The ash content in banana peel was 4.37% for unripe, 2.16% for ripe, and 5.22% for overripe stages. Ripe peel has the least ash content as the moisture in the peel has been converted into sugar. In addition, the decrease in ash content is due to the microbial breakdown of organic matter during fermentation [20]. The crude fibre content in banana peels represents the plant material's indigestible compound, primarily cellulose, hemicellulose, and lignin. The results show that ripe peel has the highest crude fibre content (24.57%), followed by overripe peel (22.13%) and unripe peel (20.37%).. The cellulose content in the ripe peel (6.9%) was higher than that of the unripe peel (3.92%) and lower than the overripe peel (22.17%). This result might be due to the higher proportion of hemicellulose and lignin compared to cellulose in the ripe peel. Moreover, the reduction in crude fibre content was due to the microbial activity that produces cellulase enzymes in the fermentation process with cellulose enzymes [20].

The fat content in the peel was found to be higher for unripe peel (7.55%) compared to the ripe (4.79%) and overripe peel (4.88%). Anjum & Sundaram, 2022 [21] stated that the unripe banana peel has a higher fat content than ripe or overripe peel due to polyunsaturated fatty acids like linoleic and α-linolenic acid. These compounds indicate that banana peels are rich in dietary sources of fat, which can

help promote heart health [22]. The ripe peel has the highest protein content, 4.07%, while the overripe peel has the lowest, 0.82%, and the unripe peel is 1.74%. It shows that the protein content of unripe and ripe peel in *Musa Paradisiaca* is lower than that in unripe (2.53%) and ripe (3.46%) peel of *Musa Spp* [23]. The increased protein content during ripening may be due to the increased activity of protein synthesis enzymes. In contrast, the decrease in protein concentration in overripe peels could be attributed to the activity of proteases, which degrade proteins.

Table 1. Nutritional Content of the *Musa Paradisiaca* Peels Across Different Ripening Stages.

Ripening Stages	Composition in Percentage (%) or gram (g))						
	Dry matter (%)	**Ash (%)**	**Crude fiber (%)**	**Cellulose (%)**	**Fat (%)**	**Protein (%)**	**Moisture (g)**
Unripe	26.48	4.37	20.37	3.92	7.55	1.74	0.894
Ripe	13.64	2.16	24.57	6.90	4.79	4.07	0.892
Overripe	23.45	5.22	22.13	22.17	4.88	0.82	0.851

3.2. Colour analysis of raw *Musa Paradisiaca* peel across different ripening stages

Table 2. Colour Analysis of *Musa Paradisiaca* Peel Across Different Ripening Stages

Day	Ripening Stages	Color Index	Sensory Evaluation Color	Physical Appearance
1	Unripe	1	Hard green	
3	Unripe	3	More green than yellow	
7	Ripe	6	Fully yellow	
10	Overripe	7	Yellow with brown speckles	

Table 2 illustrates the results of the banana peel of *Musa Paradisiaca* colour test, showcasing the changes in the day, colour, and physical characteristics at each ripening stage. The colour of banana

peel is significantly related to banana maturity. The results show that the colour of the banana peel changed from green to brown speckles as the banana matured. On day 1, the colour of the peel was tricky green, and the banana was unripe. On day 3, the colour of the peel had a slightly yellow colour on it, but the banana was still unripe. On day 7, the banana was ripe and the colour of the peel was entirely yellow. On day 10, brown spots appeared on the yellow peel, indicating the banana was overripe. According to Ma et al., 2022 [24], the colour of banana peels changes from green to yellow as a result of chlorophyll degradation, and colour transformation is related to chlorophyll degradation caused by MaSGR, MaPAO, MaACS, and MaACO genes, which eventually leads to fruit ripening. Moreover, the brown spots on banana peels may be caused by fruit browning on the outside, which occurs due to the accumulation of free radicals during storage.

3.3. Total sugar analysis of raw *Musa Paradisiaca* peel across different ripening stages

Figure 1 displays the overlapping infrared spectroscopy of sugar content in the banana peel of *Musa Paradisiaca* across different ripening stages. Sugar has strong and distinct infrared absorption bands between 900 and 1250 cm^{-1} due to C-O-H and C-O-C bonds in carbohydrates, which mainly correspond to sucrose and fructose absorption [25]. Figure 2 shows the area from 1040 to 930 cm^{-1} that is attributed to the strengthening of stretching vibrations of C–O in the C–OH group and stretching of C–C in the carbohydrate structure. The area below 930 cm^{-1} is the vibration area, characteristic of vibrations from the anomeric region of carbohydrates or deformation vibrations of C–H and C. According to Sinanoglou et al., 2023 [26], starch slowly breaks down during the banana's ripening process, which causes soluble carbohydrates like fructose and sucrose to accumulate until they become undetectable. Thus, soluble sugar is not found in the ripe and overripe stages. The rise in total sugar could be attributed to increased enzyme activity, as explained by Zhu et al., 2021 [27]. Findings indicate that enzymatic hydrolysis mediates the starch-sugar transition during banana ripening. During the overripe stage, the power of starch hydrolysis may have decreased, resulting in a decline in total sugar. Therefore, as shown in Figure 2, we can conclude that the blue-dotted region, which refers to ripe and overripe peels, exhibited lower intensity than unripe peels.

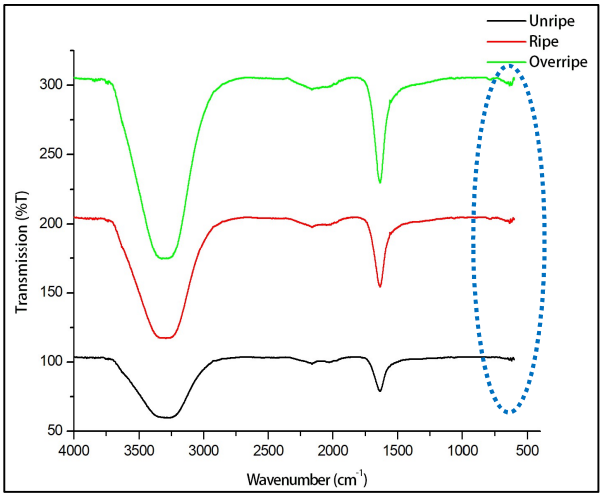

Figure 1. FTIR spectra of *Musa Paradisiaca* peel across different ripening stages

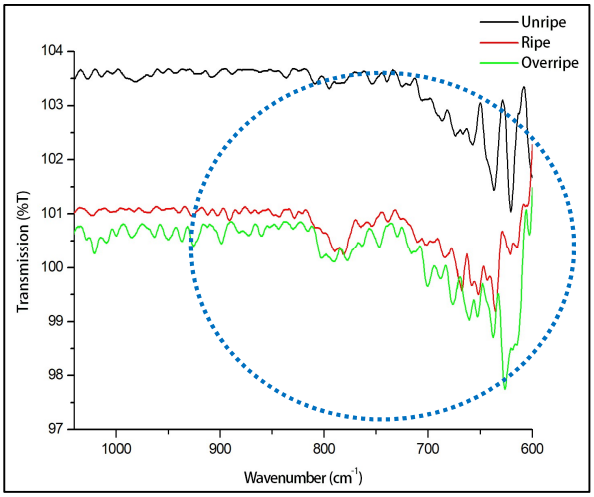

Figure 2. FTIR spectra of *Musa Paradisiaca* peel at wavelength region 600-1040 cm^{-1}

3.4. Total phenolic compound of Raw *Musa paradisiaca* peel

Phenolics are potent antioxidative compounds that positively affect human health by guarding against degenerative diseases. The banana peel is abundant in natural bioactive and antioxidative compounds, which help fight oxidative stress caused by free radical chain reactions [7]. Methanol was used to extract the phenolic in banana peel as it is a polar solvent, which makes it practical for extracting phenolic compounds. Moreover, methanol is often more efficient in extracting lower molecular-weight polyphenols [28]. Previous studies by Toupal & Coşansu, 2023 [29], showed that the methanolic extract of banana peel powder had the highest ($P < 0.05$) phenolic content (49.21 ± 2.93 mg GAE/g DW) compared to other extracting solvents such as acetone and ethanol with the total phenolic content of 10.71 ± 0.17 and 5.85 ± 0.30 mg GAE/g DW, respectively. The total phenol content compound was determined in the banana peel of *Musa Paradisiaca* by the Folin-Ciocalteu method. The Folin-Ciocalteu method involves the oxidation of hydroxyl phenolic groups, resulting in a blue complex that can be detected using a spectrophotometer. The intensity of the blue colour corresponds to the concentration of phenolic compounds present [30]. Figure 3 shows the linear equation obtained from this method, $y = 0.0051x + 0.0018$, with $R^2 = 0.9993$ approaching linearity where $R^2 = 1$. The total phenol of the peel can be calculated with the resulting sample absorbance value of 0.305. This value indicates that the banana peel of *Musa Paradisiaca* contains a total phenolic content of 7.93 mg GAE/g of powder. According to Vu et al., 2018 [31], the total phenolic content in banana peel ranges from 4.95 to 47 mg gallic acid equivalent/g dry matter (mg GAE/gm). Thus, the banana peel of *Musa Paradisiaca* is rich in dietary fibre and phenolic compounds with high antioxidant and antimicrobial activities.

3.5. Sensory evaluation of derived paper from ripe peel of *Musa Paradisiaca*

Figure 4 shows paper made from the ripe banana peel of *Musa Paradisiaca*. From the figure, it can be seen that the paper is in pale yellow. The colours indicate that the banana peel's natural pigmentation has been retained during papermaking. This phenomenon is positive because it emphasises the natural origin of the material and reduces the need for additional dyes or bleaches, which can be harmful to the environment compared to natural dyes that are environmentally friendly, biodegradable, and non-toxic. Moreover, some natural dyes are anti-allergic and safe for body contact [32].

Furthermore, the pale yellow hue gives the paper a unique aesthetic, making it potentially appealing for speciality applications. Next, the paper shows flexibility and can be torn off. The slight flexibility of the paper indicates that the fibres obtained from banana peels possess moderate strength and adhesive properties. According to Karimah et al.,2021 [33], natural fibres possess low density and a high strength-to-weight ratio, making them ideal for lightweight composite and reinforcement materials. Moreover, the mechanical properties of these fibres are influenced by their microstructure and chemical composition, with the cross-sectional area of the fibres being a significant factor affecting their strength. The smell of the paper is neutral and does not have a strong odour or scent. The neutral smell of the paper is a favourable characteristic, indicating no strong or unpleasant odours associated with the banana peel fibres. Due to its odourless nature, the paper can be used in various applications, such as food packaging or stationery goods, where smell sensitivity might be a concern. Thus, the banana peel has potential industrial applications in sanitary pads, textiles, pulp and paper, food, and reinforced composite materials [34]. Lastly, the texture of the paper is rough compared to regular paper. The rough texture of the paper suggests that the fibres from banana peels are rougher than those found in regular paper. This roughness is due to the natural structure of banana peel fibres and the processing method used. Banana fibre, obtained from the banana plant's pseudo-stem, provides a sustainable, biodegradable, and lightweight alternative to synthetic fibres for various industrial uses [34].

3.6. pH analysis derived paper from *Musa Paradisiaca* ripe peel

The obtained paper's pH is 7.08, which is close to neutral. This near-neutral pH indicates that the paper is neither too acidic nor too alkaline, making it suitable for various uses without the risk of damaging sensitive materials or reacting with other substances.

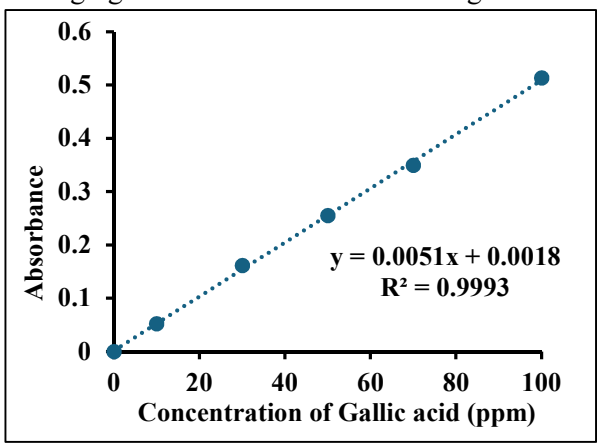

Figure 3. Calibration curve of gallic acid in ripe *Musa Paradisiaca* peel

Figure 4. Paper made from the ripe peel of *Musa Paradisiaca*

3.7. FTIR analysis of derived paper and comparison to raw ripe peel of *Musa Paradisiaca*

The ATR-FTIR spectra bands of paper derived from ripe peels of *Musa Paradisiaca* were acquired at a spectral range of 4000-600 cm^{-1} (Figure 5). Each spectrum showed absorption bands corresponding to starch, sugars, water, organic acids, and phenols. The FTIR spectra of paper derived from banana peel and raw banana peel overlap significantly, demonstrating that essential functional groups are retained during the papermaking process. Both spectra show peaks of about 3200-3400 cm^{-1} due to O-H stretching, indicating the presence of hydroxyl groups in cellulose and water. The O-H stretching of the derived paper and the raw peak were found at 3311.98 cm^{-1} and 3306.04 cm^{-1}, respectively. The peaks in the region of 2850-3000 cm^{-1} were attributed to the C-H stretching vibration from -CH_2 alkane groups for derived paper (2906 cm^{-1}) and raw ripe peel (2936.09 cm^{-1}), respectively [15]. A peak at 2160.19 cm^{-1} in the FTIR spectrum of the derived paper indicates C≡C stretching from the alkyne group. However, this peak is invisible for raw, ripe peel. The absence of this peak in raw peel suggests that these groups were not present at first but may have formed due to chemical processes, possibly caused by heat or other processing conditions. Therefore, we can conclude that the alkyne group was formed during paper production. The C=C stretching can be detected at 1640 cm^{-1} and 1595.3 cm^{-1} peaks of the derived paper and the raw peel, respectively. This peak indicates the presence of alkenes, which may come from unsaturated fatty acids or other compounds in the banana peel. This peak is associated with amines and amides, which may be present in proteins or other nitrogen-containing compounds in banana peel. The N-H bending vibration in FTIR spectra appears at 1337 cm^{-1} (derived paper) and 1404.81 cm^{-1} (raw ripe peel). This peak corresponds with amines and amides, which may be present in banana peel proteins or other nitrogen-containing compounds [15]. At a range between 1000-1300 cm^{-1}, the C-O stretching peaks of derived paper and raw peel were found at 1005 cm^{-1} and 1027.47 cm^{-1}, respectively. These peaks were attributed to the group of esters found in polysaccharides such as cellulose and hemicellulose. In banana peel and its derived paper, these peaks indicate the presence of carbohydrates that contribute to the material's structural integrity and nutritional properties.

3.8. Biodegradability of derived paper by soil burial analysis

Biodegradability refers to the ability of a material to be degraded by microbes and natural processes into simpler compounds while integrating into the environment. In this research, a 2 cm x 2 cm paper made from the banana peel was buried in the soil for 10 days, and 2 mL of water was sprinkled on top of the soil every 2 days to keep the soil's moisture [35]. After 10 days, the paper was reweighed to calculate the weight loss, which was 36.90% (Figure 6). The observed weight loss of 36.9% over the 10-day timeframe indicates that the derived paper from the ripe peel of *Musa Paradisiaca* exhibited rapid biodegradability behaviour. This result highlights its ability to quickly degrade into organic matter, indicating its potential for long-term waste management strategies. Moreover, the composition, thickness, and exposure to soil bacteria of the paper probably influenced this degradation rate, accelerating the breakdown process [36]. The weight loss after 10 days can be attributed to the action of microbes and enzymes and soil water's solubilisation of soluble paper components [36].

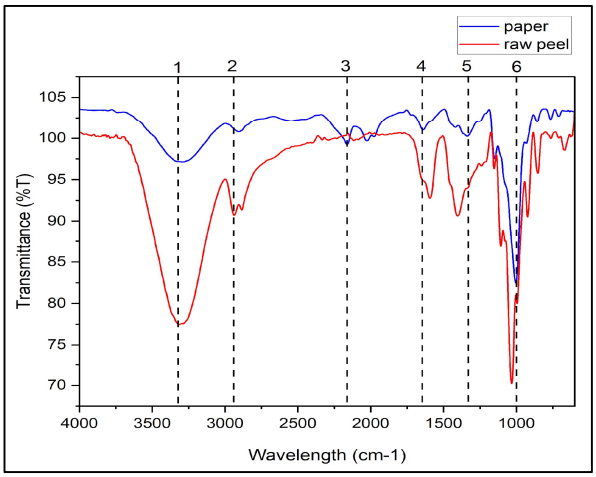

Figure 5. Characteristics peaks of derived paper and raw ripe peel of *Musa Paradisiaca*

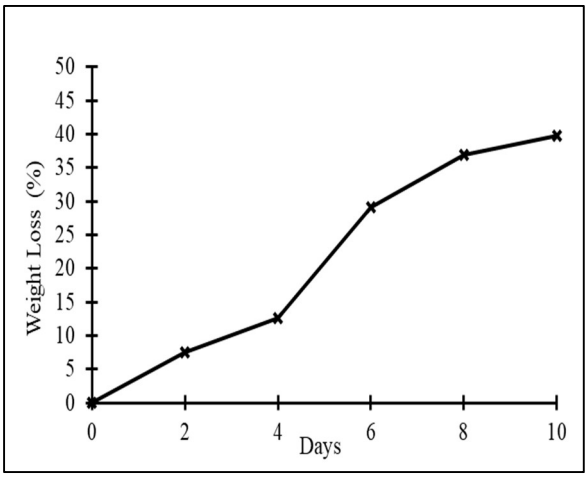

Figure 6. Percentage weight loss of derived paper from the ripe peel of *Musa Paradisiaca* in 10 days

4. Conclusion

In conclusion, the nutritional content in *Musa Paradisiaca* peel across different ripening stages has been successfully characterised. Moreover, the total phenolic compound, which is Gallic Acid content, was measured at 7.93 mg GAE/g, indicating significant antioxidant properties existed in the ripe peel of *Musa Paradisiaca.* Colour analysis also confirmed that as the banana ripens, the colour changes from green to yellow with brown speckles. These colour changes categorised the ripening stages of the peels as unripe, ripe, and overripe. The colour changes indicate that the nutritional content of banana peel varies depending on the maturity stages. The paper made from banana peel displayed a pale-yellow colour due to the pigment of the banana peel. The paper has a rough texture compared to regular paper. ATR-FTIR analysis confirmed the presence of functional groups that contribute to the ripening stages of the peel and paper's structural integrity.

Additionally, the tensile strength of the paper exhibited moderate tensile strength and rigidity. Moreover, soil burial analysis revealed that the weight loss of paper was 36.9% after 10 days, which indicated that the derived paper from the ripe peel of *Musa Paradisiaca* rapidly biodegraded naturally in the soil. Furthermore, this research can be improved by increasing the sample size and incorporating different species of bananas, which would enhance the dependability and applicability of the findings.

Next, refining the methods for extracting and processing banana peel fibres in the production of paper would enhance the quality and usability of the paper, thus increasing its commercial feasibility.

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Conflict of interest

We declare no conflict regarding the publication of the study.

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