Microbiology Research Journal International

Volume 32, Issue 11, Page 40-52, 2022; Article no.MRJI.96635
ISSN: 2456-7043
(Past name: British Microbiology Research Journal, Past ISSN: 2231-0886, NLM ID: 101608140)

Bioactive Compounds from Mangosteen Fruit Peels (*Garcinia mangostana* L.) and Assessment of their Antioxidant Potential

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MWN and HTM conceived and designed the study. Author YDMN provided the raw material and managed the literature searches. Authors KFPM, JM and ILND wrote the protocol, did bench work and wrote the first draft of the manuscript. Authors MWN and HTM performed the statistical analysis, reviewed and edited the manuscript. Author RMMB reviewed and edited the manuscript. Author GNM provided facilities. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/MRJI/2022/v32i111354

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/96635

Original Research Article

Received: 23/10/2022
Accepted: 29/12/2022
Published: 30/12/2022

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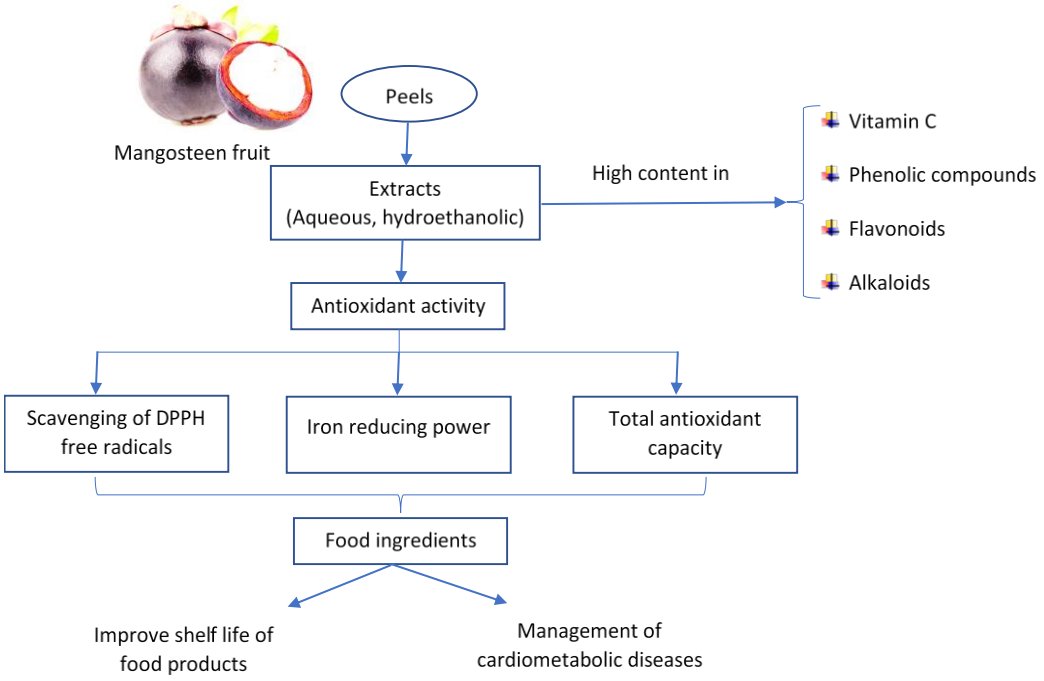
ABSTRACT

The aim of this study was to quantify the bioactive compounds in mangosteen fruit peels and assess their antioxidant activity. Peels from washed mature fruits of *Garcinia mangostana* (L.) were dried, crushed, and sieved, and the bioactive compounds were extracted using distilled water and ethanol 70%, and quantified. The antioxidant potential of the different extracts was assessed through their DPPH scavenging activity, iron reducing power, and total antioxidant capacity. Results showed that ethanol at 70% extracted more bioactive compounds compared to water. Total polyphenols content of 57.19 mg GAE/g DM, flavonoids of 35.06 mg QE/g DM, alkaloids of 4.49 mg QuiE/g DM, and vitamin C of 1.42 mg/100g DM were obtained from hydroethanolic (ethanol 70%) extract. As expected, the highest percentage of scavenging DPPH radical (85.98%) was recorded with hydroethanolic extract compared to the aqueous one (44.66%). Similar behaviors were noticed with the hydroethanolic extract regarding the iron-reducing capacity and the total antioxidant capacity. Thus, justifying the positive correlations obtained between bioactive compounds and antioxidant activities although significant ($p<0.05$) between alkaloids and DPPH scavenging activity. Mangosteen peels is a good source of bioactive compounds that might be potentially used for food preservation and the management/prevention of cardio-metabolic diseases.



Keywords: Mangosteen; fruit; peels; valorization; bioactive compounds; antioxidant activity.

1. INTRODUCTION

Mangosteen (*Garcinia mangostana* L.) is a flowering plant belonging to the family Clusiaceae (Guttiferae) and the genus Garcinia [1]. Native from tropical Asia (Malaysia, Thailand and Indonesia), mangosteen produces rounded, purplish, golfball-sized fruits with a thicky and very bitter peel [2]. The plant is mainly grown for its fruits which have a fine and delicious taste involving the mixture of acidity and sweetness [3]. The worldwide production of mangosteen fruits was estimated at 700,000 tons in 2017 [4]. The mangosteen culture was recently introduced in Cameroon, and successful trials were achieved in the agro-ecological zone of Njombé, Littoral Region [5]. Although the mangosteen fruits are highly consumed in urban area, it still remains unknown by a large part of the population due to its recent introduction in the country. The fruits are generally used as functional food and in the formulation of medicines and cosmetics as they contain several bioactive compounds endowed with antioxidant properties [6]. However, in Cameroon and elsewhere, the fruit pulps are of interest and the other parts of the fruits such as its peels are thrown in the nature where they constitute a

potential source of environmental pollution. Currently, researches are directed towards the valorization of these parts of the fruits considered as wastes. In that order of idea, Ghasemzadeh et al. [7] and Zadernowski et al. [8] made a comparative study and found that the mangosteen fruit peels contained more bioactive compounds than its pulp. Purba et al. [9] demonstrated the antioxidant activity of these bioactive compounds. In a recent study, it was suggested that the bioactive compounds from mangosteen fruit peels might play an important role in the management diabetes (type II) and obesity, in the prevention of fats accumulation (through induction of lipolysis and apoptosis in pre-adipocytes), and in the inhibition of pancreatic lipase [10].

Giving the composition and profile of bioactive compounds from plants vary according to the geographical areas of culture, it therefore appears necessary to know the content of bioactive compounds of the mangosteen fruit peels newly introduced and cultivated in Cameroon. It is in this context that the present research was designed. The main objective was to valorize the mangosteen fruit peels as a source of functional compounds endowed of biological properties. Specifically, it consisted to *(i)* extract and evaluate the bioactive compounds from mangosteen fruit peels, *(ii)* assess the antioxidant activity of these bioactive compounds, and *(iii)* determine the contribution of bioactive compounds in the antioxidant mechanism.

2. MATERIALS AND METHODS

2.1 Chemicals

All the reagents used in this study were of analytical grade and purchased from Merck (Germany). They included Folin-Ciocalteau, sodium carbonate, Ethanol 99%, gallic acid, aluminum chloride, potassium acetate, quercetin, iron chloride, hydrochloric acid, ascorbic acid, sulphuric acid, sodium dihydrogen phosphate, dibasic hydrogenophosphate, ammonium molybdate, potassium ferricyanide, trichloroacetic acid.

2.2 Biological Materials

The mangosteen fruits were provided by the Agricultural Research Institute for Development (IRAD) of Njombé, agro-ecological zone No. 4 (4°33'15.89 N and 9°37'42.84 E), Littoral Region, Cameroon. They were identified at the National Herbarium with the voucher number No. 25 666. The fruits were washed twice with distilled water and the peels were manually separated from the pulp, carefully washed again, cut into thin slices of approximately 5 cm, and dried in an oven (Memmert, Germany) for 7 days at 60°C. The dried peels were crushed, sieved (500 µm), packed into polyethylene bags, weighed and stored at 4°C for analysis.

2.3 Preparation of Extracts

Distilled water and a solution of ethanol at 70% (v/v) in distilled water were used as solvents to extracts bioactive compounds from the powder of mangosteen fruit peels. In the protocol, 5 g of powder was introduced into a 250 mL Erlenmeyer and 100 mL of solvent was added. The mixture was homogenized for 24 h at room temperature (25±1°C) using a magnetic stirrer (Lab-Line, Pyro-Multi-Magnestir, N° 1263-1). Then, it was centrifuged (Centrifuge Rotoflix 32 A) at 3500×g for 10 min and the supernatant was collected, filtered through a Whatman N°4 paper and evaporated at 60°C for 72 h until a semi-solid residue was obtained. The extracts were stored at 4°C (Labcold, Basingstocke Hants) for analysis.

2.4 Phytochemical Analyses of the Extracts

2.4.1 Determination of total polyphenols

The method described by Singleton & Rossi [11] with slight modifications was used to determine the total polyphenols' content of the extracts. Briefly, an aliquot of 0.1 mL of extract (4 mg/mL) was mixed with 0.75 mL of Folin-Ciocalteau reagent (diluted 10 times in distilled water) and left at room temperature (25±1°C) for 5 min. Then, 0.75 mL of an aqueous solution of sodium carbonate (6%, w/v) was added. The mixture was stirred using a vortex mixer and incubated at 25±1°C in the dark for 90 min. The absorbance of the blue complex formed during the reaction was read at 725 nm (UVmini-1240, UV-Vis Spectrophotometer, Shimadzu- Japan) against a blank where the extract was replaced by distilled water. Gallic acid at concentrations ranging from 0 to 800 µg/mL was used as the standard. The total polyphenols' content of the different extracts was calculated from the calibration curve (r^2=0.97) drawn with standard and expressed in micrograms of gallic acid equivalent per gram of dry matter (µg GAE/g DM).

2.4.2 Determination of flavonoid content

The quantification of total flavonoids was performed following the protocol of Aiyegoro & Okoh [12]. An aliquot of 0.2 mL of extract (4 mg/mL) was introduced into a tube, followed with the addition of 0.1 mL of aluminum trichloride ($AlCl_3$, 10% w/v), 1 mL of potassium acetate (CH_3COOK, 1M) and 2.8 mL of distilled water. The mixture was homogenized, incubated at 25±1°C for 30 min and the absorbance was read at 415 nm against the blank. Quercetin at concentrations ranging from 0 to 800 µg/mL was used as standard. The total flavonoids' content was calculated from the calibration curve (r^2=0.99) and expressed as micrograms of quercetin equivalent per gram of dry matter (µg QE/g DM).

2.4.3 Determination of alkaloid content

The determination of the alkaloid content was evaluated according to the method of Sing et al. [13] with some modifications. In the experimental procedure, 100 mg of the extract was dissolved in 10 mL ethanol (80%, v/v). The mixture was homogenized and centrifuged at 5000×g for 10 min. The bottom was discarded and 1 mL of the supernatant was taken and introduced into a tube. Then, 1 mL of the mixture [$FeCl_3$ (0.025M) + HCl (0.5M)] and 1 mL of 1,10-phenanthroline (0.05M) prepared in ethanol were added. The mixture obtained was homogenized and incubated for 30 min at 100°C in a water bath (Poly Science, USA). After incubation, the absorbance of the red coloration formed was read at 510 nm against the blank. Quinine at a concentration of 10 µg/mL was used as the standard and the alkaloid content was expressed in micrograms of quinine equivalent per gram of dry matter (µg QuiE/g DM).

2.4.4 Determination of vitamin C content

The vitamin C content of the extracts was assessed following the method described by Mouhannad et al. [14] with some modifications. Briefly, extracts' solutions at 50 mg/mL were prepared in distilled water. The solution was diluted with distilled water (50:1 v/v) and 20 mL of the mixture was taken and transferred into an Erlenmeyer of 500 mL followed with addition of 25 mL of distilled water and 1 mL of starch (0.25 g of soluble starch in 50 mL of boiling distilled water at 79°C). The mixture was titrated with a solution of iodine 0.05 M (2 g KI and 1.3 g of I_2, in 1 L of distilled water) under agitation of a magnetic stirrer (IKA® C-MAG HS 7, Germany) until the formation of a blue-black color that persists for 30 s. The vitamin C content was expressed in mg of extract per 100 g of dry matter.

2.5 Evaluation of Antioxidant Potential of the Extracts

2.5.1 Determination of DPPH (2,2diphenyl-1-picrylhydrazyl) radical scavenging activity

The DPPH scavenging activity of the extracts from the mangosteen fruit peels was evaluated using the method described by Sanchez-Moreno et al. [15]. The extracts were prepared at different concentrations (1.0, 5.0, 10.0, 15.0, and 20.0 mg/mL) and 50 µL was mixed with 1.95 mL of a freshly prepared DPPH methanolic solution (0.025 g/L). After 30 min of incubation at 25±1°C in the dark, the absorbance was read at 515 nm. Methanol was used as a negative control while ascorbic acid (vitamin C) was used as a positive control. The controls were prepared as for the test sample where the extract solution was replaced by methanol or ascorbic acid. The absorbance of the solution was read at 515 nm against the blank. The percentage of inhibition of the DPPH radical was calculated using the following formula:

$$DPPH\ inhibition_{(\%)} = \left(\frac{OD_{control} - OD_{sample}}{OD_{control}}\right) \times 100$$

The IC_{50} value corresponding to the concentration of antioxidants necessary for scavenging 50% of DPPH radical, was calculated from the graph of the DPPH inhibition percentage as a function of the concentrations of extracts. As the IC_{50} value of an extract is low, that extract is considered as active.

2.5.2 Determination of the ferric reducing antioxidant power (FRAP)

The reducing power of the extracts was determined by the method of Oyaizu [16]. In the protocol, solutions of extracts at 0.25, 0.50, 0.75 and 1.0 mg/mL were prepared. An aliquot of 1 mL of the extract was mixed with 2.5 mL of phosphate buffer solution 0.2M (pH 6.6) and 2.5 mL of potassium ferricyanide solution ($K_3Fe(CN)$ 6.1%, w/v). The mixture was incubated in a water bath at 50°C (Poly Science, USA) for 20 min. Then, 2.5 mL of trichloroacetic acid solution 10% (w/v) were added to the mixture to stop the reaction and the tubes were centrifuged at 3000×g for 10 min. 2.5 mL of the supernatant

was mixed with 2.5 mL of distilled water and 0.5 mL of ferric chloride solution ($FeCl_3$, 0.1%). The absorbance of the mixture was read at 700 nm against the blank. Distilled water and ascorbic acid (0.25 µg/mL) treated under the same conditions as the samples were used as positive and negative controls, respectively. The iron reduction capacity (Fe^{3+}) was expressed in µg of ascorbic acid equivalent per gram of dry matter (µg AAE/g DM).

2.5.3 Determination of the total antioxidant capacity

The total antioxidant capacity (TAC) of the extracts was evaluated using the phosphomolybdenum method described by Prieto et al. [17]. An aliquot of 0.2 mL of extract at different concentrations (0.50, 0.625, 0.75, 0.875, and 1.00 mg/mL) was mixed with 2 mL of reactive solution (sulfuric acid 0.6 M, sodium dihydrogenophosphate 28 mM, and ammonium molybdate 4 mM). The tubes were plugged and incubated at 95°C for 90 min in a water bath. After incubation, the tubes were cooled and the absorbance was read at 695 nm against the blank (3 mL of reagent solution and 0.3 mL of methanol). The TAC of the extracts was calculated using the calibration curve generated with ascorbic acid at concentrations ranging from 0.01–0.5 mg/mL (r^2=0.988) and expressed in milligrams of ascorbic acid equivalent per gram of dry matter (mg AAE/g DM).

2.6 Statistical Analyses

All experiments were repeated three times and the results were expressed as a mean ± standard deviation. The mean values of responses obtained from the two extracts were compared using the Student t-test and statistical significance was set at $p<0.05$. Pearson's correlation was performed to assess the relationship the bioactive compounds of extracts and the antioxidant activities. All tests were done using the Statistical Package for Social Sciences (SPSS) version 20.0.

3. RESULTS

3.1 Bioactive Compounds of Different Extracts

The bioactive compounds of the different extracts were quantified and the results are presented in Table 1. The mangosteen fruit peels contained polyphenols, flavonoids, alkaloids and vitamin C at concentrations which vary significantly ($p<0.05$) with the extraction solvent. Generally, ethanol 70% extracted more polyphenols (57.19±0.46 mg EAG/g DM vs 27.07±0.57 mg EAG/g DM obtained with distilled water as solvent), flavonoids (35.06±1.46 mg EQ/g DM vs 2.01±0.48 mg EQ/g DM obtained with distilled water as solvent), alkaloids (4.49±0.00 mg EQui/g DM vs 3.35±0.03 mg EQui/g DM obtained with distilled water as solvent) as well as vitamin C for which 1.42±0.01 mg/100g DM was obtained compared to 0.55±0.01 mg/100g DM recorded with distilled water (Table 1).

3.2 Antioxidant Activities of Mangosteen Fruit Peels' Extracts

3.2.1 Capacity to scavenge DPPH radicals

The ability of extracts from mangosteen fruit peels to scavenge the DPPH radicals is depicted in Fig. 1. Independent of solvent used, the extracts were active in a concentration dependent manner. While considering the extraction solvent, the hydroethanolic extract was significantly more active than the aqueous one. The maximum inhibition percentage of DPPH radicals (85.98%) was obtained with 5 mg/mL of the hydroethanolic extract, while with the aqueous extract, it was obtained with 20 mg/mL (83.50%). The extract concentration that inhibits 50% of the DPPH free radicals was calculated and the results obtained showed that the hydroethanolic extract has an IC_{50} of 0.29 mg/mL while the aqueous one has an IC_{50} of 1.05 mg/mL. Although the ethanolic extract was significantly ($p<0.05$) more active as it showed the lowest IC_{50} value, both of the two extracts were less active than the vitamin C used as control for which an IC_{50} value of 3.92 µg/mL was recorded.

3.2.2 Iron reducing power

As observed in Fig. 2, all the extracts showed ability to reduce iron. The reducing power was proportional to extracts' concentration and the highest reducing power was noticed at the extract concentration of 1 mg/mL. Considering the effect of extraction solvent, an opposite observation was made. Aqueous extract with a reducing power of 48.99 mg EAA/g DM was significantly ($p<0.05$) more active compared to hydroethanolic extract for which a reducing power of 24.77 mg EAA/g DM was obtained.

3.2.3 Total antioxidant capacity

The total antioxidant capacity of the extracts increases as the extraction concentration

increases (Fig. 3). The maximum total antioxidant capacity (0.53 mg EAA/g DM for the hydroethanolic extract and 0.19 mg EAA/g DM for the aqueous extract) was reached at the extracts' concentration of 1 mg/mL. Generally, the hydroethanolic extract showed a total antioxidant capacity significantly ($p<0.05$) higher than the aqueous extract independently of the tested concentrations.

3.3 Correlation between the Bioactive Compounds and the Antioxidant Activities of Extracts

Regarding the aqueous extract of mangosteen fruit peels, only alkaloids were positively ($r^2=1.0$) and significantly ($p<0.05$) correlated with scavenging activity. Although non-significant ($p>0.05$), the total antioxidant capacity was negatively correlated with vitamin C ($r^2=-0.09$), flavonoids ($r^2=-0.58$), total phenolics ($r^2=-0.09$) and alkaloids ($r^2=-0.91$). The scavenging activity was positively correlated with total phenolics ($r^2=0.50$), flavonoids ($r^2=0.86$), and vitamin C ($r^2=0.50$). The reducing power was negatively correlated with total phenolics ($r^2=-0.22$) and vitamin C ($r^2=-0.22$), but positively correlated with flavonoids ($r^2=0.29$) and alkaloids ($r^2=0.73$).

Considering the hydroethanolic extract of mangosteen fruit peels, no significant ($p>0.05$) correlations were recorded. Vitamin C, flavonoids and total phenolics were negatively correlated with total antioxidant capacity with r^2 of -0.50, -0.56, and -0.50, respectively. Only alkaloids were positively correlated with total antioxidant capacity ($r^2=0.32$). Negative correlations were obtained between the reducing power and

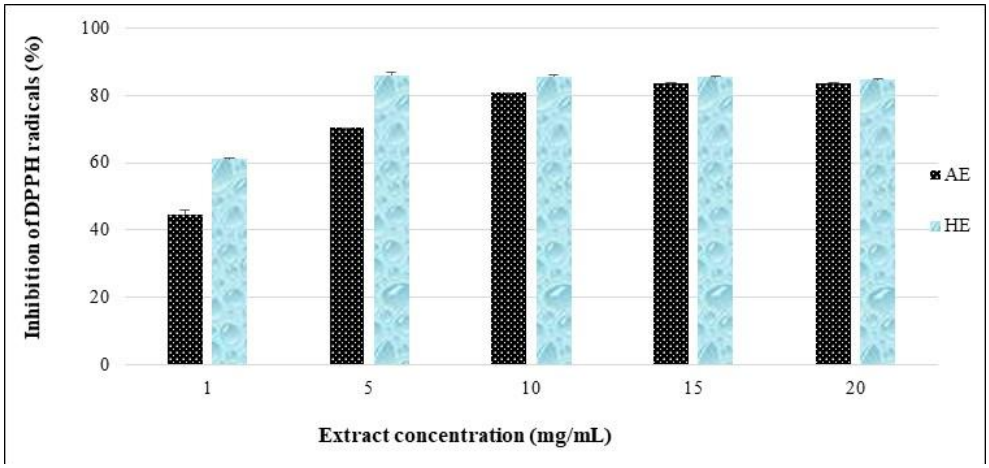


Fig. 1. Inhibition percentage of DPPH radicals of the aqueous and hydroethanolic extracts from mangosteen fruit peels

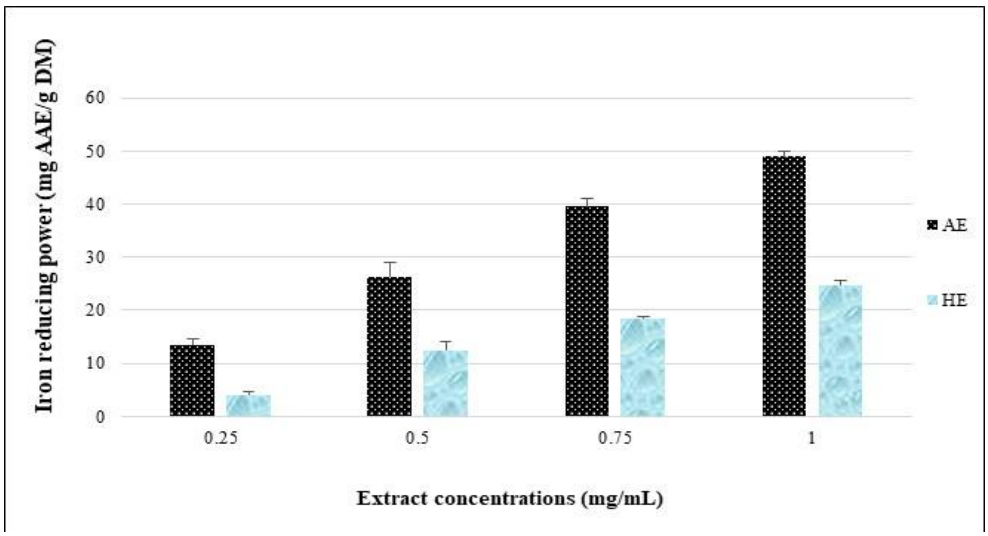


Fig. 2. Iron reducing power of the aqueous and hydroethanolic extracts of mangosteen fruit peels

Table 1. Contents in total phenolics, flavonoids, alkaloids and vitamin C of extracts from mangosteen fruit peels

Extracts	Bioactive compounds			
	Total Phenolic (mg GAE/g DM)	Flavonoids (mg QE/g DM)	Alkaloids (mg QuiE/g DM)	Vitamin C (mg/100g DM)
AE	27.07±0.57[a]	2.01±0.48[a]	3.35±0.03[a]	0.55±0.01[a]
HE	57.19±0.46[b]	35.06±1.46[b]	4.49±0.00[b]	1.42±0.01[b]

AE=Aqueous Extract; HE=Hydroethanolic Extract; Values bearing different superscript letters in the same column are significantly different at p<0.05

Table 2 Correlation between bioactive compounds of different extracts from mangosteen fruit peels and antioxidant activities

Extracts	Antioxidant tests	Alkaloids	Total Phenolic	Flavonoids	Vitamin C
Aqueous extract	TAC	r^2=-0.910; p=0.272	r^2=-0.096; p=0.939	r^2=-0.581; p=0.606	r^2=-0.096; p=0.939
	FRAP	r^2=0.731; p=0.478	r^2=-0.225; p=0.856	r^2=0.292; p=0.811	r^2=-0.225; p=0.856
	DPPH	r^2=1.00; p=0.000*	r^2=0.500; p=0.667	r^2=0.866; p=0.333	r^2=0.500; p=0.667
Hydroethanolic extract	TAC	r^2=0.327; p=0.788	r^2=-0.500; p=0.667	r^2=-0.569; p=0.614	r^2=-0.500; p=0.667
	FRAP	r^2=-0.308; p=0.801	r^2=0.123; p=0.922	r^2=-0.950; p=0.203	r^2=0.123; p=0.922
	DPPH	r^2=-0.327; p=0.788	r^2=0.500; p=0.667	r^2=0.569; p=0.614	r^2=0.500; p=0.667

*r^2=Correlation coefficient; p=P-value. DPPH=2, 2-diphenyl-1 picrylhydrazyl; FRAP=ferric reducing antioxidant power; TAC=total antioxidant capacity. *indicates a significant at p<0.05*

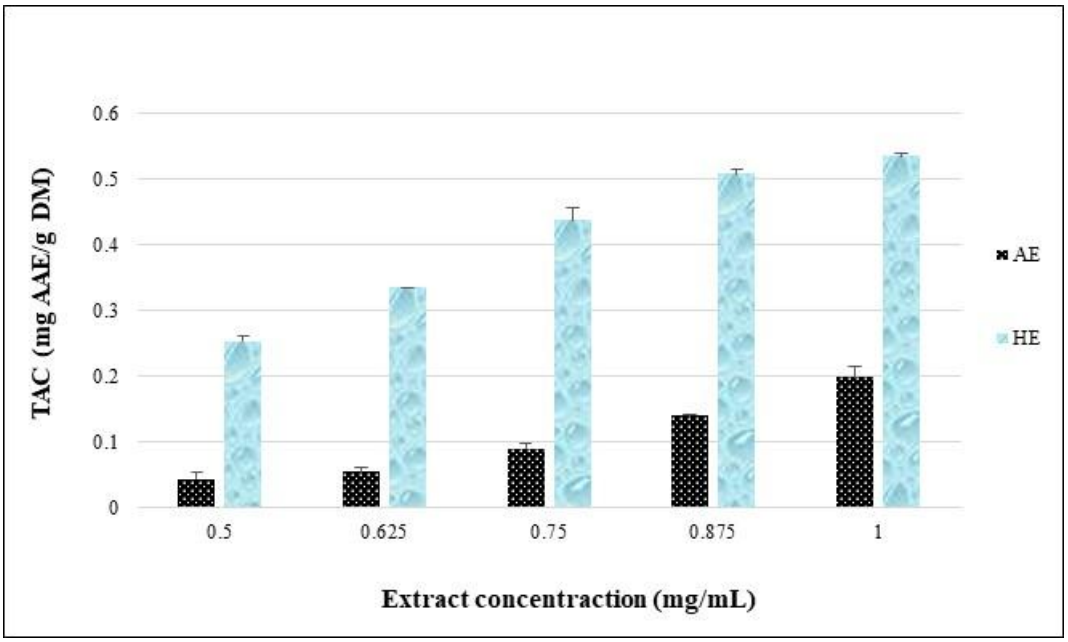


Fig. 3. Total antioxidant capacity of the aqueous and hydroethanolic extracts of mangosteen fruit peels

alkaloids (r^2=-0.32) and flavonoids (r^2=-0.95), and also between the scavenging activity and alkaloids (r^2=-0.32). However, the reducing power was positively correlated to total phenolics (r^2=0.12) and vitamin C (r^2=0.12). Positive correlations with r^2 of 0.5, 0.56, and 0.50 were obtained between the scavenging activity and the total phenolics, flavonoids and vitamin C, respectively.

4. DISCUSSION

Fruit peels are generally considered as wastes and are usually drawn in nature, leading to an environmental pollution. In this study, we have decided to valorize the mangosteen fruit peels as functional ingredients that might be used in the food industry for food preservation purpose or in the medical field for the management and/or prevention of cardiometabolic diseases. For that, the peels of mangosteen fruits were powdered and bioactive compounds were extracted using two solvents: distilled water and ethanol: distilled water 70% (v/v). The results obtained in this study showed that, the mangosteen fruit peels contains bioactive secondary metabolites such as polyphenols (27.07 - 57.19 mg EAG/g DM), flavonoids (2.01 - 35.06 mg EQ/g DM), and alkaloids (3.35 - 4.49 mg EQui/g DM) as well as the micronutrient vitamin C (0.55 - 1.42 mg/100g DM). Generally, the highest contents in bioactive compounds (polyphenols, flavonoids, alkaloids, vitamin C) were noticed in hydroethanolic extract. This could arise from the polarity of the hydroethanolic solvent. Indeed, ethanol is an organic solvent that can easily pass through the cell walls and membranes thus facilitating the extraction of a large amount of low polar compounds. It was reported in the literature that biological active compounds present in plant materials such as alkaloids, tannins, terpenoids, flavonoids and phenolic compounds are insoluble secondary metabolites [18,19]. Dibacto et al. [20] also reported that ethanol 70% extracted more polyphenols and flavonoids compared to distilled water. Moreover, the presence of distilled water at 30% in that solvent might also enable the extraction of some water soluble bioactive compounds, leading to an increase in their contents. Indeed, addition of water to organic solvent increases the solubility of compounds by modulating their polarity through a weakening of hydrogen bonds [21].

The total polyphenols content of the hydroethanolic extract obtained in this study (57.19 mg EAG/g DM) was higher than that reported by González et al. [22] ethanolic extract of *Passiflora edulis* peels, a fruit that the peel has the same sticky structure like mangosteen fruit. They found a total polyphenols content of 37.70±0.13 mg EQ/g of extract. However, opposite observation was noticed regarding flavonoids as the value reported by these authors

(55.60±0.11 mg EQ/g) was higher than that obtained in this study (35.06 mg EQ/g DM). Regarding the aqueous extract of mangosteen fruit peels, their polyphenols and flavonoids contents were higher than that reported by Ramli et al. [23] with aqueous extract of *P. edulis* peels (total polyphenols of 7.273±0.002 mg EGA/g and flavonoids of 8.364±0.002 mg EQ/g). This could be ascribed to the composition of peel which varies from a fruit to another. The high content of polyphenols and flavonoids (which are bioactive compounds endowed with biological activity) in the mangosteen fruit peel suggests the potential use of these wastes as functional ingredients. Besides these bioactive secondary metabolites, the presence of vitamin C is these peels suggests their potential use as a novel and green foods preservative ingredient. To strengthen these hypotheses, the antioxidant activity of the extracts was assessed. Three methods were used as extract constituents might act through different mechanisms. They were the free radicals scavenging activity, the iron reducing power and the total antioxidant capacity.

One of the most widely used, easiest and efficient method to assess the antioxidant activity of a compound is the scavenging model of DPPH radical. It measures the ability of a compound to donate hydrogen radicals to scavenge DPPH radicals [24]. In this study, all the mangosteen fruit peels extracts were able to scavenge the DPPH radicals and convert it into species (DPPH-H or DPPH-R) which are a more stable. The greatest inhibition percentage of the DPPH radicals was recorded with the hydroethanolic extract of mangosteen fruit peels. This could be attributed to its high contents in total phenolics, flavonoids and vitamin C. Indeed, the presence of hydroxyl groups in the structure polyphenols, flavonoids and vitamin C confers to these latter a strong ability to give more hydrogen atoms to stabilize free radicals [25]. The ability of phenolic compounds and flavonoids to donate a proton leading to the stabilization of DPPH radical was also noticed by Baschieri & Amorati [26] and Siano et al. [27]. Vitamin C was highlighted by as a powerful antioxidant thanks to its crucial role in the suppression of free radicals [28,29]. Moreover, the electron donating ability of vitamin C and flavonoids lead to the conversion of free radicals into a more stable form as reported by Dibacto et al. [20]. The positive correlations between the scavenging activity of the both extracts and their total phenolics, flavonoids and vitamin C contents also justify the involvement of these bioactive compounds in the antioxidant mechanisms. Thus, the presence polyphenols, flavonoids and vitamin C in mangosteen fruit peels suggests that byproducts as a potential functional food ingredient useful to fight against the oxidative stress and its consequences like cardiovascular and neurodegenerative diseases mainly due to the free radicals which attack and cause damage to our cells.

Regarding the aqueous extract of mangosteen fruit peels, only alkaloids were positively (r^2=1.0) and significantly ($p<0.05$) correlated with scavenging activity. However, that observation was no made with hydroethanolic extract despite its highest alkaloids content. This could be ascribed to the chemical structure of the alkaloids extracted with distilled water and suggests that further analyses on the alkaloids profile of the aqueous extract of mangosteen fruit peels should be investigated in order to identify these novel alkaloids endowed with powerful scavenging activity. Račková et al. [30] also reported that the scavenging mechanism of alkaloids depends on their chemical structure and increases with their degree of hydroxylation. Indeed, some alkaloids contain phenolic, OH, OCH_3, NH_2 and NH functional groups. In presence of free radicals, they can donate their hydrogen and end the chain reaction with the formation of the oxidized form of DPPH which is stable [31].

Another antioxidant mechanism of the extracts assessed in this study was their reducing power through the ferric reducing antioxidant power (FRAP). This method is based on the capacity of a compound to donate electron leading to the reduction of Fe^{3+} into Fe^{2+} [32,33]. The mangosteen fruit peels independently of the extraction solvent showed ability to reduce ferric ions in a dose dependent manner. Azima et al. [34] also reported that mangosteen fruit peel extracts possessed a good reducing power which is higher compared to other extracts from fruit peels like guava and *Clitoria ternatea*. In this study, the reducing power of extracts showed different behavior compared to scavenging activity where the hydroethanolic extract with the highest content in bioactive compounds was more active. Indeed, aqueous extract exhibited the highest reducing power. This can arise from the chemical structure of compounds extracted with distilled water as solvent. Kaurinovic & Vustag [35] also pointed out the good correlation between the reducing power and the chemical structure of bioactive compounds rather than their contents. The highest correlation of the

reducing power was recorded in the present study with alkaloids (r^2=0.73) from aqueous extract of mangosteen fruit peels. This can be explained by the chemical structure of alkaloids extracted with distilled water. Indeed, some alkaloids possess in their side chains of isoprene unit a high electron density. In their ferric reducing power mechanism, they act as electron donor leading to the purge radical species [36]. The position and the number of hydroxyl groups in the chemical structure of the alkaloids also play a critical role in their ferric reducing power [37]. The reducing power of extracts from mangosteen fruit peels suggests their potential use in the medical field to manage and prevent oxidative damage in neurodegenerative disorders including aging, atherosclerosis, cancer, diabetes, Parkinson's and Alzheimer's diseases which are associated to transition metal ions and formation of reactive oxygen species. They can substitute of synthetic compounds for which side effects are continuously reported.

With regard to total antioxidant capacity, both extracts were active in reducing Molybdate (VI) to Molybdate (V) in a dose-dependent manner. This observation can be related to the exponential development of the reduction power when the concentration of the extract increases [38]. The hydroethanolic extract exhibited the highest total antioxidant capacity (0.53 mg EAA/g DM) compared to aqueous extracts. Notwithstanding that observation, it is noteworthy to note that in aqueous extract, the total antioxidant capacity was negatively correlated with total phenolics (r^2=-0.09), flavonoids (r^2=-0.58), vitamin C (r^2=-0.09) and alkaloids (r^2=-0.91). While in hydroethanolic extract, a positive correlation was made only between the total antioxidant capacity and alkaloids (r^2=0.32). This suggests that either alkaloids or other non-identified compounds of the extracts such as tannins, saponins, polysaccharides, and anthocyanins might be responsible of the total antioxidant capacity assessed through the reduction of molybdate (VI) to molybdate (V). These results corroborate those of Kadum et al. [39] and Farahmandfar et al. [40] who showed that the total antioxidant capacity is often dependent on the presence of some alkaloids and polyphenols rather than the quantity of flavonoids and others.

This study is the first of its kind relating to evaluate the bioactive compounds and antioxidant potential of mangosteen fruit grown in Cameroon. Perhaps the main limitation of this study is the fact that an *in vivo* study in rats were not conducted. Indeed, an in-depth study on toxicity and metabolic disorders in rats of mangosteen fruit peels will allow the valorization of this waste.

5. CONCLUSIONS

This study indicates that bioactive compounds with different features can be extracted from mangosteen fruit peels using distilled water and ethanol 70% as extraction solvents. In addition, mangosteen fruit peels is a good and natural source of vitamin C, phenolic compounds, flavonoids and alkaloids. The aqueous and hydroethanolic extracts from these peels displayed free radicals scavenging activity and iron reducing power. They also demonstrated excellent total antioxidant capacity thus suggesting their use as natural antioxidants in substitution of their chemical counterparts. The present study also suggests that in spite of chemical products which are already available on markets, natural alternatives should be considered in the governmental measures for food preservation as well as the prevention and management of metabolic diseases.

FUNDING INFORMATION

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

DATA AVAILABILITY

Upon request, the data used in this study are available from the corresponding author.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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https://www.sdiarticle5.com/review-history/96635