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Assessment of Mineral Profile, Bioactive Compounds, and Antioxidant Activity of Mangosteen (*Garcinia Mangostana* L.) Fruit Kernels

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Key words

Mangosteen fruit kernels; Minerals profile; Bioactive compounds; Antioxidant activity.

Abstract

Garcinia mangostana L. is a tropical fruit increasingly consumed in Cameroon, while its kernels are generally discarded as waste. This study evaluated mangosteen kernels as a potential functional ingredient for preventing and managing cardiometabolic diseases. Kernels were isolated, cleaned, sliced, freeze-dried, and powdered. Mineral composition was determined by atomic absorption spectrophotometry. Bioactive compounds were extracted using distilled water, hydroethanol (70:30, v/v), and ethanol and quantified spectrophotometrically. Antioxidant activity was assessed using DPPH radical scavenging, ferric-reducing power, and total antioxidant capacity (TAC) assays. The kernels contained high levels of calcium (471.05 mg/100 g DM) and magnesium (162.79 mg/100 g DM), while zinc reached 1.82 mg/100 g DM and potassium occurred in trace amounts. Ethanolic extract exhibited the highest total polyphenol (194.11 ± 0.66 mg GAE/g DM) and alkaloid (4.77 ± 0.05 mg QuiE/g DM) contents, whereas aqueous extract showed the highest flavonoid content (1.69 ± 0.11 mg QE/g DM). Hydroethanolic extract displayed the strongest DPPH scavenging activity (59.90%), ferric-reducing capacity (179.538 mg AAE/g DM), and TAC (1.318 mg AAE/g DM). Principal component analysis indicated that antioxidant activity was associated primarily with extraction solvent. These findings highlight mangosteen kernels as a promising source of minerals and bioactive compounds.

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1.Introduction

Mangosteen (*Garcinia mangostana* L.) is an exotic fruit belonging to the Clusiaceae family (Guttiferae) and is native to Southeast Asia, particularly Malaysia, Thailand, and Indonesia [1,2]. Indonesia is among the world's leading producers of mangosteen, which is consumed fresh or processed into products such as jams and juices [3]. Mangosteen is a round, purple fruit with a bitter outer rind enclosing a sweet, white pulp containing approximately five to six segments. Commonly referred to as the "Queen of Fruits" because of its distinctive sweet and sour taste, mangosteen is an agricultural commodity of considerable commercial value [4,5]. In addition to its desirable sensory properties, mangosteen fruit is a source of antioxidants, particularly xanthones, as well as vitamins C, B1, B2, and B6 and minerals such as calcium, potassium, and magnesium [6,7].

According to data from the Food and Agriculture Organization of the United Nations, global mangosteen production reached approximately 1.6 million tonnes in 2019 [8]. The growing interest in mangosteen can be attributed to its diverse applications in the food, cosmetic, and medicinal sectors, owing to the presence of numerous bioactive compounds associated with antioxidant, anti-inflammatory, antitumor, and neuroprotective properties [4,9,10]. In some countries, mangosteen pulp is also traditionally used for its potential health benefits, particularly in relation to cardiovascular disorders and cancer [11]. These nutritional and potential health-promoting properties have contributed to the expansion of mangosteen cultivation worldwide.

Cameroon is among the countries where mangosteen has been relatively recently introduced. The plant was initially cultivated at an experimental site in Njombé, located in the monomodal forest agroecological zone of the Littoral Region of Cameroon [12]. Following successful experimental cultivation, mangosteen is now grown in several areas of the country, and its fruits are increasingly available in local markets.

Although mangosteen pulp is commonly consumed fresh, the peels and kernels are generally discarded as waste, potentially contributing to environmental pollution. However, these by-products could be valorized based on their nutritional and phytochemical composition. Ovalles-Mangallanes et al. [13] reported that mangosteen peels and kernels contain bioactive compounds, including xanthones, flavonoids, and tannins, which have been associated with potential health-promoting properties. Consequently, mangosteen kernels could be processed into value-added ingredients for the development of functional food products, including juices, jams, confectionery products, bread, cookies, infant porridges, and distilled products [13].

Nevertheless, information on the mineral composition and antioxidant properties of mangosteen kernels grown in Cameroon remains limited. Because the chemical composition of plant materials may vary according to geographical origin and growing conditions, characterizing the nutritional and bioactive compound profiles of mangosteen kernels produced in Cameroon is of particular interest. To the best of our knowledge, previous studies on mangosteen fruit in Cameroon have primarily focused on the pulp [14,15], leaving the potential value of the kernels largely unexplored.

Therefore, this study aimed to investigate the potential valorization of mangosteen kernels as functional ingredients for food and other industrial applications. Specifically, the objectives were to determine the mineral profile and bioactive compound content of mangosteen fruit kernels, evaluate the antioxidant activities of extracts obtained using different solvent systems, and investigate the relationships among the measured variables using principal component analysis.

2. Materials and Methods

2.1. Chemical Reagents

The chemicals used in this study included nitric acid (HNO_3, 98%), Folin–Ciocalteu reagent [$(HO)_3C_6H_2CO_2$, H_2O], aluminum chloride ($AlCl_3$), sodium carbonate (Na_2CO_3), quercetin ($C_{15}H_{10}O_7 \cdot 2H_2O$), ethanol ($C_2H_5OH$, 99%), gallic acid ($C_7H_6O_5$), ferric chloride ($FeCl_3$), potassium acetate ($CH_3COOK$), sulfuric acid ($H_2SO_4$, 98%), hydrochloric acid (HCl, 12 N), sodium dihydrogen phosphate (NaH_2PO_4), ascorbic acid ($C_6H_8O_6$), ammonium molybdate ($H_{24}Mo_7N_6O_{24}$), dibasic sodium phosphate (Na_2HPO_4), trichloroacetic acid (CCl_3CO_2H), and potassium ferricyanide [$K_3Fe(CN)_6$]. All chemicals were purchased from Merck (Germany) and were of analytical grade.

2.2. Plant Material Sampling and Preparation

Mature mangosteen fruits harvested in June 2022 were obtained from the Institute of Agricultural Research for Development (IRAD) in Njombé, located in Agroecological Zone IV (4°33′15.89″ N, 9°37′42.84″ E), Littoral

Region, Cameroon. The plant material was identified at the National Herbarium of Cameroon and assigned voucher specimen number 25,666.

The fruits were sorted, washed with distilled water, and peeled. The kernels were collected, cut into thin slices, and freeze-dried using a Christ Beta 1-2 freeze dryer (Bioblock Scientific, France). The dried material was subsequently ground and sieved through a 500-µm mesh. The resulting powder was weighed and stored at −20°C until further analysis.

2.3. Mineral Profile of Mangosteen Kernels

The mineral composition of mangosteen kernels, including calcium (Ca), magnesium (Mg), potassium (K), and zinc (Zn), was determined by flame atomic absorption spectrometry using an air–acetylene flame (PerkinElmer AAnalyst 400). Following sample ashing at 450°C for 6 h, the resulting ash was extracted with 1 M HNO_3. Measurements were performed at the appropriate analytical wavelengths: 422.7 nm for Ca, 285.2 nm for Mg, 213.9 nm for Zn, and 766.5 nm for K.

Calibration curves were established over a concentration range of 0–10 mg/L and exhibited coefficients of determination (R^2) ≥ 0.995. The limits of detection (LOD) and quantification (LOQ) were determined according to IUPAC recommendations using the equations LOD = 3σ/a and LOQ = 10σ/a, respectively. Quality control procedures included the analysis of reagent blanks, certified reference material (NIST 1573), and spiked samples, with recoveries ranging from 90% to 110%. Reagent blank values were subtracted from sample measurements, and all samples were analyzed in triplicate. Results were expressed as mg/100 g dry matter (DM) and reported as mean ± standard deviation.

2.4. Phytochemical Analysis of Plant Material

2.4.1. Preparation of Extracts

Briefly, 0.4 g of freeze-dried mangosteen kernel powder was separately mixed with 100 mL of each extraction solvent: distilled water, ethanol–distilled water (70:30, v/v), or ethanol. Each mixture was homogenized using a magnetic stirrer (LAB-LINE PYRO-MULTI-MAGNESTIR, No. 1263-1) and allowed to macerate for 10 h at room temperature (25 ± 1°C) with intermittent stirring.

The resulting mixtures were centrifuged and filtered through Whatman No. 4 filter paper, and the pellets were discarded. The resulting filtrates were dried at 50°C for 24 h, weighed, and stored for subsequent analyses. The extraction yield was calculated using the following equation:

$$\text{Extraction yield (\%)} = \frac{\text{Mass of obtained extract (g)}}{\text{Initial mass of mangosteen kernel powder (g)}} \times 100$$

2.4.2. Determination of Total Polyphenol Content

Total polyphenol content was determined according to the method described by Singleton and Rossi [16], with slight modifications. Briefly, 100 µL of extract (4 mg/mL) was mixed with 750 µL of Folin–Ciocalteu reagent diluted tenfold with distilled water and allowed to stand at room temperature (25 ± 1°C) for 5 min. Subsequently, 750 µL of an aqueous sodium carbonate solution (6%, w/v) was added. The mixture was homogenized and incubated in the dark at room temperature for 90 min.

The absorbance of the resulting blue complex was measured at 725 nm using a UV–Vis spectrophotometer (UVmini-1240, Shimadzu, Japan) against a blank in which the extract was replaced with the corresponding sample dilution solvent. Gallic acid solutions at concentrations of 0, 100, 200, 400, 800, and 1000 µg/mL, prepared in ethanol, were used to construct the calibration curve. Total polyphenol content was calculated using the calibration equation ($y = 0.0015x$; $R^2 = 0.995$). Results were expressed as milligrams of gallic acid equivalents per gram of dry matter (mg GAE/g DM).

2.4.3. Determination of Total Flavonoid Content

The total flavonoid content of the extracts was determined using the colorimetric method described by Aiyegoro and Okoh [17]. Briefly, 500 µL of extract (4 mg/mL) was added to a tube containing 1500 µL of methanol, followed by 100 µL of aluminum chloride solution (10%, w/v), 1000 µL of 1 M potassium acetate, and 2800 µL of distilled

water. The mixture was homogenized and incubated at room temperature for 30 min. Absorbance was subsequently measured at 415 nm against a blank.

Quercetin solutions at concentrations of 0, 100, 200, 400, 800, and 1000 µg/mL, prepared in ethanol, were used to establish the calibration curve. Total flavonoid content was calculated from the quercetin calibration equation ($y = 0.0013x$; $R^2 = 0.977$). Results were expressed as milligrams of quercetin equivalents per gram of dry matter (mg QE/g DM).

2.4.4. Determination of Total Alkaloid Content

Total alkaloid content was determined according to the method described by Singh et al. [18], with slight modifications. Briefly, 0.1 g of mangosteen kernel powder was separately mixed with 10 mL of each extraction solvent: distilled water, ethanol–water (70:30, v/v), or ethanol. The mixtures were homogenized and centrifuged at 5000 × g for 10 min.

An aliquot (1000 µL) of the resulting supernatant was mixed with 1000 µL of a solution containing $FeCl_3$ (0.025 M) and HCl (0.5 M), followed by 1 mL of an ethanolic 1,10-phenanthroline solution (0.05 M). The resulting mixture was homogenized and incubated in a water bath (PolyScience, USA) at 100°C for 30 min. The absorbance of the resulting red-colored complex was measured at 510 nm against a blank.

Quinine solutions at concentrations of 0, 100, 200, 400, 800, and 1000 µg/mL were used to construct the calibration curve. Total alkaloid content was calculated using the quinine calibration equation ($y = 0.0422x$; $R^2 = 0.9967$). Results were expressed as milligrams of quinine equivalents per gram of dry matter (mg QuiE/g DM).

2.5. Evaluation of the Antioxidant Potential of the Extracts*

2.5.1. DPPH Radical Scavenging Activity

The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity of mangosteen kernel extracts was evaluated according to the method described by Sánchez-Moreno et al. [19]. Briefly, 1950 µL of freshly prepared methanolic DPPH solution (0.025 g/L) was added to 50 µL of mangosteen kernel extract at different concentrations (1, 2, 3, and 4 mg/mL). The mixture was incubated in the dark at room temperature for 30 min, after which the absorbance was measured at 515 nm.

The extraction solvent without extract was used as the negative control, whereas ascorbic acid (0–0.5 µg/mL) was used as the positive control. DPPH radical scavenging activity was calculated using the following equation:

$$\text{DPPH radical scavenging activity (\%)} = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

where *Acontrol* is the absorbance of the negative control and *Asample* is the absorbance of the sample.

The half-maximal inhibitory concentration (IC_{50}) values were determined graphically by regression analysis.

2.5.2. Determination of Ferric-Reducing Power

The ferric-reducing power of the extracts was determined according to the method described by Oyaizu [20]. Briefly, 1000 µL of extract at different concentrations (1, 2, 3, and 4 mg/mL) was mixed with 2500 µL of phosphate buffer (0.2 M, pH 6.6) and 2500 µL of potassium ferricyanide solution [$K_3Fe(CN)_6$, 1%, w/v]. The mixture was incubated at 50°C for 20 min. Subsequently, 2500 µL of trichloroacetic acid (TCA, 10%, w/v) was added to terminate the reaction, and the tubes were centrifuged at 3000 rpm for 10 min.

An aliquot (2500 µL) of the resulting supernatant was mixed with 2500 µL of distilled water and 500 µL of ferric chloride solution ($FeCl_3$, 0.1%). Absorbance was measured at 700 nm against a blank. Ascorbic acid (100–1000 µg/mL) was used as the standard. Ferric-reducing power was expressed as milligrams of ascorbic acid equivalents per gram of dry matter (mg AAE/g DM).

2.5.3. Determination of Total Antioxidant Capacity (TAC)

The total antioxidant capacity (TAC) of the extracts was determined using the phosphomolybdenum method described by Prieto et al. [21]. Briefly, 200 µL of extract at different concentrations (1, 2, 3, and 4 mg/mL) was mixed with 2000 µL of reagent solution containing 0.6 M sulfuric acid, 4 mM ammonium molybdate, and 28 mM

sodium dihydrogen phosphate. The tubes were capped and incubated in a water bath (PolyScience, USA) at 95°C for 90 min.

After cooling, absorbance was measured at 695 nm against a blank. TAC was determined using a calibration curve generated with ascorbic acid at concentrations ranging from 0.01 to 0.50 mg/mL (R^2 = 0.988) and expressed as milligrams of ascorbic acid equivalents per gram of dry matter (mg AAE/g DM).

2.6. Statistical Analysis

All experiments were performed in triplicate, and the results were expressed as mean ± standard deviation. Data normality was assessed using the Shapiro–Wilk test. Mean values obtained for the three extracts were compared using one-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) post hoc test. Differences were considered statistically significant at $p < 0.05$.

Pearson's correlation analysis was used to evaluate the relationships between the phytochemical constituents of the extracts and their antioxidant activities. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 20.0. Principal component analysis (PCA) was conducted to investigate the relationships among bioactive compounds, mineral composition, and antioxidant activities using XLSTAT version 2014.5.03 (Addinsoft, Inc., New York, NY, USA).

3. Results

3.1. Mineral Profile of Mangosteen Fruit Kernels

Table 1 presents the mineral composition of mangosteen fruit kernels, expressed as mg/100 g dry matter (DM). Calcium was the most abundant mineral detected, with a concentration of 471.05 ± 14.11 mg/100 g DM, followed by magnesium (162.79 ± 0.88 mg/100 g DM) and zinc (1.82 ± 0.33 mg/100 g DM). Potassium was detected only in trace amounts.

Table 1. Mineral profile of mangosteen fruit kernels

Mineral	Contents
Calcium (mg/100 g DM)	471.05±14.11
Potassium (mg/100 g DM)	traces
Magnesium (mg/100 g DM)	162.79±0.88
Zinc (mg/100 g DM)	1.82±0.33

DM: Dry Matter; Values are expressed as mean ± standard deviation of triplicate trails.

3.2. Bioactive Compounds in the Different Extracts

Extraction yields of 16.78%, 11.57%, and 12.32% were obtained using hydroethanol, ethanol, and distilled water, respectively. Phytochemical analysis of the mangosteen kernel extracts revealed the presence of total polyphenols, flavonoids, and alkaloids in all three extracts.

The ethanolic extract exhibited the highest total polyphenol content (194.13 ± 0.66 mg GAE/g DM), whereas lower values were recorded for the aqueous (128.65 ± 10.56 mg GAE/g DM) and hydroethanolic (126.54 ± 13.26 mg GAE/g DM) extracts. Significant differences were observed among the extracts ($p < 0.05$).

The flavonoid content ranged from 1.09 ± 0.01 mg QE/g DM in the hydroethanolic extract to 1.68 ± 0.11 mg QE/g DM in the aqueous extract, with significant differences among the extracts ($p < 0.05$).

Alkaloid contents were 2.26 ± 0.03, 2.47 ± 0.08, and 4.77 ± 0.11 mg QuiE/g DM in the aqueous, hydroethanolic, and ethanolic extracts, respectively. Significant differences were observed among the three extracts ($p < 0.05$) (Table 2).

Table 2. Total polyphenol, flavonoid, and alkaloid contents of different mangosteen fruit kernel extracts

Extracts	Bioactive compounds		
	Total Phenolic (mg GAE/g DM)	Flavonoids (mg QE/g DM)	Alkaloids (mg QuiE/g DM)
AE	128.65±10.56^a	1.68±0.11^a	2.26±0.03^a
HE	126.54±13.26^a	1.09±0.01^b	2.47±0.08^b
EE	194.13±0.66^b	1.38±0.16^b	4.77±0.11^c

AE: Aqueous Extract; HE: Hydro-ethanolic Extract; EE: Ethanolic Extract. mean ± standard deviation bearing different superscript letters in the same column are significantly different at p<0.05.

3.3. Antioxidant Activities of Mangosteen Fruit Kernel Extracts

3.3.1. DPPH Radical Scavenging Activity

The DPPH radical scavenging activities of the different mangosteen kernel extracts are presented in Figure 1. Regardless of the extraction solvent, all extracts exhibited concentration-dependent DPPH radical scavenging activity. The hydroethanolic extract exhibited significantly greater DPPH radical scavenging activity than the ethanolic and aqueous extracts ($p < 0.05$).

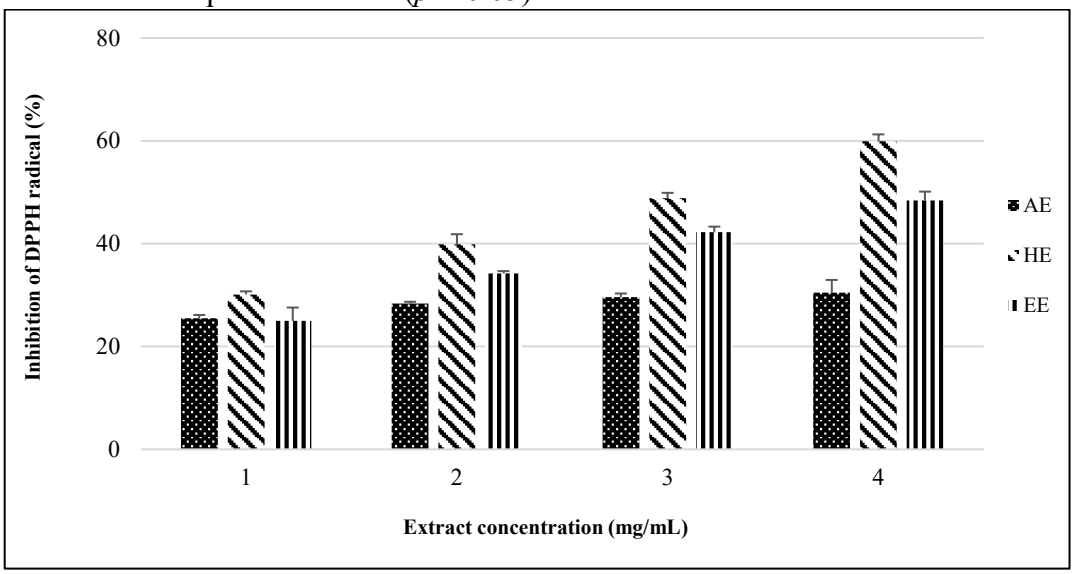

Figure 1. DPPH radical scavenging activity of aqueous, hydroethanolic, and ethanolic extracts of mangosteen fruit kernels. AE: aqueous extract; HE: hydroethanolic extract; EE: ethanolic extract.

3.3.2. Ferric-Reducing Power

Figure 2 presents the ferric-reducing power of the different mangosteen kernel extracts. All extracts exhibited ferric-reducing activity. The hydroethanolic and ethanolic extracts showed significantly greater reducing capacities (179.53 ± 1.58 and 154.92 ± 3.29 mg AAE/g DM, respectively) than the aqueous extract (40.62 ± 2.38 mg AAE/g DM) ($p < 0.05$). For all extracts, ferric-reducing activity increased with increasing extract concentration, with the highest reducing power observed at 4 mg/mL.

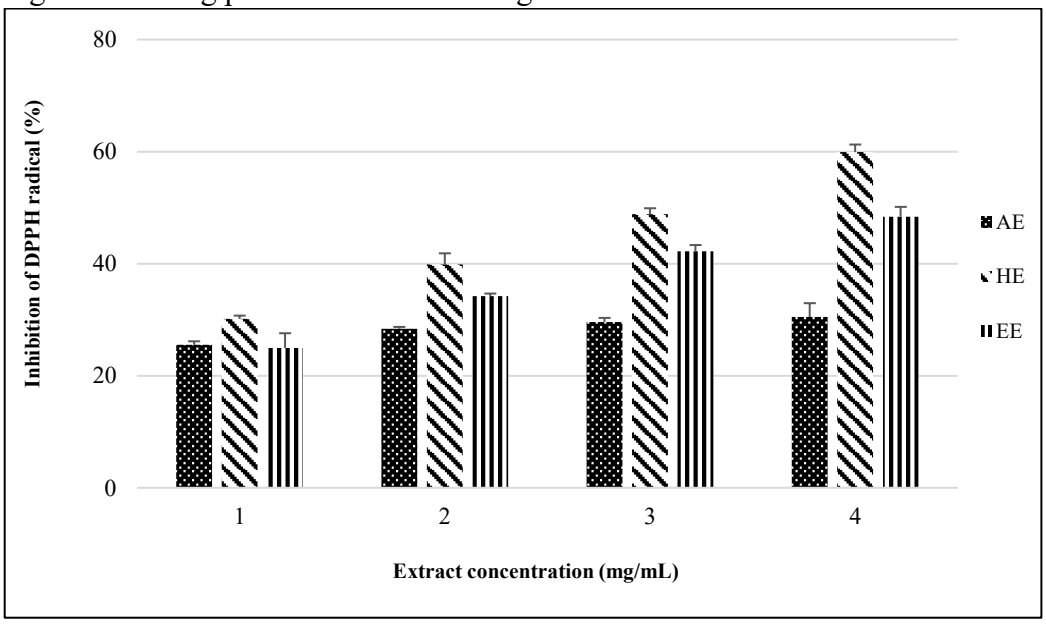

Figure 2. Ferric-reducing power of aqueous, hydroethanolic, and ethanolic extracts of mangosteen fruit kernels. AE: aqueous extract; HE: hydroethanolic extract; EE: ethanolic extract.

3.3.3. Total Antioxidant Capacity

As shown in Figure 3, the total antioxidant capacity (TAC) increased with increasing extract concentration. Significant differences in TAC were observed among the aqueous, hydroethanolic, and ethanolic extracts ($p < 0.05$). For all extracts, the highest total antioxidant capacity was observed at a concentration of 4 mg/mL.

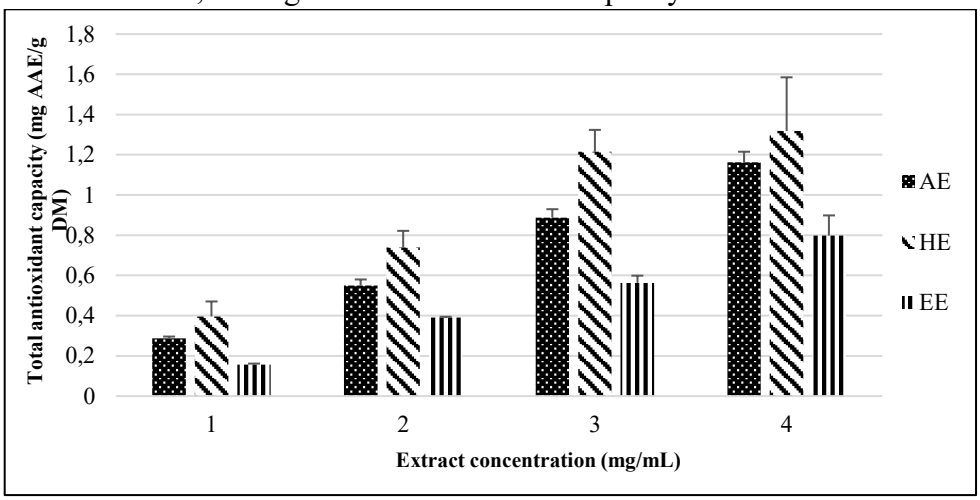

Figure 3. Total antioxidant capacity of aqueous, hydroethanolic, and ethanolic extracts of mangosteen fruit kernels. AE: aqueous extract; HE: hydroethanolic extract; EE: ethanolic extract.

3.3.4. Principal Component Analysis of Mangosteen Fruit Kernel Extracts

Principal component analysis (PCA) was performed to investigate the relationships among the bioactive compounds (total polyphenols, flavonoids, and alkaloids), extraction yield, and antioxidant activities assessed using the DPPH, ferric-reducing, and TAC assays (Figure 4).

The PCA revealed three main clusters. The first cluster comprised the aqueous extract and flavonoid content, suggesting an association between aqueous extraction and higher flavonoid recovery. The second cluster included the hydroethanolic extract, DPPH radical scavenging activity, TAC, and extraction yield. This association suggests that hydroethanol may favor the extraction of compounds contributing to DPPH radical scavenging activity and total antioxidant capacity, potentially including bioactive constituents other than the quantified polyphenols, flavonoids, and alkaloids.

The third cluster comprised the ethanolic extract, ferric-reducing activity, total polyphenols, and alkaloids. This association suggests that ethanol was particularly effective in extracting polyphenols and alkaloids and that these compounds may contribute to the observed ferric-reducing activity.

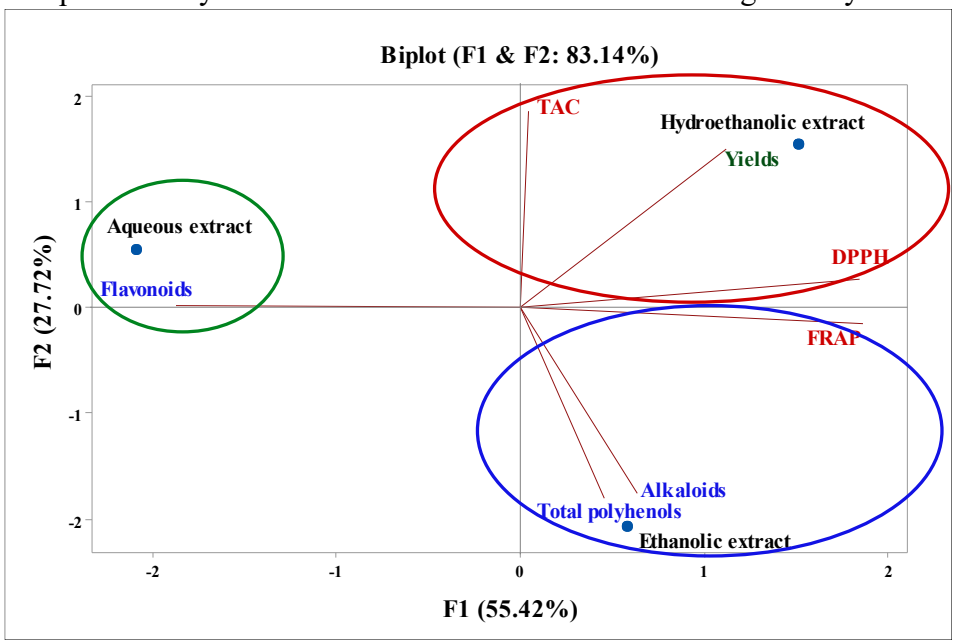

Figure 4. Principal component analysis showing the distribution of bioactive compounds, extraction yield, and antioxidant activities of the different mangosteen fruit kernel extracts on the F1 × F2 factorial plane.

4. Discussion

Fruit kernels are generally considered agro-food waste and are frequently discarded into the environment, potentially contributing to environmental pollution. The valorization of such by-products as functional food ingredients therefore represents a promising approach to reducing waste while identifying new sources of nutritionally and biologically relevant compounds. Plant-based foods and plant-derived ingredients containing bioactive compounds are increasingly attracting consumer and scientific interest because of their potential health-promoting properties [22,23]. Fruit kernels, in particular, have been reported as potential sources of nutrients and bioactive compounds [24]. The present study focused on mangosteen kernels, a by-product of an exotic fruit relatively recently introduced into Cameroon and increasingly consumed by the local population.

Among essential nutrients, minerals play important roles in numerous physiological processes, including muscle function, immune responses, energy metabolism, protection against oxidative damage, hormonal regulation, nerve transmission, DNA and protein synthesis, and acid–base balance [25,26]. Sani et al. [27] reported that kernels from tropical fruits, including durian, rambutan, mango, papaya, and mangosteen, contain nutritionally relevant constituents such as proteins, carbohydrates, lipids, minerals, and bioactive compounds.

Calcium is an essential mineral involved not only in maintaining bone health but also in neuromuscular function, cardiac activity, immune function, and other important physiological processes [28]. In the present study, mangosteen kernels contained 471.05 ± 14.11 mg/100 g DM of calcium. This value was higher than the concentrations of 6.5–11.3 mg/100 g DM reported by Ali-Mohamed and Khamis [29] for date kernels. However, differences between studies should be interpreted cautiously because of variations in plant species, geographical origin, environmental conditions, and analytical methods. Given the established physiological importance of calcium, including its role in bone health and blood pressure regulation [30–32], the relatively high calcium content observed in mangosteen kernels suggests their potential as an ingredient in calcium-enriched food formulations.

Potassium is an essential electrolyte required for the normal functioning of cells, nerves, and muscles and contributes to the maintenance of acid–base balance [33]. In the present study, potassium was detected only in trace amounts in mangosteen kernels. This finding differs from the value of 294.40 mg/100 g DM reported by Boussena and Zahida [34] for Algerian date kernels. This difference may be attributable to differences in fruit species, geographical origin, growing conditions, or analytical procedures.

Magnesium is an essential micronutrient involved in a wide range of metabolic, regulatory, and structural processes [30]. It serves as a cofactor for numerous enzymes involved in inflammatory and oxidative pathways and has also been associated with neurological and immune functions [35–38]. The mangosteen kernels analyzed in the present study contained 162.79 ± 0.88 mg/100 g DM of magnesium, a value higher than the 61.3–69.5 mg/100 g DM reported by Ali-Mohamed and Khamis [29] for date kernels. Considering the physiological importance of magnesium, particularly in cardiovascular function and blood pressure regulation [32], this finding further supports the potential nutritional value of mangosteen kernels.

Zinc was also detected in mangosteen kernels at a concentration of 1.82 ± 0.33 mg/100 g DM. Zinc plays an important role in antioxidant defense, including its involvement in antioxidant enzymes such as superoxide dismutase, and contributes to the regulation of inflammatory and immune responses [37,39,40]. Overall, the mineral profile observed in this study indicates that mangosteen kernels contain nutritionally relevant amounts of calcium, magnesium, and zinc. These findings suggest their potential for valorization as an ingredient in food formulations, although further studies are required to determine mineral bioavailability and establish their actual contribution to dietary requirements.

In addition to minerals, the present study investigated bioactive compounds, including total polyphenols, flavonoids, and alkaloids. Three relatively environmentally friendly extraction systems—distilled water, hydroethanol (70:30, v/v), and ethanol—were evaluated to determine their effects on extraction yield and phytochemical composition. The polarity and physicochemical properties of extraction solvents are known to influence the recovery of bioactive compounds from plant materials [41].

In the present study, hydroethanol produced the highest extraction yield, followed by distilled water and ethanol. The lower yield obtained with ethanol may be related to differences in solvent polarity and the solubility of the compounds present in mangosteen kernels. This finding differs from that of Dibacto et al. [42], who reported efficient extraction of bioactive compounds from plant materials using ethanol. Differences in extraction performance may reflect variations in the chemical composition of the plant matrix and the affinity of individual compounds for solvents of different polarities. Mixed-solvent systems have also been reported to enhance the extraction of a broader range of bioactive compounds [44].

The different solvents extracted polyphenols (126.54–194.13 mg GAE/g DM), flavonoids (1.09–1.68 mg QE/g DM), and alkaloids (2.26–4.77 mg QuiE/g DM) in varying proportions. No direct relationship was observed between overall extraction yield and the concentrations of the specific phytochemical groups quantified. Hydroethanol produced the highest extraction yield, whereas distilled water yielded the highest flavonoid content and ethanol yielded the highest total polyphenol and

alkaloid contents. These findings indicate that a high extraction yield does not necessarily correspond to a high concentration of a specific class of bioactive compounds, consistent with previous observations [45].

The aqueous extract exhibited the highest flavonoid content, which may be related to the polarity and chemical structures of the flavonoids present in the kernels. The solubility of phytochemicals, including flavonoids, varies according to their molecular structure and the polarity of the extraction solvent [46]. Conversely, total polyphenols and alkaloids were more concentrated in the ethanolic extract, suggesting a greater affinity of these compounds for ethanol under the extraction conditions used [42]. Although hydroethanol produced the highest overall extraction yield, it was not associated with the highest concentration of any of the three quantified phytochemical classes. This finding suggests that the hydroethanolic solvent may have extracted other constituents that were not quantified in the present study, potentially including tannins, saponins, polysaccharides, proteins, or other soluble compounds. Further chemical characterization would be required to confirm this hypothesis.

Regarding antioxidant activity, the hydroethanolic extract exhibited the strongest DPPH radical scavenging activity and total antioxidant capacity and also showed substantial ferric-reducing activity, despite having a significantly lower total polyphenol content than the ethanolic extract. This finding suggests that the antioxidant potential of the extracts may depend not only on the total concentration of the quantified phytochemicals but also on their chemical composition and possible interactions.

Several factors may explain this observation. First, the intermediate polarity of the hydroethanolic solvent may facilitate the extraction of a broader spectrum of antioxidant compounds than either water or ethanol alone, potentially including minor but highly active constituents such as certain tannins or proanthocyanidins. Second, synergistic or additive interactions among different constituents of the crude extract may contribute to its overall antioxidant activity. Third, the presence of antioxidant compounds not quantified in the present study, such as saponins, terpenes, or other phenolic constituents, cannot be excluded. These findings are consistent with those of Bourgou et al. [44], who reported that 70% acetone and 70% ethanol extracts exhibited strong antiradical and total antioxidant activities. They are also consistent with previous reports indicating that the overall antioxidant activity of plant-derived extracts may result from the combined effects of multiple phytochemical constituents [47].

To the best of our knowledge, this study is among the first to characterize the mineral composition, selected bioactive compounds, and antioxidant properties of mangosteen fruit kernels obtained from plants cultivated in Cameroon. The findings provide preliminary evidence supporting the potential valorization of this generally discarded fruit by-product as a source of minerals and bioactive compounds. However, the study has several limitations. The individual bioactive constituents responsible for the observed antioxidant activities were not structurally characterized, and the biological effects of the extracts were not evaluated using cellular or *in vivo* models. Further studies involving detailed phytochemical profiling, compound identification, bioavailability assessment, toxicity evaluation, and *in vivo* investigations are therefore needed before conclusions can be drawn regarding the potential role of mangosteen kernel-derived ingredients in the prevention or management of cardiometabolic diseases.

5. Conclusion

The findings of this study demonstrate that mangosteen kernels are a natural source of essential minerals, particularly calcium, magnesium, and zinc. Phytochemical analysis revealed that ethanol was the most effective solvent for extracting total polyphenols and alkaloids, whereas distilled water yielded the highest flavonoid content. All extracts exhibited antioxidant activity, with the hydroethanolic extract showing the strongest overall antioxidant potential. These findings highlight the importance of mixed-solvent systems for extracting a broader range of bioactive compounds from plant materials rather than focusing exclusively on the enrichment of a single class of phytochemicals. Overall, the mineral composition and antioxidant properties of mangosteen kernels support their potential valorization as a functional food ingredient. However, further studies, including detailed phytochemical characterization, bioavailability assessment, safety evaluation, and *in vivo* investigations, are required to establish their potential applications in the development of products aimed at addressing micronutrient deficiencies and supporting the prevention or management of cardiometabolic diseases.

Authors' Contribution Statement

Maxwell Wandji Nguedjo and Hippolyte Tene Mouafo: Conceptualization, Methodology, Experiment, Formal analysis, Validation, Writing-Review & Editing ; Kevin Fabrice Paul Mandeng: Methodology, Experiment, Formal analysis, Writing-original draft ; Jafarou Mounpou: Experiment, Writing-original draft ; Imelda Lucresse Nouteza Djuikoo: Experiment, Review & Editing; Dany Joël Ngassa Ngoumen: Formal analysis, Writing-Review & Editing ; Yves Didier Mboma Nseme: Collected Mangosteen fruit; Ruth Edwige Kemadjou Dibacto; Experiment, Review & Editing ; Boris Ronald Tonou Tchuente: Review & Editing; Melanie Ngondam: Review & Editing ; Gabriel Nama Medoua: Supervision the work. All authors read and approved the final version of the manuscript.

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Availability of Data

All relevant data are within the manuscript.

Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of the manuscript.

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