

Comparative Solvent Extraction, Phytochemical Profiling, and Antioxidant Evaluation of Banana (*Musa sp.*) Peel

Suhil Salem Mabruk Elsarrah ^{1*}, Raja Ahmid Saleh ²,
Asma Salem Elmabruk Alsarrah ³

^{1,2} Department of Chemistry, Faculty of Science, University of Ajdabiya, Libya.

³ Adjunct Faculty, Rochester Christian University, Rochester, MI, USA.

*Email: suhil.salem@uoa.edu.ly

الاستخلاص المقارن بالمذيبات والتوصيف الكيميائي النباتي الأولي وتقييم النشاط المضاد للأكسدة لقشور الموز (*Musa sp.*)

سهيل سالم المبروك الصراح ^{1*}، رجاء احمد صالح ²، أسماء سالم المبروك الصراح
^{2,1} قسم الكيمياء، كلية العلوم، جامعة اجدابيا، ليبيا.
³ جامعة روتشستر المسيحية، روتشستر، ولاية ميشيغان، الولايات المتحدة الأمريكية.

Received: 10-06-2026	Accepted: 22-08-2026	Published: 07-09-2026
		
Copyright: © 2026 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).		

Abstract

Banana (*Musa sp.*) peel is an abundant agricultural and food-processing by-product containing phytochemical constituents with potential antioxidant and value-added applications. This study evaluated the effects of extraction solvents on crude extract recovery and conducted preliminary phytochemical and antioxidant characterization of dried banana peel. Peel powder was extracted using 50% aqueous ethanol, water, methanol, ethanol, acetone, diethyl ether, and n-hexane. Qualitative phytochemical screening, Folin–Ciocalteu and aluminum chloride colorimetric assays, DPPH radical-scavenging analysis, and thin-layer chromatography were performed. The highest crude extract recovery was obtained using 50% aqueous ethanol (43.32%), followed by water (43.00%), methanol (37.08%), ethanol (30.62%), diethyl ether (6.30%), acetone (6.08%), and n-hexane (5.13%) in decreasing order. Phytochemical screening revealed the presence of carbohydrates, reducing constituents/sugars, tannins, flavonoids, phenolic compounds, and fixed oils and fats in the peel extracts. Among the evaluated polar extracts, 50% aqueous ethanol consistently produced the highest aluminum chloride assay response. DPPH analysis of the ethanolic extract demonstrated concentration-dependent radical-scavenging activity, reaching 85.53% inhibition at the highest reported concentration. TLC revealed eight distinguishable chromatographic zones. These findings demonstrate that the solvent composition influences banana peel extraction and support further quantitative and chromatographic investigations of banana peel as a potentially valuable plant byproduct.

Keywords: banana peel; *Musa sp.*; solvent extraction; phytochemical screening; antioxidant activity; waste valorization.

المخلص

تُعد قشور الموز (*Musa sp.*) من المخلفات الزراعية ومخلفات تصنيع الأغذية المتوافرة بكثرة، وتحتوي على مكونات كيميائية نباتية ذات تطبيقات محتملة كمضادات للأكسدة وفي إنتاج منتجات ذات قيمة مضافة. هدفت هذه الدراسة إلى تقييم تأثير مذيب الاستخلاص في مردود المستخلص الخام، وإجراء توصيف أولي للخصائص الكيميائية النباتية والنشاط المضاد للأكسدة لقشور الموز المجففة. استُخلص مسحوق القشور باستخدام إيثانول مائي بتركيز 50%، والماء، والميثانول، والإيثانول، والأسيتون، وثنائي إيثيل الإيثر، والهكسان. وأجري الفحص النوعي للمركبات الكيميائية النباتية، واختبار فولين-سيوكالتيو، واختبار كلوريد الألومنيوم اللوني، وتحليل تثبيط الجذور الحرة باستخدام DPPH، وكروماتوغرافيا الطبقة الرقيقة. حقق الإيثانول المائي بتركيز 50% أعلى مردود للمستخلص الخام (43.32%)، تلاه الماء (43.00%)، ثم الميثانول (37.08%)، والإيثانول (30.62%)، وثنائي إيثيل الإيثر (6.30%)، والأسيتون (6.08%)، والهكسان (5.13%). وأظهر الفحص الكيميائي النباتي وجود الكربوهيدرات، والسكريات والمكونات المختزلة، والتانينات، والفلافونويدات، والمركبات الفينولية، والزيوت الثابتة والدهون. ومن بين المستخلصات القطبية التي جرى تقييمها، أعطى الإيثانول المائي بتركيز 50% أعلى استجابة باستمرار في اختبار كلوريد الألومنيوم. كما أظهر تحليل DPPH للمستخلص الإيثانولي نشاطاً في إزالة الجذور الحرة يعتمد على التركيز، حيث بلغت نسبة التثبيط 85.53% عند أعلى تركيز تم اختبارها. وتوضح هذه النتائج أن تركيب المذيب يؤثر في استخلاص مكونات قشور الموز، كما تدعم إجراء دراسات كمية وكروماتوغرافية إضافية لتقييم قشور الموز بوصفها منتجاً نباتياً ثانوياً ذا قيمة محتملة.

الكلمات المفتاحية: قشور الموز؛ جنس الموز (*Musa sp.*)؛ الاستخلاص بالمذيبات؛ الفحص الكيميائي النباتي؛ النشاط المضاد للأكسدة؛ تثمين المخلفات.

1. Introduction

The increasing generation of agricultural and food-processing residues has stimulated interest in strategies for converting plant-derived waste into valuable chemicals and functional food ingredients. Fruit peels are a particularly important component of this waste stream because they are frequently discarded despite containing carbohydrates, fibers, lipids, minerals, and diverse secondary metabolites. Therefore, the valorization of such materials may simultaneously reduce waste and provide renewable sources of compounds with potential applications in the food, pharmaceutical, nutraceutical, and related industries (Alara et al., 2021; Majerska et al., 2019; Nirmal et al., 2023; Rifna et al., 2023).

Banana (*Musa sp.*) is extensively consumed worldwide, while the peel is generally discarded following consumption or processing. Banana peels represent approximately 30% of the fruit, highlighting the substantial quantity of residual biomass generated by banana consumption and processing (González-Montelongo et al., 2010). Rather than being considered solely waste, banana peels represent a chemically complex plant matrix that contains several classes of potentially valuable constituents (Bishnoi et al., 2023; Hikal et al., 2022; Putra et al., 2022; Zou et al., 2022).

Previous investigations have demonstrated the presence of phenolic constituents in banana peels, including gallic acid, as well as other phytochemical classes such as anthocyanins, carotenoids, sterols, and triterpenes. Banana peels have also been reported to contain higher levels of some antioxidant constituents than the edible pulp (Someya et al., 2002). These

observations provide a biochemical basis for investigating banana peels as a potential source of naturally derived antioxidants (González-Montelongo et al., 2010; Someya et al., 2002; Hikal et al., 2022).

Phenolic compounds are particularly relevant because of their capacity to participate in oxidation-reduction reactions and radical-scavenging processes. Flavonoids, tannins, phenolic acids, and other related secondary metabolites contribute to the antioxidant properties of plant extracts. Consequently, the recovery of these constituents from food-processing residues represents an attractive approach for developing value-added products from otherwise underutilized biomass (Dias et al., 2021; Avram et al., 2022).

However, the recovery of phytochemicals from plant materials is strongly dependent on extraction conditions. Among these variables, solvent composition and polarity are particularly important because plant-derived compounds differ considerably in polarity, molecular structure, solubility, and their interactions with the surrounding matrix. As the solvent composition can influence both the extraction yield and the recovery of antioxidant constituents, solvents spanning substantially different polarity ranges were compared (Alara et al., 2021; Herrera-Pool et al., 2021; Ojong et al., 2026; Sultana et al., 2009).

Highly nonpolar solvents preferentially recover lipophilic constituents, whereas polar solvents facilitate the extraction of polar compounds. Moreover, mixtures of water and organic solvents may behave differently from the corresponding pure solvents because the addition of water alters the solvent polarity and affects extraction efficiency. Thus, a direct comparison of multiple extraction systems provides useful information for identifying the conditions that maximize recovery from a specific plant matrix (Alara et al., 2021; ĩmece, 2026; Putra et al., 2022; Wani & Dhanya, 2025).

In the present study, banana peels were extracted using n-hexane, diethyl ether, acetone, ethanol, methanol, 50% aqueous ethanol, and water. The experimental results demonstrated substantial differences in crude extract recovery, ranging from 0.513 g for n-hexane to 4.332 g for 50% aqueous ethanol from 10 g of the starting peel material. This approximately eightfold difference between the lowest and highest recoveries provides a clear basis for examining solvent-dependent extraction behavior.

Beyond the crude extraction yield, chemical screening is necessary because a higher mass yield does not necessarily indicate a greater recovery of compounds relevant to the antioxidant activity. Accordingly, the experimental work incorporated qualitative phytochemical screening for carbohydrates, reducing constituents/sugars, tannins, flavonoids, fixed oils and fats, and phenolic compounds. Phenolic constituents were further evaluated using the Folin–Ciocalteu assay with gallic acid as the calibration standard, and flavonoid-associated responses were evaluated using an aluminum chloride colorimetric assay with quercetin as the reference standard. Recent studies on banana peels have evaluated the total phenolic and flavonoid content when characterizing the bioactive compounds recovered (Avram et al., 2022; Gatasheh, 2026; Islam et al., 2023).

Antioxidant activity was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging assay. This assay provides a spectrophotometric measure of radical-scavenging behavior and is widely used to evaluate antioxidant-rich plant extracts. Recent studies have incorporated DPPH measurements for the antioxidant characterization of banana-peel extracts. Thin-layer chromatography (TLC) was used to obtain a preliminary chromatographic profile of the extracts. Together, these complementary approaches enable the evaluation of extraction efficiency, phytochemical composition, antioxidant behavior, and preliminary chemical

complexity without requiring advanced instrumentation for compound identification (Avram et al., 2022; Islam et al., 2023).

Therefore, the objective of the present study was to compare solvents of different polarities for extracting constituents from dried banana peels and to conduct preliminary phytochemical characterization of the resulting extracts through extraction yield determination, qualitative phytochemical screening, Folin–Ciocalteu and aluminum chloride colorimetric assays, DPPH radical-scavenging activity, and thin-layer chromatography (TLC). This study further sought to determine which solvent system provided the greatest recovery under the experimental conditions employed.

2. Materials and Methods

2.1 Study design

A comparative experimental design was employed to investigate the effect of solvent type on the extraction of constituents from dried banana peel. Solvents spanning a range of polarities were evaluated, and the recovered extracts were subjected to phytochemical and antioxidant analyses.

The overall experimental workflow, including banana peel preparation, Soxhlet extraction using solvents of different polarities, and subsequent phytochemical and antioxidant characterization, is illustrated in Figure 1.

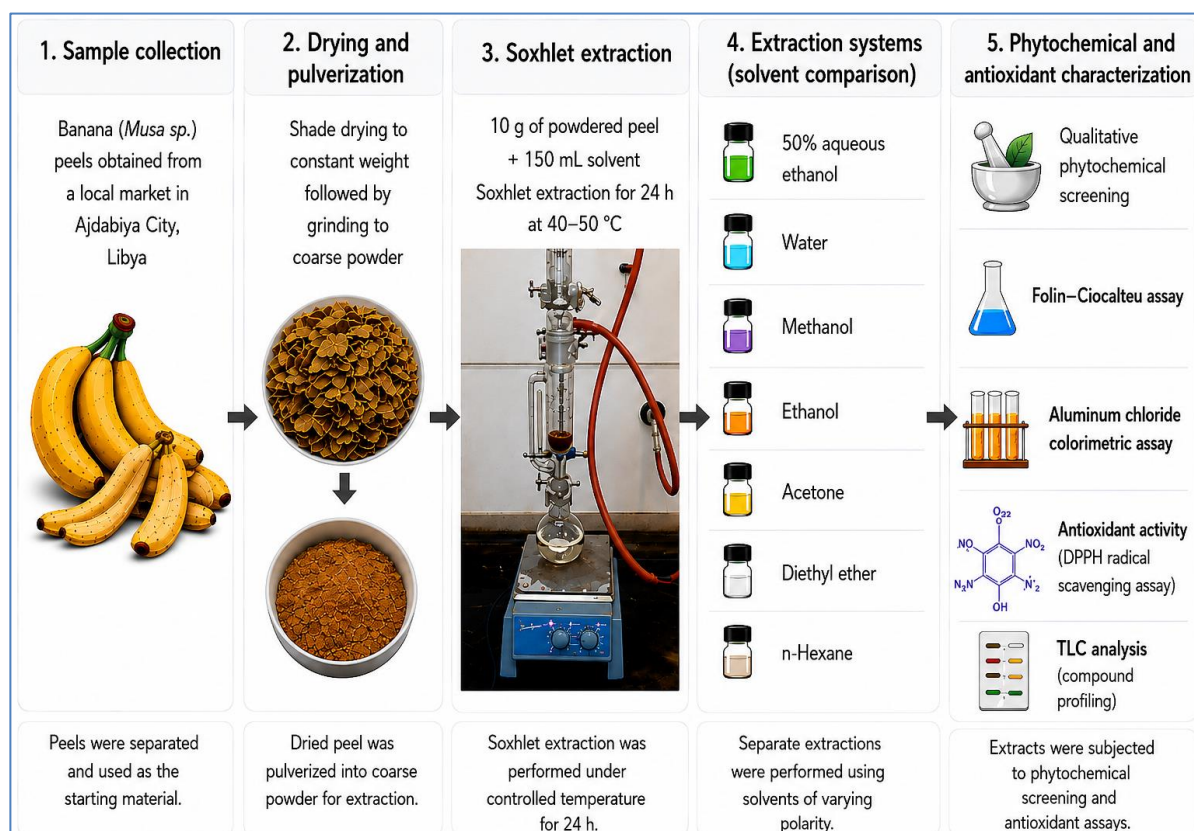


Figure 1. Experimental workflow for solvent extraction and preliminary phytochemical and antioxidant characterization of banana (*Musa sp.*) peel.

2.2 Plant material and sample preparation

Banana (*Musa* sp.) fruits grown in Libya were purchased in June from a local market in Ajdabiya City, Libya. The peels were separated, washed with distilled water, shade-dried at ambient temperature, and pulverized into a coarse powder for extraction.

2.3 Chemicals and reagents

Folin–Ciocalteu phenol reagent (Merck, Darmstadt, Germany), ferric chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$; Merck, Darmstadt, Germany), hydrochloric acid (Merck, Darmstadt, Germany), DPPH (2,2-diphenyl-1-picrylhydrazyl; Sigma, USA), gallic acid (Sigma, USA), and sodium carbonate (Riedel-de Haën [RDH], Germany) were used for the phytochemical and antioxidant analyses. Potassium acetate, aluminum chloride (AlCl_3), quercetin, potassium hydroxide (KOH), phenolphthalein, and ascorbic acid were used as required for the assays.

The extraction solvents included absolute ethanol (MRS Scientific; A.R. quality, $\geq 99.5\%$ v/v), methanol, acetone, diethyl ether, distilled water, and *n*-hexane. Chloroform was used as the mobile phase for thin-layer chromatography (TLC), while petroleum ether (boiling range 60–80 °C) was used for fixed-oil extraction.

2.4 Instruments and Apparatus

The principal laboratory equipment used in this study included an analytical balance (Pioneer PA413, OHAUS Corporation, Pine Brook, NJ, USA; maximum capacity 410 g; readability 0.001 g), a UV–visible spectrophotometer (CE 7400 Series, Cecil Instruments, UK), and a hot-air oven equipped with a programmable temperature controller (PMTc-3040, Nutronics). Spectrophotometric measurements were performed at 765, 420, and 517 nm for the Folin–Ciocalteu, aluminum chloride, and DPPH radical-scavenging assays, respectively. Soxhlet extraction was performed using a conventional glass Soxhlet apparatus heated with an electrothermal heating mantle. The dried banana peels were pulverized using a porcelain mortar and pestle. Conventional laboratory glassware, reflux, and titration apparatus were used as required.

2.5 Solvent extraction

Approximately 10 g of pulverized banana peel was extracted with 150 mL of the selected solvent using a Soxhlet apparatus for 24 h. The extraction systems evaluated were 50% aqueous ethanol, water, methanol, ethanol, acetone, diethyl ether, and *n*-hexane. Following extraction, the extracts were filtered, and the solvents were removed. The concentrated extracts were stored at 4 °C until analysis. Soxhlet extraction is a conventional solid–liquid extraction technique involving the repeated contact of the plant matrix with a condensed solvent, and the extraction behavior is influenced by the solvent properties and chemical characteristics of the extractable constituents. Extraction recovery was calculated using the following equation:

$$\text{Extraction recovery (\%)} = \frac{\text{Mass of dried extract (g)}}{\text{Initial mass of banana-peel powder (g)}} \times 100$$

2.6 Preliminary phytochemical screening

The banana peel extracts were subjected to qualitative phytochemical screening for major classes of secondary and primary metabolites using conventional pharmacognostic procedures. Carbohydrates were assessed using Molisch's test, and reducing constituents were evaluated using Fehling's reagent. Tannins and phenolic compounds were investigated using a ferric chloride-based reaction. Flavonoids were evaluated by treatment with sodium hydroxide, and the development of an intense yellow color was considered a positive reaction. Fixed oils and fats were evaluated using filter paper and saponification tests (Evans, 2009).

2.7 Fixed-Oil Extraction and Physicochemical Evaluation

A 10-g portion of banana peel powder was extracted with 150 mL of petroleum ether (boiling range 60–80 °C) using a Soxhlet extractor. The recovered fixed oil was subsequently evaluated for its acid, saponification, and ester values using standard analytical procedures. The results were expressed as milligrams of potassium hydroxide per gram of oil (mg KOH/g oil) (International Union of Pure and Applied Chemistry [IUPAC], 1987).

2.7.1 Acid Value

The acid value of the extracted fixed oil was determined by titration with potassium hydroxide. Approximately 0.5 g of oil was accurately weighed and mixed with 5 mL of a solvent mixture consisting of equal volumes of ethanol and diethyl ether, which was neutralized with 0.1 M potassium hydroxide using phenolphthalein as the indicator. The mixture was titrated with 0.1 M potassium hydroxide with constant shaking until a pink color developed and persisted for at least 15 s. The acid value was calculated as follows (IUPAC, 1987). The acid value (mg KOH/g) was calculated as $5.61 \times V/W$, where V is the volume of 0.1 M KOH used for titration (mL) and W is the oil mass (g).

2.7.2 Saponification Value

Approximately 0.5 g of the extracted oil was accurately weighed into a flask, and 10 mL of 0.5 M alcoholic potassium hydroxide was added with the glass beads. The mixture was heated under reflux for 1 h and titrated immediately with 0.5 M hydrochloric acid while hot, using 1 mL of phenolphthalein solution as the indicator. A blank determination was performed under the same conditions. The saponification value was calculated as follows (IUPAC, 1987). Saponification value (mg KOH/g) = $28.05 \times (B - S)/W$, where B is the volume of 0.5 M HCl used for the blank (mL), S is the volume used for the sample (mL), and W is the oil mass (g), respectively.

2.7.3 Ester Value

The ester value was calculated as the difference between the saponification and acid values (IUPAC, 1987). Ester value (mg KOH/g) = Saponification value – Acid value.

2.8 Folin–Ciocalteu Assay

The Folin–Ciocalteu assay was performed using the Folin–Ciocalteu colorimetric method with modifications (Singleton & Rossi, 1965). Ethanolic banana peel extract solutions were prepared at concentrations of 1, 2, 3, and 4 mg/mL. One milliliter of each extract solution was mixed with 1 mL of Folin–Ciocalteu phenol reagent and 10 mL of deionized water. The mixture was maintained at room temperature for 10 min, after which 1 mL of 15% (w/v) sodium carbonate solution was added. Absorbance was measured at 765 nm using a UV–visible spectrophotometer. The measurements were performed in triplicate, and the recorded values were averaged. The gallic acid calibration relationship was $A = 8.596X + 0.02$ ($R^2 = 0.990$), where A represents the absorbance, and X represents the amount of gallic acid used (mg).

2.9 Aluminum Chloride Colorimetric Assay

Flavonoid-associated responses of the aqueous, methanolic, ethanolic, and 50% aqueous-ethanolic extracts were evaluated using an aluminum chloride colorimetric assay, with quercetin as the reference standard (Chang et al., 2002). One milliliter of the extract solution at concentrations of 0.01, 0.02, 0.03, and 0.04 mg/mL was transferred to a 10-mL volumetric flask, followed by the addition of 5 mL of distilled water and 0.1 mL of 1 M potassium acetate

solution. After 5 min, 0.5 mL of 10% AlCl_3 solution was added, and the final volume was adjusted to 10 mL with distilled water. The mixture was thoroughly mixed and maintained at room temperature for 30 min before use. Absorbance was measured at 420 nm using UV–visible spectrophotometry.

Quercetin was used as the reference standard. The quercetin calibration concentrations were 0.1, 0.5, 1.0, 2.5, and 5.0 mg/mL, with corresponding mean absorbance values of 0.285, 0.345, 0.478, 0.799, and 1.399, respectively, at a wavelength of 420 nm.

2.10 DPPH radical-scavenging assay

The antioxidant activity of the ethanolic banana peel extract was evaluated using the DPPH radical-scavenging assay, based on the methods described by Brand-Williams et al. (1995) and Sultana et al. (2009) with slight modifications. The assay mixture contained 2 mL of 1.0 mmol/L DPPH solution prepared in ethanol and 2 mL of the ethanolic banana peel extract or ascorbic acid standard solution at concentrations of 0.01, 0.02, 0.03, and 0.04 mg/mL. The solutions were rapidly mixed and incubated in the dark at room temperature for 30 min. The absorbance was measured at 517 nm using a UV–visible spectrophotometer. Ascorbic acid was used as the positive control. DPPH inhibition was calculated as follows: DPPH inhibition (%) = $[(A_0 - A)/A_0] \times 100$. Where A_0 represents the absorbance of the DPPH control and A represents the absorbance in the presence of the test sample.

2.11 Thin-layer chromatography

Thin-layer chromatography (TLC) was used to separate the constituents of the ethanolic banana peel extract using conventional methods. Silica gel was used as the stationary phase, and chloroform was used as the mobile phase. The developed chromatogram was examined under ultraviolet light. The retention factor (R_f) was calculated as the ratio of the distance traveled by each detected component to the distance traveled by the solvent front (Stahl, 1969).

2.12 Data Presentation and Statistical Considerations

Spectrophotometric measurements were performed in triplicate, and the mean values were calculated. The results are presented descriptively as mean values of triplicate measurements; standard deviations and inferential statistical analyses were not performed. Accordingly, comparisons among the extracts should not be interpreted as being statistically significant.

3. Results

3.1 Effect of solvent on extraction recovery

Soxhlet extraction of banana (*Musa* sp.) peel using solvents of different polarities resulted in substantial differences in the recovery of crude extracts. Among the seven extraction systems evaluated, 50% aqueous ethanol produced the highest extract mass (4.332 g), corresponding to a recovery of 43.32%, followed closely by water (4.300 g; 43.00% recovery). Methanol and ethanol produced recoveries of 37.08% and 30.62%, respectively, whereas lower recoveries were obtained with diethyl ether (6.30%), acetone (6.08%), and n-hexane (5.13%) extractions. The recovery with 50% aqueous ethanol was approximately 8.4-fold higher than that with n-hexane. The solvent-dependent extraction recoveries are presented in Figure 2 and Table 1.

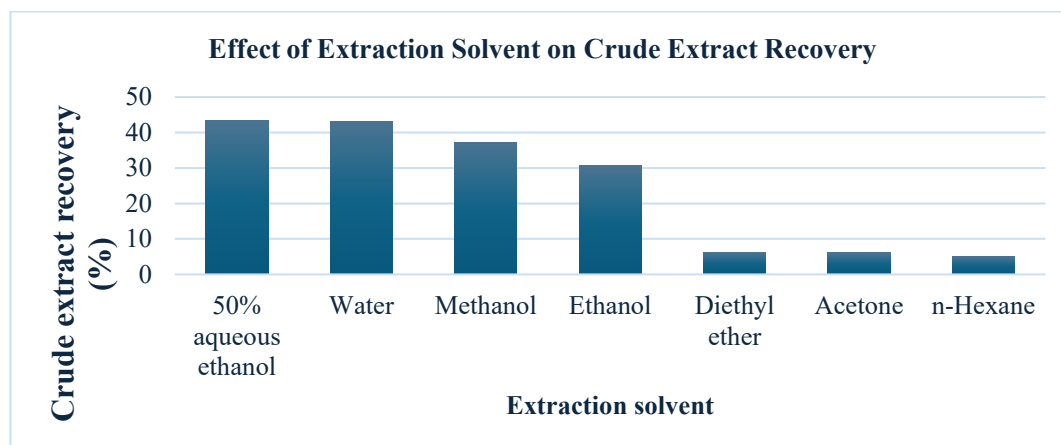


Figure 2. Effect of extraction solvent on crude extract recovery from banana (*Musa* sp.) peel.

Table 1. Effect of solvent type on crude extract recovery from banana (*Musa* sp.) peel.

Solvent	Extract mass (g)	Recovery (%)
50% aqueous ethanol	4.332	43.32
Water	4.300	43.00
Methanol	3.708	37.08
Ethanol	3.062	30.62
Diethyl ether	0.630	6.30
Acetone	0.608	6.08
n-Hexane	0.513	5.13

Note. Recovery (%) = (dried extract mass/10 g starting material) × 100.

These results demonstrate the pronounced effect of the solvent system on the extractable material. The recovery with 50% aqueous ethanol was approximately 8.4-fold higher than that with n-hexane. Previous studies on banana peels have also demonstrated that extraction conditions and solvent systems substantially influence the recovery of phenolics and other extractable constituents (Cegledi et al., 2024; Gatasheh, 2026; İmece, 2026; Putra et al., 2022).

3.2 Preliminary phytochemical profile

Qualitative phytochemical screening produced positive reactions for carbohydrates, reducing constituents/sugars, tannins, flavonoids, fixed oils and fats, and phenolic compounds. The results are presented in Table 2.

Table 2. Preliminary phytochemical profile of banana (*Musa* sp.) peel

Phytochemical class	Test	Result
Carbohydrates	Molisch's test	+
Reducing constituents/sugars	Fehling's test	+
Tannins	Ferric chloride (FeCl ₃)	+
Flavonoids	Sodium hydroxide	+
Fixed oils and fats	Qualitative lipid test	+
Phenolic compounds	5% FeCl ₃	+

+ indicates a positive qualitative reaction to the test.

Positive reactions were observed for all evaluated phytochemical classes. The detection of tannins, flavonoids, phenolic compounds, and reducing constituents/sugars is consistent with previous phytochemical investigations that have described banana peels as a source of multiple classes of secondary metabolites (Hikal et al., 2022; Khan et al., 2025).

3.3. Fixed Oil Fraction

Petroleum ether extraction yielded 6.3% (w/w) fixed oil. The extracted oil had an acid value of 11.68 mg KOH/g, saponification value of 437.58 mg KOH/g, and ester value of 425.90 mg KOH/g. The results are presented in Table 3.

Table 3. Physicochemical properties of the fixed oil fraction of banana (*Musa sp.*) peels.

Parameter	Result
Fixed oil	6.3% (w/w)
Acid value	11.68 mg KOH/g
Saponification value	437.58 mg KOH/g
Ester value	425.90 mg KOH/g

3.4. Folin–Ciocalteu Assay Response of Banana (*Musa sp.*) Peel Extract

The Folin–Ciocalteu assay showed an increase in absorbance with increasing ethanolic banana peel extract concentration. Mean absorbance values of 0.851, 0.972, 1.100, and 1.320 were recorded at extract concentrations of 1, 2, 3, and 4 mg/mL, respectively. The results are shown in Figure 3.

The gallic acid calibration relationship was $A = 8.596X + 0.02$ ($R^2 = 0.990$), where A represents the absorbance, and X represents the amount of gallic acid in mg. The concentration-dependent response was consistent with previous studies reporting phenolic-associated responses in banana peel extracts (Avram et al., 2022; Gatasheh, 2026; Islam et al., 2023).

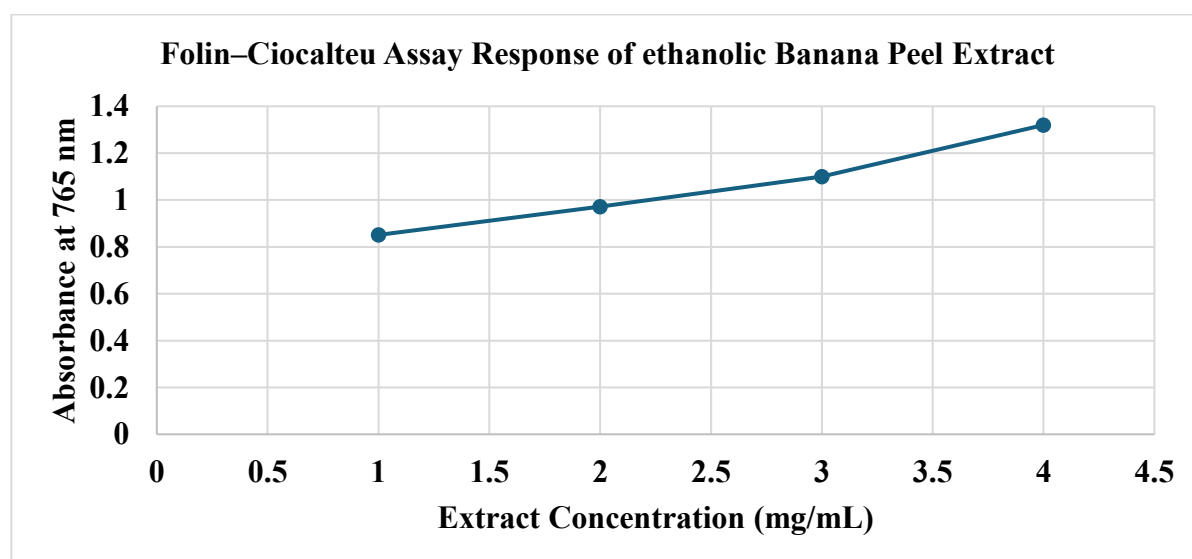


Figure 3. Concentration-dependent Folin–Ciocalteu assay response of ethanolic banana (*Musa sp.*) peel extract measured at 765 nm.

3.5 Aluminum Chloride Assay Response

The aluminum chloride assay showed concentration-dependent increases in absorbance for the 50% aqueous ethanolic, methanolic, ethanolic, and aqueous extracts. At every tested

concentration, the 50% aqueous ethanolic extract produced the highest absorbance. Its absorbance increased from 1.200 at 0.01 mg/mL to 2.450 at 0.04 mg/mL. Methanolic and ethanolic extracts produced slightly lower responses, whereas the aqueous extract showed the lowest absorbance. The results are presented in Table 4 and Figure 4.

Table 4. Flavonoid-associated absorbance of banana-peel extracts at 420 nm

Concentration (mg/mL)	50% aqueous ethanol	Methanol	Ethanol	Water
0.01	1.200	1.059	0.988	0.627
0.02	1.768	1.690	1.430	1.002
0.03	2.090	1.988	1.918	1.474
0.04	2.450	2.350	2.315	2.050

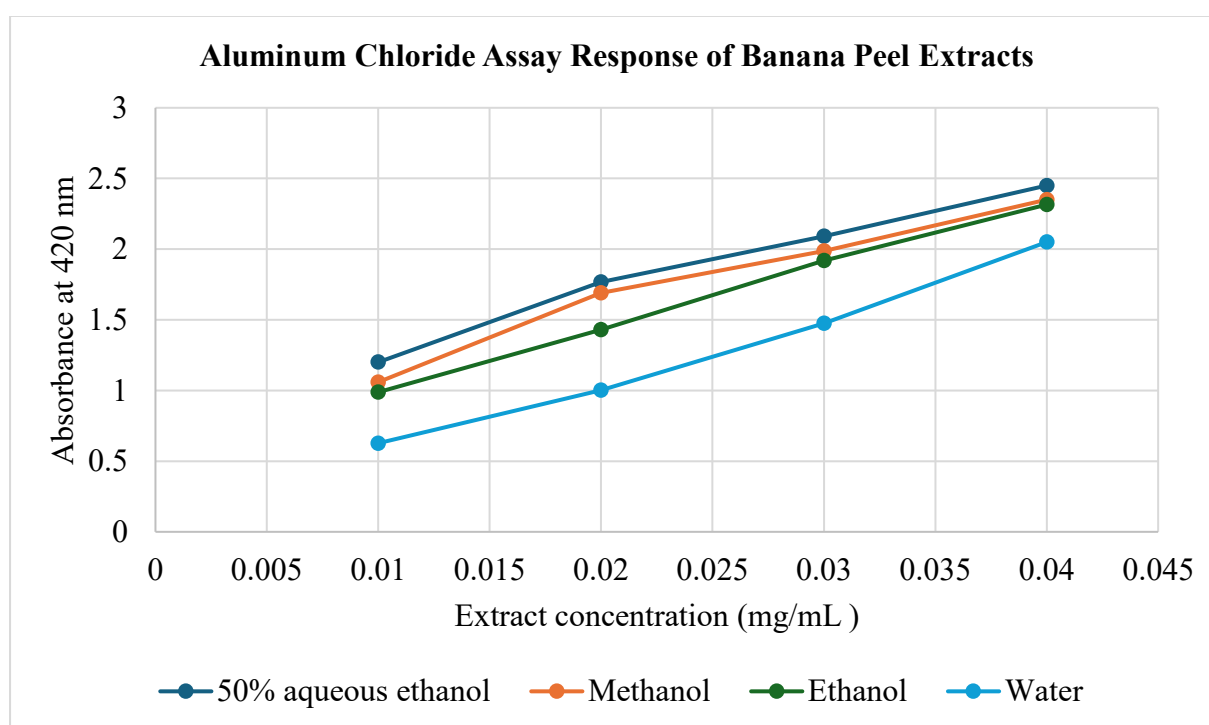


Figure 4. Aluminum chloride assay response of banana peel (*Musa sp.*) extract obtained using different extraction solvents.

The concentration-dependent responses observed for the polar extracts are consistent with previous studies demonstrating the presence and solvent-dependent recovery of flavonoids from banana peels (Avram et al., 2022; Putra et al., 2022). A quercetin calibration curve was constructed using the recorded standard concentrations and corresponding mean absorbance values at 420 nm. Linear regression of the calibration data produced the equation $A = 0.2292C + 0.2441$ ($R^2 = 0.9989$), where A represents the absorbance at 420 nm and C represents the quercetin concentration (mg/mL) (Figure 5).

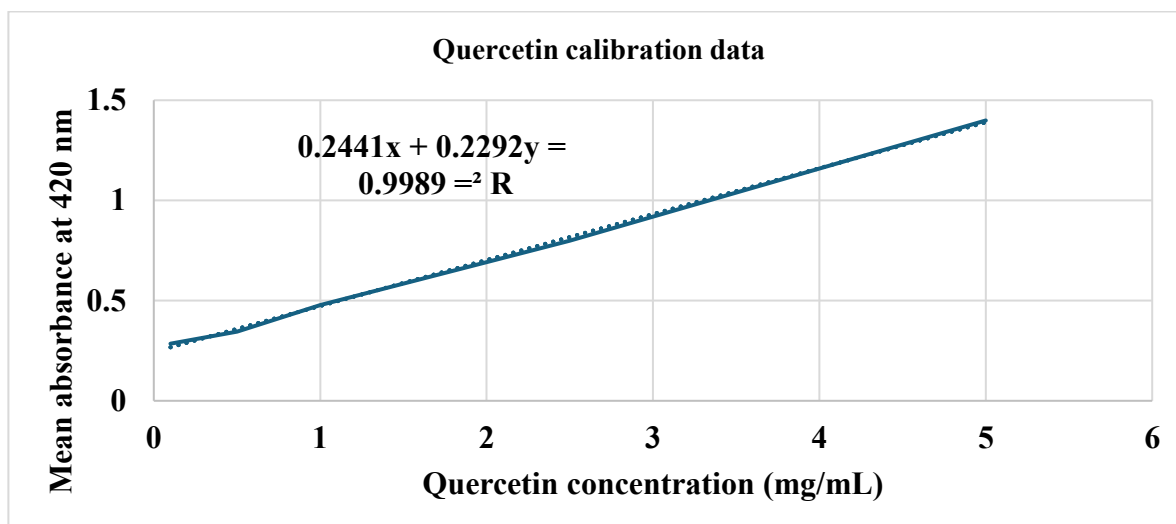


Figure 5. Quercetin calibration curve for the aluminum chloride colorimetric assay at 420 nm.

3.6 DPPH Radical-Scavenging Activity

The ethanolic banana peel extract exhibited concentration-dependent DPPH radical-scavenging activity. The percentage inhibition increased from 52.37% at 0.01 mg/mL to 85.53% at 0.04 mg/mL of the extract. At the highest concentration investigated, ascorbic acid produced 92.32% inhibition. Previous studies have reported substantial DPPH radical-scavenging activity in banana peel extracts, supporting the antioxidant potential of banana peel constituents (Avram et al., 2022; Islam et al., 2023). The results of this study are presented in Table 5 and Figure 6.

Table 5. DPPH Radical-Scavenging Activity of Ethanolic Banana Peel Extract and Ascorbic Acid

Concentration (mg/mL)	Ethanolic banana-peel extract (%)	Ascorbic acid (%)
0.01	52.37	21.58
0.02	75.68	89.68
0.03	79.71	90.71
0.04	85.53	92.32

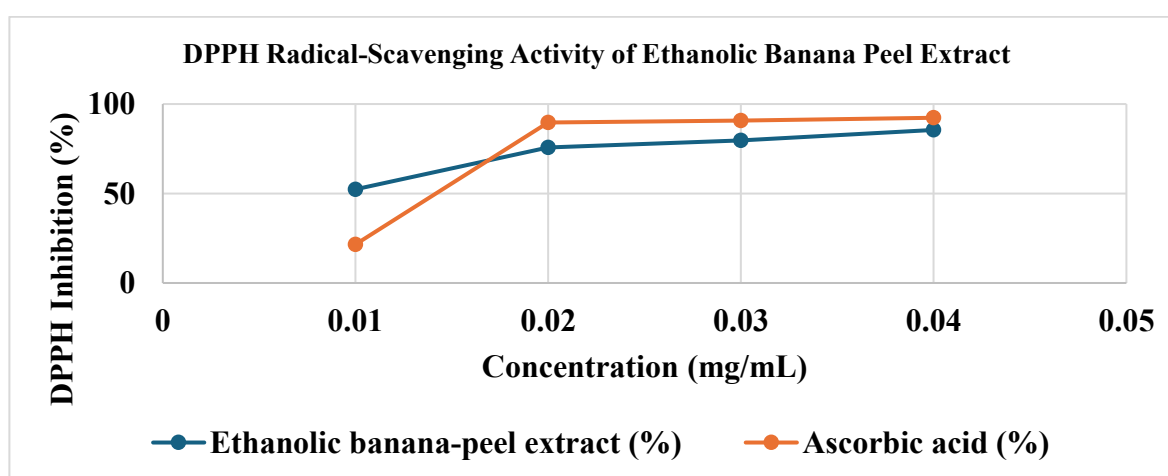


Figure 6. Concentration-dependent DPPH radical-scavenging activity of ethanolic banana (*Musa* sp.) peel extract compared with ascorbic acid.

3.7 Thin-layer chromatographic profile

Thin-layer chromatography revealed eight chromatographically distinguishable zones with R_f values of 0.0809, 0.1904, 0.2500, 0.6880, 0.7380, 0.8095, 0.8785, and 0.9875. As authentic reference compounds and confirmatory analytical techniques were not included in the present study, the chemical identities of the constituents represented by these zones could not be determined. The chromatographic profiles are shown in Figure 7.

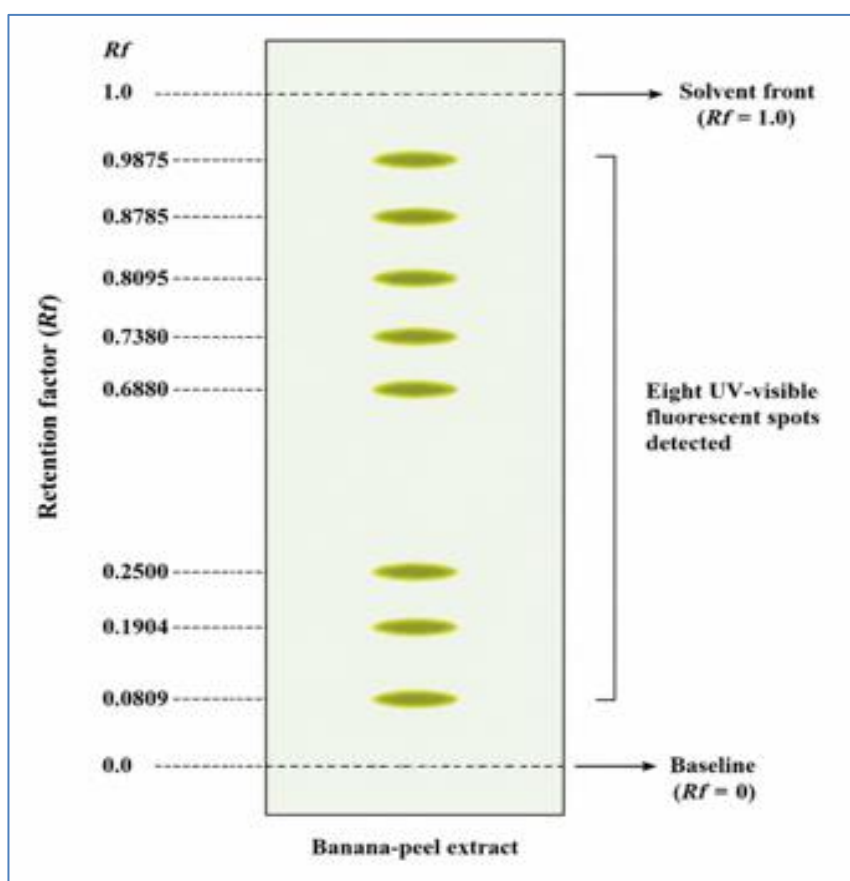


Figure 7. Thin-layer chromatographic profile of ethanolic banana (*Musa* sp.) peel extract showing eight chromatographically distinguishable zones and their corresponding retention factor (R_f) values.

4. Discussion

4.1. Effect of solvent type on extraction recovery

The present study demonstrated a pronounced effect of solvent type on the recovery of crude constituents from dried banana (*Musa* sp.) peel. Among the seven extraction systems investigated, 50% aqueous ethanol produced the highest crude extract recovery (43.32%), followed by water (43.00%), methanol (37.08%), and absolute ethanol (30.62%). Considerably lower recoveries were obtained using diethyl ether (6.30%), acetone (6.08%), and n-hexane (5.13%). These results indicate that the banana peel matrix contains a substantial proportion of constituents preferentially soluble in polar or hydroalcoholic media rather than in nonpolar solvents. The results clearly demonstrate a solvent-dependent recovery pattern.

This behavior is consistent with the general principle that extraction efficiency depends strongly on solvent polarity and the chemical characteristics of the compounds present in the plant matrix. Recent studies on banana peels have shown that extraction conditions and solvent composition significantly influence the recovery of phenolic and other bioactive constituents (Alara et al., 2021; Herrera-Pool et al., 2021; Putra et al., 2022; Rifna et al., 2023). Aqueous-organic solvent systems can provide effective extraction by modifying solvent polarity and improving the recovery of compounds with different physicochemical characteristics.

The slightly greater recovery obtained with 50% aqueous ethanol compared to that obtained with water is particularly noteworthy. Water alone can recover substantial amounts of highly polar constituents, including soluble carbohydrates and hydrophilic compounds. However, the addition of ethanol changes the polarity of the extraction medium and may broaden the range of compounds that can be solubilized. Therefore, a greater mass yield of a hydroalcoholic extract should not be automatically interpreted as evidence of a greater concentration of any single phytochemical class, as crude extracts represent complex mixtures of compounds with different chemical properties (Alara et al., 2021; Herrera-Pool et al., 2021; Sultana et al., 2009). The relatively low recoveries obtained with n-hexane and diethyl ether suggest that, under the conditions employed, a larger proportion of the extractable material was recovered using polar and hydroalcoholic solvents than using non-polar solvents. These nonpolar solvents are expected to primarily recover lipid-associated and other hydrophobic fractions rather than the broader mixture of phenolic, carbohydrate, and related polar constituents. The marked difference between 50% aqueous ethanol and n-hexane illustrates the importance of matching solvent properties with the chemical characteristics of the target fraction (Alara et al., 2021; Ojong et al., 2026).

From a practical perspective, the performance of 50% aqueous ethanol is relevant to future valorization studies. Contemporary banana peel literature increasingly emphasizes ethanol-based and other greener extraction systems, along with ultrasound-assisted, microwave-assisted, enzymatic, and other emerging extraction technologies (Cegledi et al., 2024; Ímece, 2026; Putra et al., 2022; Wani & Dhanya, 2025).

4.2. Preliminary phytochemical composition

Qualitative screening confirmed positive reactions for carbohydrates, reducing constituents/sugars, tannins, flavonoids, fixed oils and fats, and phenolic compounds. The presence of several chemically distinct classes is consistent with recent literature describing banana peels as complex plant by-products containing phenolics, flavonoids, tannins, carbohydrates, dietary fiber, carotenoids, lipids, and other potentially valuable constituents (Bishnoi et al., 2023; Hikal et al., 2022; Zou et al., 2022).

The detection of phenolic compounds and flavonoids is particularly important in the context of antioxidant activity. Banana peel has been reported to contain phenolic compounds including catechin, epicatechin, gallic acid, tannins, and anthocyanin-related constituents, although composition can vary with plant material and extraction conditions. The qualitative findings of this study provide preliminary support for subsequent spectrophotometric and radical-scavenging assays (Avram et al., 2022; Dias et al., 2021; Hikal et al., 2022).

However, qualitative phytochemical reactions cannot identify or quantify individual compounds. Therefore, a positive colorimetric reaction should be interpreted as evidence consistent with a phytochemical class rather than as confirmation of a specific compound. Recent banana research increasingly incorporates instrumental approaches, such as chromatographic profiling and mass spectrometric characterization, for compound-level identification. Consequently, the present study is best positioned as a preliminary

phytochemical characterization rather than a comprehensive metabolomic analysis (Khan et al., 2025).

4.3. Fixed oil fraction

The banana peel material yielded 6.3% (w/w) of fixed oil. The extracted oil had an acid value of 11.68 mg KOH/g, saponification value of 437.58 mg KOH/g, and ester value of 425.90 mg KOH/g. These findings indicate that banana (*Musa* sp.) peels contain a measurable lipid fraction that may be relevant to broader waste utilization strategies in the future.

Recent reviews have described banana peels as heterogeneous biomass containing lipids, carbohydrates, fibers, minerals, and phytochemical constituents, supporting their potential use in various value-added applications. Banana by-products have been investigated as sources of functional ingredients, fermentation substrates, adsorbent materials, and other value-added products (Bishnoi et al., 2023; Manzoor & Ahmad, 2021; Putra et al., 2022; Zou et al., 2022). However, the physicochemical values reported for fixed oils should be interpreted with caution. The study did not determine fatty acid composition using GC or GC–MS, and no comparison of individual lipid species was possible. Therefore, these data are best regarded as baseline physicochemical measurements that can guide future compositional studies.

4.4. Folin–Ciocalteu assay response

The Folin–Ciocalteu assay showed a progressive increase in absorbance with increasing ethanolic banana peel extract concentration. The mean absorbance values of 0.851, 0.972, 1.100, and 1.320 were recorded at extract concentrations of 1, 2, 3, and 4 mg/mL, respectively, demonstrating a clear concentration-dependent response. The gallic acid calibration relationship was $A = 8.596X + 0.02$ ($R^2 = 0.990$), where A represents the absorbance, and X represents the amount of gallic acid in mg. This response is consistent with previous studies reporting the presence of phenolic constituents in banana peel extracts and their associated antioxidant properties (Avram et al., 2022; Gatasheh, 2026; Islam et al., 2023). The concentration-dependent Folin–Ciocalteu assay results are shown in Figure 3.

4.5. Aluminum chloride assay response

The aluminum chloride assay revealed a clear concentration-dependent increase in absorbance for 50% aqueous ethanol, methanol, ethanol, and aqueous extracts of the samples. At each tested concentration, the 50% aqueous ethanolic extract produced the greatest absorbance, increasing from 1.200 at 0.01 mg/mL to 2.450 at 0.04 mg/mL. Methanol and ethanol produced slightly lower responses, whereas the aqueous extract consistently produced the lowest absorbance.

These findings complement the crude extraction-recovery results but should be distinguished from them. Although water produced nearly the same total extract mass as 50% aqueous ethanol, the hydroalcoholic extract produced a stronger response to aluminum chloride. This distinction indicates that the crude extraction yield and flavonoid-associated colorimetric responses are not interchangeable.

Banana peel studies and reviews have consistently identified flavonoids as an important phytochemical group recovered from this plant by-product, with the extraction efficiency affected by the solvent system and processing conditions (Dias et al., 2021; İmece, 2026; Wani & Dhanya, 2025).

4.6. DPPH radical-scavenging activity

The ethanolic banana peel extract demonstrated a concentration-dependent increase in DPPH radical-scavenging activity, increasing from 52.37% inhibition at the lowest tested concentration (0.01 mg/mL) to 85.53% at the highest tested concentration (0.04 mg/mL). At

the highest concentration, the response approached that of the ascorbic acid reference, which showed 92.32% inhibition.

These findings indicate that the ethanolic banana peel extract contains constituents capable of participating in radical-scavenging reactions. Phenolic compounds and flavonoids in banana peels are frequently associated with antioxidant activity, and the DPPH assay is widely used for the preliminary evaluation of their radical-scavenging capacities. Previous studies have demonstrated substantial DPPH radical-scavenging activity in banana peel extracts. González-Montelongo et al. (2010) evaluated banana peel extracts obtained using solvents of different polarities, including ethanol and ethanol–water, and demonstrated that the extracts possessed substantial DPPH radical-scavenging capacity, with antioxidant activity varying according to the extraction solvent and the conditions. Avram et al. (2022) also reported antioxidant activity in banana peel extracts prepared using 50% ethanol, while Gatasheh (2026), Islam et al. (2023), and Ímece (2026) demonstrated the influence of extraction conditions on the recovery of phenolic constituents and the antioxidant activity of banana peel extracts. Collectively, these observations are consistent with the concentration-dependent radical-scavenging response observed for the ethanolic extract in the present study.

However, direct numerical comparisons among studies should be made cautiously because differences in banana cultivar and ripening stage, extraction procedures, solvent composition, extract and DPPH concentrations, reaction conditions, and methods used to express antioxidant activity can influence the reported results. Therefore, the present findings support previous evidence that banana peels contain ethanol-extractable constituents with radical-scavenging activity but should not be interpreted as demonstrating superior antioxidant activity compared to previously reported extracts.

4.7. Thin-layer chromatographic profile

TLC produced eight fluorescent spots with R_f values ranging from 0.0809 to 0.9875. The broad range of chromatographic mobilities indicates that the extract contains multiple constituents with different interactions with the stationary and mobile phases (Stahl, 1969).

TLC remains useful for the preliminary chemical fingerprinting of plant extracts when advanced chromatographic methods are not used. Khan et al. (2025) combined qualitative phytochemical analysis with TLC profiling to characterize the chemical diversity among banana (*Musa sp.*) cultivars.

In the absence of authentic standards, spectroscopic confirmation, or chromatographic–mass spectrometric analysis, the eight detected zones cannot be assigned to specific compounds and should be interpreted as chromatographically distinguishable components of the extract.

4.8. Relevance to banana-peel valorization

In summary, the extraction yield, phytochemical, flavonoid-associated, phenolic-associated, DPPH, and TLC findings support the broader concept of banana peel as a potentially useful biomass resource, rather than an inert food processing residue. Recent reviews have emphasized banana peel valorization through the recovery of polyphenols, dietary fiber, functional ingredients, bioactive extracts, fermentation substrates, biomaterials, and other products using sustainable and circular economy approaches (Bishnoi et al., 2023; Nirmal et al., 2023; Putra et al., 2022; Wani & Dhanya, 2025; Zou et al., 2022).

The present study contributes to this concept by showing that solvent selection substantially alters extract recovery and that a 50% aqueous ethanol system produced both the highest crude extract recovery and the strongest flavonoid-associated response among the polar extracts investigated. These results support hydroalcoholic extraction as a useful starting point for future studies on its optimization.

Modern extraction technologies, including ultrasound-assisted and microwave-assisted extraction, have been investigated as alternatives to conventional solvent extraction for recovering bioactive compounds from banana peels, with potential advantages in terms of extraction time, solvent requirements, and processing efficiency. However, the present study retains its value as a conventional baseline study because the same extraction platform was used across multiple solvents, allowing for direct observation of solvent-dependent differences under comparable conditions (Cegledi et al., 2024; Putra et al., 2022; Rifna et al., 2023).

4.9. Study limitations

Several limitations should be considered when interpreting the findings of this study. First, the investigation relied primarily on crude extraction recovery, qualitative phytochemical screening, colorimetric assays, DPPH radical-scavenging analysis, physicochemical measurements, and thin-layer chromatography rather than compound-specific chromatographic identification. Consequently, the individual phenolic and flavonoid constituents could not be identified or quantified.

Second, this study was descriptive and exploratory in nature. The reported spectrophotometric values represent mean measurements obtained in triplicate; however, standard deviations and inferential statistical analyses were not available. IC_{50} values and confidence intervals were not determined for the DPPH assay. In addition, DPPH radical-scavenging activity was evaluated for the ethanolic banana peel extract, rather than across all seven solvent extracts. Accordingly, the antioxidant findings should not be interpreted as a direct comparative assessment of antioxidant activity among all extraction systems.

Third, although banana (*Musa* sp.) fruits were grown in Libya and obtained from a local market in Ajdabiya City in June, the specific cultivar and ripening stages were not documented. These factors may influence the phytochemical composition, extraction recovery, and antioxidant characteristics of banana peels; therefore, they should be considered when interpreting the results of this study.

Finally, advanced compound identification and quantitative analytical techniques, including HPLC-DAD, LC-MS/MS, GC-MS, and NMR, were beyond the scope of the present study. Therefore, the findings should be regarded as preliminary phytochemical and antioxidant characterization that provides baseline evidence for more comprehensive future studies. Future studies should document banana cultivars and ripening stages, compare antioxidant activity across all extraction systems, retain complete replicate-level datasets for statistical analysis, and incorporate advanced chromatographic and spectroscopic techniques for compound identification and quantification.

5. Conclusions

This study demonstrated that the solvent composition markedly influenced the recovery of extractable constituents from dried banana (*Musa* sp.) peels. Among the seven extraction systems evaluated, 50% aqueous ethanol produced the highest crude extraction recovery (43.32%), followed by water (43.00%), methanol (37.08%), and absolute ethanol (30.62%). Acetone, diethyl ether, and n-hexane produced substantially smaller extract masses than methanol.

Qualitative phytochemical screening confirmed the presence of carbohydrates, reducing constituents/sugars, tannins, flavonoids, phenolic compounds, and fixed oils or fats in the extracts. The 50% aqueous ethanolic extract consistently produced the highest aluminum chloride assay response among the evaluated polar extracts. In contrast, the ethanolic extract exhibited concentration-dependent DPPH radical-scavenging activity, achieving 85.53%

inhibition at the highest concentration tested. TLC of the ethanolic banana peel extract revealed eight chromatographically distinct zones, indicating the presence of multiple constituents. Overall, the results indicate that banana (*Musa* sp.) peel is a chemically diverse agricultural and food-processing by-product with potential value-added applications. Considering both the crude extraction recovery and aluminum chloride assay response among the evaluated polar extracts, 50% aqueous ethanol was identified as a promising solvent system for further investigations. Because compound-specific identification and inferential statistical comparisons were not performed, these findings should be interpreted as baseline evidence, rather than definitive quantitative characterizations. Future studies should combine optimized green extraction methods with chromatographic identification, quantitative profiling, and biological validation.

6. Recommendations and Future Perspectives

Future investigations should focus on identifying and quantifying individual banana peel constituents using HPLC-DAD, UHPLC-MS/MS, GC-MS, and other complementary spectroscopic techniques. Particular attention should be given to phenolic acids, flavonoids, catecholamines, and other antioxidant constituents reported in recent studies on banana peels. Extraction optimization should compare conventional Soxhlet extraction with greener approaches, such as ultrasound-assisted extraction, microwave-assisted extraction, subcritical water extraction, and ethanol–water systems. Recent reviews indicate that such approaches may reduce extraction time and solvent consumption while maintaining or improving the phytochemical recovery (Cegledi et al., 2024; Putra et al., 2022; Rifna et al., 2023; Wani & Dhanya, 2025).

Future studies should include complete replicate-level datasets so that the results can be reported as mean $\pm$ standard deviation, statistically compared across solvents, and modeled using appropriate optimization approaches. Phenolic and flavonoid contents should be expressed in standardized quantitative units, such as mg GAE/g and mg QE/g, only when the corresponding calibration and calculation datasets are complete and traceable.

Biological evaluation should be broadened beyond DPPH to include complementary antioxidant assays and, where scientifically justified, antimicrobial, anti-inflammatory, enzyme inhibition, and cell-based investigations. This would help establish whether the phytochemical profile translates into functionally relevant biological activity.

Finally, banana (*Musa* sp.) peels should be investigated within a broader waste valorization framework to enhance their utilization efficiency. Contemporary literature supports the potential use of these byproducts as sources of functional ingredients, dietary fibers, antioxidant extracts, biomaterials, fermentation substrates, and other value-added products (Bishnoi et al., 2023; Nirmal et al., 2023; Putra et al., 2022; Zou et al., 2022).

References

- Alara, O. R., Abdurahman, N. H., & Ukaegbu, C. I. (2021). Extraction of phenolic compounds: A review. *Current Research in Food Science*, 4, 200–214. <https://doi.org/10.1016/j.crfs.2021.03.011>
- Avram, I., Gatea, F., & Vamanu, E. (2022). Functional compounds from banana peels are used to decrease the effects of oxidative stress. *Processes*, 10(2), 248. <https://doi.org/10.3390/pr10020248>

- Bishnoi, S., Sharma, S., & Agrawal, H. (2023). Exploration of the potential application of banana peel for its effective valorization: A review. *Indian Journal of Microbiology*, 63(4), 398–409. <https://doi.org/10.1007/s12088-023-01100-w>
- Brand-Williams, W., Cuvelier, M. E., & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT - Food Science and Technology*, 28(1), 25–30. [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5)
- Cegledi, E., Dobroslavić, E., Pedisić, S., Magnabosca, I., Zorić, M., Pavić, R., Šuto, M., Štargl, O., Repajić, M., & Elez Garofulić, I. (2024). Green approaches for the extraction of banana peel phenolics using deep eutectic solvents. *Molecules*, 29(15), 3672. <https://doi.org/10.3390/molecules29153672>
- Chang, C.-C., Yang, M.-H., Wen, H.-M., & Chern, J.-C. (2002). Estimation of total flavonoid content in propolis using two complementary colorimetric methods. *Journal of Food and Drug Analysis*, 10(3), 178–182. <https://doi.org/10.38212/2224-6614.2748>
- Dias, M. C., Pinto, D. C. G. A., & Silva, A. M. S. (2021). Plant flavonoids: Chemical characteristics and biological activity. *Molecules*, 26(17), 5377. <https://doi.org/10.3390/molecules26175377>
- Evans, W. C. (2009). *Trease and Evans' pharmacognosy* (16th ed.). Saunders Elsevier. <https://doi.org/10.1016/B978-0-7020-2933-2.X0001-9>
- Gatasheh, M. K. (2026). Extraction of polyphenols from unripe banana peels via response surface methodology and analysis of in vitro bioactive properties. *BioResources*, 21(2), 4678–4700. <https://doi.org/10.15376/biores.21.2.4678-4700>
- González-Montelongo, R., Lobo, M. G., & González, M. (2010). Antioxidant activity in banana peel extracts: Testing extraction conditions and related bioactive compounds. *Food Chemistry*, 119(3), 1030–1039. <https://doi.org/10.1016/j.foodchem.2009.08.012>
- Herrera-Pool, E., Ramos-Díaz, A. L., Lizardi-Jiménez, M. A., Pech-Cohuo, S., Ayora-Talavera, T., Cuevas-Bernardino, J. C., García-Cruz, U., & Pacheco, N. (2021). Effect of solvent polarity on the ultrasound assisted extraction and antioxidant activity of phenolic compounds from habanero pepper leaves (*Capsicum chinense*) and its identification by UPLC-PDA-ESI-MS/MS. *Ultrasonics Sonochemistry*, 76, 105658. <https://doi.org/10.1016/j.ultsonch.2021.105658>
- Hikal, W. M., Said-Al Ahl, H. A. H., Bratovcic, A., Tkachenko, K. G., Sharifi-Rad, J., Kačániová, M., Elhourri, M., & Atanassova, M. (2022). Banana peels: A waste treasure for human being. *Evidence-Based Complementary and Alternative Medicine*, 2022, 7616452. <https://doi.org/10.1155/2022/7616452>
- İmece, A. (2026). Influence of extraction parameters on bioactive compounds and antimicrobial activity of banana peel using ethanol-water solvent. *Journal of the Institute of Science and Technology*, 16(1), 167–181. <https://doi.org/10.21597/jist.1745262>
- International Union of Pure and Applied Chemistry (IUPAC). (1987). *Standard methods for the analysis of oils, fats, and derivatives* (7th ed.). Blackwell Scientific Publications.
- Islam, M. R., Kamal, M. M., Kabir, M. R., Hasan, M. M., Haque, A. R., & Hasan, S. M. K. (2023). Phenolic compounds and antioxidants activity of banana peel extracts: Testing and optimization of enzyme-assisted conditions. *Measurement: Food*, 10, 100085. <https://doi.org/10.1016/j.meafao.2023.100085>
- Khan, A., Swennen, R., Panda, S. K., Schoofs, L., & Luyten, W. (2025). Qualitative phytochemical analysis, thin-layer chromatographic profiling, and antimicrobial potential of banana cultivars. *Electronic Journal of Biotechnology*, 78, 64–75. <https://doi.org/10.1016/j.ejbt.2025.07.005>

- Majerska, J., Michalska, A., & Figiel, A. (2019). A review of new directions in managing fruit and vegetable processing by-products. *Trends in Food Science & Technology*, 88, 207–219. <https://doi.org/10.1016/j.tifs.2019.03.021>
- Manzoor, A., & Ahmad, S. (2021). Banana peel: Characteristics and consideration of its extract for use in meat products preservation: A review. *ACS Food Science & Technology*, 1(9), 1492–1506. <https://doi.org/10.1021/acsfoodscitech.1c00235>
- Nirmal, N. P., Khanashyam, A. C., Mundanat, A. S., Shah, K., Babu, K. S., Thorakkattu, P., Al-Asmari, F., & Pandiselvam, R. (2023). Valorization of fruit waste for bioactive compounds and their applications in the food industry. *Foods*, 12(3), 556. <https://doi.org/10.3390/foods12030556>
- Ojong, C., Besong, S. A., & Aryee, A. N. A. (2026). Solvent-based extraction recovers phytochemicals from medicinal plants demonstrating anticancer and chemopreventive potential: A review. *Molecules*, 31(7), 1202. <https://doi.org/10.3390/molecules31071202>
- Putra, N. R., Aziz, A. H. A., Faizal, A. N. M., & Che Yunus, M. A. (2022). Methods and potential in valorization of banana peels waste by various extraction processes: In review. *Sustainability*, 14(17), 10571. <https://doi.org/10.3390/su141710571>
- Rifna, E. J., Misra, N. N., & Dwivedi, M. (2023). Recent advances in extraction technologies for the recovery of bioactive compounds derived from fruit and vegetable waste peels: A review. *Critical Reviews in Food Science and Nutrition*, 63(6), 719–752. <https://doi.org/10.1080/10408398.2021.1952923>
- Singleton, V. L., & Rossi, J. A., Jr. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture*, 16(3), 144–158. <https://doi.org/10.5344/ajev.1965.16.3.144>
- Someya, S., Yoshiki, Y., & Okubo, K. (2002). Antioxidant compounds from bananas (*Musa Cavendish*). *Food Chemistry*, 79(3), 351–354. [https://doi.org/10.1016/S0308-8146\(02\)00186-3](https://doi.org/10.1016/S0308-8146(02)00186-3)
- Stahl, E. (Ed.). (1969). *Thin-layer chromatography: A laboratory handbook* (2nd ed.). Springer-Verlag. <https://doi.org/10.1007/978-3-642-88488-7>
- Sultana, B., Anwar, F., & Ashraf, M. (2009). Effect of extraction solvent/technique on the antioxidant activity of selected medicinal plant extracts. *Molecules*, 14(6), 2167–2180. <https://doi.org/10.3390/molecules14062167>
- Wani, K. M., & Dhanya, M. (2025). Unlocking the potential of banana peel bioactives: Extraction methods, benefits, and industrial applications. *Discover Food*, 5, Article 8. <https://doi.org/10.1007/s44187-025-00276-y>
- Zou, F., Tan, C., Zhang, B., Wu, W., & Shang, N. (2022). The valorization of banana by-products: Nutritional composition, bioactivities, applications, and future development. *Foods*, 11(20), 3170. <https://doi.org/10.3390/foods11203170>

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of JLABW and/or the editor(s). JLABW and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.