JOURNAL OF FOOD AND BIOTECHNOLOGY

Original Research Article ISSN 3041- 6299 Open Access

Characterization of Cellulose and Assessment of Plant Extracts for Antioxidant–Based Edible Film

Odeyemi, T. A., Owuamanam, C. I., Ofoedum, A. F.*, Ugwoezuonu, J. N., Elemuo, G. K., Iroagba, L. N., Okezie, F. P., and Eze, O. J.

Department of Food Science and Technology, School of Engineering and Engineering Technology, Federal University of Technology, Owerri, Imo State, Nigeria

Corresponding author: **Ofoedum, Arinze Francis** | E-mail: **ofoedum.arizona.edu@gmail.com**

Citation: Odeyemi, T. A., Owuamanam, C. I., Ofoedum, A. F., Ugwoezuonu, J. N., Elemuo, G. K., Iroagba, L. N. , Okezie, F. P., and Eze, O. J. (2026). Characterization of Cellulose and Assessment of Plant Extracts for Antioxidant-Based Edible Film. *Journal of Food and Biotechnology.* **48 to 57.**
DOI: https://doi.org/10.51470/FAB.2026.7.1.34

15 January 2026: Received | 11 February 2026: Revised | 07 March 2026: Accepted | 03 April 2026: Available Online

Abstract

This study aimed to characterize cellulose extracted from banana peels and pineapple crown leaves and assess the antioxidant properties of selected plant extracts (gingerol, garlic oil, and avocado oil) as promising raw materials for edible film production. The Banana peels and Pineapple crown leaves were washed, oven-dried, and pulverized to obtain powder samples, BPP and PCP. Cellulose was extracted from BPP and PCP following a series of steps: dewaxing with 70% ethanol, alkali treatment with 5% NaOH, and finally bleaching with 30% hydrogen peroxide to obtain banana peel cellulose (BPC) and pineapple crown leaves cellulose (PCC). Plant extracts, gingerol, garlic oil, and avocado oil, were also extracted from their respective plant sources using bulk cold pressing and solvent extraction, and were named GRA, GOA, and AOA, respectively. The cellulose samples (BPC, PCC, and CCC) were characterized using FT-IR and SEM, and the physicochemical properties (pH, moisture content, swelling power, and solubility) of the cellulose samples were determined using standard methods. BPC and PCC had yields of 8.10% and 12.60%, respectively, while GRA, GOA, and AOA had yields of 8.2%, 6.4%, 10.1% respectively. The mean values for pH of BPC, PCC, and CCC were 6.53, 6.44, and 6.68respectively. The mean values of moisture of PCC, BPC, and CCC were 8.50, 6.50, and 7.50 respectively. The mean values of swelling power of PCC, BPC, and CCC were 3.60, 3.90, and 3.90, respectively. BPC and PCC were not soluble in any solvent, while CCC was only soluble in deionized water. The antioxidant properties analysis revealed highly significant antioxidant activity of GRA (78.75) in DPPH assay, GOA (50.60^a) in ABTS assay, and AOA (22.72^a) in FRAP assay. The characterization of BPC, PCC, and CCC evaluated using FT-IR revealed that most lignin and hemicellulose were successfully removed at (≈ 1730 cm^{-1}), and SEM revealed the surface morphology of the cellulose samples. This proves that the cellulose samples and the plant extracts are promising raw materials for film production.

Keywords: *plant extracts, cellulose, antioxidant activity, physiochemical properties, characterization, agricultural wastes, edible films.*

Introduction

There has been a growing global concern regarding the environmental impact of traditional packaging materials, such as plastics, which are non-biodegradable and contribute to pollution and waste accumulation [28]. The research and application of sustainable packaging materials have significantly changed as a result of this issue. Edible films and plant-based materials have become attractive substitutes among the several kinds of sustainable packaging materials.

Edible films have attracted more interest as it has the potential to overcome the problems associated with plastic packaging [24]. It serves as a barrier against mass transfer (of vapour, water, gas, solutes), aiming to improve the handling of the food product and to extend its shelf life [5]. They are derived from various food-grade biopolymers, including protein (like gelatin, casein, and gluten), polysaccharides (like starch, cellulose, and pectin), and lipids (like waxes). According to [27]. the permeability and the mechanical properties of edible films are not on par with conventionally used synthetic plastic films. But it is no news that a combination of the insignificant materials, such as plasticizers, emulsifiers, vigorous ingredients, specifically antimicrobial and antioxidants, can be employed to enhance the efficacy [6]. Cellulose-based edible films are renewable, natural, and biodegradable. The primary structural element of plant cell walls is cellulose, a complex carbohydrate. Found in plants, algae, and certain bacteria, it is the most prevalent organic substance on the planet. Microfibrils, which are lengthy structures made up of both crystalline and amorphous components, are produced by cellulose in its native state. Because cellulose has several hydroxyl groups throughout its chemical chains, it is known to interact well with water. In water, cellulosic materials expand and scatter.

However, [8] supported [44] on their views that water acts as an antisolvent, and much better dissolution is obtained in its absence to dissolve (highly crystalline) celluloses. Cellulose used for edible films can be in the form of Microcrystalline Cellulose, Carboxymethyl Cellulose, Hydroxypropyl Cellulose, Hydroxypropyl

Methyl Cellulose, or Hydroxyethyl Cellulose. Cellulose can be obtained from various lignocellulose biomass sources, such as wood and non-wood lignocellulose biomass, agricultural wastes, and municipal/industrial lignocellulose waste [29]. The extraction of cellulose from agricultural waste such as pineapple crown leaves and banana peels represents an innovative approach to waste management and resource utilization.

Globally, over 100 billion bananas (*Musa acuminata*) are consumed annually, making it a popular fruit, with countries like India, China, and Indonesia leading in consumption. According to [1], views which were supported by [2] lots of production and consumption of bananas comes with a lot of waste production, comprising 30-40% of total weight, resulting in approximately 3.5 million tons of banana peel (BP) waste per year. Additionally, the pineapple (Ananas comosus), a fruit that is widely consumed worldwide, produces 3 billion tons of by-products annually, including pineapple crown leaves, which have led to environmental contamination and issues with agricultural land.

Ibrahim *et al*. view on banana peel, on a dry basis, contains about 7.6-9.6% cellulose, 10-21% pectin, 6.4-9.4% hemicellulose, 6-12% lignin, and some low molecular compounds on dry basis, which was supported by [50] Studies also show that pineapple crown leaves (PCL) are made up of 79-83% cellulose, 19% hemicellulose, and 5-15% lignin [4]. The cellulose content of these agricultural wastes makes them useful in edible film production.

In addition to cellulose, incorporating natural plant extracts into edible films has gained attention for their potential health benefits. The incorporation of antioxidants from plant-based extracts in edible films enhances the functionality of the film. The presence of high concentrations of phenolic compounds is responsible for the strong antioxidant activity of plant-origin active substances channelized into films, which are also reported to have modified physiochemical, mechanical and barrier properties [9]. Gingerol, garlic oil, and avocado oil are notable examples of plant extracts recognized for their antioxidant properties, and when incorporated in edible films, increase the shelf life by reducing oxidative rancidity due to their strong antioxidant properties. This synergistic approach of combining cellulose with natural extracts can lead to the development of active packaging systems that not only preserve food but also contribute to consumer health [47] [49] and [50].

The increasing environmental concerns associated with synthetic plastic packaging have led to a growing interest in developing biodegradable and sustainable alternatives for food packaging applications. The use of agro-food waste and by-products to develop sustainable packaging materials is an approach that can be used as a solution for mitigating the negative impacts and concerns caused by packaging waste [3]. Agricultural wastes such as pineapple crowns leaves and banana peels are rich in cellulose, which can be valorized into eco-friendly materials like edible films. However, cellulose obtained from different plant sources often varies in yield, purity, crystallinity, and mechanical properties, depending on the extraction and purification methods employed [18]. These variations directly influence the functionality and performance of the final film, including its strength, transparency, and barrier properties [29].

Moreover, the incorporation of plant extracts containing natural antioxidants into cellulose-based edible films is a promising method to prevent or reduce the deterioration of food quality, thus contributing to preserving and extending the shelf life of food [37][48]. Despite this potential, there is limited research that characterizes cellulose derived specifically from pineapple crowns and banana peels and evaluates their compatibility with plant extracts for antioxidant edible film production. This knowledge gap hinders the optimization and practical application of such biopolymers in the food packaging industry.

Therefore, there is a need to extract and characterize cellulose from pineapple crowns and banana peels, and to assess the incorporation of antioxidant-rich plant extracts in the production of edible films, to determine their suitability and effectiveness as sustainable food packaging materials.

The main objective of this study is to characterize cellulose extracted from banana peels and pineapple crown leaves and assess the antioxidant properties of selected plant extracts (gingerol, garlic oil, and avocado oil) for edible film production. The specific objectives of this study include: to extract cellulose from banana peels and pineapple crown leaves. to determine the physiochemical properties of the extracted cellulose (Swelling power, pH, solubility, moisture content), to characterize the extracted cellulose using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM), to carry out selected plant extracts extraction, to evaluate the antioxidant activities of the plant extracts using assays such as DPPH, FRAP, ABTS.

The increasing demand of waste management and food safety led to the introduction of biodegradable and edible packaging materials in the food industry. Conventional plastic used as a packaging material poses a major environmental concern as they are not biodegradable. This study focuses on the use of banana peels and pineapple crown leaves to create cellulose edible film and enrich them with antioxidants derived from plant-based extracts such as ginger garlic oil and avocado oil.

Banana peels and pineapple crown leaves are often discarded so they do not pose a risk to the security of the fruit itself. The by-products are rich in bioactive compounds, and by utilizing these by-products, we can contribute to waste reduction while simultaneously harnessing its potential for edible film formation. The characterization of cellulose extracted from banana peels and pineapple crowns is essential for understanding its potential applications in food packaging. Enriching the edible films obtained from banana peel and pineapple crown cellulose with antioxidants from garlic oil, gingerol, and avocado oil not only enhances their functional property but also provides health benefits to the consumer. This research addresses the possible innovative approach to food preservation, providing a benefit of food quality while promoting sustainable practices. This research is justified by its potential to create eco-friendly packaging solutions and enhance food safety and nutritional value. It supports the growing demand for healthier, biodegradable packaging materials.

MATERIALS AND METHOD

Materials

Sources of materials

The materials needed for this research work were locally sourced. Bananas, pineapple crown leaves, cellulose, gingers, garlic cloves, and avocados were gotten from Relieve market.

Equipment and Chemical reagents

The equipment such as oven, magnetic stirrer, weighing scale, aluminum foil, water bath, whatman filter paper, pH meter, hot plate, glass rod, beakers, volumetric flasks, round bottom flasks, measuring cylinder and other glass wares were gotten from the department of Food Science and Technology and Industrial Chemistry department, FUTO./ Duration of Research: The study was carried out at D. The chemical and reagents used were of analytical grade. 70% ethanol, 95% ethanol, 5% w/v Sodium hydroxide (NaOH), 30% Hydrogen peroxide were used.

Sample preparation

Cellulose was extracted from banana peels and pineapple crown leaves following series of steps starting from the preparation of banana peel powder and pineapple crown leaves powder to the extraction of cellulose itself.

Banana Peel Powder (BPP) and Pineapple Crown Leaves Powder (PCP) Preparation

With minor adjustments, this was carried out in accordance with [11]. After properly cleaning the banana peels and pineapple crown leaves under running water, they were soaked in distilled water for an hour to get rid of any debris or dust that might have stuck to their surfaces. Following a tissue paper wipe, the peels and crown leaves were dried for ten hours at 60°C in an oven. A knife mill was used to grind the dried peels and crown leaves once they had cooled to room temperature. Large particles were removed from the BPP and PCP by passing them through a 200µm screen. Weighing and storing BPP and PCP allowed for additional extraction.

Extraction of Banana Peel Cellulose (BPC) and Pineapple Crown Leaves Cellulose (PCC)

The samples, BPP and PCP, were first dewaxed according to [12]. 220g of BPP and 235g of PCP were macerated in 440ml and 470ml of 70% ethanol for 3 days respectively. The samples were put in water bath at 60°C for 40 minutes and washed with distilled water 3 times. After neutral pH of 7 was obtained, the samples were filtered using whatman filter paper to obtain insoluble residue. The insoluble residue of both samples were then left to dry overnight.

The dewaxed BPP and PCP were then be subjected to alkali treatment according to [10] with little modification.

Alkali Treatment

The BPP and PCP were treated with, 5% w/v Sodium hydroxide, NaOH, at 950ml for 220g and 1640ml of 235g respectively for removing lignin and hemicellulose. The solutions were kept for stirring at 60°C for 4 h in the water bath. The solutions were filtered and the filter cakes (remaining solid) were washed several times with distilled water until neutral pH was reached. The solids obtained were then kept for drying in the oven overnight at 40°C.

Bleaching Treatment

This was done according to [7] with little modification. Following alkali treatment, the first bleaching process was performed by using 600ml of 30% (w/v) hydrogen peroxide solution each for both BPC and PCC for 12h at 25°C. The solutions were filtered and the solids obtained were washed several times with distilled water until neutral pH has reached. The obtained solids were then bleached the second time using 500ml of 30% hydrogen peroxide each for both BPC and PCC at 55°C for 3h. The solutions were filtered and the solids obtained were washed several times with distilled water until neutral pH was obtained. The obtained bleached BPC and PCC were kept for drying in the oven overnight at 40°C.

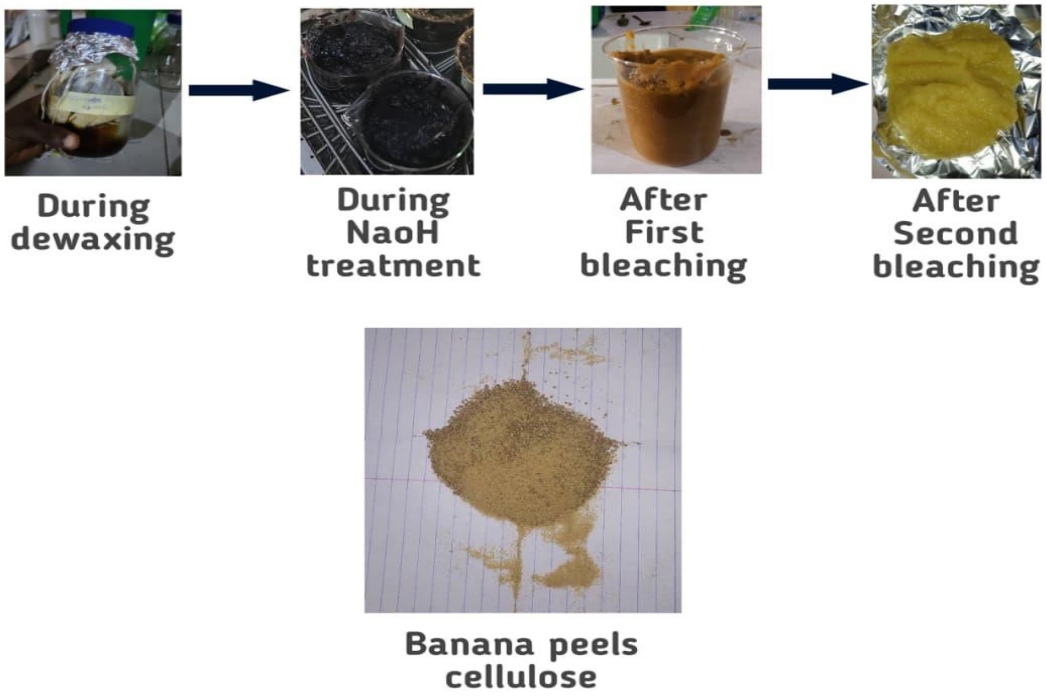


Plate 1: Extraction Process of Banana Peel Cellulose (BPC)

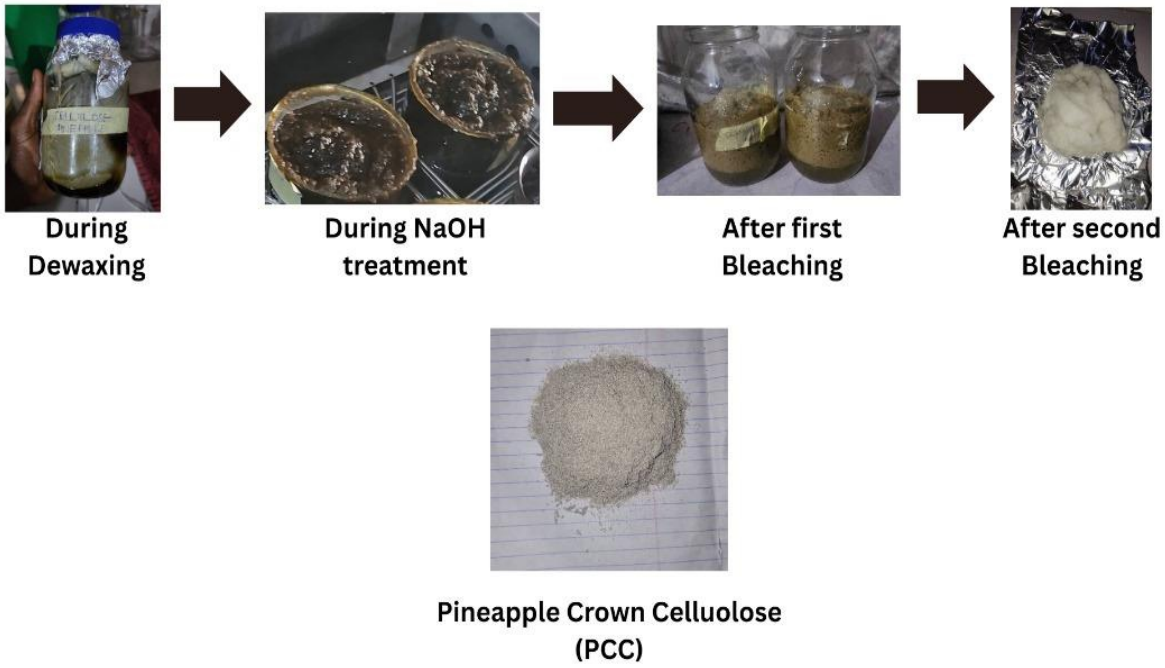


Plate 2: Extraction Process of Pineapple Crown leaves Cellulose (PCC)

Extraction of Gingerol, Ginger Oil, and Avocado Oil

Gingerol extraction using the Bulk Cold Pressing method

The extraction of gingerol was carried out using bulk cold pressing and solvent-assisted maceration. Gingerol was extracted with 95% food-grade ethanol [29]. 1000ml of 95% ethanol was used in the extraction of 1250g of mashed fresh ginger. After 24hrs the ethanol was then evaporated to obtain the extract. The obtained gingerol was stored in an airtight amber bottle.

Garlic oil extraction using the Bulk Cold Pressing method

The extraction of garlic oil was carried out according to [14] and [17]. Fresh garlic cloves were peeled, crushed, and blended. A portion of 1000 g was wrapped in a muslin cloth and soaked in 567ml of 95% food-grade ethanol for 24 hours. The ethanol was then evaporated to obtain the extract. The obtained garlic oil was stored in an airtight amber bottle.

Avocado oil extraction using the Solvent Extraction method

This was done according to [16] with little modifications. Avocado oil was extracted using hexane as the solvent. Ripe avocado pulp was scooped and air-dried for a few minutes to reduce excess surface moisture. A portion of 20 g of the dried pulp was tied in a muslin cloth and soaked in 100ml of hexane. The sample was allowed to stand for 48 hours, after which the muslin cloth was pressed to recover the solvent-oil mixture. The filtrate was concentrated using a magnetic stirrer at 60 °C and finally heated in a water bath until complete solvent evaporation. The obtained avocado oil was stored in airtight amber bottles.

Plate 3: Ginger extract

Plate 4: Garlic extract

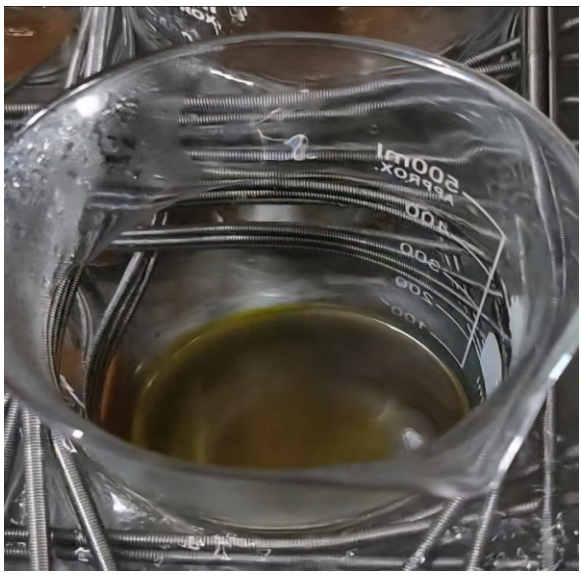


Plate 5: Avocado extract

Analysis conducted

Physiochemical properties of cellulose (BPC, PCC and CCC)

The various cellulose samples were analyzed for its physiochemical properties

Moisture content

The moisture content of the cellulose was measured using standard hot air oven drying method [21] with little modifications. 10g weight of the sample was placed in a clean crucible and weighed. The sample was then dried in an oven at 105 °C for a specified duration of 3 hours to evaporate moisture. After drying, the sample was cooled in a desiccator to prevent moisture absorption and weighed again. The moisture content was calculated as the percentage weight loss relative to the initial sample weight, using the formula: Moisture Content (%) = ((Initial weight - Dry weight) / Initial weight) × 100.

pH Determination

A pH meter was used to perform the test. One gram of the cellulose sample was dissolved in ten milliliters of distilled water in order to do the measurement. The electrodes of the pH meter were placed into the solution, and the pH value was measured afterward [20].

Solubility

The cellulose samples were analyzed further to explore their solubility in different solvents. The following solvent were used; deionized water, acetonitrile, acetone, ethanol, and methanol. 1 g of cellulose sample was added in falcon tube and 10 ml of the respective solvent was added in it and sonicated for 15 min. Solubility of cellulose was visually observed [41].

Swelling power

1g of the sample was transferred into a weighed graduated 50 ml centrifuge tube. Distilled water was added to give a total volume of 40 ml. The suspension was stirred uniformly with a stirrer, avoiding excessive speed, so as not to cause fragmentation of the cellulose. The sample was heated at 85°C in a thermostatically regulated temperature bath for 30 min with constant stirring. The tube was removed, wiped dry on the outside and cooled to room temperature. It was then centrifuged for 15 min at 560 rpm [13]. The swelling power was then determined by measuring the volume of the swollen gel after it has settled and then calculated as the ratio of the swollen gel's volume to the initial dry weight of the sample.

Cellulose (BPC, PCC, CCC) Characterization

Fourier Transform Infrared Spectroscopy (FT-IR)

This was carried out according to [14] with some modifications. The FTIR spectra of the cellulose samples were recorded on a Fourier Transform Infrared Spectrometer Shimadzu Prestige 21. The samples were blended with KBr powder and then pressed into thin pellets. The samples were measured in the wavelength range from 4000 cm-1 to 450 cm-1 at a resolution of 4cm–1.

Scanning Electron Microscopy (SEM)

The surface morphologies of the samples were determined using Scanning Electron Microscope (JOEL JSM 610 LA model) at different magnifications. The differences in morphologies were obtained [21].

Antioxidants test

The plant extracts were subjected to antioxidant test. This was used to know the antioxidants potential of the plant extracts.

DPPH Test

This assay was done according to [25]. A measured portion of the extracts was mixed with 3 ml of distilled water each, and then 2.8 ml of the extract solution was mixed with 0.2 ml of 1mM methanolic solution of DPPH. The mixture was shaken and maintained at room temperature in the dark for 30 min. After measuring the absorbance at 517 nm wavelength, the percentage of DPPH radical scavenging activity was calculated as follows:

DPPH scavenging effect (%) = Abs DPPH – Abs plant extract / Abs DPPH x 100.

FRAP Test

According to [25], the FRAP reagent was first prepared by mixing 1 part of 10 mmol/L 2, 4, 6-tri (2-pyridyl)-s-triazine, 10 parts of 300 mmol/L sodium acetate buffer (pH 3.6), and 1 part of 20 mmol/L ferric chloride. Then, 1.5 mL of FRAP reagent was added to 50 µL of the sample, incubated at room temperature for 4 min, and measured at 593 nm using a spectrophotometer.

The plant extracts were measurement and each were mixed with 10 mL of ethanol for about 30 minutes. Finally, the solution was filtered to obtain a clear extract for the FRAP assay.

ABTS Test

According to [22], 2.6 mM ABTS solution was mixed with 2.6 mM potassium persulfate. This mixture was stored in a dark place at room temperature for 16 h before use. The mixture was then diluted with methanol to achieve an absorbance of 0.7 ± 0.02 at 734 nm. Subsequently, 2 mL of the ABTS solution was combined with 1 mL of various samples. The ABTS solution and samples were mixed and kept in the dark at room temperature for 2 h. The absorbance of the mixtures was then measured with a spectrophotometer at absorbance of 734 nm.

Finally, an inhibition versus concentration graph was plotted and analyzed. The percentage inhibition was calculated using the following equation:
Inhibition (%) = (Ac−As)/Ac x 100
Where, Ac is the absorbance of the standard solution and as is the absorbance of the extract sample

RESULTS AND DISCUSSION

Physical Appearance of BPC and PCC

The dewaxing process and chemical treatment given to BPP and PCP was for the purpose of extracting cellulose from BPP and PCP. These treatments had an effect on the colour and texture of both BPC and PCP. The initial colour of the BPP was dark brown even after the dewaxing and alkali treatment with 70% ethanol and 5% NaOH, respectively, while that of PCP was dirty green and olive green after alkali treatment with 5% NaOH. BPC and PCC underwent a discolouration from a light brown colour during the first bleaching to a light yellowish brown during the second bleaching and a very light brown colour to white, respectively. The change in colour of the samples in each step of the extraction was due to the leaching out of the lignin, tannin, pectin, starch, hemicellulose and other non-cellulosic components [19]. The yellowish brown colour of BPC obtained is in contrast to the results of [23] *who* obtained a light yellowish brown colour after the first bleaching and a pure white colour after the second bleaching. This may be due to the mechanical treatment carried out and the use of sodium hypochlorite (NaOCl) in his study. The obtained white colour of PCP bears similarity to the colour obtained in [29].

The resulting cellulose samples were found to be crystalline in nature, which is consistent with the inherent structure of cellulose derived from plant sources. One of the significant findings was the inability of the extracted cellulose to dissolve in water. This result can be attributed to its crystalline structure, which is characteristic of cellulose. The crystalline regions hinder the accessibility of water molecules, preventing dissolution. This behavior aligns with observations reported by other researchers in the field.

Extraction yield of BPC and PCC

BPC yield

The powdered sample, BPC, in this study weighed 220g before to extraction (W_1) and 17.81g following oven drying (W_2). 8.10g was the computed percentage of extracted yield. With the exception of the addition of mechanical treatment and the acid hydrolysis treatment method for cellulose extraction, [41], reported an extraction yield of BPC of 22.49%. [29] reported an 8.9% yield in a different research. The maturity stage of the banana peel used may have an impact on the amount of cellulose removed as well as other non-cellulose components, including pectin, hemicellulose, and lignin, which could explain the variation in extraction yield between the two studies and this one.

Both ripe and unripe banana peels were used in this investigation. Because the cellulose concentration of ripe and unripe peels differs, this combination had an impact on the cellulose production. The drying process also affected the cellulose yield since variations in the drying oven's temperature may have caused cellulose to degrade.

PCC yield

The powdered material, PCC, in this study weighed 235g prior to extraction (W_1) and 29.52g following oven drying (W_2). 12.6g was the computed percentage of extracted yield. The BPC extraction yield obtained is different from the 45% reported by [30] who employed nearly identical techniques with the exception of adding mechanical treatment. This may be explained by the kind of raw material, the location, the sample preparation, and the analysis technique [14].

Extraction yield of plant extracts

The extraction of gingerol, garlic oil, and avocado oil was successfully carried out using Bulk cold pressing and solvent-assisted methods. The yield obtained in this study was compared with values reported in authentic literature. The yield obtained in this study falls within the reported ranges in some literature. Gingerol had a yield of 8.2%, which is consistent with [38], who reported 7–9%. Garlic oil had a yield of 6.4%, which also aligns with [11] (5–7%). Avocado oil yielded 10.1%, comparable to Jhoseline and Luz (2020), who observed 9–12%. These similarities suggest that the extraction techniques used in this study are reliable and reproducible.

Physiochemical Properties

The results of the physiochemical analysis of the cellulose samples in Table 4.1 showed a significant difference ($p<0.05$) in the physiochemical properties of the samples tested.

pH

The results indicate that there were no significant differences in pH among the pineapple crown leaves cellulose (6.44), banana peel cellulose (6.53), and control cellulose (6.53) samples, as the differences between the means were less than the LSD value of 0.24. The pH values are slightly acidic to near neutral, suggesting that the source of cellulose has minimal impact on the resulting pH of the films. [31] reported similar pH results for cellulose gotten from rice husks, which ranged from 6.83 to 6.94, indicating a close-to-neutral pH.

Moisture content (%)

Significant differences in moisture content were observed between pineapple crown leaves cellulose (8.50%) and banana peel cellulose (6.50%), with pineapple crown cellulose being more significant than Banana cellulose, exceeding the LSD of 1.66. The control cellulose (7.50%) showed no significant difference from either. This suggests that the source of cellulose does influence moisture content, which is critical for the functionality of edible films. Moisture content varies significantly based on the structural characteristics of cellulose, which can be affected by the plant species and part of the plant used. The moisture content indicates that cellulose fibers are well-known for their hydrophilic properties, allowing them to absorb water from the environment. The moisture content of fibers varies between 5 and 10%. The moisture content of the cellulose samples obtained falls within this variation range. However, a study using molecular dynamics simulations found that the mechanical properties of cellulose are best when the moisture content is around 4% [7].

Swelling Power

Swelling power reveals information about the structural properties of cellulose by reflecting its capacity to absorb water and expand. Since the discrepancies between the means were less than the LSD value of 1.05, the results show that there were no significant differences in swelling power between the cellulose samples made from pineapple crown leaves (3.60), banana peels (3.90), and control cellulose (3.90). Crystallinity and the existence of amorphous patches are two elements that affect cellulose's swelling [23]. Because of the denser molecular packing that prevents water penetration, higher crystallinity typically results in less swelling.

Table 1: Physiochemical properties of Cellulose samples

Cellulose	pH	Moisture (%)	Swelling Power
Pineapple Crown leaves Cellulose	6.44^{a}±0.02	8.50^{a}±0.71	3.60^{a}±0.14
Banana peel Cellulose	6.53^{a}±0.04	6.50^{b}±0.71	3.90^{a}±0.14
Control Cellulose	6.68^{a}±0.04	7.50^{ab}±0.71	3.90^{a}±0.14
LSD	0.24	1.66	1.05

Values are means of duplicate determination and those with different superscript in the same column are significantly different at p<0.05.

Solubility

Five solvents were used to analyze the cellulose samples. The solvents used include deionized water, ethanol, acetone, acetonitrile, and methanol. PCC was found to be insoluble in methanol, deionized water, acetone, acetonitrile, and ethanol. This insolubility suggests a high degree of crystallinity and strong intermolecular hydrogen bonding within the cellulose structure, which hinders its dispersion in these solvents. Cellulose are known to have significant hydrogen bond networks joining the molecular chains, and yet they are recalcitrant to aqueous solvents [14]. BPC showed partial solubility in deionized water, with some solute settling and some floating, but it was insoluble in the other solvents. This behavior suggests a complex composition, where some components are water-dispersible while others are not. The partial solubility may be due to the presence of residual pectin or other water-soluble compounds in the extract. This partial solubility could be advantageous or disadvantageous for edible film formation, depending on the desired properties of the film. This property would limit its direct use as a primary film-forming agent without modification. In contrast, CCC exhibited a different behavior. It was soluble in deionized water, forming a viscous, colloidal solution [33]. However, it was insoluble in ethanol, methanol, acetone, and acetonitrile. Its solubility in water makes it suitable for film production.

Antioxidant Properties

Table 4.2 displaying the antioxidant analysis of the cellulose samples revealed a significant difference ($p<0.05$) in the samples' antioxidant qualities.

DPPH assay

In the DPPH assay, the oil sample GRA exhibited the highest antioxidant activity, with a value of 78.75 mg/ml. This was significantly higher than the other samples, particularly AOA (71.47 mg/ml) and GOA (46.79 mg/ml). The high DPPH value of GRA suggests that it contains a high concentration of phenolic compounds capable of neutralizing free radicals [35].

A study on vegetable oils found that oils rich in phenolic compounds showed higher DPPH radical scavenging activity (Aleksander *et al.,* 2008). The lower activity in GOA may indicate a lower content of these antioxidant compounds.

ABTS assay

The ABTS assay revealed that GOA had the highest antioxidant capacity at 50.60 mg/ml, closely followed by GRA at 50.56 mg/ml, while AOA showed a lower value of 48.59 mg/ml. It revealed that there was no significant difference between GOA and GRA, but both samples are significantly higher than AOA. The ABTS assay measures the ability of antioxidants to scavenge the ABTS radical cation, which is a different type of free radical than that used in the DPPH assay (American Chemical Society). The comparable activity of GRA and GOA in the ABTS assay may indicate that these oils contain different types of antioxidant compounds that are more effective at neutralizing ABTS radicals. This highlights the importance of using multiple assays to assess antioxidant activity, as different compounds may react differently with different radicals [36].

FRAP assay

In the FRAP assay, AOA demonstrated the highest antioxidant activity (22.72 mg/ml), significantly surpassing GRA (21.09 mg/ml) and GOA (16.39 mg/ml). The FRAP assay measures the ability of antioxidants to reduce ferric ions (Fe3+) to ferrous ions (Fe2+), indicating their reducing power (Shah and Modi, 2020). The higher reducing power of AOA suggests that it may be particularly effective at preventing oxidative stress by reducing metal ions involved in oxidation reactions. This reducing power could be attributed to the presence of compounds such as phytosterols or other reducing agents [40].

Table 2: Antioxidant properties of plant extracts (AOA, GOA, GRA)

Oil Samples	DPPH (mg/ml)	ABTS (mg/ml)	FRAPS (mg/ml)
AOA	71.47^{b}±0.40	48.59^{b}±0.06	22.72^{a}±0.61
GOA	46.79^{c}±0.69	50.60^{a}±0.21	16.39^{c}±0.26
GRA	78.75^{a}±0.04	50.56^{a}±0.05	21.09^{b}±0.21
LSD	1.08	0.30	0.95

Mean values with different superscripts in the same column are significantly different at p<0.05
Note: DPPH - 2-Diphenyl-1-picrylhydrazyl Radical Scavenging Activity
ABTS -2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) Radical Cation Decolorization Assay
FRAP -Ferric Reducing Antioxidant Power
Key: AOA- Oil extracted from Avocado fruit
GOA- Oil extracted from Garlic
GRA- Oil extracted from Ginger (containing gingerol)

FT-IR Spectroscopy

Fig 4.1 below shows the FT-IR results of the cellulose samples. Fourier Transform Infrared (FTIR) spectroscopy was used to identify the functional groups and structural features of the cellulose samples. A broad O–H stretching band at 3200–3600 cm^{-1} indicated strong intra- and intermolecular hydrogen bonding, more pronounced in banana peel cellulose, suggesting higher crystallinity. Peaks at 2850–2920 cm^{-1} represented C–H stretching of aliphatic $–CH_2$ groups, while the 1630–1650 cm^{-1} band reflected O–H bending from absorbed water, showing the hydrophilic nature of cellulose.

Additionally, absorption bands near 1600 cm^{-1} are attributed to C=O stretching vibrations, which may arise from carbonyl groups or other functional groups introduced during the extraction process. The presence of this peak can indicate the degree of modification or purity of the cellulose sample. Higher intensity in this region may suggest the presence of impurities or degradation products. Both banana peel and pineapple crown celluloses show clean, broad spectra without strong carbonyl (≈ 1730 cm^{-1}), indicating that most lignin and hemicellulose were successfully removed. These findings align with previous studies [46].

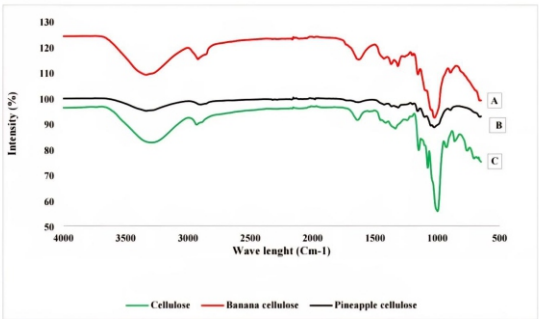
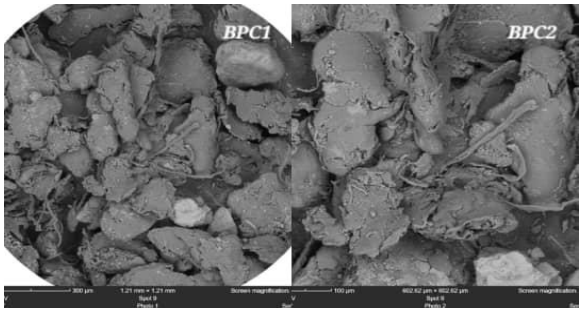


Fig 1: FT-IR Spectroscopy of BPC, CCC and PCC

Scanning Electron Microscopy (SEM)

The Scanning Electron Microscopy was used to study the surface morphologies of cellulose samples of pineapple crown leaves (PCC), control cellulose (CCC) and banana peels (BPC).The Banana Peel Cellulose (BPC) and Pineapple Crown Leaves Cellulose (PCC) exhibit a highly elongated and fibrillar architecture, which is the expected result of chemical treatments (alkali and acid hydrolysis) designed to get rid of lignins and hemicelluloses, leaving behind the crystalline cellulose microfibrils. BPC exhibited a more compact and fibrillar structure with smoother surfaces, suggesting more effective delignification and exposure of crystalline cellulose. This finding differs from Cheng *et al.* (2017), who reported irregular shapes of the cellulose. In contrast, the control Cellulose (CCC) appears as irregular, blocky, or granular fragments, lacking the long, defined fibrillar structure seen in BPC and PCC. This morphology is typical of processed cellulose materials like powdered microcrystalline cellulose (MCC) or chemically modified forms like carboxymethyl cellulose (CMC), which are often more amorphous or highly fragmented due to extensive mechanical or chemical processing.



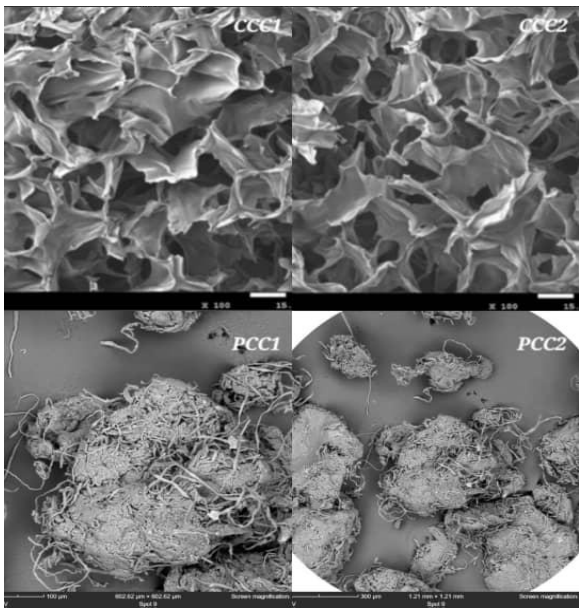


Plate 4: SEM of BPC, PCC and CCC

Conclusion and Recommendation

Conclusion

This study successfully characterized cellulose extracted from banana peels (BPC) and pineapple crown leaves (PCC) and evaluated the antioxidant properties of selected plant extracts (gingerol, garlic oil, and avocado oil) to assess their suitability for antioxidant-based edible films. The extraction process, which involved dewaxing with 70% ethanol, alkali treatment with 5% NaOH, and bleaching with 30% hydrogen peroxide, effectively isolated cellulose from both agricultural waste sources. This method resulted in a cellulose yield of 12.6% from pineapple crown leaves (PCC) and 8.10% from banana peels (BPC). Furthermore, the plant extracts were successfully obtained with yields of 8.2% for gingerol (GRA), 6.4% for garlic oil (GOA), and 10.1% for avocado oil (AOA).

The extracted cellulose was thoroughly characterized, revealing key physicochemical and structural properties. All samples (PCC, BPC, and control) exhibited a near-neutral pH suitable for food applications. Significant differences were noted in moisture content, with PCC (8.50%) being higher than BPC (6.50%). The samples also showed distinct solubility behaviors: PCC was insoluble in all tested solvents, BPC was partially soluble in deionized water, and the control cellulose (CCC) was soluble in deionized water. Structural characterization by FTIR spectroscopy confirmed the successful removal of most lignin and hemicellulose, evidenced by the absence of the characteristic peak at approximately 1730 cm^{-1}. Additionally, SEM imaging revealed that BPC and PCC possessed the expected elongated and fibrillar architecture, contrasting with the irregular, blocky fragments of the control cellulose.

The assessment of the plant extracts demonstrated significant, though varied, antioxidant potential across different assays. Gingerol (GRA) exhibited the highest radical scavenging activity in the DPPH assay (78.75 mg/ml). In the ABTS assay, garlic oil (GOA) and gingerol (GRA) showed the highest and statistically similar activities (50.60 mg/ml and 50.56 mg/ml, respectively), both significantly higher than avocado oil (AOA).

Conversely, avocado oil (AOA) showed the highest ferric reducing power in the FRAP assay (22.72 mg/ml). In conclusion, this research validates that banana peels and pineapple crown leaves are viable sources of cellulose. The characterization analyses confirm the successful extraction of fibrillar cellulose, and the antioxidant assays confirm the potent activity of the selected plant extracts. These findings underscore the strong potential for combining these cellulose biopolymers with the antioxidant extracts to develop functional, active edible films, contributing to sustainable and health-oriented food packaging solutions.

Recommendation

- Further research should focus more on optimizing the extraction parameters (e.g., temperature, time, and concentration of reagents) for dewaxing, alkali treatment, and bleaching to maximize cellulose yield and purity from both BPC and PCC.
- Further work should focus on adjusting solvent concentration, time, and temperature to increase the efficiency of plant extracts and reduce the risk of degrading heat-sensitive compounds.
- Advanced extraction methods such as ultrasound-assisted and supercritical CO_2 extraction, should be explored further to reduce solvent use and environmental impact.
- Scale-Up and Industrial Testing Pilot-scale production trials are necessary to assess the feasibility of applying these extracts in commercial packaging systems.
- Investigate the biodegradability of the proposed developed edible films from BPC and PCC incorporated with plant extracts in various environments to confirm their environmental impact and sustainability, supporting the shift towards eco-friendly packaging solutions.
- Broader Comparative Studies – Future studies could investigate other natural bioactive compounds (e.g., turmeric, moringa, neem extracts) to broaden the pool of options for functional packaging.

Acknowledgment: The cooperation of all the staff of the Department of Food Science and Technology, Federal University of Technology, Owerri, is hereby acknowledged.

Concurrent Interest: No conflicts of interest exist.

REFERENCES

1. Adriana, P., Alexia, V., Ana, C., Mônica, H., Débora, T., & Rafaela, C. (2020). Coating with chitosan-based edible films for mechanical/biological protection of strawberries. *International Journal of Biological Macromolecules, 151*, 1004–1011.
2. Ahmed, M., Nabi, B., Mia, S., Ahmad, I., & Zzaman, W. (2025). Valorization of plant-based agro-waste into sustainable food packaging material: Current approach and functional application. *Applied Food Research, 5*(2), 101368.
3. Aleksandar, R., Isidora, M., Nebojša, T., Tatjana, C., Saša, V., & Momir, M. (2014). Antioxidant activity of rosemary (*Rosmarinus officinalis* L.) essential oil and its hepatoprotective potential. *BMC Complementary and Alternative Medicine, 14*, 225.
4. Amara, C., El Malidi, A., Medimagh, R., & Khwaldia, K. (2021). Nanocellulose-based composites for packaging application. *Current Opinion in Green and Sustainable Chemistry, 31*, 100512.
5. Ancuta, P., & Sonia, A. (2023). A novel approach about edible packaging materials based on oilcakes—A review. *Polymers, 15*(16), 3431.
6. Anna, K., Katarzyna, K., Katarzyna, P., Mariola, S., Ewa, S., & Paulina, H. (2021). Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality—A review. *Agronomy, 11*(5), 813.
7. Anton, I., Dhena, R., Jayanudin, M. Y., Desiana, & Fachriza, H. (2017). Antimicrobial activity of chitosan-based edible film enriched with red ginger essential oil. *Research Journal of Pharmaceutical, Biological and Chemical Sciences, 8*(3), 1523–1530.
8. Anita, M., Vasileios, M., Georgios, P., Nikolaos, K., Marcos, A., Theodora, A., Ellie, P., Anna, O., & Alexandros, T. (2024). Avocado and its by-products as natural sources of valuable anti-inflammatory and antioxidant bioactives. *Applied Sciences, 14*(14), 5978.
9. Aziz, T., Li, W., Zhu, J., & Chen, B. (2024). Developing multifunctional cellulose derivatives for environmental and biomedical applications. *International Journal of Biological Macromolecules, 275*, 134695.
10. Changhong, L., Tao, J., Weilei, L., Wenzhuo, H., Ling, Y., & Lei, Z. (2021). Effects of hydroxyethyl cellulose and sodium alginate edible coating on strawberries. *LWT – Food Science and Technology, 148*, 111770.
11. Claus, C. (2022). Classification and application of edible films in food packaging applications: An overview. *Food Infotech*.
12. Dalal, H., Maha, K., Sanaa, K., & Samat, Y. (2022). Thyme: Biological, chemical, and therapeutic properties. *Nutrients, 14*(10), 2104.
13. Dariusz, K., Urszula, S., Tomasz, S., Monika, B., Małgorzata, M., & Katarzyna, L. (2021). Corn starch and methylcellulose edible films incorporated with plant extract. *International Journal of Biological Macromolecules, 190*, 969–977.
14. Datta, R. (2024). Enzymatic degradation of cellulose in soil: A review. *Heliyon, 10*(1).
15. Debnath, B., Haldar, D., & Purkait, K. (2021). Synthesis and application of crystalline cellulose from agricultural wastes. *Carbohydrate Polymers, 273*, 118537.
16. Elsa, D., & Roberto, C. (2021). Edible films and coatings as food-quality preservers. *Foods, 10*(2), 249.
17. Fereidoon, S., & Abul, H. (2020). Preservation of aquatic food using edible films and coatings. *Critical Reviews in Food Science and Nutrition*.
18. French, A. (2022). How crystalline is my cellulose specimen? *BioResources, 17*(4), 5557–5561.
19. Hadi, S., Erpan, D., Hengameh, H., Jiraporn, J., Lester, C., Rommel, G., & Jannek, K. (2021). Cellulose and its derivatives towards biomedical applications. *Cellulose, 28*, 1893–1931.
20. Hideno, A. (2020). Thermogravimetric analysis-based characterization of biomass. *BioResources, 15*(3), 6217–6229.
21. Hospodarova, V., Singovszka, E., & Stevulova, N. (2018). Characterization of cellulosic fibers by FTIR spectroscopy. *American Journal of Analytical Chemistry, 9*(6), 303.
22. Hyun-Joo, J., Hyun-Jin, L., Dong-Kyu, Y., Da-Som, J., Ji-Han, K., & Chi-Ho, L. (2017). Antioxidant and antimicrobial activities of garlic. *Food Science and Biotechnology, 27*(1), 219–225.

23. Ilias, G., Eleftherios, B., Efterpi, C., & Panagiota, F. (2018). Oregano: A feed additive with functional properties. *Academic Press*.
24. Jhoseline, G., & Luz, M. (2020). Oxidative stability and shelf life of avocado oil. *Scientia Agropecuaria, 11*(1), 1–14.
25. Jia, X., Peter, V., Anita, U., & Xiaoqing, Y. (2017). Rosemary as a natural antioxidation solution. *European Journal of Lipid Science and Technology, 119*(6), 1600439.
26. Jiang, Z., & Ngai, T. (2022). Chemically modified cellulose for food packaging. *Polymers, 14*(8), 1533.
27. Kim, D., Park, S., Um, S., & Kim, J. (2019). Advances in cellulose-based materials for food packaging. *Trends in Food Science & Technology, 91*, 357–368.
28. Kirubanandan, S., Hamid, D., Swambabu, V., Gil, G., & Warren, B. (2019). Nanocellulose films as barriers. *Sustainable Materials and Technologies, 22*, e00115.
29. Klemm, D., Kramer, F., Moritz, S., Lindström, T., Ankeofors, J., Gray, D., & Doris, A. (2011). Nanocelluloses: A new family of materials. *Angewandte Chemie International Edition, 50*(24), 5438–5466.
30. Leyla, B., Pier, H., & Ali, G. (2014). Garlic: A review of its therapeutic effects. *Avicenna Journal of Phytomedicine, 4*(1), 1–14.
31. Li, S., & Chen, G. (2020). Agricultural waste-derived hydrogels. *Journal of Cleaner Production, 251*, 119669.
32. Madhushree, M. V., Vairavel, P., Mahesha, G., & Bhat, K. (2024). Review of cellulose-based materials. *Journal of Natural Fibers, 21*(1).
33. Magalhães, S., Fernandes, C., Pedrosa, J., Alves, C., Modronho, B., Ferreira, P., & Rasteiro, M. (2023). Eco-friendly cellulose modification methods. *Polymers, 15*(14), 3138.
34. Magdalena, W., Agnieszka, G., Anna, M., Renata, W., & Daniel, Z. (2024). Oregano essential oil properties. *Molecules, 29*(2), 435.
35. Mahmoud, A. E., Hassan, M. O., Hossam, K. A., et al. (2024). Antibacterial potential of 6-gingerol. *Saudi Pharmaceutical Journal, 32*(5), 102041.
36. Márcio, M., Alexandra, E., Maria, C., José, A., & Cristina, S. (2023). Antimicrobial and antioxidant edible films. *Foods, 12*(12), 2308.
37. Maria, A., Karina, C., Patrícia, P., & Débora, O. (2021). Banana peel polysaccharides. *Food Research International, 149*.
38. Ofoedum, A.F. *et al.* (2024) 'Antioxidant activities and sensory evaluation of functional beverages produced by incorporation of crude extracts from tropical spices', *Journal of Food Legumes*, 37(4), pp. 462–471.Monika, G., & Jochen, W. (2017). Cellulose fibers in food systems. *Food Chemistry, 229*, 828–836.
39. Nurdin, R., Sri, M., Rukman, A., & Bohari, B. (2022). Antioxidant properties of avocado peel. *Journal of Advanced Pharmaceutical Technology & Research, 13*(3), 166–170.
40. Nuria, M., Jose, A., Juana, F., & Manuel, V. (2023). Chitosan edible films and coatings. *Polymers, 15*(2), 396.
41. Osman, E., & Aykut, O. (2018). General characteristics of edible films. *Journal of Food Biotechnology Research, 2*(1), 3.
42. Poisson, J., & Zhang, K. (2024). Optical properties of cellulose. *Accounts of Materials Research, 5*(8), 920–932.
43. Qingying, L., Alomgir, M., Yuanbo, Z., Jianwu, D., Suqing, L., Wen, Q., & Yaowen, L. (2022). Gelatin-based composite films. *Journal of Food Engineering, 313*, 110762.
44. Raziyeh, Y., Mohammed, K., Mansour, R., Seyed, A., & Amir, M. (2023). Thyme antioxidant properties. *Journal of Food Quality*.
45. Samah, M., Hoda, S., Ahmed, M., & Ayat, F. (2024). Hydroxyethyl cellulose films. *International Journal of Biological Macromolecules, 268*.
46. Ofoedum, A.F., Owuamanam, C.I., Ndukauba, O.E, Iroagba, L.N., Ugwoezuonu J.N., Abbah, E.C. & Anaeke, J.E.. (2023). Phytochemicals from Selected Tropical Spices and Agro-Food Wastes. Utilization and Applications in Health Sectors: A Review. *European Journal of Theoretical and Applied Sciences, 1*(5), 681-696. DOI: 10.59324/ejtas.2023.1(5).58.
47. Olawuni, I.A, Uzoukwu, A.E., Agunwah, I.M., Ofoedum, A.F. and Onyeneke,E.N. (2019). Incorporation of Peanut Butter as Substitute for Shortening in Biscuit Production. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) e-ISSN: 2319-2402*
48. Ofoedum, A.F., Chikelu, E.C., Nwuka, M.U., Olawuni, I.A., Uzoukwu, A.E., Alagbaoso, S.O. and Odeyemi, T.A. (2024). Antioxidant activities and sensory evaluation of functional beverages produced by incorporation of crude extracts from tropical spices. Journal of Food Legumes. 37(4): 462-471.
49. AF Ofoedum, CI Owuamanam, JO Iwouno, IA Olawuni, EC Abbah, NC Uyanwa, EJ Anaeke and SL Ofoedum (2026). Functional and storage stabilities of functional beverages developed from crude extracts from tropical spices (*Zingiber officinale, Monodora myristica* and *Tetrapluera tetraptera*). Journal of food Legumes 38(4): 131-00, 2025. DOI: 10.53550/jfl.v38.i4.313
50. Nwuka M. U, Nwosu, J. N, Ogueke, C. C, Kabuo, N. O, and Ofoedum A. F (2026). Composition, Nutraceutical Potentials and Utilization of Avacado (*Percea americana*) Seeds in the Development of a Functional Beverage (Tea): A Review. *Journal of Food and Biotechnology.* 01 to 12. DOI: https://doi.org/10.51470/FAB.2026.7.1.01