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Antioxidant Activity of Ethanol Extract Combination of Cavendis Banana Peel (*Musa acuminata*) and Kepok Banana Peel (*Musa paradisiaca*) Using the DPPH Method

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Abstract

Banana peels, often considered agricultural waste, are rich in bioactive compounds with significant antioxidant potential. This study evaluates the antioxidant activity of a combined ethanol extract from Cavendis (Musa acuminata) and Kepok (Musa paradisiaca) banana peels using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay. The extraction was performed via maceration with 96% ethanol, yielding 9.13%. Phytochemical analysis identified key compounds including flavonoids, tannins, saponins, and steroids/terpenoids, which are known to exhibit antioxidant properties. The extract demonstrated strong radical scavenging activity with an IC50 of 6.47 ppm and an Antioxidant Activity Index (AAI) of 5.40, comparable to Vitamin C (IC50 = 6.29 ppm; AAI = 5.56). These results indicate a synergistic effect from combining the two banana peel varieties, enhancing antioxidant efficacy beyond that reported for individual peels. This study supports the potential use of Cavendis and Kepok banana peel extracts as sustainable natural antioxidants for application in food preservation, nutraceuticals, and cosmetics. Future work should focus on optimizing extraction methods, detailed phytochemical profiling, stability assessment, and in vivo validation to advance product development and maximize health benefits.

Keywords: antioxidant activity; cavendis banana peel; kepok banana peel; IC50; DPPH

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INTRODUCTION

Antioxidants play a crucial role in mitigating the detrimental effects of free radicals, which are implicated in the pathogenesis of various degenerative diseases such as cancer, cardiovascular diseases, diabetes, and neurodegenerative disorders (Aly et al., 2017). Free radicals are unstable molecules containing one or more unpaired electrons, rendering them highly reactive and capable of damaging cellular components including proteins, lipids, and DNA (Türker & Savlak, 2021). Although the human body possesses intrinsic antioxidant defense mechanisms, these systems are often insufficient to fully counteract oxidative stress induced by external factors such as pollution, unhealthy diet, and ultraviolet radiation exposure (Samiasih et al., 2023). Therefore, supplementation with exogenous antioxidants, particularly those derived from natural sources, is essential to maintain physiological redox homeostasis (Pereira et al., 2016).

Recent studies have highlighted the significant potential of natural antioxidants from plant extracts and agro-industrial waste as safer alternatives to synthetic antioxidants, which are often associated with toxicity and carcinogenicity risks (Vu et al., 2016). Banana peel, frequently discarded as organic waste, is rich in bioactive compounds such as flavonoids, saponins, tannins, and other phenolics exhibiting potent antioxidant activities (Sutjiatmo et al., 2021; Türker & Savlak, 2021). These compounds inhibit oxidative damage by donating electrons to free radicals, thereby stabilizing these harmful molecules and protecting cellular integrity (Pereira et al., 2016).

Banana peel is a widely available organic residue in tropical countries like Indonesia, where banana (Musa spp.) is among the most consumed fruits; nevertheless, the peel is often underutilized (Bassuony, 2015). Studies have shown that banana peel contains bioactive constituents such as flavonoids, saponins, tannins, and polyphenols that exert antioxidant, antimicrobial, and anti-inflammatory effects (Sutjiatmo et al., 2021; Türker & Savlak, 2021). Türker and Savlak (2021) reported that catechin and gallocatechin, flavonoid subclasses, demonstrate significant antioxidant activity, surpassing that found in the pulp (Khoozani et al., 2019). Additionally, Sutjiatmo et al. (2021) observed that extracts from Raja Bulu banana peel possess notable in vitro anticancer potential by inhibiting cancer cell proliferation. Active compounds in banana peel have also been shown to reduce malondialdehyde (MDA) levels, a biomarker of oxidative damage, in various animal models (Samiasih et al., 2023). Furthermore, banana peel exhibits considerable antimicrobial activity, inhibiting pathogens such as Escherichia coli and Staphylococcus aureus, suggesting its applicability as a natural food preservative (Arista et al., 2023; Bassuony, 2015).

The antioxidant efficacy of banana peel extracts is strongly influenced by the extraction method employed (Anjum et al., 2022). Optimal extraction techniques enable greater yield and stability of bioactive compounds. Ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) have been demonstrated to be more effective in isolating phenolic compounds compared to conventional maceration (Vu et al., 2016; Vu et al., 2019). UAE enhances solvent penetration via ultrasonic waves, facilitating the release of bioactives, whereas MAE rapidly and uniformly heats samples, reducing extraction time and preventing degradation of sensitive compounds (Vu et al., 2019). However, this study employed maceration due to its simplicity and cost-effectiveness, albeit without optimization; therefore, future work should explore UAE and MAE to improve extraction efficiency. Besides extraction methodology, environmental factors such as temperature, pH, and storage conditions also impact the stability of bioactive compounds (Šeremet et al., 2022; Lopes et al., 2022). Thus, optimizing extraction and storage parameters is critical to preserve antioxidant activity consistently (Hidayati et al., 2020).

Despite the demonstrated antioxidant potential of banana peel extracts (Khamsaw, 2024), challenges remain in their application, notably the stability of active compounds during processing and storage. Phenolic constituents are susceptible to degradation by light, oxygen, and elevated temperatures (Lopes et al., 2022). Moreover, bioavailability—the extent to which bioactives are absorbed and utilized by the body—is a key consideration. Dietary fiber present in banana peel may enhance bioactive absorption within the gastrointestinal tract (Kumari, 2023). Nonetheless, comprehensive phytochemical profiling combined with metabolomic analyses is warranted to elucidate the bioactivity and absorption mechanisms of key compounds.

While numerous studies have investigated antioxidant properties of individual banana peel varieties (Okolie et al., 2016), research on the synergistic antioxidant effects of combining Cavendis (Musa acuminata) and Kepok (Musa paradisiaca) banana peels remains scarce. Prior reports indicate that IC50 values for single-variety banana peels range between 80 and 120 ppm, whereas the current study demonstrates a substantially lower IC50 of 6.47 ppm for the combined extract, indicating a marked synergistic enhancement. Additionally, variability in

extraction methods, extract concentration, and environmental conditions during assays can affect antioxidant activity outcomes. Hence, this study aims to evaluate the antioxidant activity of ethanol extracts from combined Cavendis and Kepok banana peels using the DPPH assay, comparing their efficacy against the standard antioxidant Vitamin C. The findings are anticipated to contribute to the development of more effective, sustainable, and applicable natural antioxidant sources, particularly for food and pharmaceutical industries.

METHOD

Research Design

This study was designed as an experimental laboratory investigation to evaluate the antioxidant activity of ethanol extracts from a combination of Cavendis banana peel (Musa acuminata) and Kepok banana peel (Musa paradisiaca) using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay. The DPPH method was selected due to its efficacy in assessing the capacity of antioxidant compounds to scavenge free radicals via the reduction of DPPH radicals, which is indicated by a color change from purple to yellow. This color change was quantitatively measured using a UV-Vis spectrophotometer at a wavelength of 517 nm (Pereira et al., 2016). The study employed a comparative approach, including positive control (Vitamin C) and negative control (pure DPPH solution). Antioxidant activity was quantified based on the inhibitory concentration (IC50), which represents the extract concentration required to inhibit 50% of DPPH radicals. Additionally, the Antioxidant Activity Index (AAI) was calculated to objectively classify antioxidant potency. All experiments were conducted under controlled conditions to ensure accuracy and reproducibility, including routine spectrophotometer calibration and measurement replication (Khang et al., 2021).

Population and Samples

The study population consisted of Cavendis (Musa acuminata) and Kepok (Musa paradisiaca) banana peels, selected for their high potential as natural antioxidant sources. Samples were obtained using purposive sampling, based on specific criteria including optimal ripeness, freedom from contaminants, and absence of fermentation or physical damage. Approximately 1 kg of each banana peel type was collected from a local market in Mataram, West Nusa Tenggara. The samples were processed into dried simplicia using a combined drying method—initially air-dried for three days at room temperature (25–30°C) in a closed environment to prevent contamination, followed by oven drying at 50°C for two days to ensure moisture reduction and inhibit fungal growth. The dried peels were then ground into a fine powder to facilitate extraction. Sample selection and pretreatment were performed meticulously to ensure optimal extract quality reflecting antioxidant activity (Nofianti et al., 2021).

Research Instrument

A combination of laboratory instruments was employed to ensure accuracy and validity in antioxidant activity testing. Key materials included Cavendis and Kepok banana peels, 96% ethanol as solvent, DPPH powder as the antioxidant activity indicator, and Vitamin C as the positive control. Instruments used comprised a UV-Vis spectrophotometer for absorbance measurements at 517 nm, a rotary evaporator for solvent removal from macerated filtrate, and a temperature-controlled oven for drying simplicia samples. All instruments were routinely calibrated prior to use to maintain measurement accuracy. Moreover, all chemicals utilized were of high purity to avoid interference in antioxidant assays (Pereira et al., 2016).

Validity and reliability in this study were ensured through systematic procedures. Firstly, the UV-Vis spectrophotometer was routinely calibrated using standard reference materials to guarantee precise and reliable absorbance measurements (Khang et al., 2021). Secondly, each sample was tested in triplicate (n=3) to reduce data variability and enhance confidence in the results. Positive controls (Vitamin C) and negative controls (pure DPPH solution) were

included in every assay to verify procedural effectiveness. The use of these internal standards minimized variability arising from external factors. Furthermore, spectrophotometric data were cross-validated against previous studies to assess consistency (Pereira et al., 2016).

Table 1. Sample measurement equipment

Instrument	Function
UV-Vis Spektrofotometer	Measures absorbance at 517 nm wavelength
Rotary evaporator	Evaporates solvent from extract filtrate
Temperature-Controlled Oven	Dries banana peel at low temperature
Blender	Grinds dried samples into powder
Test Tubes	Reaction vessels for antioxidant assays
Micropipette	Precisely measures solution volumes

Data Collection Techniques

Data collection was systematically conducted to ensure the validity and reliability of obtained results. The data collection process encompassed several key stages: sample preparation, bioactive compound extraction, phytochemical screening, antioxidant activity assay using the DPPH method, and calculation of IC50 values alongside the Antioxidant Activity Index (AAI).

Sample Preparation

Sample preparation aimed to ensure the quality and purity of materials used in the study. Cavendis and Kepok banana peels were sourced from a local market in Mataram, West Nusa Tenggara. Samples were selectively chosen based on criteria including optimal ripeness, absence of contaminants, lack of fermentation, and no physical damage to the peel. Peels were thoroughly washed under running water to remove dirt and pesticide residues. Subsequently, the peels were cut into small pieces to accelerate drying and increase the surface area exposed to air. Drying was conducted in two stages: first, air-drying for three days at room temperature (25–30°C) in a closed environment to avoid contamination; second, oven drying at 50°C for two days to optimize moisture reduction and prevent fungal growth. The dried samples were then ground using a blender into a fine, homogeneous powder. The resulting simplicia powder was stored in airtight glass containers wrapped with aluminum foil to protect from direct light exposure and preserve the stability of bioactive compounds (Nofianti et al., 2021).

Extraction of Bioactive Compounds

This method was chosen for its ability to extract polar and semi-polar compounds such as flavonoids, tannins, and polyphenols without damaging their chemical structures (Pereira et al., 2016). A total of 150 grams each of Cavendis and Kepok banana peel powders were placed in dark glass jars to prevent compound degradation due to light exposure. The powders were then macerated in 1 liter of 96% ethanol and stirred intermittently every 24 hours for six days to ensure thorough solvent penetration and optimal extraction of bioactive compounds. Following maceration, the solution was filtered using filter paper to separate the filtrate from solid residues. The filtrate was concentrated using a rotary evaporator at 50°C to remove the solvent and obtain a concentrated extract. This process was carefully controlled to prevent thermal degradation of bioactive compounds. The concentrated extract was subsequently stored in dark glass containers at low temperature to maintain compound stability until further analysis (Khang et al., 2021).

Phytochemical Screening

Phytochemical screening was conducted to qualitatively identify secondary metabolites that play significant roles in antioxidant activity, including flavonoids, tannins, saponins, and steroids/terpenoids. This analysis aimed to provide information on the types of bioactive compounds present in the ethanol extract combination of Cavendis and Kepok banana peels

(Sutjiatmo et al., 2021). The flavonoid test involved adding magnesium powder and 10 drops of concentrated hydrochloric acid (HCl) to 1 mL of extract, with a positive result indicated by the formation of a brick-red color. The saponin test consisted of adding distilled water to 1 mL extract, heating, and vigorously shaking; stable foam formation indicated saponin presence. The tannin test was performed by adding 1–2 drops of 1% $FeCl_3$ to 1 mL extract, with a positive indication shown by a greenish-black color change. Steroid and terpenoid tests involved the addition of acetic anhydride and concentrated sulfuric acid to 1 mL extract; a blue coloration signified steroids, while purple indicated terpenoids. These phytochemical results formed the basis for interpreting the compounds contributing to the antioxidant activity of the Cavendis and Kepok peel extract combination (Nofianti et al., 2021).

Antioxidant Activity Assay Using DPPH Method

The antioxidant activity assay was performed using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) method, a standard technique for evaluating free radical scavenging capacity. The principle of this method is the reduction of DPPH free radicals by antioxidants, indicated by a color change of the solution from purple to pale yellow, which is then quantified using a UV-Vis spectrophotometer at 517 nm (Pereira et al., 2016). The DPPH solution was prepared by dissolving 10 mg of DPPH powder in 100 mL of 96% ethanol. The Cavendis and Kepok banana peel extracts were diluted to obtain test concentrations of 10, 20, 30, 40, and 50 ppm. Subsequently, 0.2 mL of each sample solution was mixed with 3.8 mL of DPPH solution and incubated in the dark at room temperature for 30 minutes. Following incubation, the absorbance of the solutions was measured using the UV-Vis spectrophotometer at 517 nm. These measurements were then used to calculate the IC50 value and the Antioxidant Activity Index (AAI).

Calculation of IC50 and Antioxidant Activity Index (AAI)

The IC50 value, defined as the inhibitory concentration required to scavenge 50% of DPPH radicals, was calculated. Lower IC50 values indicate stronger antioxidant capacity. IC50 was derived from the relationship between extract concentration (ppm) and percentage inhibition, analyzed using linear regression. The general regression equation used was $Y = aX + b$, where Y represents the percentage inhibition, a is the slope, b is the intercept, and X is the extract concentration required to achieve 50% inhibition. The IC50 was obtained by substituting Y with 50 in the regression equation. Subsequently, the Antioxidant Activity Index (AAI) was calculated to assess the strength of antioxidant activity, taking into account the initial concentration of DPPH used. AAI values were classified into four categories: <0.5 (weak activity), 0.5–1.0 (moderate activity), 1.0–2.0 (strong activity), and >2.0 (very strong activity). The IC50 and AAI values were analyzed and compared with standard antioxidants such as Vitamin C to evaluate the efficacy of the combined ethanol extract of Cavendis and Kepok banana peels in scavenging DPPH free radicals. These parameters are crucial for understanding the extract's potential as an effective natural antioxidant source applicable in food and pharmaceutical sectors (Nofianti et al., 2021; Pereira et al., 2016).

Data Analysis Techniques

This study employed both qualitative and quantitative data analysis. Qualitative data were obtained from phytochemical screening, identifying flavonoids, tannins, saponins, steroids, and terpenoids. Quantitative data comprised IC50 and Antioxidant Activity Index (AAI) measurements obtained via the DPPH assay. Data analysis was performed using statistical software (e.g., SPSS version X or Microsoft Excel), ensuring accuracy and reliability of results. The IC50 and AAI values were presented in tables and graphs to facilitate interpretation and comparison with previous studies (Pereira et al., 2016; Nofianti et al., 2021). This analysis aimed to evaluate the antioxidant potential of the combined Cavendis and Kepok banana peel extracts as an effective natural antioxidant source.

RESULTS AND DISCUSSION

Extraction Yield Results

Extraction was carried out using the maceration method with 96% ethanol as solvent over six days with periodic stirring. A total of 150 grams each of Cavendis banana peel powder (Musa acuminata) and Kepok banana peel powder (Musa paradisiaca) were used in the process. After filtration and solvent evaporation using a rotary evaporator at 50°C, a concentrated extract weighing 27.38 grams was obtained. The extraction yield was calculated to be 9.13%, indicating a moderate extraction efficiency that is slightly below the optimal yields (>10%) reported in previous studies (Sutjiatmo et al., 2021). Detailed extraction results and yields are presented in Table 2.

Table 2. Ethanol Extract Results of Combination of Cavendish Banana Peel and Kepok Banana Peel

Fresh Banana Peel Weight	Simplicity Powder Weight	Ethanol Solvent 96%	Maseration Results	Extract Weight	% Extract Yield
1 kg Cavendis & 1 kg Kepok	150 g Cavendis & 150 g Kepok	1 Liter	500 mL	27.38 g	9.13

Phytochemical Screening Results

Phytochemical screening was conducted to identify bioactive compounds present in the ethanol extract of combined Cavendis and Kepok banana peels. The results indicated the presence of several major bioactive compounds: flavonoids, tannins, saponins, and steroids/terpenoids. Flavonoids were indicated by a brick-red color change; tannins by a greenish-black color; saponins by the formation of stable foam upon shaking; and steroids/terpenoids by green (steroids) and purple (terpenoids) coloration. These bioactive compounds play significant roles in the antioxidant activity of the extract, as supported by previous research (Türker & Savlak, 2021). Detailed phytochemical screening results are shown in Table 3.

Table 3. Phytochemical Screening Results of Ethanol Extract of Combination of Cavendish Banana Peel and Kepok Banana Peel

Compound Group	Observation	Result
Flavonoid	Brick-red coloration	√
Tanin	Greenish-black coloration	√
Saponin	Stable foam formation	√
Steroid/Terpenoid	Green (steroids) and purple (terpenoids) colors	√

Antioxidant Activity Using DPPH Method

The antioxidant activity of the combined ethanol extract from Cavendis and Kepok banana peels was assessed using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) method. This assay aimed to determine the extract's capacity to scavenge free radicals by measuring IC50 and AAI values. The results showed: (1) IC50 of the combined banana peel extract was 6.47 ppm; (2) IC50 of Vitamin C (positive control) was 6.29 ppm; (3) AAI of the combined extract was 5.40; and (4) AAI of Vitamin C was 5.56. According to Molyneux's classification (2004), both samples fall under the "very strong antioxidant" category (IC50 < 50 ppm). These values indicate that the antioxidant activity of the combined banana peel extract approaches that of Vitamin C. Detailed percentage inhibition data are presented in Table 4, while graphical representations of concentration vs. inhibition percentages are shown in Figures 1 and 2 for the combined extract, and Figures 3 and 4 for Vitamin C.

Table 4. Percentage of Free Radical Inhibition by Combination Extract of Cavendish and Kepok Banana Peels and Vitamin C

Sample	Concentration (ppm)	Blank Absorbance	Sample Absorbance	% Inhibition
Combined Cavendis & Kepok Peel Extract	10	0.905	0.668	26.18
	20		0.692	23.53
	30		0.724	20.00
	40		0.750	17.12
	50		0.782	13.59
Vitamin C (Positive Control)	10	0.905	0.608	32.81
	20		0.617	31.82
	30		0.625	30.93
	40		0.667	26.29
	50		0.684	24.41

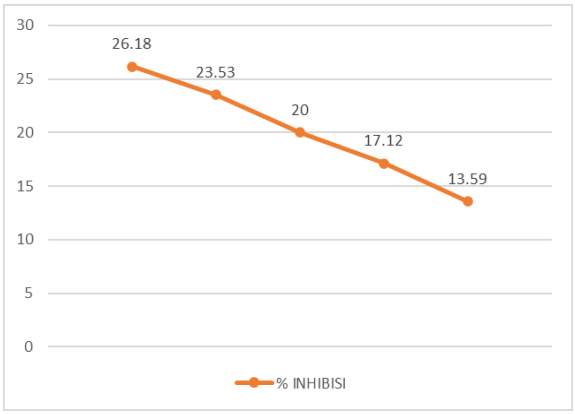

Figure 1. Linear Regression Curve of Combined Cavendis and Kepok Banana Peel Extract

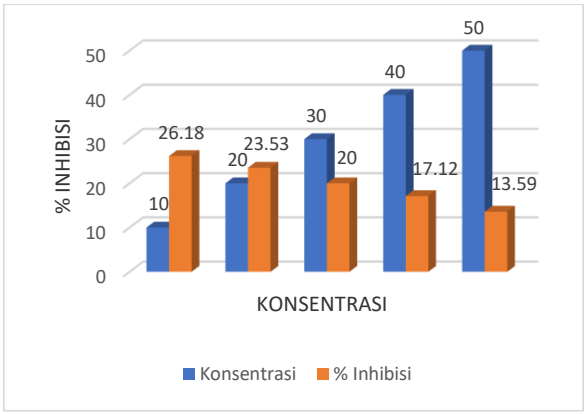

Figure 2. Relationship Between Concentration and Percentage Inhibition of Combined Banana Peel Extract

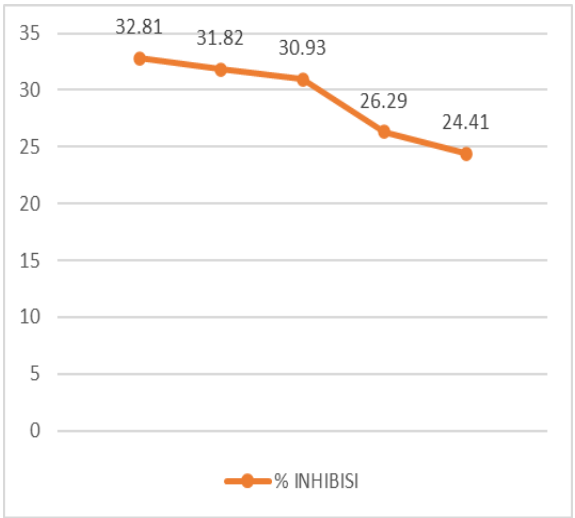

Figure 3. Linear Regression Curve of Vitamin C

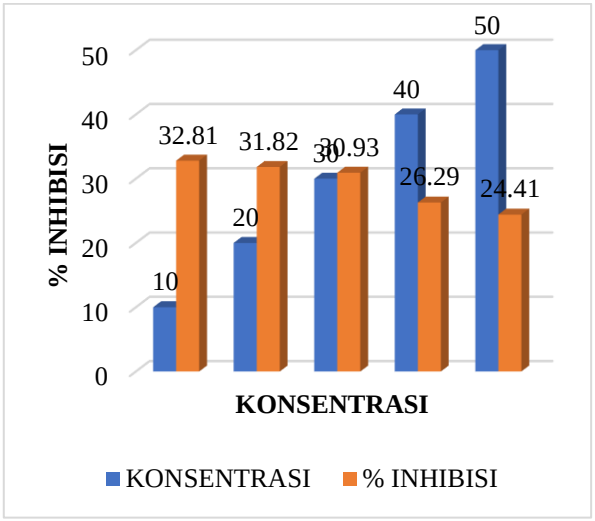

Figure 4. Relationship Between Concentration and Percentage Inhibition of Vitamin C

Linear Regression Graph and IC50 Values

The linear regression graph demonstrates a strong negative correlation between extract concentration and percentage inhibition. This indicates that as extract concentration increases, the measured absorbance decreases, reflecting enhanced antioxidant activity. The IC50 value

was calculated from this regression equation (Table 5) by substituting Y with 50, representing the concentration needed to inhibit 50% of free radicals. Overall, these results indicate that the combination of Cavendis and Kepok banana peels exhibits very strong antioxidant activity, approaching the efficacy of Vitamin C as the positive control. Further detailed analysis of these findings is discussed in the Discussion section.

Table 5. IC50 value of ethanol extract of combination of cavendish banana peel and kepok banana peel and vitamin C

Sample	Linear Regression Equation	Value of IC50 (ppm)	Value of AAI DPPH / IC50	Clasification
Combined Cavendis and Kepok Banana Peel Extract	Y = -3.159x + 29.561	6.47	5.40	Very strong antioxidant
Vitamin C	Y = -2.233x + 35.951	6.29	5.56	Very strong antioxidant

Discussion

The current study investigated the antioxidant potential of the combined ethanol extract of Cavendis (Musa acuminata) and Kepok (Musa paradisiaca) banana peels, utilizing a conventional maceration extraction method with 96% ethanol as solvent. The extraction yielded 9.13%, a value somewhat lower than previously reported yields exceeding 10% (Sutjiatmo et al., 2021). Several factors likely contribute to this moderate yield, including the relatively short maceration duration of six days, extraction temperature, and raw material quality. Literature suggests that optimal maceration time spans from 7 to 14 days, which allows better solvent penetration and more efficient extraction of bioactive compounds from plant cell walls (Khacharat et al., 2022).

Extending extraction time could improve yield by enabling more complete dissolution of phenolics and flavonoids, which reside within the cellular matrix of the peel. Similarly, extraction temperature must balance maximized solubility and stability of thermolabile compounds. The rotary evaporator's role in concentrating the extract at 50°C was critical to prevent thermal degradation of sensitive phytochemicals, underscoring the need for precise control over extraction parameters to optimize recovery (Pereira et al., 2016).

The choice of 96% ethanol as solvent was grounded in its recognized efficacy in extracting polar to semi-polar phytochemicals such as flavonoids, tannins, and saponins. These compounds are typically soluble in ethanol-water mixtures, and 96% ethanol represents a common optimal polarity for maximizing yield (Pereira et al., 2016). However, slight variations in ethanol concentration can dramatically affect extraction efficiency, as solvent polarity influences the solubility of individual phenolic compounds (Vu et al., 2016). Future studies could examine alternative extraction techniques, such as ultrasound-assisted extraction (UAE) or microwave-assisted extraction (MAE), which have been shown to enhance yield and preserve antioxidant activity by reducing extraction time and thermal exposure (Vu et al., 2019). Such advanced methods might also improve the sustainability and scalability of extraction processes for industrial applications.

Phytochemical screening revealed the presence of flavonoids, tannins, saponins, and steroids/terpenoids in the combined extract. These classes of secondary metabolites are well-documented contributors to antioxidant activity, acting via multiple complementary mechanisms (Türker & Savlak, 2021). Flavonoids, notably catechins and gallocatechins identified in banana peels (Türker & Savlak, 2021; Khoozani et al., 2019), exert antioxidant effects primarily through electron or hydrogen atom donation to neutralize reactive oxygen species (ROS). Their hydroxyl groups stabilize free radicals by resonance delocalization, effectively interrupting oxidative chain reactions (Parvez et al., 2023). Additionally, flavonoids

inhibit lipid peroxidation, protecting cell membranes from oxidative damage and reducing cellular apoptosis induced by oxidative stress (Khacharat et al., 2022). Tannins complement these effects by acting as both primary antioxidants—directly scavenging free radicals—and secondary antioxidants—chelating metal ions and thus preventing radical formation (Khacharat et al., 2022). Their ability to bind proteins and heavy metals further limits oxidative damage and enhances overall cellular protection.

Saponins contribute to antioxidant activity through electron donation similar to flavonoids, while also possessing antimicrobial properties that may aid in preserving food products or enhancing pharmaceutical formulations (Bassuony, 2015; Arista et al., 2023). Steroids and terpenoids regulate intracellular oxidative metabolism, suppressing free radical generation pathways (Nofianti et al., 2021). The presence of these diverse bioactive classes likely accounts for the observed potent antioxidant effects, highlighting the advantage of using combined banana peel varieties to harness a broader phytochemical spectrum and possible synergistic interactions.

The DPPH assay results support this hypothesis. The combined Cavendis and Kepok peel extract exhibited an IC50 of 6.47 ppm and an AAI of 5.40, values closely comparable to Vitamin C's IC50 of 6.29 ppm and AAI of 5.56. According to Yunus et al. (2020), these IC50 values firmly place both samples within the "very strong antioxidant" category (IC50 < 50 ppm). The proximity of the extract's antioxidant capacity to that of Vitamin C—one of the most widely recognized and effective natural antioxidants—underscores its significant potential. This strong activity is attributable to the combined bioactive profiles, as flavonoids and tannins are known to efficiently scavenge DPPH radicals by donating electrons or hydrogen atoms (Khacharat et al., 2022). The synergistic effect of multiple antioxidant compounds likely enhances radical scavenging efficacy beyond what single compounds can achieve alone.

When compared with other banana peel varieties, the combined extract displays superior antioxidant activity. For instance, Siji & P.V. (2017) reported a much higher IC50 of 115 µg/mL for Raja Bulu banana peel extract, reflecting moderate antioxidant activity. This stark difference demonstrates the enhanced potency of the Cavendis-Kepok combination, possibly due to a richer or more diverse phytochemical content. Rahmi et al. (2022) similarly highlighted this increased activity relative to other varieties. The close relationship between total phenolic content and antioxidant capacity is well established, with higher phenolic levels correlating to lower IC50 values, as confirmed by Nofianti et al. (2021). This indicates that the Cavendis and Kepok peels likely contain elevated phenolic concentrations, reinforcing their potential as superior antioxidant sources.

Variability in antioxidant activity among banana varieties is further supported by comparative studies. Sutjiatmo et al. (2021) again demonstrated moderate activity in Raja Bulu peel, while Wijaya et al. (2023) found stronger antioxidant effects in Kedondong leaf extracts, emphasizing that species, environmental growth conditions, and extraction methods influence phytochemical profiles and antioxidant potency. Parvez et al. (2023) corroborated the positive correlation between flavonoid and phenolic content and antioxidant strength, suggesting that environmental factors and genetic differences affect biosynthesis of these compounds. This variability underlines the importance of selecting specific banana varieties and optimizing extraction protocols for targeted antioxidant applications.

The strong antioxidant activity of the Cavendis-Kepok extract indicates significant potential for practical applications. In the food industry, the extract could serve as a natural preservative to inhibit lipid oxidation, extending shelf life and enhancing nutritional quality. Its antimicrobial properties also suggest utility as a food safety agent (Bassuony, 2015; Arista et al., 2023). In pharmaceuticals, the extract's potent antioxidant effects could contribute to the development of supplements or therapeutic agents targeting oxidative stress-related diseases such as diabetes, cardiovascular disorders, and neurodegeneration (Aly et al., 2017; Samiasih

et al., 2023). Cosmetic formulations may also benefit from its antioxidant and anti-inflammatory properties, providing protective effects against UV-induced skin damage and aging (Khang et al., 2021). Moreover, the valorization of banana peels aligns with sustainable development goals by transforming agricultural waste into valuable bioactive resources, reducing environmental burdens and promoting circular economy practices (Khamsaw, 2024). Given the global abundance of banana peel waste, particularly in tropical countries like Indonesia, leveraging these bioresources can foster economic and environmental benefits simultaneously.

Nonetheless, several challenges remain before widespread application. Stability of bioactive compounds during processing and storage must be ensured, as phenolic compounds are sensitive to light, oxygen, and heat (Lopes et al., 2022). Bioavailability is another critical factor; although fiber content in banana peels may aid phenolic absorption (Kumari, 2023), in vivo studies are necessary to confirm efficacy and safety. Furthermore, mechanistic insights into antioxidant pathways—such as modulation of endogenous defense systems (e.g., Nrf2 pathway activation)—should be explored to substantiate health claims (Khacharat et al., 2022; Parvez et al., 2023).

Future research should thus focus on optimizing extraction methods—potentially incorporating UAE or MAE—to enhance yield and preserve bioactivity (Vu et al., 2019). Isolation and characterization of specific active compounds via chromatographic techniques (TLC, HPLC) will provide clearer insights into composition and synergism. In vivo testing and clinical evaluations are essential to establish efficacy, safety, and dosage guidelines. Formulation studies exploring the extract's incorporation into functional foods, nutraceuticals, supplements, and topical cosmetics will facilitate translation from bench to market.

CONCLUSION

This study successfully demonstrated that the combined ethanol extract of Cavendis (Musa acuminata) and Kepok (Musa paradisiaca) banana peels possesses exceptionally strong antioxidant activity. The extract exhibited an IC50 value of 6.47 ppm and an Antioxidant Activity Index (AAI) of 5.40, values which are notably comparable to those of Vitamin C—the gold standard natural antioxidant—with an IC50 of 6.29 ppm and AAI of 5.56. This finding positions the combined banana peel extract within the category of very strong antioxidants, underscoring its significant potential as an effective free radical scavenger.

The potent antioxidant activity can be largely attributed to the rich phytochemical composition identified in the extract, which includes flavonoids, tannins, saponins, and steroids/terpenoids. Each of these bioactive compounds contributes through diverse mechanisms such as hydrogen or electron donation, metal chelation, and modulation of oxidative metabolic pathways, thereby providing comprehensive protection against oxidative stress and related cellular damage.

Importantly, this research highlights the value of utilizing agricultural waste—specifically banana peels, which are abundantly generated and often discarded in tropical regions—as a sustainable source of natural antioxidants. Valorization of such agro-industrial byproducts aligns with global sustainability goals and circular economy principles, as it reduces environmental waste while simultaneously producing high-value bioactive ingredients. The ability to harness bioactive compounds from banana peel waste not only adds economic value but also offers environmentally friendly alternatives to synthetic antioxidants, which have raised concerns over toxicity and carcinogenicity.

From an application perspective, the combined Cavendis and Kepok peel extract shows promising potential across multiple industries. In the food sector, its antioxidant and antimicrobial properties could serve as natural preservatives to improve shelf life, maintain food quality, and enhance nutritional profiles of products. In the pharmaceutical domain, the extract could be developed into nutraceutical supplements or adjuvants targeting oxidative

stress-related conditions such as cardiovascular diseases, diabetes, cancer, and neurodegenerative disorders. Additionally, in cosmetics, the potent antioxidant properties may be leveraged for skin care formulations to protect against photoaging and environmental damage, contributing to healthier skin and anti-inflammatory benefits.

Despite these promising findings, several critical steps remain to realize the full potential of the extract for commercial and therapeutic use. First, optimization of the extraction process is essential to maximize yield and preserve the bioactivity of the compounds. Emerging technologies such as ultrasound-assisted extraction and microwave-assisted extraction should be explored to enhance efficiency and sustainability. Second, ensuring the stability of bioactive compounds during processing and storage is paramount, given the susceptibility of phenolics and flavonoids to degradation by light, oxygen, and heat. Third, bioavailability and in vivo efficacy must be thoroughly evaluated through animal models and clinical trials to establish safety, appropriate dosing, and therapeutic benefits. Understanding the metabolic fate and absorption of these compounds will clarify their true antioxidant impact in human physiology. Finally, the development of standardized formulations and delivery systems is necessary to ensure consistent quality and functionality of end products.

The study not only provides strong evidence for the antioxidant efficacy of combined Cavendis and Kepok banana peel extracts but also supports the sustainable valorization of banana peel waste as a natural source of valuable phytochemicals. This research paves the way for future multidisciplinary efforts to translate laboratory findings into practical applications that benefit public health, food security, and environmental sustainability. With further optimization and validation, this natural antioxidant blend holds significant promise for incorporation into functional foods, nutraceuticals, pharmaceuticals, and cosmetic products, contributing to a healthier society and a greener planet.

RECOMMENDATION

Building on the promising results of this study, future research should prioritize optimizing the extraction process by investigating advanced techniques such as ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE), which can enhance yield and better preserve the bioactive compounds compared to conventional methods. Alongside improving extraction efficiency, comprehensive chemical characterization using analytical tools like thin-layer chromatography (TLC) and high-performance liquid chromatography (HPLC) is essential to identify and quantify the key antioxidant constituents, facilitating a deeper understanding of their synergistic effects and supporting extract standardization. Additionally, the stability of the extracts must be evaluated under various environmental and processing conditions—including temperature, light exposure, oxygen, and pH variations—to ensure that antioxidant activity is maintained throughout storage and product formulation.

Protective strategies such as encapsulation could be explored to enhance shelf life and preserve bioactivity. Furthermore, rigorous in vivo studies using appropriate animal models are needed to assess the bioavailability, metabolism, safety, and actual antioxidant efficacy of the extracts in living systems, focusing on oxidative stress markers and disease models linked to oxidative damage. Subsequent human clinical trials will be critical to confirm safety, effective dosing, and health benefits.

Lastly, translational research aimed at developing functional products—such as dietary supplements, functional foods, cosmetics, and pharmaceuticals—should be undertaken, including pilot-scale production and consumer acceptance testing. Exploring synergistic combinations with other natural antioxidants may further boost efficacy. Overall, an integrated, multidisciplinary approach combining extraction optimization, phytochemical profiling, biological validation, and product development is vital to fully harness the potential of Cavendis and Kepok banana peel extracts as natural antioxidants. This will promote sustainable

utilization of agricultural waste while delivering valuable health-promoting products across food, pharmaceutical, and cosmetic industries.

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