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Physical and Phytochemical Properties of the Rind of Five Watermelon Cultivars

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Abstract

Watermelon is known for its good thirst-quenching power; its important water content is one of its major characteristics. This very juicy character of the fruit associated with an important quantity of by-products constitutes a weak point of profitability to its transformation. Indeed, next to the sweet, juicy, refreshing pulp with exceptional gustative quality, there is a large number of by-products that are not consumed, not valorized, and are considered as waste. This study aims to provide some solutions to this problem, which hinders the processing of watermelon in Burkina Faso. The physicochemical parameters, phytochemical composition, and some biological properties of watermelon rind were evaluated. In other words, substances of nutraceutical interest and their properties were measured in watermelon rind to find useful uses for them. The determination of the dimensions was done by direct measurements. Physicochemical parameters were determined by standard methods. The phytochemical composition was determined by spectrometric methods. The analysis of the samples showed significant variability for the different physical parameters of the fruits. Interesting physical properties such as the water absorption and water holding capacity of the dried rind powder (nearly 1000%) were revealed. Moreover, the fruit rind showed remarkable photochemical composition and antiradical properties. As such, watermelon rind could be incorporated into other culinary preparations, in animal nutrition.

Keywords

Watermelon, By-Products, Nutraceutical Properties, Rind

1. Introduction

Watermelon is a highly prized tropical fruit in Burkina Faso. Its production has been increasing in recent years and represents an important source of income for rural and urban households involved in the sector. Watermelon pulp is indeed very juicy and contains a diversity of nutrients beneficial to human health [1] [2]. Attempts to process watermelon face a major profitability handicap [3]. Indeed, in most countries including Burkina Faso, only the pulp of the ripe fruit is consumed as a slice or as fresh juice or jam [4]. Thus, in addition to the various nutritional benefits of watermelon pulp, the processed by-products, including the skin which represents 30% - 33% of the total weight of the fruit [5], constitute a significant loss from an economic standpoint. The high-water content of the fruit and the share of these by-products about the total mass of the whole fruit constitute a limit to the economic profitability of the various processing operations. These watermelon by-products, especially the rind, which are not used and are considered as waste [6] [7] could be better valorized [8] [9] [10]. For instance, in Burkina Faso, rind and seeds are considered agricultural waste or used to a lesser extent for feeding some animals. However, the literature reports that these parts of watermelon, especially the rind, possess biological activities and compounds of nutritional and therapeutic interest (citrulline, cucurbitacin, phenolic compounds) [11] [12]. Among these substances of interest, citrulline, and the cucurbitacin in the rind are is distinguished. Other studies have shown that watermelon rind has antimicrobial, antidiabetic, anticancer, and health-promoting properties. To date, no study has been conducted on the "uneaten" parts of the watermelon cultivars grown in Burkina Faso reporting on their properties or uses. This study, therefore, aims to highlight the properties of watermelon by-products to valorize them. The objective of this study was to search for compounds of interest in watermelon rind and to apply in vitro tests to evaluate their therapeutic and nutritional properties and propose ways of valorization.

2. Materials and Methods

2.1. Materials

The biological material consisted of the fruits of five watermelon cultivars (**Table 1**) from four localities in the country: Nouna, Kaya, Bobo Dioulasso, and Ouagadougou (**Figure 1**). For this study, only the rind of the fruit was used. The white part of the ripe fruit (generally not eaten) was called the rind. A sampling of cultivars was conducted from September to December 2020.

2.2. Methods

2.2.1. Physical Properties

Measurement of physical parameters: Fruit weight (FW) and dimensions of the fruit and rind thickness were performed according to the protocol described by Yau *et al.* [13].

The average weight of the whole fruit was determined by weighing with a

Table 1. Watermelon cultivars selected for this study.

Code	Variety name	Fruit characteristics*	Repetition
KK	Kaolack	Fruit shape: spherical Color: light green with fine stripes	12
KA	Kasmira	Fruit shape: spherical to elongated; Color: light green with clear green stripes	12
LG	Charleston gray	Fruit shape: elongated Color: white with fine stripes not very visible	12
SB	Sugar baby	Fruit shape: spherical Color: dark green to dark	12
CS	Crimson sweet	Fruit shape: spherical Color: dark green with large light-green stripes	12

*Description produced in the laboratory.

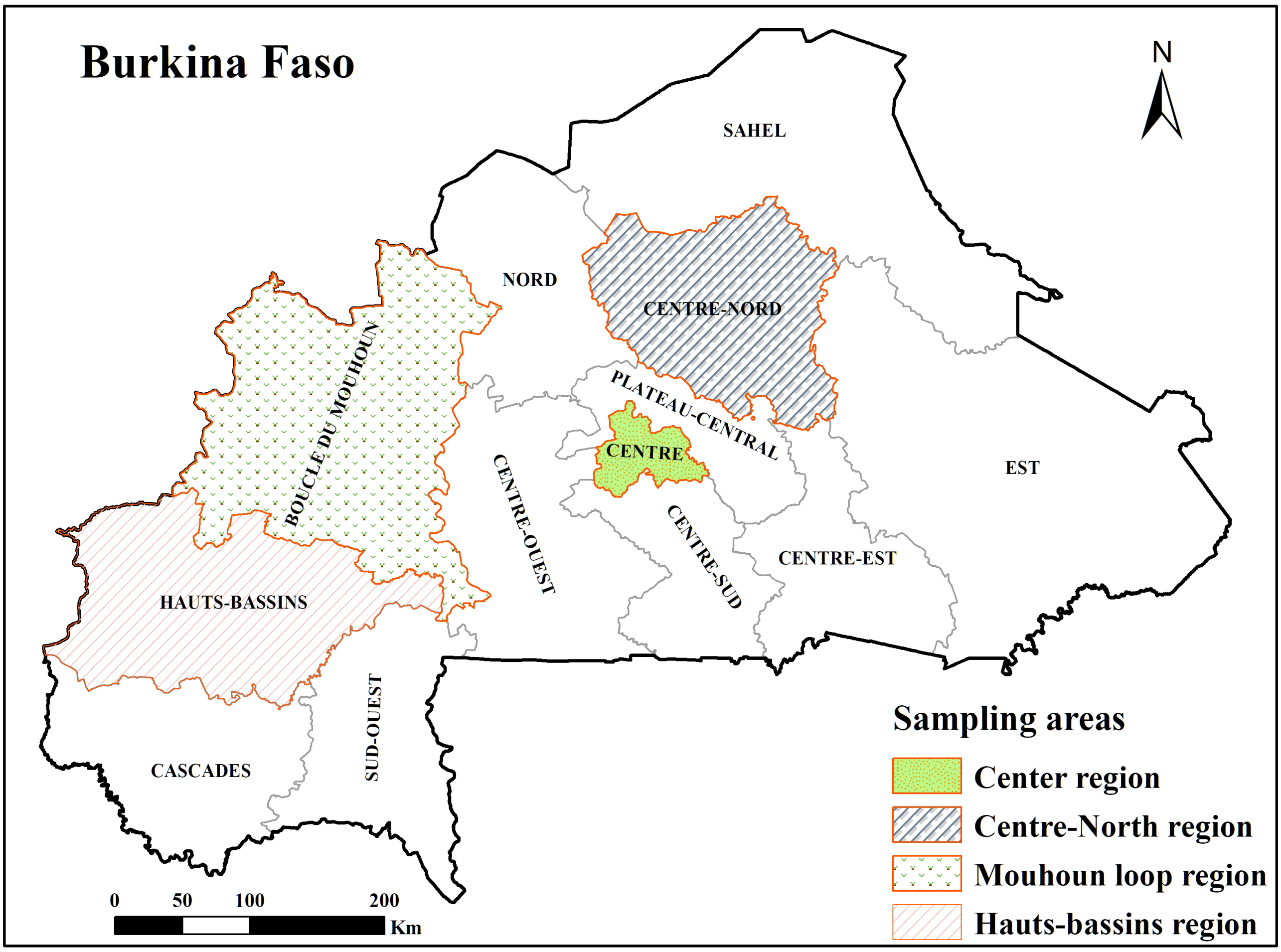

Figure 1. Sampling areas.

digital electronic scale (Gramera p250, max = 5 kg, d = 1 g). Five fruits of each variety were weighed and the arithmetic mean of these three measurements is taken as the average fruit weight of the variety.

The fruit diameter (FD) and the fruit length (FL) were measured manually. The rind thickness (RT) was determined using a caliper (Cocraf digital Vernier Caliper Art. no 40-7541 0 - 150 mm r = 0.01 mm). The sphericity (overall shape) of the fruit was assessed as described by Bande *et al.* [14]. The fruit was designated either spherical, if FL/FD ≈ 1, or elongated or ovoid, if FL/FD ≠ 1.

2.2.2. Determination of Moisture Content and Dry Matter

Determination of water and dry matter content was performed according to the thermogravimetric method [15].

2.2.3. Determination of Water Absorption and Water Holding Capacity

Water absorption capacity (WAC) measurement was performed according to the modified version of the protocol cited by Köhn *et al.* [16]. It consisted of weighing 2.5 g of sample into each centrifuge tube (plastic Falcon type tubes of 50 mL) and adding 40 mL of distilled water followed by manual shaking for 1 minute. Immediately after, the tubes were rested for 10 minutes and then centrifuged for 25 minutes at 2900 G. The supernatant was discarded and the tubes were dried in a 50˚C air circulation oven for 20 minutes. After drying, the tubes were reweighed and the WAC of each sample was calculated as a percentage of the dry matter.

Water holding capacity (WHC) was determined by the centrifugation method cited by (Stephen & Cummings [17]. For this purpose, 0.5 g of dried rind powder was weighed into a 50 mL centrifuge tube, to which 25 mL of distilled water was added. The tops of the tubes were placed securely and the tubes were shaken for 24 hours at 37.5˚C. The tubes were then centrifuged for one hour at 14,000 G and 20˚C, the supernatant was removed, and the weight was of retained water calculated per gram of dry matter.

2.2.4. Determination of Rind Color

The color of the fruit rind and dried rind powder was determined by colorimetry using the method described by Sharma *et al.* [18]. The rind of 12 fruits of each was flashed at four points equidistant from the median region using a colorimeter (PCE-CMS 1).

Similarly, dried rind powder of each variety was placed on white paper and flashed as before. The color was read according to the units of the colorimetric space "CIE LAB". The determined parameters were: L*, a*, b*, dE*, C*, and h*.

2.2.5. Determination of Phytochemicals Composition

1) The extraction of phenolic compounds was carried out by dispersing 500 mg of the ground pulp of each sample in 15 mL of methanol 80% (v/v) under continuous agitation at 200 rotations per minute (rpm) for 4 h at 25˚C. After centrifugation at 2900 G, the collected supernatant constituted the crude extract that was used for analyses [19].

2) The determination of total phenolic compounds was performed by Folin & Ciocalteu method with some slight modifications by Dicko *et al.* [20].

The method is based on the reduction of phosphomolybdic acid of the Folin-ciocalteureagent (a yellow acid, made up of acidic polyheterocycles containing molybdenum and tungsten) by polyphenols in an alkaline medium according to Kaluza *et al.* [21]. It results in the appearance of a dark blue coloration due to the formation of a molybdenum-tungsten complex measured by spectrophotometer (Epoch; BioTeK). Results were expressed as milligram gallic acid equivalent per 100 mg dry matter (mg GAE/100mg/DM).

3) Determination of total flavonoids was carried out according to the colorimetric method with aluminum trichloride ($AlCl_3$) of Dowd adapted by Arvouet-Grand *et al.* [22]. Aluminum trichloride ($AlCl_3$) forms a yellow complex with flavonoids due to the oxygen atoms present on carbons 4 and 5 of flavonoids. The intensity of this coloration measured at 415 nm with a spectrophotometer (Epoch; BioTeK) is proportional to the flavonoid concentration. The flavonoid contents determined are expressed in mg quercetin equivalent/100mg of dry matter.

2.2.6. Determination of Tannins

The determination of hydrolyzable tannins is carried out according to the method described by Mole & Waterman [23]. For each sample (5 $mg \cdot mL^{-1}$), 1 mL was added to 3.5 mL of a solution prepared with 0.01 M ferric trichloride ($FeCl_3$) in 0.001 M hydrochloric acid (HCl). After 15 seconds, the absorbance of the mixture was read at 660 nm. The contents of hydrolyzable tannins were determined and expressed as mg Gallic Acid Equivalent per g dry extract (mg GAE/g DM).

2.2.7. Evaluation of the Antioxidant Activity *in Vitro*

1) Evaluation of antioxidant activity by the iron-reducing power assay (FRAP)

The evaluation of antioxidant activity by the iron reduction method was performed according to the method described by Hinneburg *et al.* [24].

The FRAP (Ferric Reducing Antioxidant Power) method is based on the reduction of ferric ion (Fe^{3+}) to ferrous ion (Fe^{2+}) by reducing compounds (antioxidants), which is accompanied by the appearance of an intense blue coloration measurable at 700 nm. The concentration of reducing compounds (antioxidants) in the extract is expressed in mg Ascorbic Acid Equivalent (AAE) per 100 mg of dry matter.

2) Evaluation of the antioxidant activity by the DPPH reduction test

The evaluation of antioxidant activity by 2,2-diphenyl-picrylhydrazyl (DPPH) free radical scavenging was performed as described by Sánchez-Rangel *et al.* [25].

The principle of this method is that DPPH produces stable free radicals that give a dark purple hue to the solution. When the stable free radical DPPH reacts with an antiradical, it produces discoloration of the solution, a reduction in absorbance measurable at 517 nm. The antioxidant activity was expressed as percent inhibition.

2.3. Statistical Analysis

Statistical analysis of the data was performed using XLSTAT software (Addinsoft, 2021). It consisted of analysis of variance (ANOVA) by Tukey's test at the 5% threshold for comparison of means and principal component analysis (PCA).

3. Results and Discussion

3.1. Results

Physical parameters of the fruit, namely average weight, fruit size, rind color, dry matter, water holding, and absorption capacity of dried rind powder varied significantly with variety.

The variation in average fruit weight among cultivars is shown in **Figure 2**, where the average weight was 4.94 ± 1.69 kg for all cultivars, and LG had the highest average fruit weight (5.84 ± 1.63 kg) while KK had the lowest (3.44 ± 1.48 kg).

Regarding the dimensions of the fruit, the average values were 190.30 ± 26.50 mm and 248.80 ± 74.4 mm respectively for the diameter and length of the fruit for all cultivars. The LG variety had the longest fruit length (378.70 ± 50.10 mm) and the smallest diameter (166.30 ± 25.70 mm), which translates into the highest FL/FD ratio (2.33 ± 0.48) corresponding to very elongated fruits (**Figure 3**). SB had the highest values of rind thickness (12.96 ± 2.44 mm), while LG had the lowest values (9.19 ± 2.42 mm).

Rind dry matter contents fluctuated between 5.58% and 6.88% respectively (**Figure 4(a)**). The variety LG had the highest rind dry matter contents. The average dry matter content was 6.23% ± 0.56% (or 93.76% ± 0.56% moisture content) in the rind.

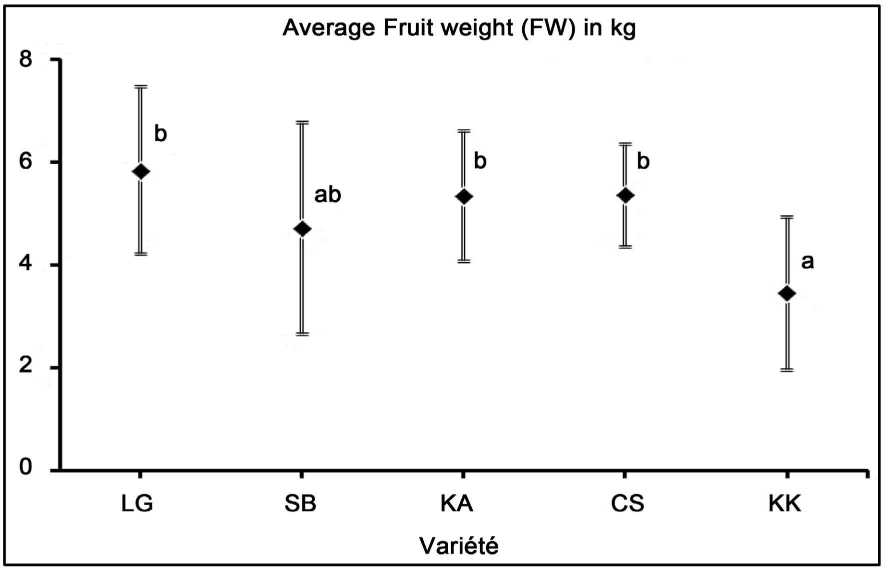

Figure 2. Average fruit weight of the cultivars studied.

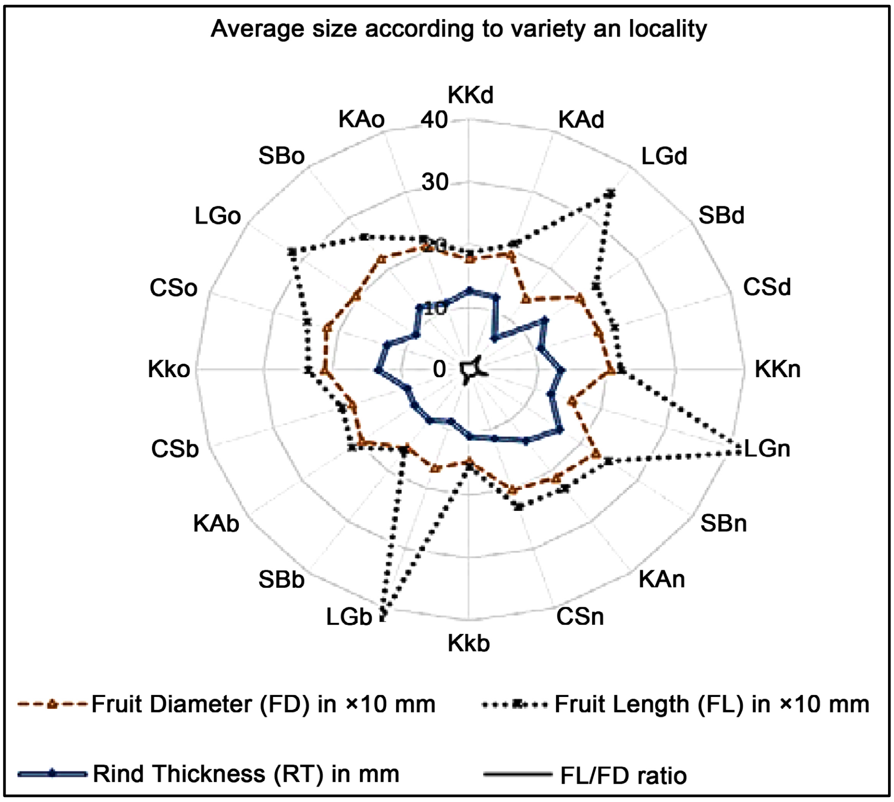

Figure 3. Average dimensions of the fruit and the rind of the studied varieties.

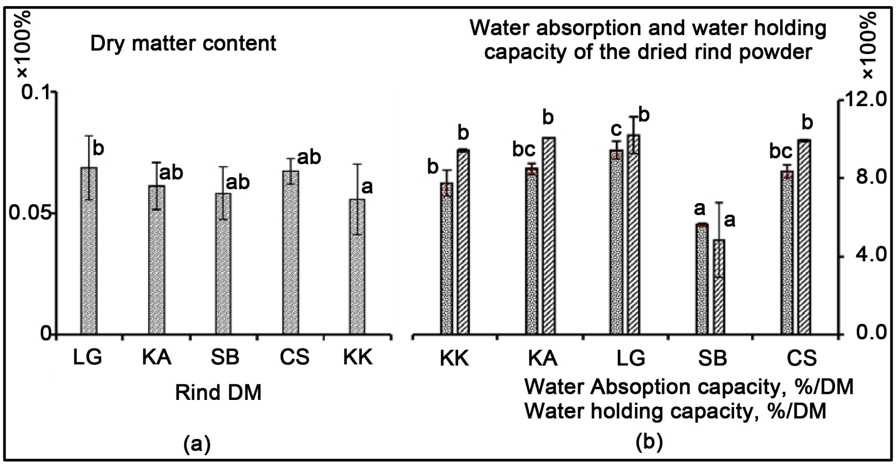

Figure 4. Average dry matter content (a), water absorption, and water holding capacity of dried rind powder (b).

The maximum water absorption and water holding capacity were up to 987.9% and 1114.7%, respectively (Figure 4(b)), with the LG variety showing the highest values. Minimum water absorption and water holding capacities were 557.5% and 292.0% respectively (variety SB). On average, the absorption capacity was 793.5% compared to a capacity of 888.6% for holding.

Except for the hue (h*), the different parameters of the rind color varied significantly between cultivars (Figure 5). Indeed, it is the variety SB presented that presents, in general, the weak values of L*, b*, and c*. The cultivars KK, KA, and LG present generally the highest values of L* of the rind. Concerning the dried rind powder, a considerable increase in the color parameters is generally noted. It became lighter, which is reflected in higher L* and a*. The LG variety had the lightest powder colors. Only the a* and h* were significantly different depending on the variety.

The fat content of the cultivars showed very low (on average 0.11% ± 0.03%/FM) fat content in the rind (Figure 6). The variety LG showed the lowest content (0.11% ± 0.05% FM) while the variety KK had the highest content (0.12% ± 0.05% FM). No significant differences by variety were noted.

3.1.1. Phytochemical Composition

The total phenolic compound contents of the rind of the five watermelon cultivars varied with a highly significant difference from 1.32 mg GAE/100mg DM

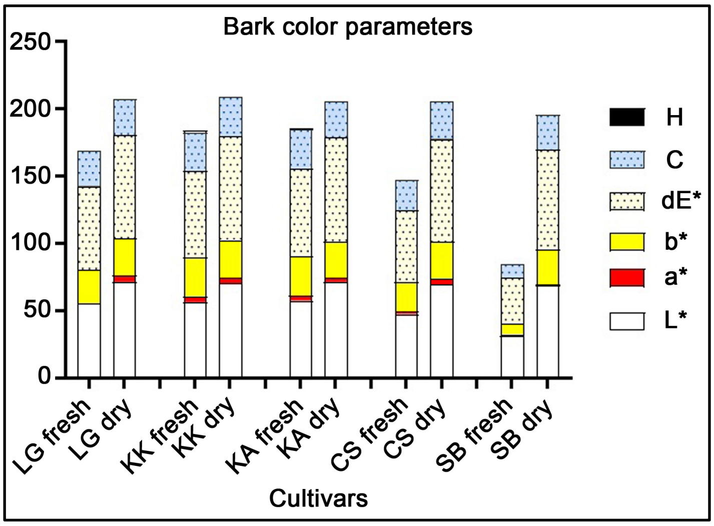

Figure 5. Color parameters of fresh rind and dried rind powder.

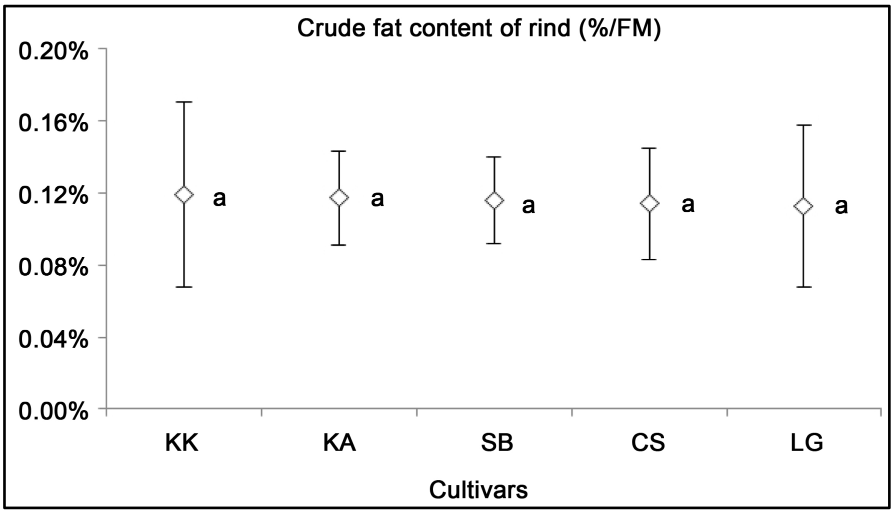

Figure 6. Crude fat content of the rind of the studied varieties.

(CS) to 1.74 mg GAE/100mg DM (SB) in the rind. As for the total flavonoid content, the CS variety still showed the highest content while the KA variety showed the lowest content (Figure 7).

3.1.2. Antioxidant Activities

Antioxidant activities of the five watermelon cultivars varied significantly depending on the variety. As such, the variety SB and which presented respectively the highest activities in the rind (78.05%) according to the DPPH method, and the variety CS presented respectively the highest activities in the rind, 9.33 mM AAE/g DM according to the FRAP method (Figure 8). Overall, the variety of KA shows high activities according to both methods.

The grouped analysis of the different variables allowed us to observe similarities between the different physical parameters of the fruit except for the diameter

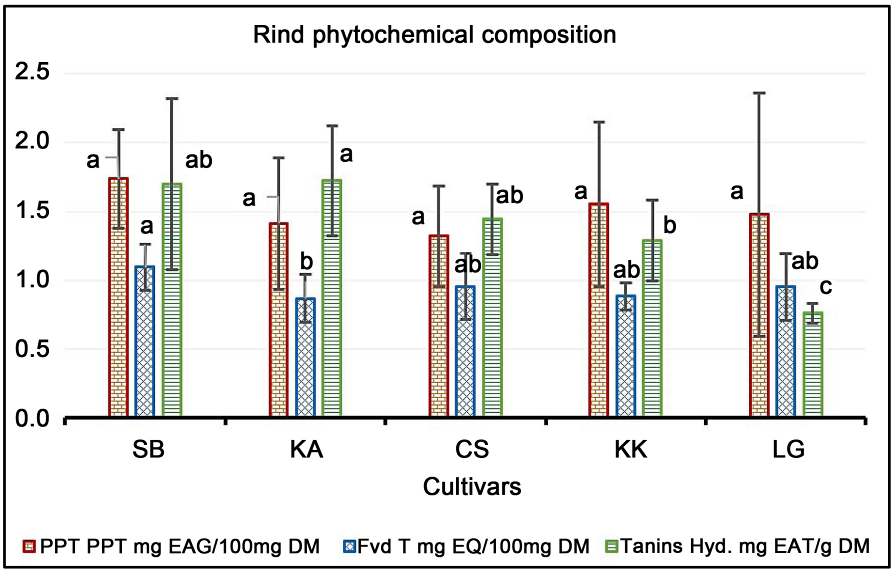

Figure 7. Phytochemical composition of rind extracts.

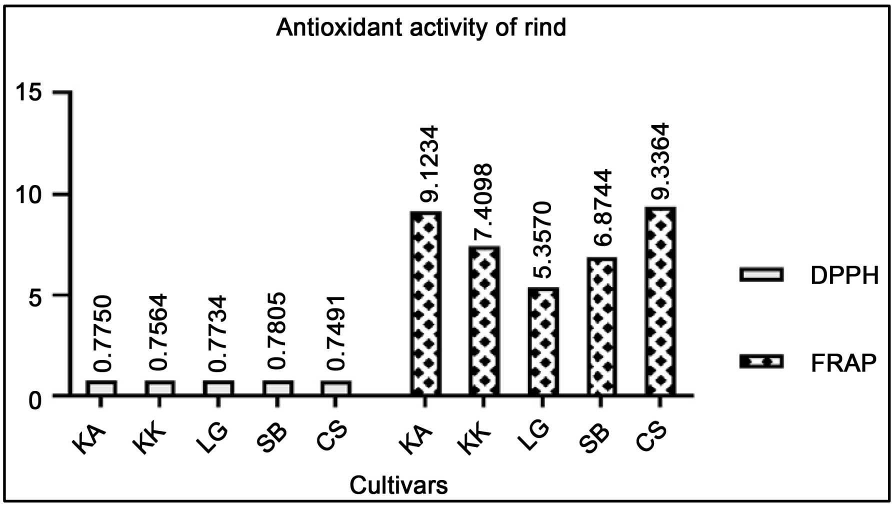

Figure 8. Antioxidant activities of rind by DPPH and FRAP methods.

and the thickness of the rind (**Figure 9**). Along the F1 axis, the positively correlated WAC, WHC, and DM were opposite to FD and RT. Along the F2 axis, TPP, TFvd, and positively correlated DPPH activity were opposite to fat content. On the other hand, the cultivars KK, KA, and CS showed more similarities with each other than with the other cultivars.

3.2. Discussion

Fruit mass and dimensions and (FL, FD) are parameters that can be affected by genetic and non-genetic factors [26]. Thus, while being variety-dependent, these parameters can be significantly affected by production conditions [27] [28]. Nonetheless, the LG variety stands out from the pack because of the particular dimensions of these fruits. The dimensions and weight of the fruit are important commercial parameters for both producers and consumers. These factors determine the ease of marketing and the price of the product. Indeed, the unit price of the fruit found on the market is essentially a function of its dimensions and therefore its weight [4] [29].

The dry matter content determined in this study was of the same order of magnitude as those previously reported [30]. Statistical analysis reveals a positive correlation between average fruit weight and dry matter content, meaning that the amount of rind generated increases with fruit mass. It is the dry matter of this rind that represents the most important fraction of by-products that can be

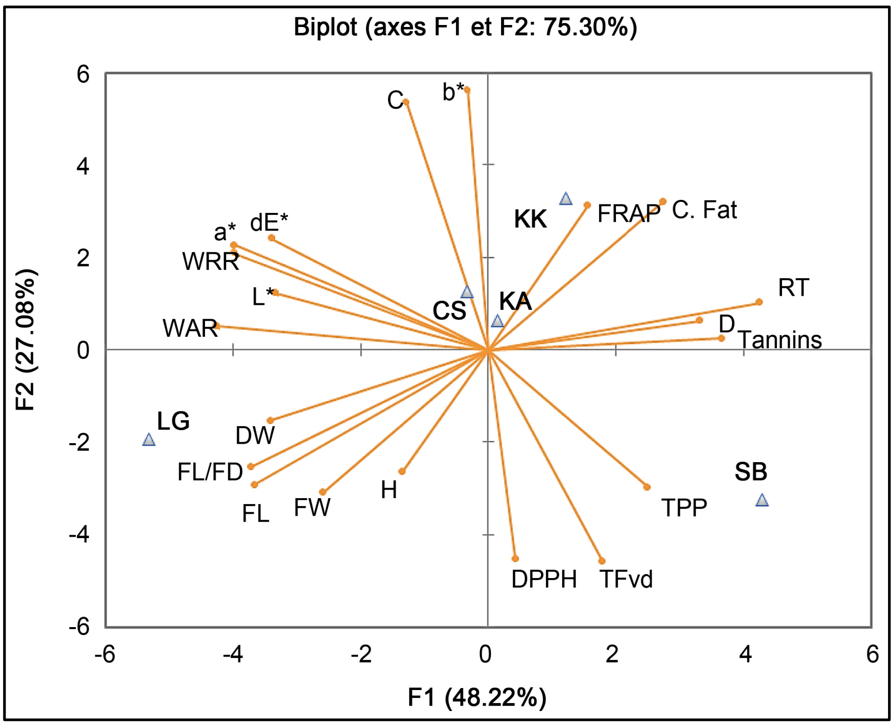

Figure 9. Principal component analysis. Legend: FL = fruit length, FD = fruit diameter, RT = rind thickness, FW = fruit weight, DM = Dry matter content, WHC = water holding capacity, WAC = water absorbing capacity, C. Fat = crude fat content, TPP = total phenolics content, TFvd = total flavonoids content, Tannins = tannins content.

recovered and used for other purposes. Indeed, studies have shown that this powder could be incorporated into animal feed. For example, work on NILE tilapia (*Oreochromisniloticus*) has shown the effectiveness of using this powder as a functional feed for fish [31] [32]. The LG variety had the highest dry matter content. It also showed the highest water absorption and water holding capacity. The water absorption rates found are higher than those reported previously [33] [34]. Because of this ability, the rind powder could be used as a thickener for food preparations such as yogurt and "dèguè", a local dish made from couscous and milk. This use would be relevant because of its incredible absorption capacity and acceptable organoleptic qualities. This incorporation could be done to make the food less calorific. Other studies have shown that the powder of the rind could be incorporated into food preparations such as biscuits, cakes, and bread for up to 10%, even improving the preservation of these products [33] [35]. Moreover, its richness in nutrients could make it a healthy food in its own right [7].

Except for h*, the color parameters (dE, L*, a*, b*, and C*) of the rind were significantly different according to variety. This is justified because the color is an essential parameter in the differentiation of cultivars. Unlike fruit dimensions, rind color is less affected by production conditions within a variety, although it may be bleached by sun exposure [4]. Moreover, the dried rind powder of the cultivars studied had little staining, as evidenced by its increased brightness, L*, and relatively low a* and b*. This property reduces the risk of significant color change in composite food preparations due to the incorporation of this powder. Indeed, the results of a study on yellow noodles, mounted that the incorporation of watermelon rind powder (up to 100 g/kg) in noodles would not significantly change the color of the finished product and would even increase the acceptability of the product [36]. The fat content is negligible in the rind (less than 1%). This low-fat content could account for its incredible water absorption and water holding capacity, as it would increase the hydrophilicity of the dry matter.

The phytochemical study of the rind shows that it is rich in secondary metabolites (polyphenols, flavonoids, tannins, and good antioxidant activity…) in comparison with previously reported results [37] [38]. This composition could justify its pharmacological properties such as antibacterial, anti-constipation, antidysentery, and antidiabetic activity reported [39]. Indeed, it has been reported that like other species of the cucurbit family, watermelon contains a wide variety of secondary metabolites [39]. The rind of watermelon contains many secondary metabolites among which we distinguish: flavonoids, polyphenols, and tannins. Moreover, these compounds are cited as having interesting biological priorities from the therapeutic point of view. These aspects will have to be further investigated with the watermelon rind extracts in vivo.

The biological properties of the extracts are partly related to their antioxidant capacity which is itself due to the biochemical composition. The FRAP antioxidant activities of the rind are comparable to the results previously reported. Indeed, according to Naz *et al.* [40], the FRAP activity would be 21.67 ± 1.21 mM AAE/g DM in the pulp juice, while Tlili *et al.* [38] reported activities of 22.0 - 23.4 mM FRAP/100g FM of the fruit. Watermelon rind exhibits higher antioxidant activities (DPPH) than pulp [41]. These different properties of the rind could make it therapeutically useful, which would help to reabsorb the number of by-products generated during the fruit processing. Moreover, the valorization of the rind will constitute an important economic and nutritional gain. Indeed, this valorization would allow reducing considerably the lost fraction of the fruit which can represent up to a third of the total mass of the fruit. Moreover, due to its richness in phytonutrients, the rind is an excellent health ally [42]. As such, watermelon rind is cited as an excellent source of Cucurbitaceae and citrulline (up to 28 mg/g DM), a precursor amino acid to arginine [43]. Cucurbitaceae is known for its therapeutic value, including the reduction of oxidative stress and anti-cancer properties [44] [45]. Citrulline's efficacy in arginine supplementation has been proven [31] [43]. The anti-diabetic and laxative properties of watermelon rind have furthermore been shown [46] [47].

The analysis of the correlations on the one hand between the different parameters and on the other hand between the parameters and the different cultivars allowed us to make some useful connections in the valorization of watermelon by-products. Indeed, a positive correlation was noted between the antioxidant activity and the content of secondary metabolites in the rind. Similarly, positive relationships were found between absorption and holding capacity, color (L*, a*, E) of the rind, and the amount of dry matter in the rind. The cultivars KK, KA, and CS were closer to each other and the phytochemical characteristics were notable. The variety LG showed the most marked physical characteristics (FW, FD, WAC, WHC, DM).

This study is based on the logic of recovering by-products from the market, the aim is to orient the use of the rind according to its characteristics rather than to recommend the production of a specific variety. The existing correlations between the studied parameters can allow for to selection of these characteristics in a grouped way. For example, the variety KA had the highest values for photochemical composition, while the variety LG had the highest physical characteristics

4. Conclusions

The results of the analysis of watermelon rind in this study show that it could be better valorized. It presents exploitable physical properties and contains significant quantities of bioactive compounds with interesting therapeutic and nutritional properties. The fresh or dried rind could be incorporated into other food preparations. Rind flour, due to its exceptional absorption capacity, can be used as a thickener. Because of its composition in secondary metabolites, the rind could present biological properties and an interesting therapeutic potential.

Further investigation would allow better exploitation of this potential.

The various avenues of by-product valorization outlined in this study could contribute to increasing the profitability of watermelon processing in Burkina Faso.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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