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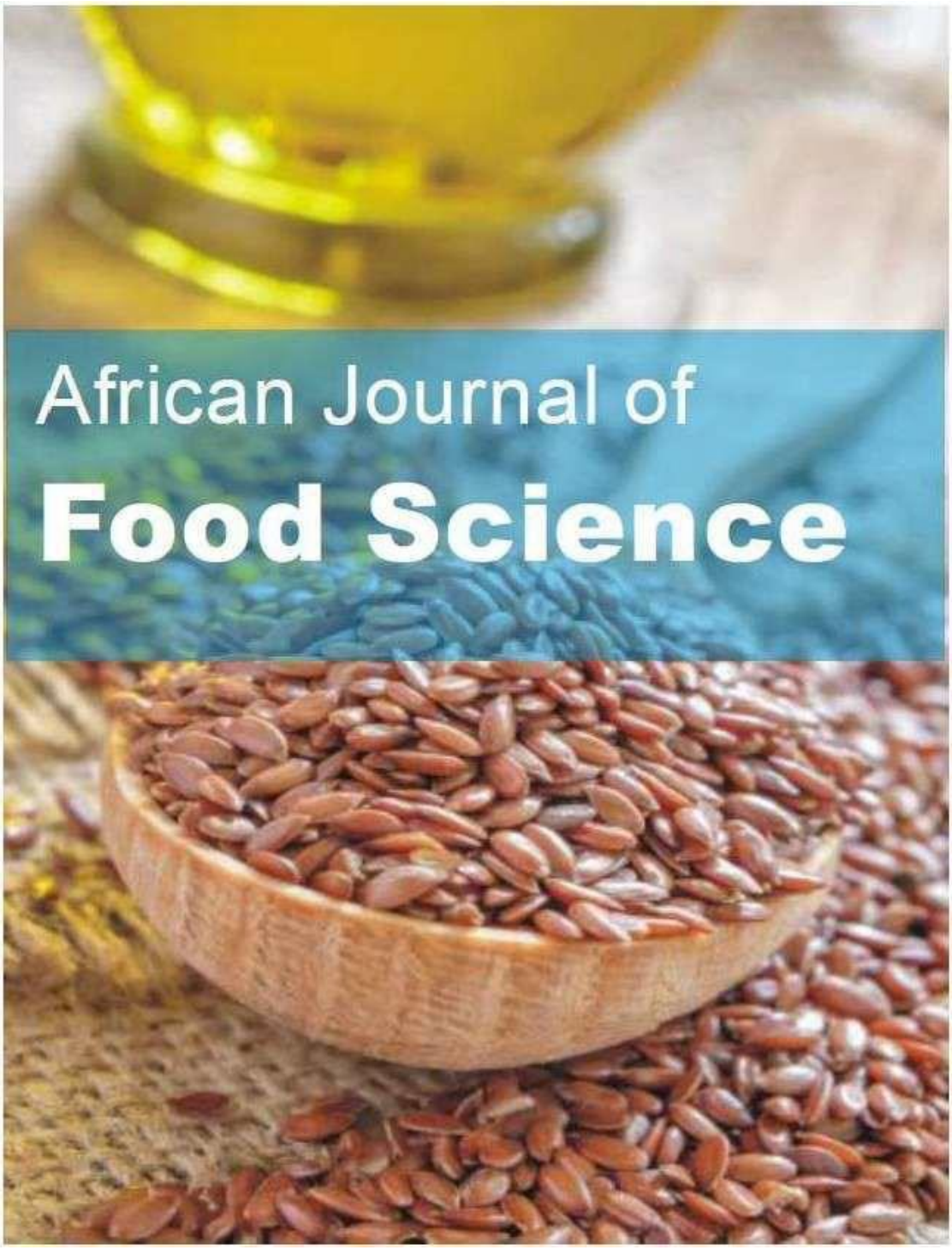

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African Journal of Food Science

Review

Waste-to-wealth; nutritional potential of five selected fruit peels and their health benefits: A review

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Waste-to-wealth is a notion describing the process of transforming waste, an end product to get rid of, into potential value-added products. The total global food waste is predicted to be approximately one third of the edible parts of food manufactured for human consumption, amounting to about 1 - 3 billion tonnes per year, which is equivalent to the total food production in sub-Saharan Africa; 842 million people in the world do not have enough food to eat. Food waste creates severe environmental and public health consequences that have a negative impact upon human well-being and their environments. This review sought to examine the nutritional, health benefits and potential of orange (*Citrus sinensis*), papaya (*Carica papaya*), pineapple (*Ananas comosus*), watermelon (*Citrullus lanatus*) and banana (*Musa sapientum*) peels termed waste to be valorized to nutrient-rich products needed in food and pharmaceutical industries. The nutritional profile (gkg^{-1}) dry weight revealed that the crude protein ranged from "[watermelon 0.55 - papaya 18.96]" and crude fiber "[watermelon 0.21 - pineapple 42.22]". The mineral analysis (mg/kg^{-1}) comprised Ca "[pineapple 8.30 - orange 162.03]"; Fe "[banana 15.15 - watermelon 45.58]"; and Zn "[banana 0.033 - orange 14.04]". All the peels had good antioxidant potential. Glycemic index ranged from "[pineapple 19 - orange 32]"; and estimated glycemic load "[Watermelon 1.93 - Orange 27.51]". Fruit peels waste can be minimized by creating public awareness on valorization of peels.

Key word: Food waste, fruit peels, nutritional analysis, antioxidant, health benefits.

INTRODUCTION

An average consumer generates 68 kg food waste annually, 49% of which could be avoided (FAO, 2018; Huho et al., 2020). Food waste may occur at any stage of the food supply chain that is, production, processing, retail and consumption. Food waste is a food that is not consumed. Global food waste ranged between one-third and one-half of all food produced (Bellemare et al., 2017). In developed countries, food waste occurred during

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production while in developing countries about a hundred kilograms of food per person per annum is wasted at the consumption stage (Makanjuola et al., 2020: Haley et al., 2021; Music et al., 2021). In the European Union, food waste was defined as any food substance, raw, cooked, that is discarded since 1975 until 2000 (Porpino, 2016). The United States Environmental Protection Agency defined food waste as “unconsumed food, food preparation, wastes from homes and commercial establishments (Baylen and Linnekin, 2016). This definition is invalid due to the fact that, if the food termed as waste is used as an input such as animal feed, fertilizer and biomass to generate output, then by definition it is not wasted. Also, the definition demonstrated practical difficulties for measuring food waste since the measurement needs tracking food waste in every stage of the supply chain and its proportion that flowed to nonfood uses. This, therefore, implied that only food that ends up in landfills should be regarded as food waste (Bellemare et al., 2017). It was predicted that the total global food waste which is approximately one third of the edible parts of food manufactured for human consumption, amounts to about 1.3 billion tonnes (1.28×10^9 long tons; 1.43×10^9 short tons) per year (Bellemare et al., 2017; Porpino, 2016; Devananda, 2017). In developing countries, it is estimated that 400 - 500 calories per day per person are going to waste, while in developed countries 1500 calories per day per person are wasted (Porpino, 2016; Baylen and Linnekin, 2016). The total food waste by consumers in industrialized countries (222 million tonnes) is almost equal to the entire food production in sub-Saharan Africa (230 million) (Bellemare et al., 2017). A 2013 report from the British Institution of Mechanical Engineers (IME) likewise estimated that 30-50% of all food produced remained unconsumed.

Each year in New South Wales, more than 25 million meals are delivered by charity from food that would otherwise be wasted. Also, the Australian economy lost $20 billion in food waste each year. This has very crucial environmental impact through the waste of resources used to produce, package and distribute the food (Bellemare et al., 2017). In Canada, it was reported that 58% (35.5 million tonnes) of all food is wasted per year (Haley et al., 2021; Music et al., 2021). The value of wasted food amounts to CA$21 billion; such amount of food would be sufficient to feed all Canadians for five months. It is estimated that about one third of this waste could be preserved and presented to those in need (Bellemare et al., 2017; Schanes et al., 2018). There are many factors that contributed to such large-scale waste. Manufacturing and processing food alone incur cost to the tune of CA$21 billion, or 4.82 million tons; per household, it is estimated that $1,766 is lost in food waste. The Government of Canada identified three main factors contributing to household waste: purchasing too much food and not consuming it before it spoiled, poorly-designed packaging that does not prevent food contamination rates, and improper disposal of food - using garbage bins instead of those intended for organic waste (Porpino, 2016; Baylen and Linnekin, 2016). Canada, Mexico, and the United States are working together under the Commission for Environmental Cooperation to address the severe problem of food waste in North America (Bloom, 2010).

According to Ministry of Environment (Denmark), over 700,000 tonnes per year of food is wasted every year in Denmark, the entire food value chain from farm to fork. In France, approximately 1.3-1.9 million tonnes of food waste is generated per annum. Out of the 10 million tonnes of food wasted in France, only 11% comes from supermarkets (Mourad, 2016). Not only does this cost the French €16 billion per year, but also the negative impact on the environment is shocking. In France, food waste emitted 15.3 million tonnes of O_2, which represented 3% of the country’s total CO_2 emission (Mourad, 2016). The University of Arizona conducted a study in 2004, which indicated that 14 to 15% of United States edible food is untouched or unopened, equivalent to $43 billion worth of discarded but edible food (Mourad, 2016). The developed countries governments have developed strategy on short-lived climate pollutants to reduce avoidable food waste within the countries (Haley et al., 2021; Music et al., 2021), For example, the Canadian government has implemented a Food Policy, which is a movement towards a more sustainable food system. In February 2019, the government brought many experts together from different countries to contribute and share ideas on how to resolve the problems of food waste across the food supply chain (Haley et al., 2021; Music et al., 2021).

In Denmark, the work of activist Selina Juul’s Stop Wasting Food movement has achieved a national reduction in food waste by 25% in 5 years (2010- 2015) (Bellemare et al., 2017; Calvo-Porral, 2016). Legislation that bans supermarkets from throwing away or destroying unsold food waste should be across the food supply chain globally (Bellemare et al., 2017). France has become the first country in the world to pass a unanimous legislation that bans supermarkets from throwing away or destroying unsold food. Instead, supermarkets are expected to donate such food to charities and food banks (Bellemare et al., 2017). In addition to donating food, many businesses claim to prevent food waste by selling soon-to-be wasted products at discounted prices. The National Pact Against Food Waste in France has outlined eleven measures to achieve a food waste reduction by half by 2025 (Bellemare et al., 2017; Devananda, 2017; Calvo-Porral, 2016). Response to the problem of food waste at all social levels varied largely, including campaigns from advisory and environmental groups, and concentrated media awareness. Almost US$4 billion is lost to food waste in sub-Saharan Africa and approximately US$940 billion is lost globally (FAO, 2018; Huho et al., 2020).

Figure 1. Varieties of fruits and their peels.
Source: Authors

FAOSTAT, according to FAO (2019), reported that almost 9.5 million people experienced intense food insecurity between the year 2016-2018 in Kenya (Julius et al., 2020). Akerele et al. (2017) estimated that almost 3-7% of food equivalent to ₦1500 per month is wasted by household in Nigeria. Almost 123 million metric tons of food is wasted yearly in Nigeria before reaching the market (Makanjuola et al., 2020). It was reported that about 1.3 billion metric tonnes of food is wasted in Nigeria due to poor or inadequate storage facilities (Adedayo et al., 2020).

Food waste is now a topical global concern and a crucial issue that needed to be resolved in order to enhance food security, reduction in greenhouse-emission, promote valorization of products, alleviate poverty and improve the health of the populace. This is why Sustainable Development Goal 12.3 agenda by the United Nations (UN), proposed a goal of halving worldwide food waste and substantially reducing global food waste by 2030 (United Nations. Sustainable Development Goals (SDGs), 2022).

In view of this, this review work was aimed to get to know the nutritional, health benefits and potential of orange (*Citrus sinensis*), papaya (*Carica papaya*), pineapple (*Ananas comosus*), watermelon (*Citrullus lanatus*) and banana (*Musa sapientum*) peels termed waste which can be valorized to nutrient-rich products needed in food and pharmaceutical industries.

FRUIT PEELS

Five selected fruit peels were focused in this review namely, the orange (*C. sinensis*), papaya (*C. papaya*), pineapple (*A. comosus*), watermelon (*C. lanatus*) and banana (*M. sapientum*) peels (Figure 1). A total of 72 papers were reviewed in this study. Introduction on waste and fruit peels comprised almost eleven percent (10.76%).

Nutritional composition of the fruit peels is made up of thirty-three percent (33.33%). Approximately twenty-eight percent (27.67%) is of the health benefits of the peels while the remaining thirty-three percent (33.33%) represented the valorization of the fruit peels. Studies on nutritional composition consist of approximately thirty-three percent (33.33%), out of which 6.82% were for orange (*C. sinensis*) peel, 6.40% for papaya (*C. papaya)* peel, 6.50% for pineapple (*A. comosus*) peel, 6.30% for watermelon (*C. lanatus*) peel and 6.98% for banana (*M. sapientum*) peel.

Reviewed studies on health benefits of the peels is 27.69%, which comprised 5.60% for orange (*C. sinensis*) peel, 5.38% for papaya (*C. papaya)* peel, 5.10% for pineapple (*A. comosus*) peel, 5.30% for watermelon (*C. lanatus*) peel and 6.31% for banana (*M. sapientum*) peel. Thirty-three percent (33.33%) of the papers are for the valorization of the fruit peels, in which 7.10% are for orange (*C. sinensis*) peel, 6.23% for papaya (*C. papaya)* peel, 6.49% for pineapple (*A. comosus*) peel, 6.29% for watermelon (*C. lanatus*) peel and 7.21% for banana (*M. sapientum*) peel.

Eighty-three percent (83.09%) of the papers reviewed spanned from year 2016 to 2021 while 13.84% spanned through 2011- 2015, 1.5% for 2011 and also 1.5% for 2008 and 2009.

Table 1. Proximate composition of the fruit peels (g/ g kg^{-1}) on dry weight basis.

Peels	Moisture content	Crude protein	Crude fiber	Crude fat	Ash content	Carbohydrate differences
Orange	9.20±0.11	12.43±0.23	14.17±0.12	3.50±0.01	7.80±0.11	52.90±2.01
Papaya	13.63±0.21	18.96±1.01	33.20±2.01	2.54±0.01	5.26±0.03	38.88±0.41
Pineapple	82.70±2.01	9.13±0.01	42.22±3.01	1.57±0.00	4.81±0.01	42.30±2.21
Watermelon	93.66±3.31	0.55±0.00	0.21±0.00	0.13±0.00	0.25±0.00	5.22±0.03
Banana	62.33±3.02	1.95±0.01	8.37±0.51	5.93±0.31	9.60±0.43	11.82±0.44

Sources: Olayinka and Etejere (2018), Kanta and Subhajat (2016), and Abdulazeez et al. (2020).

Table 2. Mineral profiles of the fruit peels (mg/ g kg^{-1}) on dry weight basis.

Peels	Orange	Papaya	Pineapple	Watermelon	Banana
Ca	162.03±10.00	11.44±1.00	8.30±0.30	11.21±0.41	19.86±2.00
Fe	19.95±2.05	27.31±3.00	25.52±1.54	45.58±4.00	15.15±1.12
Mg	65.98±5.03	16.42±1.30	45.58±2.94	1.48±0.01	44.50±2.77
Zn	14.04±1.11	1.94±0.01	6.46±0.02	1.29±0.00	0.033±0.00
Na	274.77±15.55	3.61±0.02	ND	12.65±0.40	115.10±7.00
K	1500±25.00	79.34±5.00	41.97±4.00	1.37±0.01	78.10±0.02
P	40.34±1.00	5.00±0.30	12.00±1.00	135.24	211.30±9.00
Cu	47.25±1.00	0.14±0.00	0.11±0.00	1.42±0.01	0.51±0.01
Mn	1.34±0.001	0.52±0.00	5.32±0.40	1.25±0.001	9.05±1.00

Sources: Hassan et al. (2018), Gladvin et al. (2017), Olakunle and Makanjuola (2018), and Feumba et al. (2016). ND = Below detection limit.

Nutritional composition of the orange (*C. sinensis*), papaya (*C. papaya*), pineapple (*A. comosus*), watermelon (*C. lanatus*) and banana (*M. sapientum*) peels

The proximate composition reviewed of the peels is depicted in Table 1. It was revealed that the peels moisture content ranged from orange peel (9.20 ± 0.11) to watermelon (93.66 ± 3.31) g /kg^{-1}. Crude protein of the peels followed the following sequential order: Papaya > Orange > Pineapple > Banana > Watermelon. This implied that papaya peel had outstanding protein content among the peels reviewed. The crude fibre ranged from watermelon (0.21 ± 0.00) to pineapple (42.22 ± 3.01). The crude fat ranged from watermelon (0.13 ± 0.00) to banana (5.93±0.31). Ash contents ranged from watermelon (0.25 ± 0.00) to banana (9.60 ± 0.43). This implied that all the peels are rich in minerals with the least value found in watermelon peel. The carbohydrate by differences ranged from watermelon to orange peel. This indicated that the peels, especially orange peel, are valuable raw materials for valorization of products useful in formulating composite flour and other pharmaceuticals (Ogo et al., 2021; Oboh et al., 2012). The moisture content of banana peel was (62.33 ± 3.02%) as shown in Table 1, the value is relatively higher than those reported by Hassan et al. (2018) for the plantain peels (5.43%). High moisture content in food or its processed products i s an indication of its freshness, shelf life and responsible for greater activity of water-soluble enzymes and co-enzymes needed for metabolic activities. Table 2 depicted mineral compositions of the fruit peels (mg/kg^{-1}) and revealed that the calcium content ranged from pineapple peel (8.30 mg/kg^{-1}) to orange (162.03 mg/kg^{-1}). This implied that all the peels are good sources of calcium with an outstanding result found in orange peel. Therefore, orange peel could serve as a good source of calcium which helped to regulate muscle contraction, transmit nerve impulse, strengthen bone and teeth formation (Olakunle and Makanjuola, 2018; Feumba et al., 2016). Iron content of the peels ranged from banana (15.15 mg/kg^{-1}) to watermelon (45.58 mg/kg^{-1}). Magnesium content of the peels ranged from watermelon (1.48 mg/kg^{-1}) to orange (65.98 mg/kg^{-1}) (Olakunle and Makanjuola, 2018; Feumba et al., 2016). It was reported that pineapple peel (45.58 mg/kg^{-1}) and banana peel (44.50 mg/kg^{-1}) had considerably higher magnesium content than watermelon (Ramelle et al., 2016). A normal human adult contained about 20 - 25 g magnesium and most of it is found in the bones as magnesium phosphate. This indicated that pineapple and banana peels could serve as a good alternative source of magnesium (Olakunle and Makanjuola, 2018; Feumba et al., 2016). The zinc content of the peels ranged from banana (0.033 mg/kg^{-1}) to orange (14.04 mg/kg^{-1}) (Hassan et al., 2018; Gladvin et al., 2017; Olakunle and

Table 3. Antinutrients levels of the fruit peels.

Peels	Oxalate (mg %)	Hydrogen Cyanide (mg%)	Alkaloids (%)	Phytate (%)	Total phenolic (%)
Orange	99.78±4.00	39.79±2.00	5.44±0.11	2.34±0.01	13.54±2.71
Papaya	41.02±2.11	69.83±3.20	15.36±1.11	3.16±0.12	2.65±0.10
Pineapple	129.06±6.10	71.50±4.19	16.19±1.50	1.99±0.01	1.42±0.01
Watermelon	128.40±5.09	121.02±5.02	10.09±0.61	0.70±0.00	0.91±001
Banana	280.88±9.50	116.26±4.30	6.88±0.19	6.02±1.11	7.40±1.13

Source: Feumba et al. (2016).

Table 4. Antioxidant levels of the fruit peels.

Peels	DPPH (mg/TE/g)	FRAP (mmol/Fe^{2+})	ORAC (mol TE/g)	Phenolic	Flavonoid	Vitamin C
Orange	18.20±2.11	296±9.77	0.92±0.00	38.24±2.35	5.03±0.10	166±8.90
Papaya	0.44±0.01	0.78±0.00	14.56±1.22	-	-	22.00±3.01
Pineapple	7.84±1.10	300±2.22	-	9.00±1.17	10.84±1.81	10.00±1.10
Watermelon	30.10±333	27.44±2.01	17.40±3.10	112±5.55	60.40±3.50	26.50±2.54
Banana	56.22±4.02	774±9.19	78.62±5.00	87.28±4.14	21.04±1.19	8.70±011

Sources: Devananda et al. (2017), Adedayo et al. (2016), Avneet et al. (2018), and Oboh et al. (2015).

Makanjuola, 2018). Zinc is particularly needed in cellular replication and the development of immune response. It plays an important role in growth (Hassan et al., 2018; Gladvin et al., 2017; Olakunle and Makanjuola, 2018). Sodium ranged from papaya (3.61 mg/100 /kg^{-1}) to orange (274.77 mg/kg^{-1}) while potassium ranged from watermelon (1.37 mg/kg^{-1}) to orange (1500 mg/kg^{-1}). Sodium was not detected in pineapple peel. However, it was observed that the ratio of sodium: potassium was almost 1:5 (Hassan et al., 2018; Gladvin et al., 2017; Olakunle and Makanjuola, 2018). The peels phosphorus contents ranged from papaya (5.00 mg/kg^{-1}) to banana (211.30 mg/kg^{-1}). Copper content of the peels ranged from pineapple (0.11 mg/kg^{-1}) to orange (47.25 mg/kg^{-1}). The outstanding copper content of orange peel would make it meet average daily intake of 3.5 mg. Manganese content of the peels ranged from papaya (0.52 mg/kg^{-1}) to banana (9.05 mg/kg^{-1}). This result indicated that Orange (*C. sinensis*), Papaya (*C. papaya*), Pineapple (*A. comosus*), Watermelon (*C. lanatus*) and Banana (*M. sapientum*) peels regarded as waste can actually serve as a source of micro and macronutrients in the formulation of pharmaceutical products. Pineapple peel could serve as good additive in dietary formulation for people suffering from hypertension since the reviewed report revealed that the sodium content is below detection limit (Hassan et al., 2018; Gladvin et al., 2017; Olakunle and Makanjuola, 2018).

Antinutrient level of the fruit peels is as shown in Table 3. Oxalate content of the peels ranged from papaya (41.02 mg%) to banana (280.88 mg%) (Feumba et al., 2016). There was no significant difference between oxalate levels of pineapple peel and watermelon peel. However, banana peel had highest oxalate content among the fruit peels reviewed. High oxalate content can be bound to calcium in food thus acting as chelating agent (Feumba et al., 2016). The hydrogen cyanide levels ranged from orange (39.79 mg %) to watermelon (121.02 mg %).

Health benefits of the orange, papaya, pineapple, watermelon and banana peels

DPPH (1,1-diphenyl-2-picrylhydrazyl) is frequently used in the determination of free radical scavenging ability of food components. The antioxidants activities of the fruit peels are presented in Table 4. DPPH of the peels ranged from papaya peel (0.44 mg/TE/g) to banana peel (56.22 mg/TE/g). Papaya peel had the least DPPH level while banana peel had the highest among the fruit peels reviewed. Iron content of the fruit peels ranged from papaya (0.783 mmol/Fe $^{2+}$) to pineapple (300.00 mmol/Fe $^{2+}$). Oxygen radical absorbance capacity of the fruit peels ranged from orange (0.92 mol TE/g) to banana (78.62 mol TE/g). There is dire need of information on the ORAC content of pineapple peel. The result revealed that there is correlation between total phenols and overall antioxidants capacity in foods. This is in agreement with the result of Shanthi et al. (2019). The result reveals that all the peels might be a good valuable source of antioxidants and thus might serve as good food additives

Table 5. Glycemic index and Glycemic load of the fruits that their peels were examined.

Fruits	Glycemic index international value	Glycemic index reviewed	Estimated glycemic load
Orange	31-56	52	27.51
papaya	44-47	42	16.33
Pineapple	46-73	19	8.04
Watermelon	59-85	37	1.93
Banana	28-44	45	5.32

Sources: Gbenga-Fabusiwa et al. (2018a), Premanath et al. (2011), and Foster-Powell et al. (2002).

in the formulation of functional food needed as dietary intervention. The phenolic, flavonoid and vitamin C levels of the fruit peels are shown in Table 4. Phenolic content ranged from orange (5.03) to banana (872.80). The vitamin C ranged from banana (8.70±011) to orange (166±8.90). The flavonoid ranged from orange (5.03±0.10) to watermelon peel (60.40±3.50). Globally, there is keen interest in herbal medicine with pharmaceutical potential of the bioactive compounds to be useful in the treatment of many diseases. Consequently, many drugs have been introduced into international market line by traditional medicines (Anthony et al., 2017; Swati et al., 2021; Rafiq et al., 2018). The reviewed report revealed that orange peel is a good source of vitamin C. This corroborated the report of Swati et al (2021) and Rafiq et al. (2018) that all parts of citrus plants are good source of vitamin C. Thus, orange peel might serve as a good source of vitamin C in pharmaceutical industries. The orange peels discarded as waste products to the surrounding are readily available, cheap and thus, could be utilized as low-cost nutritional dietary supplement. This may provide an effective, efficient, cheap and environment friendly resource for inventing a novel nutraceutical product (Anthony et al., 2017; Swati et al., 2021; Rafiq et al., 2018).

Table 5 reveals the glycemic index (GI) and glycemic load (GL) of fruits reviewed. The GI of the fruits were reported as follows: orange (52), papaya (42), pineapple (19), watermelon (37) and banana (43). The GI of orange, papaya and banana fell within the range stipulated by the international values. Estimated glycemic load (eGL) ranged from watermelon (1.93) to orange (27.51). Global glycemic classification classified food with GI < 60 as low while GI > 60 as high; GL ≤ 10 as low, GL < 20 as medium and ≥ 20 as high (Gbenga-Fabusiwa et al., 2019). WHO suggested dietary intervention with food low in GI and moderate GL for people living with diabetes (Gbenga-Fabusiwa et al., 2019). All the peels had moderately low GI, good protein, crude fiber, low carbohydrate. Thus, the inclusion of the individual peel in functional food formulation may serve as good functional value-added raw materials needed in dietary intervention in the management of some cardiovascular diseases like diabetes, obesity and hypertension.

Fruit peel (skin or rind) is the outer, protective covering in fruits. In general, the peel contains some tough-layered constituent dietary fiber, and phyto-nutrients that help accomplish overall wellness (Sulekha and Jaya, 2018; Anna et al., 2020). Peel thickness varied from one fruit to another even in the same family, ranging from paper thin to very thick shell (Sulekha and Jaya, 2018). The outer cover of the fruits protected underlying edible portion of fruit from harsh environmental factors, micro, macro organisms, and held some of vital health benefits. Fruit peels of some fruits like blueberries, grapes, guava and kumquat carried higher concentration of anti-oxidants such as anthocyanin pigments, tannins, catechins than in their flesh (pulp) (Sulekha and Jaya, 2018). Blue or purple color fruit peels are rich in anthocyanidin glycosides while yellow color fruits have xanthine, carotenes and lutein pigments (Sulekha and Jaya, 2018). Major components of these pigments are present just underneath its outer layer. Peels are rich source of rough dietary fibers, also known as non-starch polysaccharides such as hemi-cellulose, pectin, tannins and gum. These compounds increased the bulk of the food and helped prevent constipation by reducing gastro-intestinal transit time (Sulekha and Jaya, 2018). They further bound to the toxin chemicals in the food and protected their exposure to gut mucus membrane, thereby offering protection from colon cancer risk (Sulekha and Jaya, 2018). Furthermore, dietary fibers bound firmly to bile salts (produced from cholesterol) and eliminated them from the gut, thus, in turn, helped lower serum LDL cholesterol levels (Olayinka and Etejere, 2018). Peel is low in calories, sugar, fats; and free from cholesterol. It added bulk to the food and helped cut down overall calorie intake (Olayinka and Etejere, 2018). The fruit peels of some fruits, indeed, contained considerable amounts of mineral and vitamins, especially in guava and citrus. Recent studies suggested that certain compounds in passion fruit peel have bronchodilator effect and can help relieve bronchospasm in asthma patients (Farid et al., 2008). Watson et al. (2008) at Tuscon University AZ, suggested that oral administration of the purple passion fruits peel extract reduced wheeze and cough and improved shortness of breath in adults with asthma. It is advised to eat fruit along with its peel in some allowed fruits. However, some caution should be taken while eating whole fruits because multiple insecticide sprays are common in the field fruits. Certain amount of this may be deposited deeply in their skin. So, fruits should be washed thoroughly before

consumption. Organically, farmed fruits are, therefore, recommended for safe use of their peels. Oftentimes, insects lay their eggs/cysts on the fruit surface. Eating raw, unwashed fruits may pose risk to health because these eggs/cysts may end up deposited deep inside the brain, a condition known as neuro-cysticercosis. Excess fiber content in the peel may cause indigestion in children (Farid et al., 2008).

The *genus Citrus* is a family of Rutaceae and it comprised 140 genera and 1,300 species (Ould et al., 2017). Citrus is one of the major fruit crops in the world that are well-cultivated in tropical and subtropical region (Rafiq et al., 2018). The pericarp consisted of the outer flavedo (epicarp), largely made of parenchymatous cells and cuticle (Yerou et al., 2017). Citrus fruits health benefits are due to their vitamins, especially vitamin C, phytochemical compounds like limonoids, synephrine, hesperidin flavonoid, polyphenols and pectin. An orange fruit contains about 170 phytonutrients and more than 60 flavonoids (Swati et al., 2021). The mesocarp beneath the flavedo is made up of tubular-like cells joined together to constitute the tissue mass compressed into the intercellular area (Yerou et al., 2017; Sulekha and Jaya, 2018). In addition, consumers have become more aware of the health effects of the synthetic preservatives used in food. Hence, natural preservatives are developed from the fruit peels to meet the demand of consumers. Oyebola et al. (2017) investigated then the nutritive composition of sweet orange peels. It was reported that the crude protein content indicated that the peel could contribute to the formation of hormones that control a variety of body functions like growth, repair and maintenance of body protein. Shanthi et al. (2019) reported that orange peels have been used extensively as a functional ingredient in traditional medicine. Orange peels had the least hydrogen cyanide levels. Hydrogen cyanide is highly poisonous and is formed by the action of acids on metal cyanides. High dose of hydrogen cyanide could result in death within few minutes whereas the low dose could result in stiffness of the throat, chest, palpitation and weakening of the muscles (Feumba et al., 2016). The good news is that all the fruit peels examined are within the threshold levels (below 350 mg / 100 g) reported as safety limit (Feumba et al., 2016). Phytate present in plant food materials has good chelating effect on certain essential mineral elements like Mg, Ca, Fe and Zn producing insoluble phytate salts (Feumba et al., 2016).

Orange peel is a good source of pectin, a natural fiber that prevented health problems such as constipation and maintained the blood sugar level. The presence of pectin in orange also helped the growth of good bacteria that enhanced digestion in the intestine (Etebu and Nwauzoma, 2014). Orange peel contains natural oil useful in making the skin elastic, strong and beautiful. This oil serves as natural cleanser. It can also be used in soap and waterless hand cleansers (Etebu and Nwauzoma, 2014). The oil is a solvent, so it can effectively clean skin without the use of hazardous chemicals. Orange oil can also be used as a scent in perfumes and cleaning products (Etebu and Nwauzoma, 2014). Tea produced from the peel is a good remedy for insomnia and weight loss (Etebu and Nwauzoma, 2014). It increased metabolism, body energy and stamina as well as removing fat from the body (Pallavi et al., 2018). Orange peel is a boon for skin due to its anti-microbial, anti-inflammatory and anti-fungal properties. The dried peel flour can be used to scrub, exfoliate the skin, cure acne, pus-filled pimples, remove black heads, dark spots and pigmentation. Orange peel contained d-limonene that worked as a shield to ultra-violet rays of sun, thus serving as natural sunscreen (Pallavi et al., 2018). Applying orange peel on the skin prevented acne and aging. The anti-inflammatory properties of orange peels helped to fight hemorrhoids while the presence of flavonoids retarded the growth of cancer cells (Pallavi et al., 2018).

Papaya peels are by-products produced by removing the epicarp of papaya fruits. Papaya which belonged to Caricaceae family is reported to contain important bioactive ingredients not only in its fruit but also in the other plant parts including leaves, roots, bark, peel, seeds and flesh (Pathak et al., 2019). High medicinal potential of papaya is due to its high content of vitamins A, B and C, proteolytic enzymes like papain and chymopapain which have antiviral, antifungal and antibacterial properties (Ashutosh et al., 2020). Papaya peel tea contributed to a healthy immune system by increasing the resistance to coughs and colds due to the presence of vitamin A and C in the peel. Papaya peel is rich in iron, calcium and a good source of vitamins A, B, C and G, thus, helping to prevent the oxidation of cholesterol (Ashutosh et al., 2020). Papaya peel is useful as cosmetics and many home remedies as a sunscreen, soothing salve, pain reliever and muscle relaxant (Jyoti and Vora, 2018). The presence of vitamin A in the peel helped restore and rebuild damaged skin. Papaya peel when mixed with honey and applied on the skin can help soothe and moisturize the skin. Pavithra et al. (2017) investigated nutritional properties of papaya peel and reported that the peel contained appreciably high content of potassium. This implied that consumption of papaya peel can help regulate the body fluids and maintain normal blood pressure. Anthony et al. (2017) reported that the vitamin A content in papaya peel was significantly higher than that in the seeds. Generally, vitamin A (retinal) played a vital role in the eye physiology and function. Pineapple peel is a by-product obtained after extraction of pineapple juice.

Campos et al. (2020) reported that the pineapple peel is rich in bioactive molecules which could be a good raw material for development of a sustainable process for fruit by-product valorization. The pineapple peel contained vital micronutrients such as vitamins C and E, carotenoids and flavonoids, essential for human health maintenance. Thus, it can help to reduce signs of aging as it is claimed

to be as effective as retin-A. The peel contained enzymes that removed dead cells from the surface of the skin and helped remove wrinkles (Pathak et al., 2019; Henry et al., 2019).

It has been reported that pineapple peel is a good source of bromelain, a powerful enzyme found in high concentration in pineapple peel and the stem. It helped lower inflammation in the body, reducing swelling after surgery or injury and served as an anti-inflammatory in the sinuses and arthritis or joint pains (Lourenço et al, 2020). The peel helped fight inflammation in gums and tissues, and in addition, contained high manganese content. Manganese helped grow, strengthen and repair bones and teeth. The peel's high vitamin C content and astringent potential kept gums clean and health in oral medicine. The presence of bromelain in the fruit and the peel helped inhibit the formation of blood clotting (Cervo et al., 2014). The copper content in the juice and the peel improved the formation of healthy red blood cells while the presence of potassium helped strengthen the blood vessels and counteract large concentration of sodium, thus, stabilizing the blood pressure (Cervo et al., 2014). High concentration of bromelain and vitamin C in the peel served as anti-bacteria, mucus cutter, cough suppressant, wound healer and good immune system booster (Miiller et al., 2013). Beta carotene and vitamin C in the peel helped fight degenerative eye diseases like glaucoma. Avneet et al. (2018) examined the infusion of pineapple peel in green tea and reported that this could be employed in the production of new natural antioxidant-infused green tea beverage which will not only boost up the sustenance value but also improve sensory evaluation of the green tea.

Watermelon (*C. lantus*), a tropical fruit, belongs to the family Cucurbitaceae and is cultivated in almost all parts of Africa and South East Asia (Hema et al., 2021). It is believed to originate from the Kalahari and Sahara deserts (Hema et al., 2021). Kolawole et al. (2016) determined the effects of the methanolic extract of the watermelon peel on blood glucose concentration, liver enzymes, serum lipid profile and urea, creatinine and glycosylated hemoglobin concentration following alloxan-induced diabetes in male albino Wistar rats with a view to determining the anti-diabetic potential of watermelon peel. It was reported that there was significant reduction in blood glucose concentration after treatment with watermelon peel extracts and that water melon is a rich source of a precursor for arginine synthesis in humans (Kolawole et al., 2016). Dietary arginine supplementation has been found to reduce plasma cholesterol and alkaline phosphate (Kolawole et al., 2016). Watermelon peel was reported to possess a number of biological potentials such as antiapoptosis, antiaging, anticarcinogen, anti-inflammation, antiatherosclerosis, cardiovascular protection and improved endothelial function as well as inhibition of angiogenesis and cell proliferation activities (Kolawole et al., 2016).

Thnaa and Mahmoud (2018) investigated the effectiveness of some fortified nutritional products with sun dried banana peel on moody status of some students in Najran. It was reported that 20% banana peel's cake, biscuits and cookies improved the mood status of the students investigated and the sensory evaluation of fortified products are better than control. Dried banana peel in bakery products was recommended to improve moody status. This is due to the fact that banana peels are rich in minerals, antioxidants, phenolic and tryptophan which are converted to serotonin, which thereafter, makes anyone relax and happy. Banana peel has a vital role in improving the mood and in treatment and management of depression (Thnaa and Mahmoud, 2018). It helped improve human mood. Also, it is useful in the management and treatment of people suffering from diabetes, high cholesterol, ulcers, wounds, burns of body, constipation, diarrhea, arthritis and anemia. Mohamad Said et al. (2016) extracted antioxidant compound, ascorbic acid or vitamin C from a banana peel. The report also pointed out that banana peel is a good source of xylitol which was reported to be the first rare sugar that has global market due to its unique health benefit and ability to serve as an alternative to the current conventional sweeteners. Mosa and Khalil (2015) examined the effect of banana peels supplemented diet on acute liver failure rats. It was reported that all acute liver failure rat groups administered with different levels of fresh banana peels (5, 10 and 15%) had significant decrease in liver function, total triglyceride, total cholesterol and low-density lipoprotein cholesterol when compared with the positive control. However, there was significant increase in high density lipoprotein in all acute liver failure groups. It was therefore, suggested that eating of fresh and dried banana peels could modify the risk of acute liver failure in patients suffering from this disease. Banana peels also contained several important essential amino acids (leucine, valine, phenylalanine and threonine), crude fat and poly unsaturated fatty acids such as linoleic and α-linoleic acids (Mosa and Khalil, 2015).

Several degradative reactions caused by endogenous enzymes may affect starch and hemi-cellulose composition of the ripe banana peels resulting in high sugar content. This chemical conversion facilitated the biodegradable reactions of banana peel when needed for other biotechnological activities. Also, it has been reported that pectin quality of banana peels contained important simple sugars (glucose, rhamnose, arabinose and xylose) (Tibolla et al., 2018; Mosa and Khalil, 2015). Practical utilization of the fruit peels has led to great development of value-added food additives in food industry. It was reported that the banana peel dietary fiber concentrate served as a low-caloric functional ingredient for fiber enrichment, though, the supplementation of the peel in the food system may slightly influence the color of the final food products

(Bunyameen et al., 2020). It can also act as a buffer. Allam (2014) reported that banana peel tea is a good source of many volatile compounds. This could be adduced to the presence of many important nutrients like potassium, calcium, sodium, iron and manganese in the banana peels. It was recommended that the low sugar, low glycemic index, high amylose and amylopectin as well as α-amylase, and α-glucosidase inhibitory activities could be possible mechanisms and justification for the management of diabetes. The high amylose content in the banana could slow down the digestion rate due to highly branched amylose structure, thus limiting the rate at which glucose is released and absorbed into the blood. The ash content of the banana peel was higher than the value reported for plantain peel (7.83%) (Adedayo et al., 2016).

Turkey et al. (2016) produced the nutritious and functional gluten-free cake by substituting green banana peel flour with rice flour and reported that 5-10% substituted proportion of banana peel flour was not different from the control and was generally accepted to serve as good functional food. Chaitali et al. (2017) examined the utilization of banana peel and pulp as a functional ingredient in product development such as bread and noodles (Chaitali et al., 2017). The result suggested that banana peel extract could be a viable way of combating free radical mediated diseases. The antioxidative property of polyphenols of the banana peel will also inhibit lipid oxidation in the food products and thus prevent rancidity.

Banana peel flour extract is classified as non-toxic to normal human cells; thus, the peels can safely be utilized as a natural source of food, food additive and antioxidants. The waste generated from these peels could be useful raw materials in food and pharmaceutical industries as an alternative to produce beverages food additives and medicinal wound healing ointment. Fruits should not be avoided by people with diabetes on the basis of sweetness rather 100 - 150 g of fruit with GI ≤30 can safely be consumed per day. Oboh et al. (2015) suggested that food with low glycemic indices, strong antioxidant properties, and inhibition of α-amylase and α-glucosidase activities could be the likely mechanisms for fruits as dietary intervention in the management and prevention of type-2 diabetes.

Valorization products of the peels

There is a considerable emphasis on the recovery, recycling and upgrading of wastes. This is particularly valid for the food and food processing industry in which wastes, effluents, residues, and by-products can be recovered and upgraded to useful higher value products. The application of the fruit peels regarded as waste could serve as a good source of functional ingredients. Junk food consumption elevates the risk of cardiovascular diseases like diabetes, hypertension, obesity. Previous work done revealed that fruit peels are rich source of dietary fiber and bioactive compounds and therefore, could be used in various nutraceuticals. The reviewed report revealed that orange peel is a good source of vitamin C. This corroborated the report of Swati et al. (2021) that all parts of citrus plants are good source of vitamin C. Thus, orange peel might serve as a good source of vitamin C in pharmaceutical industries. Swati et al. (2021) reported that the extract from citrus peel has great important application in food and pharmaceutical industries as a rich source of bioactive compound. Azar et al. (2016) reported that extract of citrus peel possessed good neuroprotective effects against glutamate-induced toxicity in PC12 cell line which might be due to its antioxidant potential. Orange peel can serve as good nutraceutical resources since they are readily available and cheap, therefore can be utilized as low-cost nutritional dietary supplement. This may provide an effective, efficient, cheap and environment friendly resource for inventing a novel nutraceutical product. Quld et al. (2017) utilized orange peel powder in food (oil of olive and cream desert) to preserve the quality and reported that the peel was effective and thus, useful as antimicrobial for food preservation.

Previous work done indicated that Papaya peel is a valuable source of bioactive compounds, which can be valorized into many value-added products by fermentation such as biofuels, adsorbents, dietary fibers, biomedicine, biomaterials. The valorization of the Papaya peels into the biorefinery technique will certainly improve the value of the peel regarded as waste, thereby attaining zero waste pollution (Pathak et al., 2019). Papaya peels have great potential to accelerate the economy of developing countries like Nigeria. For example, papaya peels can be valorized to value-added cosmetics. They are useful in wastewater treatment, animal feed, and as a binder in ceramics (Ashutosh et al., 2020).

Pineapple peel is used as livestock feed (Devananda et al., 2017). Thailand, Philippines, Brazil and China are the main pineapple producers in the world supplying nearly 50% of the total output. Other important producers include India, Nigeria, Kenya, Indonesia, Mexico, Costa Rica and these countries provide most of the remaining fruit (Lourenço et al., 2021). The amount of waste derived from pineapple peels produced during food processing poses socio economic and environmental challenges with little or no industrial and commercial value. In view of this, Lourenço et al. (2021) extracted natural antioxidants from pineapple peel and suggested that the pineapple peels are very rich in bioactive ingredients which can be incorporated in food products as well as food bioactive packaging system. Previous work done revealed that polyphenolic compounds existing in pineapple peels were catechin (58.51 mg/100 g dry extracts), epicatechin (50.00 mg/100 g), gallic acid (31.76 mg/100 g), and ferulic acid (19.50 mg/100 g) (Li et al., 2014). Li et al.

(2014) reported that the peels had no polyphenolics interactions which indicated no synergistic effects.

Prabha et al. (2021) worked on valorization of watermelon peel as dietary chips fortified with composite flour and reported that the chip formulated has a major advantage of being an easy and light food, highly rich in protein. It was reported that the product had high dietary fiber a low-fat content with nil trans-fat. Studies revealed that watermelon peels could be used in the production of jam. Previous studies reported on watermelon peel revealed that it could find great application in formulating fruit butter, flour-based cookies, dehydrated candy, cake, biscuits. It could also serve as a stabilizing agent in preparation of food products due to adequate level of pectin it contains (Dubey et al., 2021; Ogo et al., 2021). Olaitan et al. (2017) examined the effect of watermelon peel flour supplementation on the quality of wheat-based cookies. It was reported that the functional properties of the cookies such as water absorption capacity and reconstitution index were greatly improved more than the foaming capacity, solubility and swelling index. This attribute made watermelon peel flour a good functional material in food formulations. The sensory evaluation report revealed that 5% inclusion of watermelon peel flour in the food formulation improved the crispness, texture, flavor and is thus, the most acceptable. Cookies supplemented with watermelon peel flour would enhance the nutritional status of consumers. Food demand is increasing progressively as the global population growth. This makes industries to device a way of improving the food supply chain as well as utilizing their waste in producing value added products.

In addition to the data reported in this review, it was reported that banana peels composed mainly of biopolymers such as lignin, pectin, cellulose, hemicellulose. Thus, banana peels can be valorized via biorefinery into biofuel, fibers for mechanical reinforcement, nanocellulose fibers, bioplastics, enzymes and food additives (Espinosa et al., 2018; Gómez et al., 2016; Rambabu et al., 2016; Tibolla et al., 2018). Also, Ramli et al. (2009) reported that the banana peel could be used in the formulation of noodles by partial substitution of wheat flour with green banana peel flour.

CONCLUSION

One third (1.3 billion tonnes) of the food produced globally for human consumption and industrial purposes every year gets wasted. 842 million people in the world do not have enough food to eat. Moreover, food wasted in an urban context created severe environmental and public health consequences that have a negative impact upon human well-being and the environment. Thus, fruit peels can be effectively utilized not only with the view of environmental management but also as value-added raw materials in the formulation of functional foods, nutraceutical and pharmaceutical products that can help in the management and prevention of chronic non-communicable diseases like diabetes, cancer and obesity which could lead to untimely death. The peels could also be recycled to conserve the environment and generate financial revenue to improve the standard of living.

RECOMMENDATION

Government at all levels should embark on policies that would control and minimize food waste worldwide. Food scientists should be fully engaged in research studies that would improve the utilization of food wastes especially fruit peels in pharmaceutical and food industries.

LIMITATION OF THE STUDY

Individual, domestic, organizations and industrial waste management orientation is very low globally.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Sieving fractionation, phenolics profile and in vivo antioxidant activities of *Dichrostachys glomerata* Forssk. powder

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Powder fractions of Dichrostachys glomerata were produced by drying the fruits to 10% moisture, grinding followed by sieving to differentiate powders of sizes <180, 180-212, 212-315 and ≥315 µm, respectively. The obtained powders were analysed for their phenolics profile and in vivo antioxidant activities in rats were evaluated. Lyophilized ethanolic extract and crude powder were used for comparison. The phenolic compounds (mg/100 g): epicatechin (19-30), caffeic acid (313-468), protocatechuic acid (338-799) and quercetin (369-639) were significantly correlated (r>0.65; p<0.05). For in vivo antioxidant properties, the rats fed with fine powders reduced their malondialdehyde in all organs from 19 to 64% (180-212 µm) and 29 to 38% (<180 µm), while increase in catalase (250-1310% and 249-1121%) and superoxide dismutase (72-251 and 5-404%) were observed, respectively in the 180-212 µm fraction and ethanolic extract powder. The 180 to 212 µm fraction with high phenolic contents protected rats from oxidation by modulating malondialdehyde, superoxide dismutase and catalase levels similar to ethanolic extract powder, although still lower than vitamin C. Thus, sieving fractionation has a huge potential as substitute to ethanol extraction of phenolic compounds from D. glomerata to obtain powder fractions usable as natural bio-functional ingredients.

Key words: Dichrostachys glomerata fruits, powder, sieve fractionation, phenolic compounds, antioxidant bioactivity.

INTRODUCTION

The manufacture of nutraceuticals (food products that offered health and fitness benefits beyond their nutritional value) is, nowadays, a research challenge in the area of food and nutrition sciences. Nutraceuticals are gaining prominence in the daily diet of many people due to the increasing prevalence of lifestyle diseases and people

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consciously taking preventive healthcare measures. Global nutraceuticals market accounted for $379.06 billion in 2017 and is expected to grow at a Compound Annual Growth Rate (CAGR) of 7.6% to reach $734.60 billion by 2026 (Globe Newswire, 2019). The nutraceutical sector included functional foods and dietary supplements among others. Dietary supplements are commercialised in a variety of forms including tablets, capsules, drinks and powders. Popular supplements are vitamins E and D, minerals like Ca and Fe, herbs and polyphenols (Hamid et al., 2014).

The ADG/CDSp (alternative drying and grinding followed by controlled differential sieving process) is a technique aiming at concentrating active plant molecules in a specific powder fraction. The technique consisted of drying at computed assisted drying rate, finely grinding of the plant material followed by sieving on column sieves of decreasing sizes. Using this technique, many authors demonstrated that powder fractionation resulted in concentrating polyphenols in finer particle size (Becker et al., 2016; Zaiter et al., 2016; Becker et al., 2017; Deli et al., 2019). Phenolic and polyphenolic compounds represented the most widely distributed plant secondary metabolites exerting their beneficial effects as free radical scavengers and chelators of pro-oxidant metals, and thus prevent oxidation. Recent reports on *Rosa canina* and *Salix alba* showed that ADG/CDSp technology has an advantage over hydroethanol solvent in extracting antioxidant compounds (Soualeh et al., 2018, 2019). Powder formulation of nutraceuticals using the ADG/CDSp technology offered an opportunity for economic growth for developing countries endowed with rich biodiversity and a good knowledge of the health benefits of certain indigenous plant species such as *Dichrostachys glomerata* fruits (Deli et al., 2020).

D. glomerata fruit is a spice widely used in Cameroon for soup seasoning. The fruits are either harvested dry or fresh then sun-dried. Studies have reported high polyphenol content, anti-inflammatory and antioxidant activities of *D. glomerata* (Deli et al., 2019). More so, CDSp fine fractions of D. glomerata concentrated more micronutrients and exhibited antioxidant activities as ethanolic extract (Deli et al., 2020). However, there is no report on the polyphenolic profile in relation to antioxidant activity of CDSp fractions. Hence the objective of this study was to evaluate the polyphenol profile and *in vivo* antioxidant activities of the CDSp powder fractions of *D. glomerata* fruits.

MATERIALS AND METHODS

Chemical reagent and sampling

The chemicals and solvents used in this study were purchased from Sigma-Aldrich (Saint Louis, USA) and were of analytical grade. Dried fruits of *D. glomerata* were purchased in a local market in Yaounde, Cameroon. They were cleaned to eliminate foreign materials, then sorted to degraded fruits before ground for powder production.

Milling of dried *D. glomerata* fruits and controlled differential sieving process

To produce the crude *D. glomerata* powder (CDG), the dried fruits were milled using an electric Ultra-Centrifugal Mill ZM 200 (Haan, Germany) operating at 12,000 rpm (8 049.6 g) with mesh sieve of 1 mm. The powder fractions were produced on an Analysette 3 Spartan apparatus (Fritsch, Idar-Oberstein, Germany). In this respect, 100 g of the crude powder was poured on a sieve column of decreasing sizes 315, 212, and 180 µm, ending with the collecting pan. The system was allowed to vibrate at an amplitude of 0.5 mm for 10 min generating powders of respective sizes >315, 212-315, 180-212 µm, and <180 µm (Figure 1). Thereafter, the powders on the respective sieves and collecting pan (CDSp powder fractions) were collected, packed in polyethylene bags and stored at 10°C until analyses.

Production of ethanolic extract powder fraction

About 100 g of *D. glomerata* crude powder was mixed with ethanol (ratio 1/10, w/v) and stirred (Variomag Poly) for 24 h at 18°C. The mixture was filtered using a Whatman paper No.1 of pore size 12-15 µm and ethanol evaporated (evaporator BUCHI - R210/215) at 40°C at a pressure of 175 mbar. The resulting solution was frozen at -18°C for 24 h and lyophilised at -60°C for 48 h. The resulting powder, called ethanolic extract powder (EE), was conditioned as the powder fractions in polyethylene bags and stored at 10°C until analyses.

Phenolic characterization of *D. glomerata* powder samples

Extraction of phenolic compounds

All the powder samples including ethanolic extract powder, <180, 180-212, 212-315 and >315 µm, respectively along with the crude powder were each used for extraction. About 2 g of powder was mixed with 20 ml methanol/water (70/30, v/v) solution. The mixture was stirred at 300 rpm for 24 h at room temperature (18±2°C) and then filtered with a Whatman No.1 (GE Healthcare companies, China) of 2-3 µm pore size. Thereafter, the supernatant was brought to 15 ml by addition of extraction solvent and stored at 4°C for phenolic profile analysis.

LC-MS analysis of phenolics

The bioactive components were determined on a LC-MS 2020 equipment (Shimadzu, Tokyo, Japan), which contained an HPLC unit coupled to an electro-spray ionization source permitting the MS detection. The injection volume was 20 µl, the quaternary pump delivered a flow rate of 0.6 ml/min and the oven temperature was set at 30°C. Separation was performed on C18 reverse phase Gemini column, having the following parameters: internal diameter 4.6 mm, length 150 mm, particle size 3 µm and pore size 130 Å. The two eluent solvents were water (A), acidified to 0.5% with formic acid, and acetonitrile (B). The 30 min used gradient was as follows: 0-10 min from 90:10 to 85:15 (A:B) (linear gradient); 10-15 min from 85:15 to 80:20 (A:B) (linear gradient); 15-18 min from 80:20 to 75:25 (A:B) (linear gradient); 18-22 min from 75:25 to 60:40 (A:B) (linear gradient); 22-25 min held at 50:50 (A:B) (isocratic); 25-28 min from 50:50 to 90:10 (A:B) (linear gradient); 28-30 min held at 90:10 (A:B) (re-equilibration step). In the mass detector, the nebulization gas flow rate was 1.5 l/ min, drying gas

Figure 1. Photos of crude powder (CDG) and CDSp powder fractions from Dichrostachys glomerata fruits.
Source: Authors

flow rate was 10 l/min, the desolvation line temperature was 250°C and the source temperature was 350°C. The probe voltage was −4 kV, and the electrospray ionization mode was in the negative. The identification of phenolic compounds in plant extracts was based on standard compounds analyses opposing m/z ratio and LC retention time (t). Quantification of the phenolics was done on a calibration curve made with each standard (protocatechuic acid, catechin, chlorogenic acid, caffeic acid, epicatechin, p-coumaric acid, ferulic acid, rutin, quercetin) (0.1-1 mg/ml) prepared in methanol/water (70:30, v/v). The linearity and sensitivity were evaluated by determining the limits of detection (LOD) and quantification (LOQ), defined as the concentration leading to a signal-to-noise ratio (S/N) of 3 and 10, respectively.

Evaluation of the antioxidant activities of *D. glomerata* powder samples

The experiment was operated on adult male Wistar rats (Rattus norvegicus), 3 months old of weight range 200-230 g according to the procedure reported earlier by Ngatchic et al. (2013) with some modifications. The animals randomly organised in groups of 5 rats per cage were housed at the animal house (25±2°C) of Biophysics, Food Biochemistry and Nutrition Laboratory, ENSAI, University of Ngaoundere in Cameroon. The rats were organised into nine (9) groups composing of 1 normal control group, 1 negative control group, 1 positive control group, and 6 experimental groups (receiving ethanolic extract powder, <180 µm, 180-212 µm, 212-315 µm, >315 µm and the crude powder). The normal control group was administered normal food while the others received high-fat diet. Before food was given to the rats, they were administered per os 1 h before, 10 ml of aqueous suspension of *D. glomerata* powder (for the experimental groups), vitamin C 1 mg/ml (for the positive control group), and distilled water (for the negative controlled group). *D. glomerata* powders were administered at a dose of 250 mg/kg while vitamin C was administered at a dose of 20 mg/kg body weight. The animals had free access to water. The experiment lasted 28 days after which the rats were fasted overnight and anesthetized with chloroform to obtain 1 to 2 ml of blood sample withdrawn by cardiac puncture. The blood was centrifuged at 3500 rpm to obtain serum, which was kept frozen at -4°C until used for analyses. Liver, kidney and heart were equally dissected and the homogenates of these organs were prepared for antioxidant markers analyses. Based on the protein content determined according to the method of Lowry et al. (1951), malondialdehyde content (MDA, µmol/mg protein), catalase (CAT, unit/mg protein) and superoxide dismutase (SOD, Units/mg protein) activities were determined in the organ homogenates and blood plasma as reported by Ngatchic et al. (2013). This study was carried out with approval from the Cameroonian National Ethics Committee Ref. No. FWIRD00001954.

Statistical analysis

Obtained data were recorded in Ms Excel and analyses were carried out in triplicates. Results were expressed as mean ± standard error mean deviation. One-way analysis of variance (ANOVA), followed by Duncan's multiple range test were used to determine significant differences ($p \leq 0.05$) among the samples using Statgraphics. Principal components analysis (PCA) was performed for structuring correlation between studied samples, phenolic content and antioxidant activities (XLSTAT, version 2016, Addinsoft, New York, US).

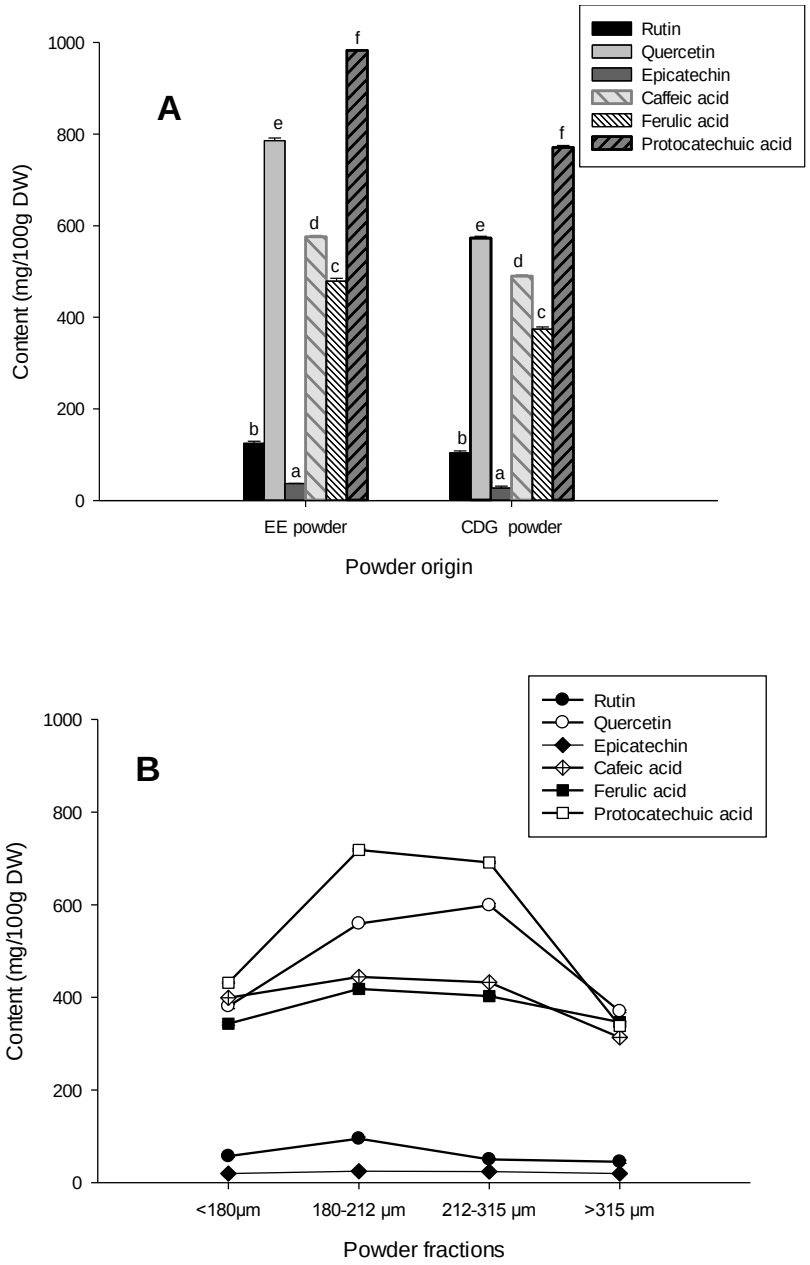

Figure 2. Changes in contents of (A) some phenolic acids, flavonoids and tannins of crude powder and ethanolic extract and (B) CDSp fraction powders from D. glomerata fruits. EE ethanolic extract powder, CDG crude Dichrostachys glomerata powder. Bars topped by different superscripted letters differed significantly ($p < 0.05$) according to Duncan's multiple range test ($n = 3$).
Source: Authors

RESULTS

Phenolics profile of *D. glomerata* powders

The phenolic contents of D. glomerata crude powder and ethanolic extract are shown in Figure 2A. The principal phenolic compounds analysed were phenolic acids (protocatechuic acid, p-coumaric acid, ferulic acid, caffeic acid and chlorogenic acid), flavonoids (quercetin and rutin) and tannins (catechin and epicatechin).

It can be seen from Figure 2A that of the nine phenolic compounds screened, p-coumaric acid, catechin and chlorogenic acid was non-detectable. When compared to commonly consumed dried fruits and vegetables, *D. glomerata* powders have higher contents of protocatechuic acid, quercetin, caffeic acid and ferulic

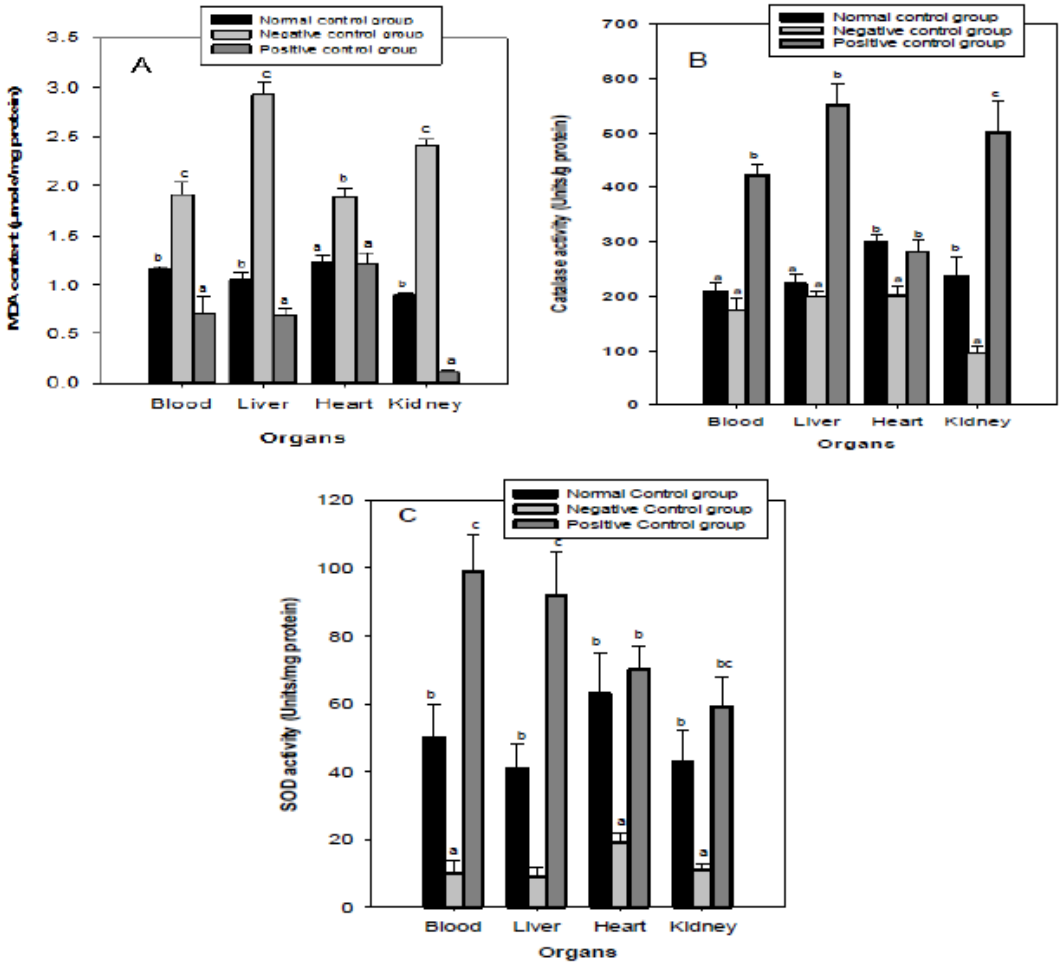

Figure 3. Variations in (A) malondialdehyde content, (B) catalase and (C) superoxide dismutase activities in some organs of normal, negative and positive control groups of rats administered with reference drugs. Bars topped by different superscripted letters differed significantly ($p < 0.05$) according to Duncan's multiple range test ($n = 3$).
Source: Authors

acid with values varied from 338-799, 369-639, 313-468 and 298-418 mg/100 g DW, respectively (M'hiri et al., 2017; Sir Elkhatim et al., 2018; Zhang et al., 2018). Rutin and epicatechin were observed at lower quantities with values ranged between 45-101 and 19-30 mg/100 g DW, respectively.

Among the examined flavonoids, quercetin was the most prominent while phenolic acids were the most represented polyphenols in the *D. glomerata* powders, with the quercetin content comparable to that of onion (*Allium cepa),* one of the most important sources of quercetin (341-647 mg/100 g DW) (Domanska et al., 2018). These values are higher than those of green beans (1.1 mg/100 g DW), white radishes (0.9 mg/100 g DW), carrots (3.75 mg/100 g DW) and celery (8.05 mg/100 g DW), as well as those reported by Cao et al. (2010) on 100 edible vegetables and fruits. The contents in each of the phenolic compounds analysed were higher in the ethanolic extract powder, while significant variation ($p < 0.05$) were found among the CDSp fractions (Figure 2B). The CDSp fraction having the highest quercetin contents was 212-315 µm, while the fraction exhibiting the highest ferulic acid, protocatechuic acid, rutin and epicatechin was 180-212 µm.

MDA content, CAT and SOD activities of D. glomerata powders

One important consequence of lipid accumulation in the body is the increase in lipid peroxidation and reduction in antioxidative enzymes. Figure 3 showed the change in MDA content, CAT and SOD activities in the plasma and some organs of rats in the control groups. It is evident from Figure 3A that there was a significant ($p < 0.05$) MDA increase in the plasma and organs of rats in the negative control, while CAT (Figure 3B) and SOD (Figure 3C) activities decreased significantly. The percentage

Table 1. Changes in antioxidant markers in different organs of rats administered with powders (crude powder, ethanolic extract powder, CDSp fractions) from *D. glomerata* fruits.

Antioxidant markers	Organs	Powder fractions obtained by CDSp				CDG powder	EE powder
		<180 µm	180-212 µm	212-315 µm	≥315 µm		
Malondialdehyde (µmol/mg protein)	Blood	0.71±0.11^{a}	0.41±0.03^{a}	1.45±0.06^{b}	1.61±0.17^{b}	1.52±0.11^{b}	0.52±0.11^{a}
	Liver	0.75±0.05^{a}	0.53±0.03^{a}	1.40±0.12^{b}	1.38±0.22^{b}	1.38±0.08^{b}	0.51±0.07^{a}
	Heart	1.25±0.25^{b}	1.00±0.10^{a}	1.41±0.41^{b}	1.41±0.18^{b}	1.42±0.02b	0.97±0.15^{a}
	Kidney	1.12±0.03^{b}	0.61±0.11^{a}	1.22±0.05^{b}	1.25±0.22^{b}	1.27±0.28^{b}	0.28±0.04^{a}
Catalase activity (Unit/mg protein)	Blood	901±40^{c}	601±70^{bc}	202±15^{a}	561±41^{b}	223±23^{a}	922±42^{c}
	Liver	1121±49^{d}	1310±42^{d}	400±36^{b}	372±30^{a}	712±29^{c}	1121±61^{d}
	Heart	354±47^{c}	438±39^{d}	268±36^{b}	380±20^{c}	169±31^{a}	500±51^{d}
	Kidney	231±31^{c}	250±22^{c}	110±13^{a}	191±18^{b}	152±15^{ab}	249±14^{c}
Superoxide dismutase activity (Unit/mg protein)	Blood	101±32^{b}	251±34^{c}	251±20^{c}	124±18^{b}	61±15^{a}	251±24^{c}
	Liver	169±71^{d}	158±8^{d}	92±21^{c}	51±17^{b}	26±4^{a}	188±14^{d}
	Heart	82±10^{c}	72±19^{c}	44±5^{a}	57±11^{b}	59±7^{b}	84±14^{c}
	Kidney	44±6^{a}	98±16^{c}	91±14^{c}	64±9^{b}	52±9^{ab}	92±12^{c}

Means ± SD for each organ, values with different letters within the same row differed significantly ($P < 0.05$) as determined by Duncan's multiple range test (n=3). EE ethanol extract powder, CDG crude *Dichrostachys glomerata* powder.
Source: Authors

increase (compared to the normal control group) in MDA ranged from 52% in the heart to 176% in the liver, while the percentage reduction in CAT and SOD ranged from 10-59% and 69-80%, respectively. The importance of administering vitamin C was the reduction in oxidation processes in the body (Deli et al., 2020). This is seen in Figure 3 where the MDA decreased significantly by 2-87% in rats administered with vitamin C (positive control group), while the CAT and SOD increased significantly from 0-148 and 11-124%, respectively.

Table 1 presented a summary of the MDA content, CAT and SOD levels in the plasma and some organs of rat administered with *D. glomerata* powders. Generally, the group administered with CDG powder showed a decrease in MDA from 14-41%, while the group administered with EE powder showed a decrease in MDA from 21-69% in all organs. Otherwise, a decrease in MDA was observed upon administration of 180-212 µm powder fraction (19-64%, in all organs), while a decrease in MDA was observed only in blood (38%) and liver (29%) for the powder fraction <180 µm. An increase was observed for other fractions (0-39%), but this was still lower as compared to the negative control group, which was 176% in the liver. However, the decrease in MDA observed for the 180-212 µm fraction and ethanolic extracts of *D. glomerata* were still significantly lower ($p < 0.05$) than the positive control group administered with vitamin C. Inversely, much more increase in CAT (250-1310% and 249-1121%) and SOD (72-251 and 5-404%) levels were observed respectively in the 180-212 µm fraction and ethanolic extract powder as compared to the vitamin C control group (11-124% increase for SOD and 0-148% increase for CAT). These results suggested an interaction between molecules in *D. glomerata* powders, which may boost the oxidative status of rats in different aspects (Yang et al., 2016; Gao et al., 2017). For instance, D. glomerata was reported by Deli et al. (2020) to be a source of oligo elements such as Cu (0.8 g/100 g), Zn (0.2 mg/100 g), Mn (2.2 mg/100 g) and Se (0.11 mg/100 g), which are components of enzymes involved in the antioxidative and detoxification processes.

DISCUSSION

Figure 4 showed the correlation between the different variables studied as well as the distribution of D. glomerata powders on the axis system F1 × F2. The two axes F1 and F2, based on the correlation between the variables, showed 84.98% variation among the powder properties. F1, which showed 61.86% of inertia, was negatively correlated to most phenolic compounds (r varying from -0.65 for ferulic acid to -0.79 for epicatechin) and the antioxidant enzymes (r varying from -0.70 for SOD in the blood to -0.89 for SOD in the liver). On the other hand, there was a positive correlation between F1 and MDA (r ranged from 0.93 to 0.98). F2 showed only 23.12% variation and was mostly correlated with quercetin (r = 0.74), SOD in the kidney (r = 0.68) and CAT in the blood (r = -0.68). The MDA content in all the organs, as shown in Figure 4, were opposite to phenolic compounds and the CAT and SOD activities, reflecting a perfect negative correlation. Thus, phenolic compounds may be implicated in reducing MDA levels, but this might

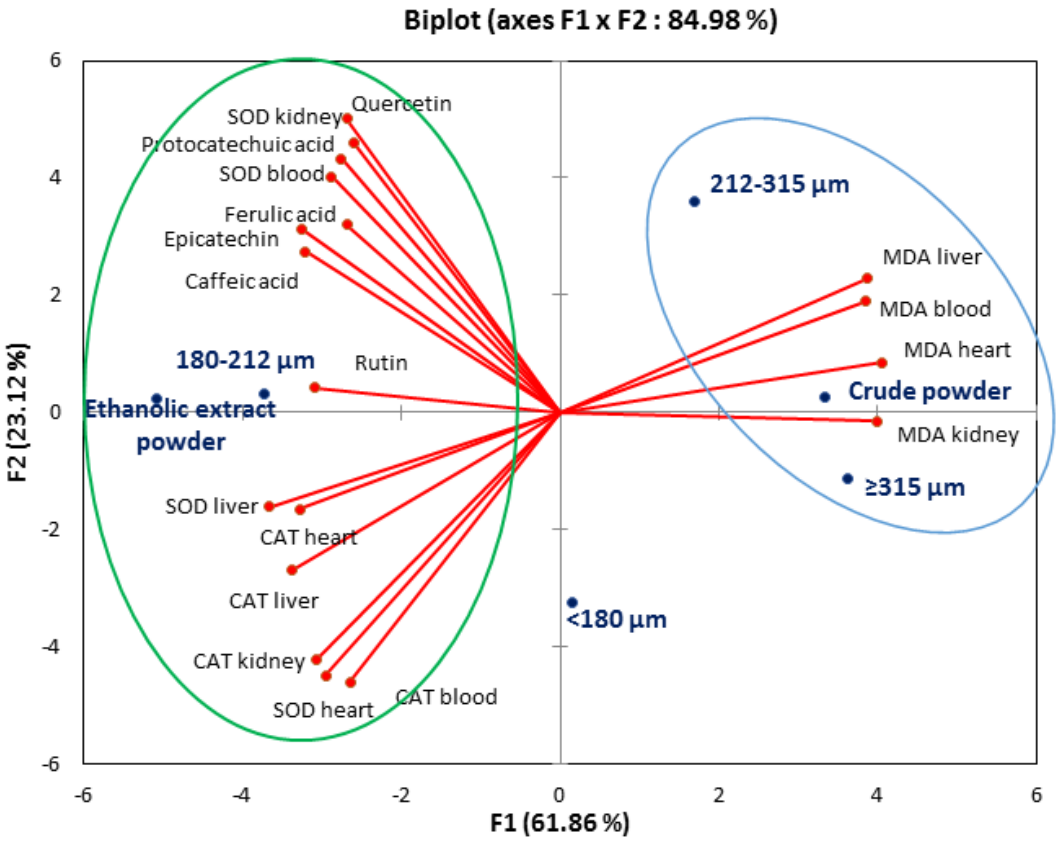

Figure 4. Correlation of variables and distribution of investigated *Dichrostachys glomerata* powders (crude powder, ethanolic extract powder and CDSp fractions). MDA malondialdehyde, CAT catalase, SOD superoxide dismutase.
Source: Authors

be mostly associated with rutin, caffeic acid and epicatechin which are more negatively correlated (ranged from -0.75 to -0.89) to MDA group. As seen in the axis system, F1 × F2, SOD activities were not very close, suggesting different behaviour vis-a-vis the phenolic compounds. The SOD in the liver and heart were closer to each other and varied in same manner as CAT, but far from the SOD in kidney and blood, which were more positively influenced by the phenolic compounds. Thus, phenolic compounds contained in the *D. glomerata* powders might have protected the kidney and plasma cells membranes against damage caused by free radicals. The structure and lipophilic property of polyphenols have been shown to be important factors from which their antioxidant activity is derived, since they affected the depth of incorporation of these compounds into the lipid phase of the cell membranes (Djeridane et al., 2010).

This justified that the powder fractions richest in phenolic compounds are classified among the powder fractions having the highest SOD and CAT activities. Similar biological effects of the powder fractions from *R. canina* and *S. alba* have been demonstrated by Soualeh et al. (2018). These authors also noted an inhibition of the MDA production in rat organs placed under oxidative stress conditions and receiving different powder fractions from *Hedera nodosa* and *Helix scrophularia* (Soualeh et al., 2019). This has been attributed to the presence of various bioactive compounds such as polyphenols, flavonoids and tannins.

Figure 4 also showed the distribution of D. glomerata powder samples in the same axis system F1 x F2. It appeared that the 180-212 µm fraction was very close to the ethanolic extract commonly used as a standard for administration to patients. These powders exhibited characteristics between high levels of antioxidant enzymes and high levels of phenolic compounds. They were opposite to *D. glomerata* crude powder, which exhibited high levels of MDA than all the powders tested. The powder fractions, which were revealed to be poor in phenolic compounds, failed in reducing the MDA levels as compared to the 180-212 µm fraction.

Conclusion

The sieve fractionation, otherwise called CDSp technology, showed significant effect on the phenolic

composition and antioxidant bioactivity of *D. glomerata* fruit powders. Epicatechin, caffeic acid, protocatechuic acid, rutin, ferulic acid and quercetin were all affected by CDSp to different extents. One granulometric class of interest 180-212 µm was highlighted for *D. glomerata* powders, which had phenolic content not far from that of ethanolic extract powder. There was a strong correlation between phenolic contents and antioxidant activities, implying that identified polyphenolic compounds were mainly responsible for the antioxidant activities of *D. glomerata* powders. More specifically, the 180-212 µm powder fraction recorded the highest antioxidant activities compared to the crude powder and other fractions. It was postulated that grinding enhanced the extraction yield of bioactive compounds and sieving induced the discrimination of these compounds according to particle size. The CDSp approach would be of interest for nutraceutical purposes by providing plant powder fractions with enhanced biological activity and contents in active compounds.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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