Biomass Conversion and Biorefinery (2025) 15:2171–2183
https://doi.org/10.1007/s13399-023-04820-7

ORIGINAL ARTICLE

Characterization, bioactive compounds, and antioxidant profiling of edible and waste parts of different watermelon (*Citrullus lanatus)* cultivars

Sania Zia[1,2,3] · Moazzam Rafiq Khan[2] · Amin Mousavi Khaneghah[4] · Rana Muhammad Aadil[2]

Received: 4 July 2023 / Revised: 13 August 2023 / Accepted: 27 August 2023 / Published online: 15 September 2023
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Abstract

Recent years have seen the introduction of several new and traditional fruit and vegetable cultivars worldwide through various breeding programs, raising an important question regarding their variability in nutritional composition. Various watermelon (*Citrullus lanatus)* cultivars are being cultivated worldwide, either at marketable or farmer level, depending on technological improvement and agricultural practices. The primary objective of this study was to investigate four fruit parts of four different watermelon cultivars, i.e., Black prince, Black chairman, Sugar baby, and Crimson sweet, commonly commercially cultivated in Pakistan. These cultivars and their respective tissues were characterized for chemical composition, minerals, vitamins, bioactive compounds, antioxidants, and antinutritional composition analysis. Significant variability ($p<0.05$) was observed in the nutritional composition of cultivars and their respective tissues. The rind and seeds had the highest crude protein, fat, total phenolics, flavonoids, antioxidant activity, and FRAP, whereas the pulp showed the lowest in all studied cultivars. Among cultivars, residual parts such as rind and seed have potentially higher nutritional composition and antioxidant activity and have significantly higher bioactive compounds than edible flesh. However, considering their excessive nutritional content, watermelon waste can be revalorized for developing nutraceutical and functional foods. This research brings attention to the significant nutritional importance of watermelon by-products, contributing to improving health, cost-efficiency, and environmental impact.

Keywords Watermelon cultivars · Flesh · Seeds · Rind · Green peel · Multivariate analysis

1 Introduction

As more consumers in industrialized nations consume more fruits and vegetables as a part of their healthier diets, therefore, the worldwide production of fruits and vegetables is necessary to satisfy increasing demand and round-the-year availability. Successfully producing fruits and vegetables depends on the cultivar adapted to meet the targeted growing regions' needs [1]. Cultivar's development programs continuously introduce and develop new cultivars and assess their performance and adaptability over several locations and years to meet the need of increasing demand in a shorter time. Watermelon (*Citrullus lanatus*) belongs to the Cucurbitaceae family and the genus *Citrullus* [2]. Various cultivars of watermelon are being cultivated worldwide, either at marketable or at the farmer level, depending on the technological improvement, agricultural practices, environmental conditions, and economy of the country where it is being cultivated. Watermelon plants are vines, which are thin,

✉ Sania Zia
saniazia0007@gmail.com

✉ Amin Mousavi Khaneghah
amin.mousavi@ibprs.pl

✉ Rana Muhammad Aadil
muhammad.aadil@uaf.edu.pk

[1] Faculty of Allied Health Sciences, University Institute of Food Science and Technology, The University of Lahore, Lahore, Pakistan

[2] National Institute of Food Science and Technology, University of Agriculture, Faisalabad 38000, Pakistan

[3] Department of Biosystem and Agricultural Engineering, Michigan State University, East Lansing, Michigan, USA

[4] Department of Fruit and Vegetable Product Technology, Institute of Agricultural and Food Biotechnology–State Research Institute, Warsaw, Poland

grooved, and covered with tiny hairs and deeply notched leave. Veins are branching and possess deep lobes and many tendrils. The plants produced solitary yellow flowers and large spherical to oblong-shaped fruits. The color of fruit may be in different shades of green, from pale yellowish green to dark blackish green. The skinny, rigid, and compact outer layer preserves the inner white flesh rind that differs in thickness and pink to red-colored inner flesh. The seeded cultivars have dark brown seeds with black ovoid-shaped seeds, whereas the seedless watermelon cultivar may have only white jelly-like seeds. Besides their commercial traits, these cultivars differ in their percent yield and nutritional composition [3].

The edible portion of watermelon flesh (WMF), representing approximately 60% of whole fruit, is largely consumed as an excellent refreshing summer fruit. In contrast, the inedible portion, such as rind (WMR), peel (WMP), and seeds (WMS), represent 40%, are major agro-solid wastes [4, 5]. Both edible and inedible portion of the watermelon provides a wide variety of essential dietary nutrients such as phenols, flavonoids, carotenoids, lipids, proteins, carbohydrates, minerals, vitamin (A, B-complex, C, and E), phytosterols, terpenoids, alkaloids, saponin, cardiac glycosides and certain specific amino acids (arginine and citrulline) [2]. Half of the watermelon is fit for human consumption, while the remaining half is discarded as waste. Approximately 42 million tonnes of watermelon by-products (rind, peel, and seeds) are generated, which are discarded indiscriminately into the environment, constituting environmental challenges despite being edible [2, 5]. However, various factors such as the continuous growth of the world population, depletion of renewable sources, reduction in land for cultivation, and over-accumulation of this waste urge the need for the valorization of these by-products to be used as a substitute ingredient and to produce functional products in food, pharmaceutical, and nutraceutical industries [6, 7]. Large quantities of these waste by-products contain a rich composition of vitamins, minerals, fibers, oils, and bioactive compounds with certain therapeutic properties. The watermelon by-products with high nutritional value have gained much interest because these are highly valued and have great potential to be added to the human diet. Watermelon rind (WMR) and watermelon seeds (WMSs) can represent low-cost raw materials rich in potentially valuable components for other industries [5, 8]. The main challenges faced by the food industries are the lack of awareness and capacity of handlers and integrated management for this solid waste to implement strategies to transform complex, heterogeneous, and disposable biomass into value-able and marketable high-value-added products, providing environmentally adequate and sustainable end [5, 9]. Therefore, it is very important for sustainability to properly treat, handle, and efficiently convert WMR and WMSs to design and develop innovative food products with added value, being a solution to maximize agricultural profit and to minimize food losses, waste, and environmental impact [2, 8, 10]. Moreover, using these by-products in food waste biorefineries to produce biofuels and other bio-based chemicals and materials can significantly reduce a huge environmental burden and provide sustainable resources for producing chemicals and biofuels [11]. Given these facts, the research study aims to characterize and identify the differentiation between the most widely grown watermelon cultivars regarding their chemical, bioactive components, and antioxidant indices. Additionally, the percentage of waste produced by each cultivar and their compositional comparison with the edible portion of the fruit ensure the possibility of reusing the waste by-products as a functional food ingredient.

2 Materials and methods

2.1 Procurement of raw material

Four commercial watermelon cultivars, Black prince, Black chairman, Sugar baby, and Crimson sweet, included local open-pollinated and exotic seeded (diploid) types with dark black, green, or striped light and dark green peel. Five uniformly sized and shaped fruits from each cultivar were chosen. Commercial features of all watermelon cultivars are presented in Table 1. The transverse section of watermelon cultivars shows different parts of each shown in Figure S1 (Supplementary material).

2.2 Chemical composition

WMF, WMR, WMP, and WMS from all watermelon cultivars were investigated for moisture, crude fat, crude protein,

Table 1 Commercial features of watermelon cultivars

Cultivar	Shape	Flesh	Rind	Seeds
Black prince	Cylindrical	Deep red	Greenish black	Brown
Black chairman	Round	Bright red	Black	Light brown
Sugar baby	Round	Medium red	Dark green	Dark brown
Crimson sweet	Cylindrical	Deep purplish red	Light and dark green striped	Blackish brown

crude fiber, total ash content, and nitrogen-free extract in triplicates on a dry weight basis [12].

2.3 Minerals and vitamin analysis

The flame photometric (Sherwood Scientific Ltd., Cambridge) method measured minerals such as sodium and potassium. In contrast, calcium, magnesium, phosphorus, and iron were measured by atomic absorption spectrophotometer (Varian AA240, Australia) [12]. Vitamin A, thiamin, riboflavin, and niacin content were determined spectrophotometrically, and vitamin C was analyzed by the titrimetric method [12].

2.4 Total phenolic and flavonoid content (TPC and TFC)

TPC was carried out using the Folin-Ciocalteau method [13]. This method used gallic acid as a standard reference, and different aliquots (7–50 µL) of gallic acid solution (0.1 mg/mL) were used to construct a standard curve. One hundred twenty-five microliters of aliquot of the extract was mixed with 0.5 mL of distilled water, followed by 125 µL of FC reagent. This prepared solution was incubated at room temperature for 6 min. Then, 1.25 mL of 7% sodium carbonate solution was added to the mixture, and samples were incubated at room temperature for 90 min. After incubation, the absorbance of each sample was measured using a UV/vis spectrophotometer (IRMECO, U2020, Germany) at 760 nm. The standard curve was constructed using gallic acid as standard at different concentrations (7–50 µL), and results were expressed as milligrams of gallic acid equivalents (GAE) per gram of dry matter (DM) [14].

TFC was determined using the aluminum chloride colorimetric method [15]. An aliquot of 0.5 mL of extracts was mixed with 1.5 mL ethanol, 0.1 mL of 1 M potassium acetate, 0.1 mL of 10% AlCL3, and 2.8 mL of distilled water. The sample mixture suspension was incubated at 25 °C for 30 min. The absorbance of the sample was measured at 440 nm using a spectrophotometer. Quercetin was used as a standard, and results were expressed as milligrams of quercetin equivalent (QE) per gram of dry matter (DM).

2.5 Citrulline

The citrulline concentration was measured according to the procedure of Zia, Khan, Aadil, and Shahid [5]. Extracts of each sample were prepared by dissolving a 0.05-g sample using 10 mL of HPLC-grade water in a glass tube. The solution was shaken for 30 min and centrifuged, and then the supernatant was taken by filtering the solution through a micro-syringe filter (0.45 µm). The citrulline content was analyzed using an HPLC system with UV-Vis detection at 207 nm. The compound was separated using a C18 column having dimensions 3-µm partial size and 250 × 4.6 mm held at room temperature (27 °C). A 0.1% phosphoric acid in an aqueous solution was used as the mobile phase, and the elution mode was set at isocratic. The samples were extracted and analyzed at a flow rate of 0.3 mL/min and a total run time of 15 min, respectively. The linear calibration curve was prepared by running commercial standards at different serial dilutions (0.1–1000 µg/mL). The citrulline concentration was calculated from the calibration curve, and the results were expressed as milligrams per gram of sample.

2.6 Antioxidant analysis

Antioxidant analysis (DPPH and FRAP) was measured according to the procedures of Akshaya, Sasikala, Nithyalakshmi, Meenakshi, Kiruthika, and Pavithra [13]. This method is based on the ability of the antioxidant to scavenge the DPPH cation radicals. 2, 2 Diphenyl-2-picrylhydrazyl is an oxidizing radical that is highly stable and reacts with free hydrogen atoms from antioxidants, forming yellow color hydrazine. A 0.1 ml supernatant was taken and diluted up to 0.5 ml with 70% ethanol. Then, the mixture was mixed with 1 ml of DPPH 0.1 mM solution. The sample was vortexed and kept for 30 min at ambient temperature in a dark place. The absorbance of each sample was measured at 517 nm using the spectrophotometer. The absorbance of a blank (solvents and DPPH solution minus sample) was measured using a spectrophotometer at 517 nm. The free radical scavenging activity of the samples was expressed as Trolox Equivalents (mg TE/g) of a sample.

The samples' antioxidant capacity (FRAP) was determined by measuring the capacity of the sample to reduce the ferric tripyrsidyltriazine into blue color. The solutions used for the FRAP assay were 20 mM FeCL3.6H2O solution, 1 mM 2,4,6-tripyridyl-s-triazine (TPTZ) in 40 mM HCL, and 0.25 M acetate buffer pH of 3.6. The working solution was freshly prepared by mixing 2.5 mL ferric chloride, 2.5 ml TPTZ solution, and 2.5 mL acetate buffer; and the buffer was kept at 37 °C before use. Each sample extract (50 µL) was mixed with 1.5 mL of FRAP solution. The mixture was allowed to react for 30 min in a dark place. The colored product (ferrous tripyridyltriaazine) formed was read using a spectrophotometer at 593 nm. The standard curve was made using ferrous sulfate as a standard. Results were expressed as ferrous sulfate (mg FeSO4) of a sample.

2.7 Anti-nutritional compounds determination

The tannin content of each sample was determined by the Follin-Denis spectrophotometer method at 760 nm and using gallic acid as standard. The colorimetric method determined the amount of saponin and alkaloids in each sample. A

spectrophotometer was used to test each sample's absorbance at 420 nm for alkaloids and 620 nm for saponin [16].

2.8 Statistical analysis

The means were compared using a one-way analysis of variance (ANOVA), and the means were separated using a posthoc Tukey's HSD test with three significance levels ($p<0.05$, $p<0.01$, $p<0.0001$). The normality of residuals was evaluated using normal probability and box plots and variance homogeneity using residuals vs. predicted values plots. Pearson correlation and regression analysis were also used to compare variables. The correlation matrix was subjected to principal component analysis (PCA), with the normalized response of the variables (yij') defined as follows:

$$y'ij = \frac{yij - \overline{y}.j}{\overline{y}i}$$

where yij is the response j obtained in the experiment, $\overline{y}.j$, and $\overline{y}i$ is the arithmetic average of the response j on the variety [17]. All the statistical analyses were performed with XLSTAT software 2018 (Addinsoft, New York, USA) and OriginPro 2021 (OriginLab, Northampton, MA, USA).

3 Results and discussion

3.1 Percent yield and chemical composition

Percent yield: Figure 1 showed a significant difference ($p<0.05$) in the percentage yield of total fruit mass. The highest percent yield of edible WMF was in Crimson sweet (66.13%), and by-products WMR, WMP, and WMS were significantly high ($p<0.05$) in Black chairman (30.86%, 5.67%), respectively. The percent yield of WMP and WMS were significantly higher ($p<0.05$) as compared to other fruits' residual waste, such as cantaloupe melon peel and seed (25 and 7%) [18] and pomegranate peel and seeds (40%) [19] of total fruit weight. The color parameter (lightness; *L**) of all cultivar's tissues measured by CIE Minolta colorimeter was varied from 32.56 to 41.52 for WMF, 62.56 to 73.84 for WMR, 25.76 to 32.85 for WMP, and 67.94 to 79.48 for WMS.

The mean values showed that fruit parts and cultivars were statistically different ($p<0.05$) in terms of moisture, protein, fat, fiber, ash, and carbohydrate contents (Table 2). The highest moisture content was in WMF, followed by WMR and WMP, and the lowest was observed in WMS on a dry weight (DW) basis among all cultivars. A significantly high difference ($p<0.05$) was found in the moisture content values of WMS among all four cultivars, with the highest moisture content in Crimson sweet WMS and the lowest in Black chairman. Protein and fat content were significantly higher ($p<0.05$) in WMS than in other parts of watermelon. Among cultivars, the highest protein and fat content were in Black chairman WMS and the lowest in Crimson sweet. The ash content was significantly ($p<0.05$) high in WMR, followed by WMP, WMF, and WMS of all studied cultivars. Carbohydrate contents were significantly high ($p<0.05$) in WMF and lowest in WMP compared to other parts of watermelon for the respective cultivars. The Black chairman has reported the highest carbohydrates in WMF, WMR, WMP, and WMS compared to the other cultivars. The difference in chemical composition among cultivars and their respective parts may be due to multiple factors such as genetics, maturity level, growth stage, storage conditions, environmental conditions, and soil fertilization that affect quantitative

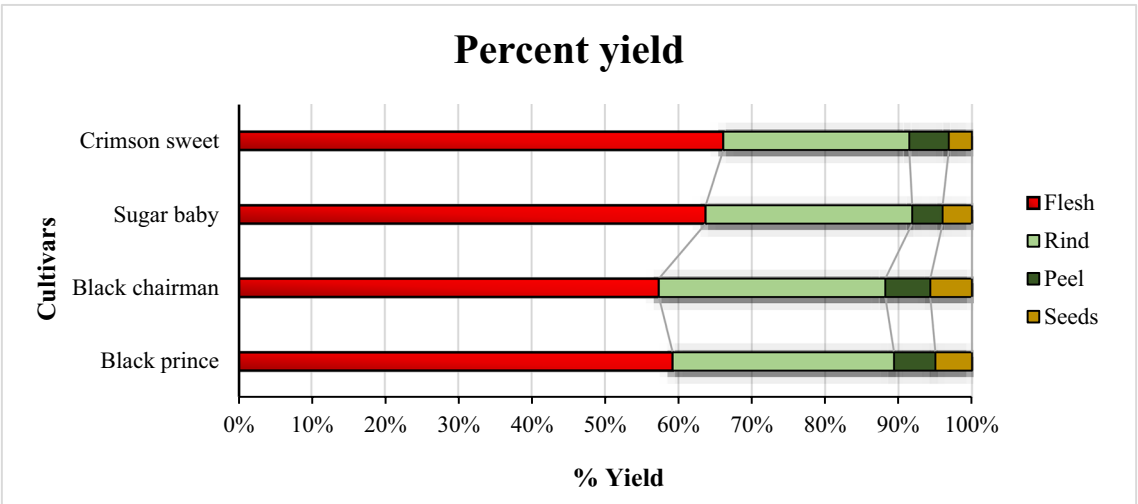


Fig. 1 Mean values of percent yield of different parts of watermelon cultivars

Table 2 Chemical composition of different parts of four watermelon cultivars (% of DW-except for moisture)

Cultivar	Moisture	Crude protein	Crud fat	Crude fiber	Ash content	Carbohydrates
Flesh						
Black prince	93.41 ± 2.12^{Aa}	4.85 ± 0.39^{Ca}	1.99 ± 0.03^{Db}	40.32 ± 1.03^{Aa}	6.11 ± 0.92^{Bbc}	48.29 ± 1.11^{Ab}
Black chairman	93.11 ± 3.29^{Aa}	5.32 ± 0.34^{Ca}	3.13 ± 0.10^{Ca}	43.09 ± 1.24^{Aa}	5.85 ± 0.97^{Cc}	55.52 ± 1.20^{Aa}
Sugar baby	92.02 ± 1.69^{Ab}	4.74 ± 0.37^{Ca}	2.83 ± 0.06^{Da}	41.65 ± 1.05^{Aa}	6.71 ± 0.81^{Cab}	45.13 ± 1.32^{Ac}
Crimson sweet	93.09 ± 2.92^{Aa}	3.53 ± 0.36^{Cb}	1.50 ± 0.02^{Dc}	39.09 ± 1.13^{Aa}	7.48 ± 1.23^{Ba}	39.46 ± 1.36^{Ad}
p value	*	*	***	Ns	**	***
Rind						
Black prince	92.57 ± 1.89^{Ba}	11.57 ± 0.89^{Bc}	9.80 ± 0.45^{Bb}	22.79 ± 1.04^{Bd}	18.45 ± 1.55^{Aa}	25.63 ± 1.23^{Bb}
Black chairman	92.75 ± 2.32^{Aa}	16.40 ± 1.26^{Ba}	10.86 ± 0.83^{Ba}	26.51 ± 1.12^{Bb}	13.67 ± 1.41^{Ac}	32.13 ± 1.25^{Ba}
Sugar baby	$91.04\pm2.42A^{Bb}$	13.69 ± 1.17^{Bb}	9.47 ± 0.82^{Bb}	29.70 ± 1.16^{Ba}	16.43 ± 1.65^{Ab}	24.62 ± 1.31^{Bb}
Crimson sweet	92.44 ± 2.37^{Ba}	9.87 ± 1.24^{Bd}	8.45 ± 0.36^{Bc}	24.19 ± 1.03^{Bc}	20.13 ± 1.00^{Aa}	28.30 ± 1.22^{Bab}
p value	*	***	***	***	***	**
Peel						
Black prince	91.61 ± 3.23^{Ca}	2.76 ± 0.19^{Dbc}	3.15 ± 0.17^{Cc}	14.65 ± 0.98^{Cc}	7.03 ± 0.19^{Bab}	7.56 ± 0.18^{Cc}
Black chairman	91.25 ± 2.43^{Ba}	3.58 ± 0.46^{Da}	4.22 ± 0.39^{Ca}	19.45 ± 1.03^{Ca}	8.41 ± 0.23^{Ba}	10.39 ± 1.27^{Da}
Sugar baby	90.49 ± 2.67^{Ba}	3.08 ± 0.48^{Db}	3.93 ± 0.32^{Cb}	17.34 ± 1.08^{Cb}	8.34 ± 0.27^{Ba}	8.91 ± 1.16^{Db}
Crimson sweet	90.76 ± 3.54^{Ca}	2.64 ± 0.35^{Cc}	2.95 ± 0.15^{Cd}	12.65 ± 1.06^{Cd}	5.63 ± 0.16^{Cb}	9.42 ± 1.18^{Db}
p value	ns	***	***	***	**	***
Seeds						
Black prince	7.40 ± 1.14^{Dc}	21.71 ± 1.39^{Ac}	31.24 ± 1.98^{Ac}	5.36 ± 0.76^{Dd}	3.74 ± 0.08^{Cb}	21.94 ± 1.24^{Bb}
Black chairman	6.95 ± 1.17^{Cd}	30.78 ± 1.66^{Aa}	47.43 ± 2.59^{Aa}	7.91 ± 0.89^{Da}	2.55 ± 0.16^{Dc}	25.35 ± 1.07^{Ca}
Sugar baby	8.33 ± 1.11^{Cb}	27.11 ± 1.23^{Ab}	39.97 ± 1.61^{Ab}	6.51 ± 0.94^{Db}	2.87 ± 0.11^{Dc}	18.89 ± 1.02^{Cc}
Crimson sweet	9.79 ± 1.16^{Da}	17.42 ± 1.52^{Ad}	26.56 ± 1.63^{Ad}	6.16 ± 0.95^{Dc}	4.65 ± 0.23^{Ca}	16.43 ± 1.14^{Cd}
p value	***	***	***	***	***	***

Data represent mean value ± standard deviation (replicates (*n*)=3). Data were analyzed by ANOVA, where the means were significant; means were separated with Tukey's HSD test ($p<0.05$). Capital letters represent a significant difference in tissues within each cultivar. Small letters represent significant differences in cultivar within each tissue. Significance level was checked at ≤0.05=*; ≤0.01=**; ≤0.0001=***; *ns*, non-significant

variation in the proximal composition [20, 21]. Results of the current study for watermelon WMF are in harmony with the earlier conclusions of Yimer and Tehulie [22] reported the proximal composition in WMF of four different cultivars such as Candy, Augusta, Lahat, and Ria. Similarly, Ugbogu and Ogodo [23] reported moisture, ash, protein, lipid, fiber, and carbohydrates as 92.93%, 0.94%, 1.22%, 0.48%, 0.10%, and 4.89%, respectively, in WMF. The WMR protein and fat were significantly higher ($p<0.05$) than other similar types of fruit peel, such as *Cucumis* melon peel (7.48 and 2.12%) [15]. The results for the WMS align with the findings of Tabiri, Agbenorhevi, Wireko-Manu and Ompouma [24]. They reported the moisture range from 7.40 to 8.00%, protein (16.33 to 17.75%), fat (26.50 to 27.83%), ash (2.00 to 3.00%), and carbohydrates (9.56 to 15.32%) in the seeds of cultivars Charleston gray, Crimson sweet, and Black diamond [24]. Moreover, Morais, Rotta, Sargi, Bonafe, Suzuki, Souza, Matsushita, and Visentainer [25] reported that WMS possesses significantly ($p<0.05$) high protein (22.3%) and total lipid (24.1%) as compared to the WMF and other similar types of seeds such as melon (17.2%, 13.9%). The WMS was significantly higher ($p<0.05$) protein and fat content when compared to other fruit seeds, such as mango seeds' protein and fat (7.99 and 11.72%) and pumpkin seeds (28.90 and 31.75%), respectively.

3.2 Minerals and vitamin composition

The mean values for the minerals showed that cultivars and their respective fruit parts were statistically different ($p<0.05$) from each other (Table 3). The sodium and iron concentrations in all examined cultivars were considerably higher ($p<0.05$) in WMF and lower in WMP. The calcium, potassium, phosphorous, and magnesium content in WMR was significantly higher ($p<0.05$) than in other parts of the watermelon. The WMP was significantly higher ($p<0.05$) in calcium, magnesium, and phosphorous compared to the WMF of all studied cultivars. WMS had significantly higher ($p<0.05$) magnesium and phosphorus levels than WMF and WMP. Black chairman and Black prince WMF, WMR, WMP, and WMS were significantly high ($p<0.05$) in sodium compared to that Sugar baby and Crimson sweet watermelon

Table 3 Mineral's composition of different parts of four watermelon cultivars (mg/100 g of DW)

Cultivar	Sodium	Potassium	Calcium	Magnesium	Phosphorous	Iron
Flesh						
Black prince	10.14 ± 1.78^{Ab}	63.17 ± 2.05^{Cb}	5.18 ± 1.28^{Db}	15.57 ± 1.92^{Db}	11.16 ± 1.54^{Cb}	7.18 ± 1.03^{Ab}
Black chairman	11.85 ± 1.89^{Aa}	67.48 ± 2.19^{Ca}	5.70 ± 1.23^{Da}	16.58 ± 2.19^{Da}	11.84 ± 1.24^{Ca}	7.78 ± 0.98^{Aa}
Sugar baby	9.65 ± 1.69^{Ac}	57.91 ± 1.98^{Cd}	4.88 ± 1.12^{Dc}	14.37 ± 1.85^{Dc}	10.44 ± 1.09^{Cc}	7.19 ± 1.27^{Ab}
Crimson sweet	8.18 ± 1.49^{Ad}	58.16 ± 1.74^{Bc}	3.56 ± 0.98^{Dd}	14.02 ± 1.91^{Dd}	9.82 ± 1.19^{Cd}	7.19 ± 1.09^{Ab}
p value	***	**	***	***	***	**
Rind						
Black prince	1.41 ± 0.24^{Cb}	96.55 ± 2.93^{Ab}	278.57 ± 5.67^{Ab}	97.40 ± 2.19^{Ab}	357.89 ± 4.45^{Ab}	1.66 ± 0.28^{Ca}
Black chairman	1.60 ± 0.19^{Ca}	113.21 ± 3.49^{Aa}	298.13 ± 6.78^{Aa}	98.57 ± 2.27^{Aa}	365.19 ± 5.27^{Aa}	1.58 ± 0.32^{Cab}
Sugar baby	1.15 ± 0.34^{Cc}	102.43 ± 3.19^{Ab}	224.56 ± 5.25^{Ac}	89.25 ± 2.37^{Ad}	294.89 ± 3.38^{Ac}	1.53 ± 0.27^{Cb}
Crimson sweet	1.06 ± 0.21^{Cd}	80.43 ± 2.17^{Ac}	194.65 ± 5.19^{Ad}	91.34 ± 2.94^{Ac}	224.94 ± 3.75^{Ad}	1.18 ± 0.19^{Cc}
p value	***	**	***	***	***	**
Peel						
Black prince	1.04 ± 0.12^{Dab}	24.37 ± 1.23^{Dd}	122.53 ± 2.96^{Bc}	20.89 ± 1.05^{Cb}	158.65 ± 2.59^{Ac}	0.21 ± 0.02^{Dc}
Black chairman	1.10 ± 0.19^{Da}	36.22 ± 2.15^{Da}	129.69 ± 3.16^{Bb}	24.05 ± 1.24^{Ca}	196.60 ± 3.48^{Ab}	0.48 ± 0.10^{Da}
Sugar baby	0.98 ± 0.11^{Cb}	32.23 ± 1.94^{Db}	131.36 ± 3.14^{Ba}	23.12 ± 1.21^{Ca}	210.43 ± 4.65^{Aa}	0.33 ± 0.06^{Db}
Crimson sweet	0.74 ± 0.07^{Dc}	29.62 ± 1.65^{Cc}	129.55 ± 2.85^{Bb}	23.84 ± 1.31^{Ca}	140.74 ± 3.94^{Ad}	0.17 ± 0.01^{Dc}
p value	**	***	**	*	***	**
Seeds						
Black prince	5.13 ± 1.22^{Bb}	82.90 ± 1.39^{Bb}	22.00 ± 1.96^{Cb}	46.83 ± 1.98^{Bb}	275.55 ± 3.19^{Ba}	3.00 ± 0.79^{Bc}
Black chairman	5.94 ± 1.17^{Ba}	83.53 ± 1.69^{Ba}	22.39 ± 1.37^{Ca}	48.62 ± 2.25^{Ba}	276.47 ± 3.28^{Ba}	3.15 ± 0.89^{Ba}
Sugar baby	4.33 ± 1.04^{Bc}	82.24 ± 2.17^{Bc}	19.28 ± 1.12^{Cd}	43.14 ± 2.68^{Bc}	262.13 ± 3.69^{Bb}	3.07 ± 0.94^{Bb}
Crimson sweet	3.17 ± 0.98^{Bd}	75.26 ± 1.83^{Ad}	19.52 ± 1.98^{Cc}	41.61 ± 1.93^{Bd}	197.40 ± 2.94^{Bc}	2.98 ± 0.82^{Bc}
p value	***	***	***	***	**	***

Data represent mean value ± standard deviation (replicates (*n*)=3). Data were analyzed by ANOVA, where the means were significant; means were separated with Tukey's HSD test ($p<0.05$). Capital letters represent a significant difference in tissues within each cultivar. Small letters represent significant differences in cultivar within each tissue. Significance level was checked at ≤0.05=*; ≤0.01=**; ≤0.0001=***; *ns*, non-significant

parts. The difference in mineral composition among cultivars and their respective parts may be due to the multiple factors, such as environmental and soil conditions and soil fertilization, that affect quantitative mineral variation [26]. These four cultivars' mineral profile was similar to Egbuonu [27] findings, which investigated certain minerals in WMR and WMS, such as iron, magnesium, phosphorous, calcium, potassium, and sodium. WMF and WMS had significantly higher ($p<0.05$) mineral content than avocado, pineapple, banana, and passion fruit [25]. The mineral composition of all parts of the watermelon was significantly lower ($p<0.05$) compared to the pulp, peel, and seeds of cucumber [28] and melon peel [15], except magnesium and calcium higher in WMR when compared to the cucumber peel (64.1 and 168 mg 100 g^{-1}) [28].

The statistical analysis for the vitamins such as vitamin A, C, and B complex (thiamin, riboflavin, and niacin) showed that cultivars and their respective fruit parts were statistically different ($p<0.05$) (Table 4). Vitamin A was significantly high ($p<0.05$) in WMS, followed by WMR, WMF, and WMP. WMR had the highest vitamin C levels ($p<0.05$), followed by WMF, WMS, and WMP. Thiamin, riboflavin, and niacin content in WMS were significantly higher ($p<0.05$) than in the other parts of all cultivars examined. Vitamin A and thiamin in all parts of all studied cultivars were significantly higher ($p<0.05$) when compared to the spaghetti squash flesh (0.084 and 0.020 mg/100 g), peel (0.089 and 0.023 mg 100 g^{-1}), and seeds (0.283 and 0.023 mg 100 g^{-1}) [29]. Black chairman and Black prince WMF, WMR, WMP, and WMS were significantly higher ($p<0.05$) in vitamin A compared to Sugar baby and Crimson sweet watermelon parts. Falade, Otemuyiwa, Adekunle, Adewusi, and Oluwasefunmi [30] reported thiamin and niacin in Rothmas as 2.2 and 1.1 mg 100 g^{-1} and in Sugar baby (1.1 and 0.33 mg 100 g^{-1}) which was greater than that of *Citrullus colocynthis* (1.6 and 0.28 mg 100 g^{-1}).

3.3 Phenolics, flavonoids, and citrulline

The statistical analysis for the TPC showed that cultivars and their respective fruit parts WMF, WMR, and WMS were statistically different ($p<0.05$) except the WMP, which is

Table 4 Vitamin's composition of different parts of four different watermelon cultivars (mg/100 g of DW)

Cultivar	Vitamin A	Vitamin C	Thiamin	Riboflavin	Niacin
Flesh					
Black prince	37.12 ± 1.16^{Cb}	6.24 ± 1.08^{Bb}	1.00 ± 0.12^{Ca}	0.06 ± 0.01^{Bb}	0.08 ± 0.01^{Ca}
Black chairman	38.95 ± 1.19^{Ca}	6.76 ± 0.94^{Ba}	1.05 ± 0.16^{Ba}	0.09 ± 0.01^{Ba}	0.11 ± 0.01^{Ba}
Sugar baby	32.70 ± 1.62^{Cc}	5.79 ± 0.92^{Bc}	1.02 ± 0.14^{Ca}	0.06 ± 0.00^{Bb}	0.10 ± 0.02^{Ca}
Crimson sweet	33.04 ± 1.28^{Cc}	5.76 ± 0.97^{Bc}	0.97 ± 0.08^{Ca}	0.05 ± 0.00^{Ab}	0.08 ± 0.01^{Ba}
p value	**	***	Ns	*	Ns
Rind					
Black prince	52.24 ± 1.95^{Bb}	9.19 ± 1.12^{Aa}	1.15 ± 0.11^{Bab}	0.06 ± 0.01^{Ba}	0.25 ± 0.02^{Bb}
Black chairman	53.50 ± 2.02^{Ba}	9.28 ± 1.28^{Aa}	1.18 ± 0.09^{Ba}	0.06 ± 0.00^{BCa}	0.26 ± 0.03^{Ab}
Sugar baby	48.49 ± 1.82^{Bc}	8.43 ± 1.17^{Ab}	1.12 ± 0.09^{Bb}	0.06 ± 0.00^{Ba}	0.30 ± 0.03^{Ba}
Crimson sweet	47.67 ± 1.54^{Bd}	8.11 ± 1.09^{Ab}	1.11 ± 0.12^{Bb}	0.04 ± 0.00^{Bb}	0.21 ± 0.01^{Ac}
p value	***	**	**	*	***
Peel					
Black prince	3.17 ± 0.85^{Db}	0.82 ± 0.02^{Db}	0.47 ± 0.06^{Dbc}	0.03 ± 0.00^{Ca}	0.04 ± 0.00^{Dab}
Black chairman	3.48 ± 0.41^{Da}	0.91 ± 0.09^{Da}	0.63 ± 0.03^{Ca}	0.04 ± 0.00^{Ca}	0.07 ± 0.01^{Ba}
Sugar baby	3.15 ± 0.52^{Db}	0.85 ± 0.07^{Db}	0.54 ± 0.05^{Dab}	0.03 ± 0.00^{Ba}	0.03 ± 0.00^{Db}
Crimson sweet	2.80 ± 0.56^{Dc}	0.81 ± 0.06^{Db}	0.43 ± 0.02^{Dc}	0.02 ± 0.00^{Ba}	0.04 ± 0.00^{Bb}
p value	**	*	**	ns	*
Seeds					
Black prince	65.71 ± 1.93^{Ab}	4.85 ± 1.01^{Cb}	2.40 ± 0.45^{Ab}	0.17 ± 0.02^{Aab}	0.30 ± 0.06^{Ab}
Black chairman	67.74 ± 2.23^{Aa}	5.26 ± 1.18^{Ca}	2.68 ± 0.24^{Aa}	0.16 ± 0.01^{Aa}	0.25 ± 0.03^{Abc}
Sugar baby	61.78 ± 2.09^{Ad}	4.20 ± 1.12^{Cc}	2.10 ± 0.29^{Ac}	0.12 ± 0.03^{Aab}	0.38 ± 0.05^{Aa}
Crimson sweet	62.87 ± 1.89^{Ac}	3.75 ± 0.98^{Cd}	2.17 ± 0.23^{Ac}	0.14 ± 0.01^{Ab}	0.19 ± 0.01^{Ac}
p value	***	***	***	*	***

Data represent mean value ± standard deviation (replicates (n)=3). Data were analyzed by ANOVA, where the means were significant; means were separated with Tukey's HSD test ($p<0.05$). Capital letters represent a significant difference in tissues within each cultivar. Small letters represent significant differences in cultivar within each tissue. Significance level was checked at ≤0.05=*; ≤0.01=**; ≤0.0001=***; n, non-significant

non-significant ($p>0.05$) in all four cultivars (Fig. 2a). As expected, representative high ($p<0.05$) phenolic concentration was in the WMR, followed by WMS, WMP, and WMF in all four cultivars. These four cultivars were poorly correlated with the amount of TPC in all parts of the fruit (R^2=0.64, p=0.089). TPC in watermelon WMF, WMP, and WMS was significantly lower ($p<0.05$) when compared to pumpkin flesh, peel, and seeds (134.59, 93.40, 224.61 mg GAE/100 g DW) [31]. Black chairman WMF was significantly higher ($p<0.05$) in TPC than Crimson sweet WMF but not significantly different ($p>0.05$) from the Black prince and Sugar baby WMF. TPC of WMR and WMS was significantly higher ($p<0.05$) in Black chairman and Black prince than that of WMR and WMS of Sugar baby and Crimson sweet. TPC results of the current study are in line with the recent conclusion of Neglo, Tettey, Essuman, Kortei, Boakye, Hunkpe, Amarh, Kwashie and Devi [32]; they reported TPC in different parts, i.e., the pulp (0.010 mg GAE g^{-1}), rind (0.026 mg GAE g^{-1}), peel (0.087 mg GAE g^{-1}), and seeds (0.042 mg GAE g^{-1}) in cultivar Charleston gray watermelon. TPC in all studied cultivars WMR and WMS were significantly higher ($p<0.05$) when compared to the aqueous extracts of melon peel (110.7 mg GAE 100 g^{-1}) and seeds (75.2 mg GAE 100 g^{-1}) [33].

A good amount of TFC was found in the WMF part of all studied cultivars, followed by WMS, WMR, and WMP (Fig. 2b). These four cultivars showed a good correlation with the amount of TFC in all parts of the fruit (R^2=0.766, p=0.022). TFC in WMF, WMP, and WMS were significantly higher ($p<0.05$) when compared to the other similar type of fruit such as pumpkin flesh, peel, and seeds (77.11, 45.0, 139.37 mg CE 100 g^{-1} DW) [31]. Black chairman and Sugar baby WMF were significantly higher ($p<0.05$) in TFC than the Black prince and Crimson sweet WMF. TFC of WMR was significantly higher ($p<0.05$) in Black chairman and Black prince than that of the WMR of Sugar baby and Crimson sweet. The TFC of WMR was also significantly higher ($p<0.05$) than other similar fruit peels, such as *Cucumis* melon peel (95.46 mg 100 g^{-1} DM [15]. TPC and TPC content variations were found even within the same variety, depending on many factors, including environmental factors, location, soil conditions, and maturity level. TFC

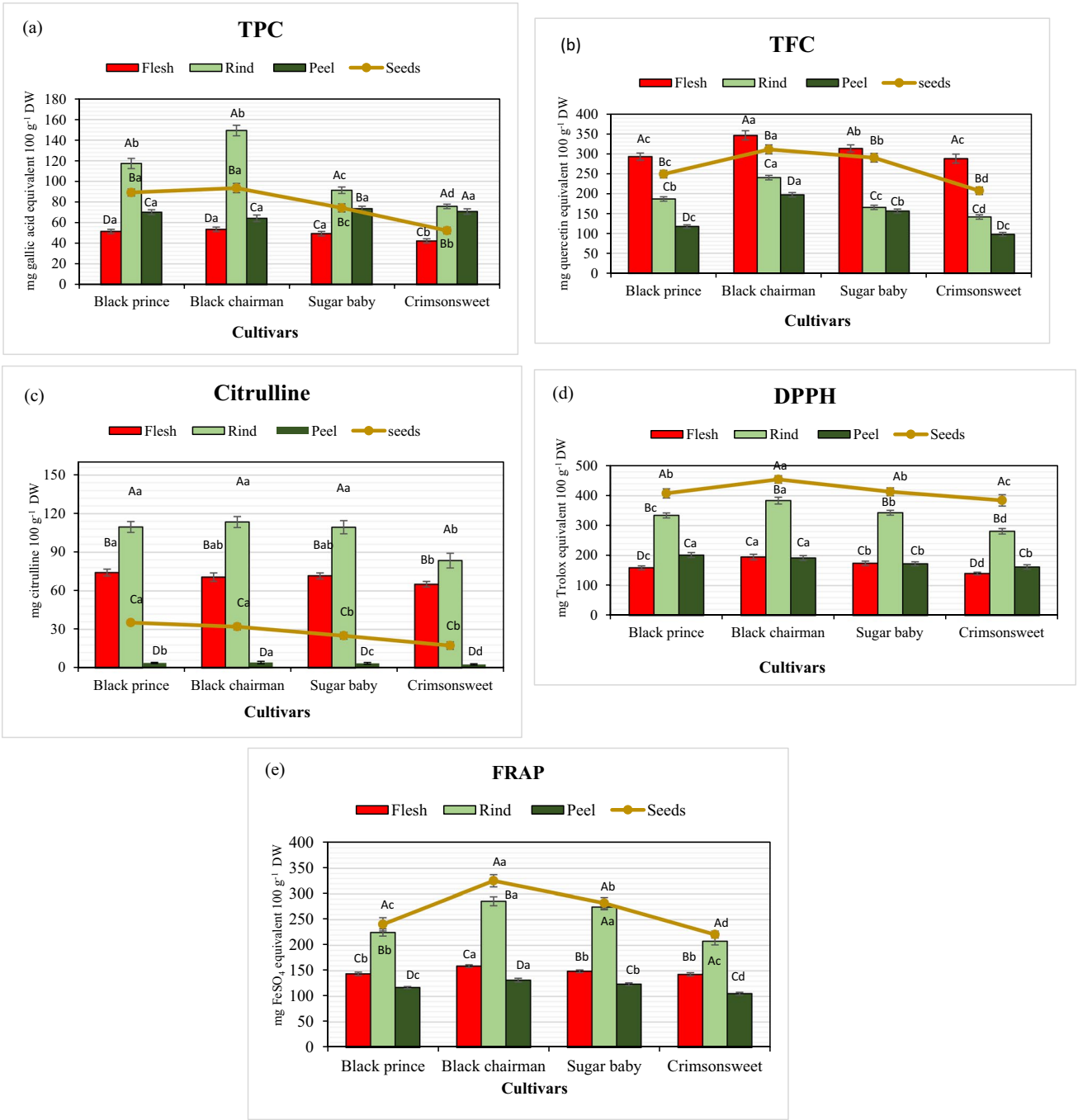


Fig. 2 Total phenolic content (TPC) (**a**), total flavonoid content (TFC) (**b**), citrulline (**c**), free radical scavenging (DPPH) (**d**), and Ferric reducing antioxidant (FRAP) (**e**) antioxidant activity content of flesh, rind, peel, and seeds of four watermelon cultivars. Data represent mean value ± standard deviation (n=3). Data were analyzed by ANOVA, when the mean were significant, means were separated with Tukey's HSD test (p<0.05). Capital letters (ABCD) represents significant difference of tissues within each cultivar. Small letters (abcd) represent significant difference of cultivar within each tissue

of WMS and WMP showed significantly higher (p<0.05) concentration in Black chairman than a Black prince and Crimson sweet. Similarly, Ho, Ramli, Tan, Muhamad and Haron [4] quantified the TPC and TFC in hot air and freeze-dried red-fleshed watermelon WMR powder extracts ranging from 127.93 to 218.39 mg GAE 100 g^{-1} dry matter (DM) and 19.46 to 193.43 mg CEQ 100 g^{-1} DM using different solvents such as water, methanol, ethanol, and acetone. Sola, Temitayo, Olufunke, and Shittu [34] reported phenols (0.304 mg/g) and flavonoids (2.675 mg/g) in watermelon seeds.

TPC and TFC in WMR and WMP were significantly higher ($p<0.05$) when compared to other fruit peels, such as papaya peel (65.48 mg GAE and 5.58 mg QE 100 g^{-1} DW) [31].

The statistical analysis for the citrulline showed that cultivars and their respective fruit parts, flesh, rind peel, and seed, were statistically different ($p<0.05$) (Fig. 2c). The citrulline content in WMR was significantly higher ($p<0.05$) and the lowest WMP of all studied cultivars. These four cultivars showed a good correlation with the amount of citrulline in all parts of the fruit ($R^2=0.908$, $p=0.0009$). The WMF of all studied cultivars showed a slightly significant difference ($p<0.05$) in citrulline content, with the highest content found in Black prince and the lowest in Crimson sweet. Black chairman WMR was significantly higher ($p<0.05$) in citrulline content than Crimson sweet WMR but not significantly different ($p<0.05$) from the Black prince and Sugar baby WMR. The WMP of all studied cultivars showed significantly lower ($p<0.05$) citrulline concentrations than the other parts of fruits, and the highest concentration was observed in Black chairman WMP. Citrulline concentration in WMS showed significantly higher ($p<0.05$) concentration in Black chairman and the Black prince, followed by Sugar baby and Crimson sweet. Hartman, Wehner, Ma, and Perkins-Veazie [35] reported citrulline (2.85 g/kg FW) in WMF, which was statistically higher than citrulline in muskmelon flesh (0.410 g/kg FW), horned melon flesh (0.090 g/kg FW), and honeydew flesh (0.163 g/kg FW). In the current study, citrulline content in the flesh was found to be lower than recently reported citrulline (22.9 mg/g DW) in red watermelon but higher than found in golden honeydew flesh (0.5 mg/g DW), apple cucumber flesh (0.2 mg/g DW), and dragon fruit flesh (0.1 mg/g DW) [36]. Similarly, the results regarding citrulline content are in line with the findings of PP, Sagar, Kar, Varghese, Singh, and Choudhary [37] reported citrulline in the rind (13.36 mg/g DW) and peel (9.78 mg/g DW) of Sugar baby watermelon. In general, genotypes, gene crossing, geographic effects, crop, maturation, soil conditions, and storage conditions are some characteristics that can affect the nutritional composition, phenolics, flavonoids, and other bioactive compounds and cause the difference in fruit composition among cultivars.

3.4 Antioxidant analysis

The DPPH values were twofold higher in the fruits' residual parts than the edible WMF, indicating the presence of a greater concentration of phenolics in the residual parts of watermelon (Fig. 2d). The DPPH showed a significant high in WMS, followed by WMR, WMP, and WMF across all cultivars examined. All four studied cultivars showed a good correlation with the free radical scavenging activity in all parts of the fruit ($R^2=0.849$, $p=0.005$). DPPH values were also positively correlated with the concentration of the phenolic ($R^2=0.912$). Black chairman WMF was significantly higher ($p<0.05$) in free radical scavenging activity, followed by Sugar baby, Black prince, and Crimson sweet WMF. DPPH value of WMR and WMS was significantly higher ($p<0.05$) in Black chairman and Sugar baby than that of WMR and WMS of Black prince and Crimson sweet. DPPH value of WMP of Black chairman and Black prince was significantly higher ($p<0.05$) than that of Sugar baby and Crimson sweet. In recent studies, Yıkmış [38] reported DPPH activity of 0.146 mg TEAC/mL in red WMF higher than the yellow WMF (0.103 mg TEAC mL^{-1}). Neglo, Tettey, Essuman, Kortei, Boakye, Hunkpe, Amarh, Kwashie, and Devi [32] reported DPPH in different parts, i.e., the pulp (33.05%), rind (34.48%), and seeds (41.10%) in cultivar Charleston gray watermelon.

FRAP assay showed that the seeds and rind showed significantly higher ($p<0.05$) ferric-reducing activity as compared to the flesh, and the peel showed the lowest FRAP values among all studied watermelon cultivars (Fig. 2e). All four studied cultivars showed a discrete correlation with the ferric-reducing activity in all parts of the fruit ($R^2=0.44$, $p=0.002$). The different antioxidant activities among different parts of fruit may be due to differences in their polyphenolic content and other nutritional constituents. WMS may have the highest antioxidant and polyphenolic content because they are the primary sites of plant metabolism and secondary metabolite synthesis [39]. All parts of Black chairman showed significantly higher ($p<0.05$) FRAP values, followed by Sugar baby, Black prince, and Crimson sweet. Higher FRAP values were reported by Ho, Ramli, Tan, Muhamad, and Haron [4] in WMR extract ranging from 319.43 to 100.18 mg FE 100 g^{-1} DM

3.5 Antinutritional compounds

Figure 3 a, b, and c show the mean values for the alkaloids, saponin, and tannin showed cultivars, and their respective parts were statistically different ($p<0.05$). As expected, representative lower antinutrient concentration was found in WMF and higher in WMP, WMR, and WMS. In all examined cultivars, the concentration of the alkaloids in WMR was considerably higher ($p<0.05$) than that in WMF (Fig. 3a). All the studied cultivars correlated with the alkaloid concentration in all parts of the fruit ($R^2=0.860$, $p=0.004$). Crimson sweet and Black prince WMF showed significantly higher ($p<0.05$) concentrations than the WMF of Sugar baby and Black chairman. Alkaloid content among the WMR of the Black prince, Black chairman, and Sugar baby was non-significant different ($p>0.05$) and lower than the WMR of Crimson sweet.

The saponin concentration in WMP was significantly higher ($p<0.05$) compared to the WMR and WMS while significantly lower ($p<0.05$) in WMF of all cultivars examined

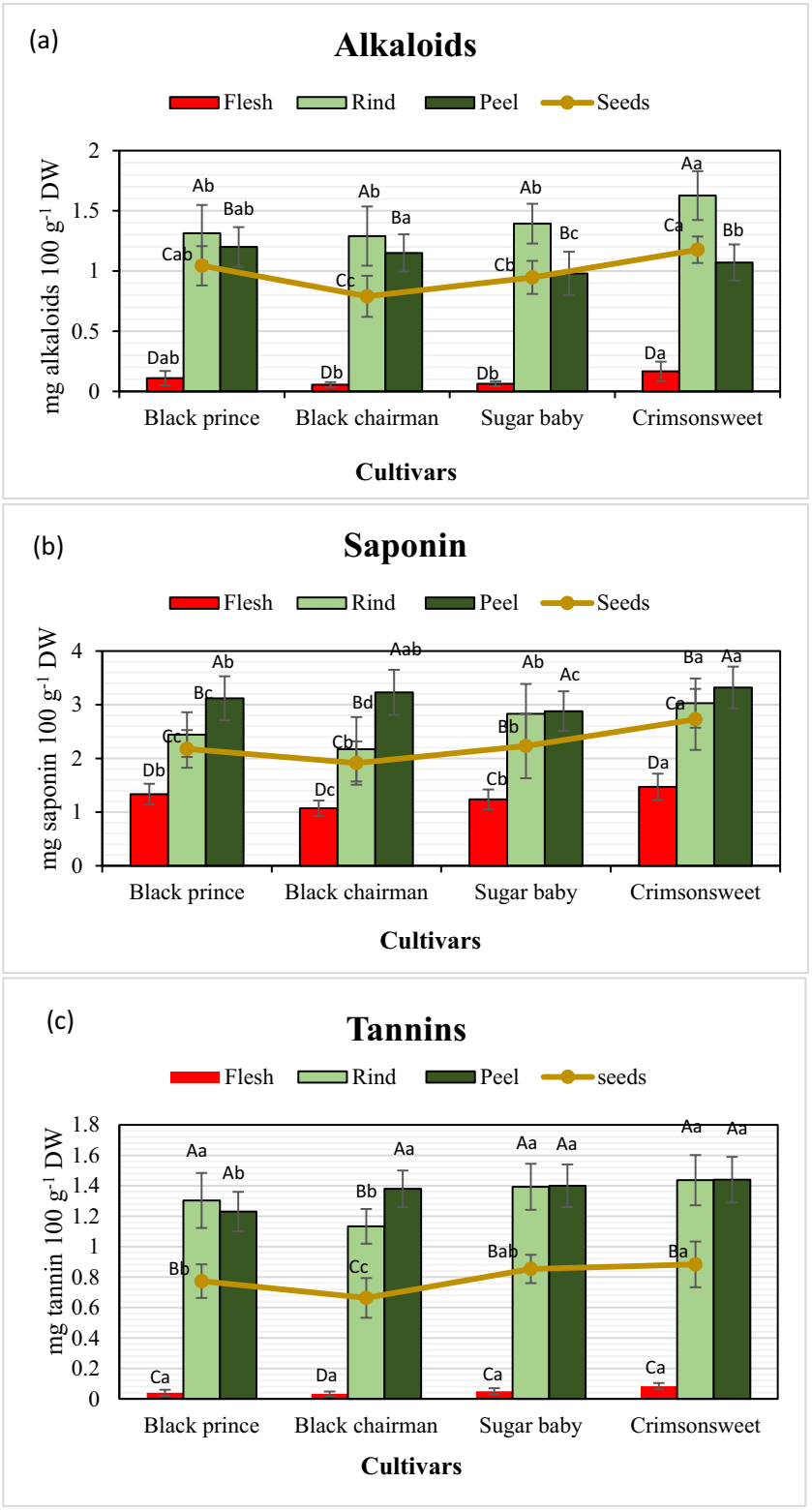


Fig. 3 Alkaloids (**a**), saponin (**b**), and tannin (**c**) content of flesh, rind, peel, and seeds of four watermelon cultivars. Data represent mean value ± standard deviation (n=3). Data were analyzed by ANOVA, when the mean were significant; means were separated with Tukey's HSD test (p<0.05). Capital letters (ABCD) represents significant difference of tissues within each cultivar. Small letters (abcd) represent significant difference of cultivar within each tissue

(Fig. 3b). These four cultivars showed a good correlation with the amount of saponin in all parts of the fruit (R^2=0.86, p=0.003). The saponin concentration in WMR, WMS, and WMP was significantly high (p<0.05) in Crimson sweet and lower in Black chairman WMR, followed by Black prince WMS and Sugar baby WMP. The mean value for tannin of all parts of the study showed very little concentration compared to alkaloids and saponin. The tannin concentration was

significantly high ($p<0.05$) in WMP and WMR and lower in WMF and WMS (Fig. 3c). All the studied cultivars showed a good correlation with the amount of tannin in all parts of the fruit ($R^2=0.88$, $p=0.001$). The WMR of Crimson sweet, Sugar baby, and Black prince were non-significantly different ($p<0.05$) in tannin content and higher than the WMR of Black chairman. Similarly, the WMP of Crimson sweet, Sugar baby, and Black chairman were non-significantly different ($p<0.05$) in tannin content and higher than the WMP of Black prince. The tannin content in WMS was significantly lower ($p<0.05$) than in WMR and WMP, and the highest was observed in crimson-sweet WMS. The tannin content in watermelon WMR and WMP was significantly lower ($p<0.05$) than in papaya peel (10.51 mg $100g^{-1}$) [31]. Oyenihi, Afolabi, Oyenihi, Ogunmokun, and Oguntibeju [40] reported alkaloid (8500 µg/mL), saponin (12900 µg/mL), and tannin (2400 µg/mL) in watermelon juice. The alkaloid and tannin content in WMF were significantly lower ($p<0.05$) than in pumpkin pulp (410.00 and 53.09 mg 100 g^{-1}) [41]. Egbuonu [27] also probed the alkaloid, saponins, and tannins in WMR (1.39, 3.0, and 1.33 mg 100 g^{-1}) and seeds (0.36, 2.31, and 0.61 mg 100 g^{-1}).

3.6 Clustering of watermelon cultivars according to the nutritional composition banquet to explain the variability

PCA was utilized to identify the variables that might account for higher variation in the datasets. Before PCA, each cultivar's data was standardized by deducting the variable mean and dividing by the SD of each cultivar variable to eliminate the biases due to the different units of the variables. The total variation's cumulative percentage (72.8%) indicates that only two principal components (PC1 and PC2) were retained (Figure S2) (Supplementary material). PC 1 and PC 2 were created as a factor on an axis and used to produce a two-dimensional projection of the samples. Table S1 shows the relationship between linear functions and their loading factors for the principal components. Table S2 presents the factor score of each variable. Both PCs were formed as linear combinations of the original responses, preserving a certain level of correlation between them. The PC1 retained approximately 38.90% of the total variance. It differentiated the samples based on the greater loading factor for fiber, carbohydrates, sodium, calcium, magnesium, phosphorous, iron, total phenolic content, DPPH, alkaloids, tannin, and saponin. Similarly, PC2 accounted for 33.95% of the variability in the original response and differentiates the samples based on protein, fat, potassium, vitamins A and C, thiamin, riboflavin, niacin, total flavonoid content, and ferric-reducing antioxidant activity (Table S2, Fig. 4a). The PC3 explained other 27.15% variability to P15 (except ash and citrulline), which does not differentiate the samples and should be dropped from the analysis. The underlying relationship in the original data set was identified through loading analysis, and the loading can be visualized as a regression vector. The presence of positive and negative factor loadings suggests that the factor exhibited higher values along the positive axis of that particular PC. Figure 4 b biplot shows the distribution of variables and watermelon cultivars with their respective tissues within two-dimensional space. The distribution of the watermelon cultivar and their respective tissue along the PC1 axis indicates that the WMR part of watermelon cultivars is on the positive side. In contrast, the WMF of the cultivar is located on the negative side. PC2 also influenced the distribution of the cultivars and their respective tissue; thus, it can be concluded that the cultivars and their respective parts' composition are different. Black chairman stands out for its highest total flavonoids, carbohydrates, sodium, and iron in WMF; total phenolic and citrulline in WMR; and protein, fat, vitamin A, thiamin, riboflavin, and ferric-reducing antioxidant capacity in WMS as compared to the other cultivars and their respective parts. A dendrogram was produced by conducting a hierarchical clustering analysis using the scores for both principal components as new variables (Figure S3) (Supplementary material), which shows the grouping of cultivars and their respective tissues into statistically different clusters. One cluster is composed of WMRs and WMS of all studied cultivars. WMF and WMP of all studied cultivars were not clustered, and WMF differed from all other parts of all studied cultivars. This multivariate analysis allows us to conclude that the Black chairman and Sugar baby cultivar and their respective parts were best described by their chemical composition, bioactive compounds antioxidant capacity. Black prince and Crimson sweet were best described by their minerals, alkaloids, tannins, and saponin content.

4 Conclusions

Chemical, bioactive compounds, and antioxidant profiles of all parts, i.e., WMF, WMR, WMP, and WMS of four watermelon cultivars, were studied. The research showed that watermelon's edible and residual waste has significant phytochemical composition and antioxidant activities. The reported results lead to two major conclusions. First, waste parts such as WMR and WMS contain a significant amount of protein, total phenolic, citrulline, and alkaloid content, and greater DPPH and FRAP values when compared to the edible WMF. Second, factor analysis enabled us to categorize the studied cultivars and their corresponding components into two distinct groups with peculiar nutritional compositions. Cluster analysis grouped the cultivars and their respective tissues together and separately according to the composition. This research study is important when

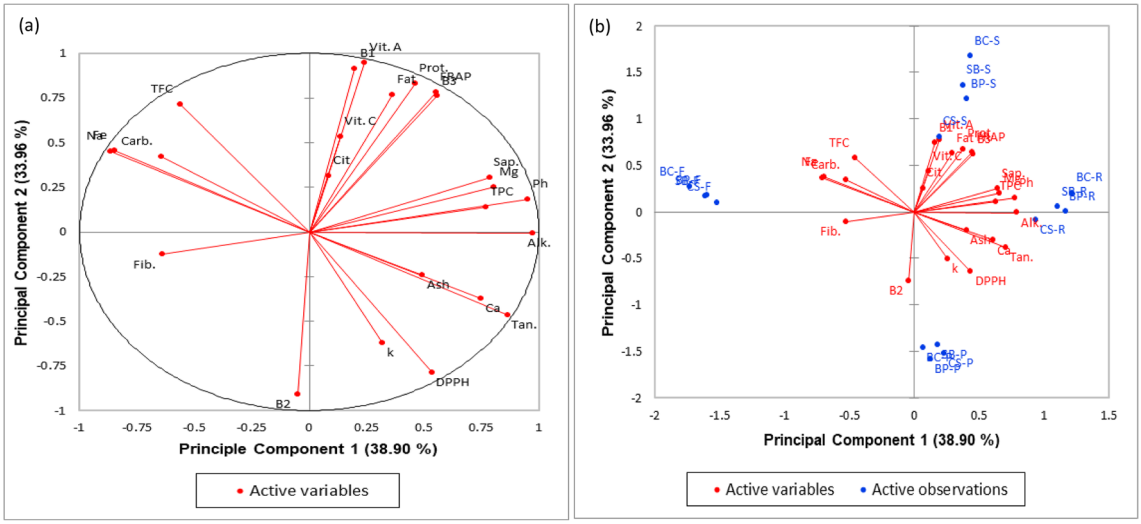


Fig. 4 Principal component analysis of four cultivars and their respective parts, i.e., flesh, rind, peel, and seeds. Graph of the loading factors (**a**) and biplot (**b**) for the two principal components; represents chemical composition parameters, minerals and vitamins composition, bioactive compounds, antioxidant capacities, and antinutritional compounds. BP-F, Black prince flesh; BC-F, Black chairman flesh; SB-F, Sugar baby flesh; CS-F, Crimson sweet flesh; BP-R, Black prince rind; BC-R, Black chairman rind; SB-R, Sugar baby rind; CS-R, Crimson sweet rind; BP-P, Black Prince peel; BC-P, Black chairman peel; SB-P, Sugar baby peel; CS-P, Crimson sweet peel; BP-S, Black Prince seeds; BC-S, Black chairman seeds; SB-S, Sugar baby seeds; CS-S, Crimson sweet seeds; MC, Moisture content; Prot, protein; Carb, carbohydrates; Fib, fiber; Na, sodium; K, potassium; Ca, calcium; Mg, magnesium; P, phosphorous; Fe, iron; Vit.A, vitamin A; Vit.B_1, vitamin B_1; Vit.B_2, vitamin B_2; Vit.B_3, vitamin B_3; Vit.C, vitamin C; TPC, total phenolic content; TFC, total flavonoid content; Cit, citrulline; Alk, alkaloids; Tan, tannins; Sap, saponin

considering the potential application of watermelon edible and residual waste for a specific food application. Using watermelon waste in diets and medicine could improve food availability, sustainability, health, and environmental impact. At the same time, the knowledge of the anti-nutritional composition of watermelon provides its potential to be utilized in pharmacological and nutraceuticals.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13399-023-04820-7.

Acknowledgements The authors express their gratitude to the Higher Education Commission (HEC), Pakistan, for their support in funding this project conducted at the University of Agriculture, Faisalabad, Pakistan. Furthermore, the author would like to acknowledge the assistance provided by Michigan State University, Michigan, USA, in the statistical analysis and interpretation of the results presented in this manuscript.

Author contribution Sania Zia: collected the literature and prepared and wrote the original manuscript draft. Moazzam Rafiq Khan: finalized figures and tables. R.M. Aadil: corrected, reviewed, and finalized the manuscript. R.M. Aadil and A Mousavi Khaneghah: supervision and editing.

Data availability Not applicable.

Declarations

Ethical approval Not applicable.

Competing interests The authors declare no competing interests.

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