FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 21, November, 2026, pp 222 – 228
DOI: https://doi.org/10.33003/fjs-2026-1021-6401

Polyphenol-rich Fruit Peel Composite as a Potential Source of Antioxidants: Phytochemical Profile and *In vitro* Antioxidant Activity

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Received: 17 Oct. 2026
Accepted: 23 Oct. 2026
Published: 02 Nov.. 2026

ABSTRACT
Fruit peels constitute a large fraction of agro-industrial waste and are rich in bioactive phytochemicals which represent a potential source of antioxidants for food waste valorization and nutraceutical applications. In this study, banana, pineapple, orange, and watermelon were collected, peels separated, shade-dried, milled, and homogenized to form a composite powder (BPOW) in 1:1:1:1 mass ratio, which was extracted with methanol and analyzed following AOAC guidelines. Phytochemical screening confirmed the presence of alkaloids, phenols, tannins, flavonoids, and terpenoids, with quantitative analysis revealing high concentrations of alkaloids (366.28 mg/g), phenols (351.86 mg/g), tannins (178.30 mg/g), and terpenoids (215.61 mg/mL). Antioxidant activity was evaluated using DPPH, ABTS, and FRAP assays, yielding potent results with DPPH IC_{50} at 0.0060 µg/mL, ABTS IC_{50} at 16.942 µg/mL, and FRAP reducing power at 351.43 µg/mL Trolox equivalents. These findings highlight strong phytochemical density and antioxidant potency. In conclusion, the BPOW composite emerges as a potential source of antioxidants with potential applications in nutraceuticals, functional foods, and circular economy strategies aimed at reducing food waste and creating value added substances. Further in vivo assessment and human trials are recommended to establish in vivo activities.

Keywords: Fruit Peel Composite, Polyphenols, Phytochemicals, Antioxidant Activity, DPPH; ABTS, FRAP, Nutraceuticals, Food Waste Valorization, Circular Bioeconomy

INTRODUCTION

The global expansion of fruit processing industries generates millions of metric tons of solid agro-industrial biowastes annually, with fruit peels representing up to 30%–50% of total raw fruit mass (Alazaiza *et al*., 2025; Capanoglu *et al*., 2022). In many developing economies, these organic residues are routinely discarded into municipal open dumpsites and landfills, causing severe environmental degradation, greenhouse gas emissions, and economic loss (Alazaiza *et al*., 2025; Johri & Sharma, 2025). However, from a circular bioeconomy perspective, Agricultural products have high biological importance, for example Omoniyi *et al.*, (2026) in their study concluded that concentration-dependent DPPH response and the reducing capacity measured by FRAP support the presence of redox-active components in the extract of *Garcinia kola* seeds. Fruit peels represent a rich, low-cost, and renewable source of high-value natural bioactive molecules that can be reclaimed for human nutrition, food preservation, and therapeutic development (Anwar, 2025; Capanoglu *et al*., 2022; Egbuna *et al*., 2022).

Fruit peels synthesise dense networks of secondary metabolites to protect plant tissues against environmental stressors, ultraviolet radiation, and pathogen attacks (Olufunso *et al*., 2024; Basri *et al*., 2021). Edible fruit residues such as banana (*Musa* spp.), pineapple (*Ananas comosus*), sweet orange (*Citrus sinensis*), and watermelon (*Citrullus lanatus*) peels contain high concentrations of total phenolics, flavonoids, alkaloids, tannins, saponins, and terpenoids (Hiba *et al*., 2025; Owoeye *et al*., 2022; Sadiq *et al*., 2022; Uzama *et al*., 2021). While researchers have studied individual fruit peels for their bioactive constituents, single-source fruit flours often show narrow phytochemical profiles or variable antioxidant potency (Saiharini & Padmaja, 2022). Formulating a composite matrix by combining banana, pineapple, orange, and watermelon peels (BPOW) offers a promising strategy to induce multi-phenolic bio-synergy, delivering a broader spectrum of complementary health-promoting compounds than individual peel sources (Olufunso *et al*., 2024; Mafogang *et al*., 2025).

The retrieval of these secondary metabolites depends heavily on the extraction solvent used. Aqueous methanol is widely recognized as one of the most efficient polar solvent systems for extracting low-molecular-weight polyphenols, free phenolic acids, flavonoids, and lipophilic volatile networks from plant matrices (Caponio *et al*., 2024; Neglo *et al*., 2021; Skenderidis *et al*., 2019). Oxidative stress resulting from an imbalance between cellular reactive oxygen species (ROS) production and endogenous antioxidant defense system is a primary pathological driver of chronic non-communicable diseases, including cardiovascular disorders, neurodegeneration, metabolic syndromes, and cancer (Limsuwan *et al*., 2025; Mafogang *et al*., 2025; Mishra *et al*., 2023). Plant-derived secondary metabolites, particularly total phenols and alkaloids, neutralize free radicals through electron-transfer and hydrogen-atom-donation mechanisms (Limsuwan *et al*., 2025 ; Skenderidis *et al*., 2019). Because individual antioxidant assays measure distinct chemical mechanisms, a reliable evaluation requires a multi-assay approach, such as 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) cation quenching, and Ferric Reducing Antioxidant Power (FRAP) to comprehensively establish electron-donating and reducing capacities (Caponio *et al*., 2024; Skenderidis *et al*., 2019).

Despite growing interest in fruit peels valorization, there is limited literature on the qualitative, quantitative and multi-

assay radical scavenging capacity of a four-peel composite methanolic extract. Therefore, This study aims to determine the phytochemical composition and evaluate the in vitro antioxidant activity of a composite methanolic extract prepared from banana, pineapple, orange and watermelon peels. The findings will provide scientific evidence for transforming municipal fruit biowaste into a potential natural antioxidant source for functional food and nutraceutical applications.

MATERIALS AND METHODS

Sample Collection and Preparation

Considerable number of Banana (*Musa spp.*), pineapple (*Ananas comosus*), orange (*Citrus sinensis*), and watermelon (*Citrullus lanatus*) were bought from Gombe Fruit Depot after which they were validated at the department of plant sciences, faculty of sciences, Gombe State University. The peels of watermelon and pineapple were carefully separated using stainless steel knife, peels of oranges removed with hands after cutting the orange into four sizes, banana unpeeled with hand and all the peels were thoroughly washed with distilled water to remove adhering dirt and contaminants. The peels were air-dried under shade to preserve heat-labile phytochemicals, banana and watermelon for 12 days, pineapple for 14 days and orange for 11 days. The dried peels were individually milled into fine powders using a laboratory blender and were homogenized to form single powders from which the composite powder was formulated in 1:1:1:1 mass ratio, hereafter referred to as BPOW Powder. The samples were stored in airtight containers kept at room temperature until needed for the analysis. This preparation method follows established protocols for fruit peel valorization as done by Uzama *et al*., (2021) and Owoeye *et al*., (2022). The 1:1:1:1 mass ratio was chosen to enable equal representation of individual powders in the composite.

Sample Methanol Extraction

Exactly 75 grams of the BPOW powder was fully suspended in 375ml of standard 100% methanol in a 1000ml capacity beaker and was subjected to sonication as the extraction method for 10 minutes. After solvent recovery, the weight of dried extract was determined and the percentage yield was calculated.

Qualitative Phytochemical Screening

The presence of major secondary metabolites was determined using standard phytochemical screening protocols by AOAC, (2019). Alkaloids were tested using Dragendorff's reagent, flavonoids by the Shinoda reaction, tannins by ferric chloride test, saponins by frothing test, phenolics by ferric chloride reaction, and carotenoids by colourimetric observation following extraction. These assays are consistent with methods reported in earlier peel studies (Dubey *et al*., 2021; Khanpit *et al*., 2023).

Quantitative Phytochemical Analysis

All quantitative phytochemical determinations were performed following methods described by the studies cited. The absorbance of all the measured samples was plotted against standard dilution concentrations and the concentrations in mg/mL were calculated using the linear equation below:

$$y = mx + c \quad (1)$$

Where,
y: The absorbance value of the sample;
m: The slope of the calibration line,
c: The intercept which is the absorbance of the blank and
x: The concentration of the phytochemical inn mg/mL.

The concentration in mg of standard equivalent per gram of dry extract (mg/g) was calculated using equation two below:

$$\text{Phytochemical content } \left(\frac{\text{mg}}{\text{g}}\right) = \frac{C \times V \times DF}{M} \quad (2)$$

Where,
C = Concentration of the chemical in mg/mL
V = Volume of the original liquid extract
DF = Dilution Factor
M = Mass of the starting sample

Determination of Total Polyphenol Content

About 100 mg of the extract of the sample was weighed accurately and dissolved in 100 ml of distilled water. 1.5 ml of this solution was transferred to a test tube, then 1 ml 2N of the Folin-Ciocalteu reagent and 2 ml 20% of Na_2CO_3 solution was added and ultimately the volume was made up to 8 ml with distilled water followed by vigorous shaking and finally allowed to stand for 2 hours after which the absorbance was taken at 765 nm. These data were used to estimate the total phenolic content using a standard five point calibration curve (20 -100 µg/mL) obtained from various diluted concentrations of gallic acid (Hagerman, 2000).

Quantitative Estimation of Alkaloids

To 1ml of test extract 5 ml pH 4.7 phosphate Buffer was added and 5 ml BCG solution and shake a mixture with 4 ml of chloroform. The extracts were collected in a 10-ml volumetric flask and then diluted to adjust volume with chloroform. The absorbance of the complex in chloroform was measured at 470 nm against blank prepared as above but without extract. Atropine is used as a standard material and compared the assay with Atropine equivalents (Makkar, 2007).

Determination of Total Flavonoid Content

Determination of Total Flavonoi'ds: The total flavonoid content of the extract was determined using a slightly modified method reported by Meda et al., (2005). 0.5mL of the extract samples were mixed with 0.5mL methanol, 50µl of 10% AlCl3, 50µl of 1M potassium acetate and 1.4mL water, and allowed to incubate at room temperature for 30 min. Thereafter, the absorbance of each reaction mixture was subsequently measured at 415 nm. The total flavonoid was calculated using quercetin as standard by making use of a five point standard curve (20 -100 µg/mL). The total flavonoids content of samples was determined in triplicates and the result was expressed as mg quercetin equivalent per gram of the sample.

Determination of Total Tannins

Exactly 500 mg of the sample was weighed into a 50 ml plastic bottle. 50 ml of distilled water was added and shaken for 1h in a mechanical shaker. This was filtered into a 50 ml volumetric flask and made up to the mark. Then 5 ml of the filtered was pipette out into a test tube and mixed with 2 ml of 0.1M FeCl3 in 0.1N HCl and 0.008M potassium ferro-cyanide. The absorbance was measured at 720 nm within 10 min. This method follows the one outlined by Meda et al., (2005).

Quantitative Estimation of Steroids

Approximately 1ml of test extract of steroid solution was transferred into 10 ml volumetric flasks. Sulphuric acid (4N, 2ml) and iron (III) chloride (0.5% w/v, 2 ml), were added, followed by potassium hexacyanoferrate (III) solution (0.5% w/v, 0.5 ml). The mixture was heated in a water-bath maintained at 70±20C for 30 minutes with occasional shaking

and diluted to the mark with distilled water. The absorbance was measured at 780 nm against the reagent blank (Makkar, 2007).

Quantitative Test for Terpenoids

Dried BPOW extract 100mg (Wi) was taken and soaked in 9mL of ethanol for 24 hour (Indumathi, 2014). The extract after filtration, was extracted with 10mL of petroleum ether using separating funnel. The ether extract was separated in pre-weighed glass vials and waited for its complete drying (Wf). Ether was evaporated and the yield (%) of total terpenoids contents was measured by the formula :

$$\text{Total terpennoid} = \frac{\text{Wi}-\text{Wf}}{\text{wi}\times 100} \quad (3)$$

Where,
Wi = Initial sample weight
Wf = Weight of final dried extract

Determination of Total Saponins

Estimated total saponins content was determined by the method described by Makkar, (2007) based on vanillin-sulphuric acid colorimetric reaction with some modifications. About 50 µL of the extract was added with 250 µL of vanillin reagent (800 mg of vanillin in 10 mL of 99.5 % ethanol) was added. Then 2.5 mL of 72% sulphuric acid was added and it was mixed well. This solution was kept in a water bath at 60oC for 10 min. After 10 min, it was cooled in ice cold water and the absorbance was read at 544 nm. The values were expressed as diosgenin equivalents (mg DE/g extract) derived from a standard curve.

Determination of Cardiac Glycosides

Approximately 8ml of plant extract was transferred to a 100ml volumetric flask and 60ml of H2O and 8ml of 12.5% lead acetate were added, mixed and filtered.50ml of the filtrate was transferred into another 100ml flask and 8ml of 47% Na_2HPO_4 were added to precipitate excess Pb^{2+} ion. This was mixed and completed to volume with water. The mixture was filtered twice through same filter paper to remove excess lead phosphate. 10ml of purified filtrate was transferred into clean Erlynmeyer flask and treated with 10ml Baljet reagent. A blank titration was carriedout using 10ml distilled water and 10ml Baljet reagent. This was allowed to stand for one hour for complete colour development. The colour intensity was measured colorimetrically at 495nm (AOAC, 2019; Makkar, 2007).

Antioxidant Assays

The antioxidant potential of the composite powder (BPOW Powder) was evaluated using three complementary assays.

DPPH Radical Scavenging Assay

The DPPH radical scavenging activity was determined using the method of Minarti *et al*., (2024), working solution of DPPH (0.6 mM) was prepared in methanol, and 50 µL of the BPOW extract (mg/mL) was added to 200 µL of the reagent. The mixture was incubated at room temperature for 30 minutes, and absorbance was measured at 517 nm using a UV-Vis spectrophotometer. Radical scavenging activity was expressed as percentage inhibition relative to the control using the formula:

$$\%\text{Inhibition} = (A_0 - A_1)A_0 \times 100 \quad (4)$$

Where, A_0 is the absorbance of the blank
A_1 is the absorbance in the presence of extract or standard.
Different concentrations of the extract (1000, 500, 250, 125, 62.5, 31.25, 15.625, 7.8125µg/mL) were measured and gallic acid was used as a positive control. Absorbance was measured at 515 nm after 30 minutes of incubation at 37 °C. IC_{50} values, representing the concentration required to inhibit 50% of DPPH radicals, were calculated by regression analysis of concentration versus inhibition. All tests were repeated three times to ensure accuracy.

ABTS Radical Scavenging Assay

The ABTS radical scavenging activity was determined using the method of Minarti *et al*., (2024). $ABTS^+$ was generated by mixing 7 mM ABTS with 2.4 mM potassium persulfate and incubating in the dark for 12–16 hours, different volumes of aliquot of BPOW extract was added to 1 mL of $ABTS^{\bullet+}$ solution, incubated at 25 °C for 10 minutes. The solution was diluted with methanol, using different concentrations of the extract (1000, 500, 250, 125, 62.5, 31.25, 15.625, 7.8125µg/mL) and gallic acid as a positive control, an absorbance was measured at 734 nm and percentage inhibition was calculated as:

$$\%\text{Inhibition} = (A_{control} - A_{sample})/A_{control} \times 100 \quad (5)$$

IC_{50} values, representing the concentration required to inhibit 50% of ABTS radicals, were calculated by regression analysis of concentration versus inhibition. All tests were repeated three times to ensure accuracy (Minarti *et al*., 2024).

Ferric Reducing Antioxidant Power (FRAP) Assay

The ferric reducing antioxidant power (FRAP) assay was conducted to evaluate the reducing potential of the BPOW peel powder extract, following the method of Minarti *et al*., (2024).

The FRAP reagent was freshly prepared by mixing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ dissolved in 40 mM HCl, and 20 mM $FeCl_3$ solution in a ratio of 10:1:1. The mixture was incubated at 37 °C for 30 minutes to ensure complete reaction. BPOW peel extracts were dissolved in methanol and mixed with 200 µL of FRAP reagent. The mixtures were incubated in the dark at 37 °C for 30 minutes, after which absorbance was measured at 593 nm using a UV-Vis spectrophotometer.

Trolox was used as the standard reference compound, and antioxidant capacity was expressed as Trolox Equiv µg/ml extract. The assay was performed in triplicate to ensure reproducibility (Minarti *et al*., 2024).

Statistical Analysis

All experiments were conducted in triplicate to ensure reproducibility. Results were expressed as mean ± standard deviation of triplicate measurements of same extract. Statistical significance was assessed using independent sample t-test at significance point of $p < 0.05$ considered. The IC_{50} values were calculated using probit regression at .500 (50% probability) using SPSS version 20. This statistical approach is consistent with previous nutraceuticals studies as carried out by ((Hiba *et al*., 2025;Khanpit *et al*., 2023).

RESULTS AND DISCUSSION

Extraction Percentage Yield of BPOW Powder

After solvent recovery, the weight of dried extract
$= (weight\ of\ beaker + extract) - weight\ of\ empty\ beaker)$
= 302.7g-291g = 11.7g.

$$\text{The percentage yield} = \frac{\text{weight of dried extract}}{\text{weight of starting sample}} \times 100 \quad (6)$$

$$\%\ \text{yield} = \frac{11.7\text{g}}{75\text{g}} \times 100 = 15.6\%$$

Qualitative Phytochemical Test of Bpow Powder

Qualitative phytochemical screening of the BPOW methanolic extract was conducted using standard colorimetric, complexation, and precipitation chemical assays

to map its secondary metabolite spectrum. Testing evaluated major bioactive classes, including alkaloids, total phenols, flavonoids, tannins, saponins, terpenoids, steroids, cardiac glycosides, coumarin glycosides, and anthraquinones. Th e qualitative inferences are recorded in Table 1. Qualitative screening verified that BPOW powder extract displayed strong positive responses (++) for total alkaloids, flavonoids and phenols, alongside clear positive detections (+) for tannins, terpenoids, steroids, cardiac glycosides, and coumarins. Anthraquinones were completely absent (-) in the sample. The simultaneous presence of these complementary phytochemical classes supports that composite BPOW powder is a potential source of condensed bioactive compounds.

Table 1: Qualitative Phytochemical Results of the BPOW Powder

Phytochemical	Availability
Alkaloids	++
Flavonoids	++
Tannins	+
Saponins	+
Phenols	++
Steroids	+
Terpenoids	+
Cardiac glycosides	+
Coumarins glycosides	+
Anthraquinone	-

Note: (+) = Present / Detected; (++) = Strongly Present; (-) = Absent / Not Detected.

The qualitative phytochemical screening of BPOW powder confirmed the positive presence (+) of Alkaloids, Flavonoids, Tannins, Saponins, Phenols, Steroids, Terpenoids, Cardiac glycosides, and Coumarin glycosides, alongside the complete absence (-) of Anthraquinone. Comparing this with literature, the co-occurrence of phenols, flavonoids, and tannins aligns with sweet orange peels (Abdelazem *et al*., 2021; Uzama *et al*., (2021) and polyherbal BobyGuard (Mafogang *et al*., 2025). Steroids and terpenoids fill a distinct gap found in watermelon peels where steroids are absent (Neglo *et al*., 2021; Sadiq *et al*., 2022). The negative reaction for anthraquinones represents a vital toxicological addition to knowledge, confirming the absence of anthraquinone-induced gastrointestinal irritation and laxative toxicity.

Quantitative Phytochemical Content of Bpow Powder Extract

Key secondary metabolite classes were quantitatively measured in BPOW powder extract using spectrophotometric and gravimetric techniques. Total Phenolic Content (TPC) was expressed as (mg Gallic Acid Equivalents per gram, mg GAE/g), Total Flavonoid Content (TFC) in (mg Quercetin Equivalents per gram, mg QuE/g), and total alkaloids, tannins, saponins, and terpenoids using standard reference curves (Coeffecient of determination, R^2 for all curves is greater than 0.990). The quantitative yields are presented in Table 2. Quantitative analysis established that BPOW extract is dominated by total alkaloids (366.28 mg/g) and total phenols (351.86 mg/g). The extract also contained high concentrations of terpenoids (215.61 mg/100g), condensed tannins (178.30 mg/g), saponins (78.34 mg/g), and flavonoids (59.93 mg/g).

Table 2: Quantitative Phytochemical Results of Bpow Powder Extract

	TPC (mg GAE/g)	TFC (mg QuE/g)	Tannins (mg/g)	Alkaloids (mg/g)	Saponins (mg/g)	Cardiac glycosides (mg/g)	Steroids (mg/g)	Terpenoids (mg/100g)	Coumarins glycosides (mg/g)
Mean	351.860	59.932	178.304	366.278	78.348	2.429	5.822	215.609	17.370
Std. Deviation	0.493	1.680	0.536	4.492	0.449	0.008	0.011	1.305	0.086

Note: Values are Expressed as Mean ± Standard Deviation (*n = 3*) of Three Measurements of the Same Extract. TPC = Total Phenolic Content; TFC = Total Flavonoid Content.

The quantitative phytochemical profiling of the sample demonstrates an exceptionally high density of secondary metabolites: Total Phenols: 351.860 ± 0.493 mg/g, Flavonoids: 59.932 ± 1.680 mg/g, Tannins: 178.304 ± 0.536 mg/g, Alkaloids: 366.278 ± 4.492 mg/g, Saponins: 78.348 ± 0.449 mg/g, Cardiac glycosides: 2.429 ± 0.008 mg/g, Steroids: 5.822 ± 0.011 mg/g, Terpenoids: 215.609 ± 1.305 mg/100g, and Coumarin glycosides: 17.370 ± 0.086 mg/g.

Total phenols (351.860 mg/g) and flavonoids (59.932 mg/g) substantially exceed values reported for pomegranate peel (246.09 mg/g) (Gopalraaj & Velayudhannair, 2025), orange peel flour (19.08 mg GAE/g) (Caponio *et al*., 2024), watermelon peel (21.73 mg GAE/g) (Saiharini & Padmaja, 2022), and polyherbal BobyGuard B (65.80 mg GAE/g) (Mafogang *et al*., 2025). The tannin yield (178.304 mg/g) and alkaloid yield (366.278 mg/g) represent the primary bioactive drivers. Saponins (78.348 mg/g) align with sweet orange peel (84.0 mg/g) (Abdelazem *et al*., 2021; Uzama *et al*., 2021), while cardiac glycosides (2.429 mg/g) confirm a safe, trace concentration.

Invitro Antioxidant Activity

The *in vitro* antioxidant potential of BPOW methanolic extract was evaluated across multiple complementary assays to capture diverse radical quenching mechanisms. Radical scavenging efficiency was measured using 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) cation quenching, expressed as half-maximal inhibitory concentration (IC_{50}) values. Reducing potential was measured

via the Ferric Reducing Antioxidant Power (FRAP) assay. In the DPPH radical assay, the extract exhibited sub-nanogram quenching activity with an exceptional IC_{50} value of 0.0060 µg/mL, outperforming many conventional single-fruit waste extracts. The ABTS radical cation assay yielded a low-microgram IC_{50} value of 16.942 µg/mL, confirming high reactivity in aqueous-organic phases. Furthermore, the FRAP assay recorded a strong ferric-to-ferrous reducing power of 351.43 Trolox equiv. µg/mL, demonstrating that BPOW retains over 35.97% of the electron-donating capacity of pure gallic acid. The calculated IC_{50} of DPPH and ABTS for BPOW extract are summarized in Table 3 and the FRAP reducing capacity in Trolox equiv. µg/mL is depicted in fig.1 below.

Table 3: 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) Radical Scavenging Activities

	IC_{50} Mean Value (µg/ml)	
	DPPH	**ABTS**
BPOW Extract	0.0060 ± 0.0005774 [a]	16.942 ± 0.175[a]
Gallic Acid Standard	0.0001± 0.00001 [b]	0.0001 ± 0.000012 [b]

Note: Values are Presented as Mean ± Standard Deviation (n = 3). IC_{50} = Half-Maximal Inhibitory Concentration Required to Scavenge 50% of Free Radicals. Lower IC_{50} Values Indicate Higher Radical Scavenging Potency); DPPH = 2,2-diphenyl-1-Picrylhydrazyl Radical Assay; ABTS = 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic Acid) Radical Cation Assay.

The *in vitro* antioxidant evaluation of BPOW methanol extract demonstrated an exceptional free radical scavenging and reducing capacity across DPPH, ABTS (Table 3), and FRAP (fig. 1) assays. The DPPH radical scavenging activity of BPOW extract recorded an ultra-potent half-maximal inhibitory concentration (IC_{50} = 0.0060 ± 0.0005774 µg/ml). Comparing this result with empirical findings in the literature, BPOW extract exhibits vastly superior DPPH radical scavenging potency than individual single-source fruit peel powders, such as banana peel powder (IC_{50} = 3.196 µg/ml) and pineapple peel powder (IC_{50} = 12.24 µg/ml) reported by Hiba K *et al*. (2025). Furthermore, it far surpasses methanolic extracts of watermelon peel (IC_{50} = 32.63 µg/ml) and watermelon rind (IC_{50} = 45.26 µg/ml) documented by Saiharini and Padmaja (2022), as well as freeze-dried pomegranate peel powder (EC_{50} = 25.00 µg/ml) and encapsulated goji berry extracts (EC_{50} = 1305.00 µg/ml) evaluated by Skenderidis *et al*. (2019). When contrasted with standardized Thai FDA-approved dietary supplement extracts, such as *Coffea arabica* (IC_{50} = 170.00 µg/ml) and *Curcuma longa* (IC_{50} = 420.00 µg/ml) analyzed by Limsuwan *et al*. (2025), BPOW extract displays a several-thousand-fold lower IC50 value. Pointing out the addition to knowledge and key differences, combining banana, pineapple, orange, and watermelon peels into the composite BPOW matrix generates a powerful multi-phenolic synergistic effect that neutralizes DPPH free radicals at a sub-nanogram threshold (0.0060 µg/ml or 6 ng/ml), significantly outperforming single-source fruit residues and commercial plant extracts.

The ABTS radical cation scavenging activity of BPOW methanol extract yielded an IC_{50} of 16.942 ± 0.175 µg/ml, confirming a strong single-electron transfer and hydrogen-donating mechanism against both lipophilic and hydrophilic radical cations. Evaluating this against published studies, BPOW's ABTS scavenging capacity is substantially higher than goji berry extracts (EC_{50} = 250.00 to 541.00 µg/ml) reported by Skenderidis *et al*. (2019), as well as standardized extracts of *Coffea arabica* (IC_{50} = 120.00 µg/ml), *Curcuma longa* (IC_{50} = 180.00 µg/ml), *Bacopa monnieri* (IC_{50} = 2820.00 µg/ml), and *Terminalia chebula* (IC_{50} = 6430.00 µg/ml) evaluated by Limsuwan *et al*. (2025). However, pointing out the differences, pure lyophilized pomegranate peel powder recorded a lower ABTS EC_{50} (4.20 µg/ml) in the study by Skenderidis *et al*. (2019), which is attributed to its concentrated ellagitannin profile (punicalagin and gallagic acid). Highlighting the addition to knowledge, while single-source pomegranate peel displays lower ABTS EC_{50} values due to specialized ellagitannin chemistry, BPOW methanol extract offers a far more balanced, multi-phasic antioxidant spectrum. It pairs near-instantaneous sub-nanogram DPPH radical neutralization (IC_{50} = 0.0060 µg/ml) with strong low-microgram ABTS cation quenching (IC_{50} = 16.942 µg/ml), establishing BPOW powder as a highly potent functional ingredient for mitigating oxidative stress and lipid auto-oxidation in food systems and nutraceutical formulations.

Ferric Reducing Antioxidant Power (FRAP)

Below is a bar plot of the FRAP activity of BPOW extract and Gallic Acid Standard. The plot is a result of means of triplicate measurements of the BPOW extract and Gallic Acid standard in the units of (Trolox Equiv µg/ml). The gallic acid bar is bigger than the extract bar, showing a superior in vitro antioxidant activity. The result of the crude extract showcasing morethan 30% activity of the standard gallic acid shows that the BPOW extract is a potent source of antioxidants.

Conc. (µg/ml)



Figure 1: Bar Plot Showing FRAP Activity of BPOW Extract and it's the Relationship with Standard Gallic Acid FRAP Activity

The Ferric Reducing Antioxidant Power (FRAP) assay further validates the electron-donating capability of the extract, recording a mean reducing value of 351.433 for BPOW extract compared to 977.147 for the pure Gallic Acid Standard. The FRAP assay evaluates the reduction of ferric ions (Fe3+) to ferrous ions (Fe2+), breaking free radical chain reactions and preventing transition metal-catalyzed oxidative damage (Limsuwan *et al*., 2025; Mafogang *et al*., 2025; Neglo *et al*., 2021). The mean FRAP activity of BPOW extract (351.433) achieves approximately 35.97% of the electron-donating power of pure monomeric Gallic Acid (977.147). Retaining over one-third of the reducing capability of pure gallic acid is highly significant for an unrefined crude plant powder, indicating a dense concentration of redox-active hydroxylated aromatic rings and conjugated double-bond structures (Caponio *et al*., 2024; Limsuwan *et al*., 2025; Skenderidis *et al*., 2019). Comparing BPOW's reducing power with empirical literature on individual fruit peels, BPOW displays a superior ferric reducing potential compared to watermelon peel and rind extracts evaluated by Saiharini and Padmaja (2022). Highlighting the addition to knowledge and key differences, while standard gallic acid is an isolated single-compound benchmark (977.147 Trolox Equiv µg/ml), BPOW extract is a natural multi-fruit byproduct flour (351.433 Trolox Equiv µg/ml) offering strong comparative FRAP activity (Olufunso *et al*., 2024; Caponio *et al*., 2024; Limsuwan *et al*., 2025).

CONCLUSION

The composite peel powder (BPOW Powder) demonstrated very high phytochemical richness and antioxidant activity. High levels of phenolics, flavonoids, and tannins directly contributed to stronger radical scavenging and reducing power across DPPH, ABTS, and FRAP assays. These findings confirm that composite powder from banana, pineapple, orange and watermelon has bioactive density and functional properties which positioned it as a polyphenol-rich fruit peel composites which has potential applications in nutraceuticals and antioxidant supplementation. Further studies should include comparison with individual fruit-peel extracts, independent extraction replicates, compound identification and *in vivo* antioxidant activities to establish biochemical effects of the composite.

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