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Research article

Comparative proximate composition and bioactive compounds in flesh and rind of mini watermelon

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Abstract

Importance of the work: In accordance with the changing lifestyle and consumption patterns, watermelon production has shifted from large-sized to small-sized fruits having desirable quality attributes. Hence, analyses of fruit quality traits are crucial to develop improved mini watermelon cultivars.

Objectives: To appraise promising mini watermelon genotypes with enhanced nutritional compositions and bioactive compounds.

Materials & Methods: Fruit physical attributes, proximate compositions and bioactive compounds were evaluated of the flesh and rind of five mini watermelon genotypes: BARI watermelon-1 (W_1), BARI watermelon-2 (W_2), L-32468 (W_3), L-32236 (W_4) and L-32394 (W_5).

Results: There was wide genotypic diversity for fruit morphological aspects and significant variability regarding nutritional attributes and bioactive compounds. Among the studied genotypes, W_1 stood out with the highest total soluble solids (10.79°Brix), rind vitamin C (29.70 mg/100 g) and total phenolic content (89.74 mg gallic acid equivalent (GAE)/100 g) accompanied by higher fruit weight (3.19 kg). In addition, the flesh of the W_3 genotype had the highest β carotene (0.17 mg/100 g), total phenolic content (107.08 mg GAE/100 g) and total flavonoid content (18.37 mg quercetin equivalent (QE)/100 g). However, the rind of the W_5 genotype had the maximum sugar and total flavonoid contents (17.17 mg QE/100 g).

Main findings: BARI watermelon-1 and L-32468 could be exploited for table purposes and used in a breeding program to develop mini watermelon cultivars with more attractive fruit in terms of quality acceptance and nutritional value. Furthermore, the rind of BARI watermelon-1 and L-32394 enriched with bioactive compounds could be utilized as dietary supplements in relevant food industries to develop functional food products which would decrease the solid waste in the environment.

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Introduction

Watermelon (*Citrullus lanatus*) is one of the most popular fruits of the Cucurbitaceae family and is widely distributed in tropical and subtropical regions (Gladvin et al., 2017). It is largely consumed as a refreshing summer fruit, much appreciated because of its attractive color, delicate taste and high water content to quench a summer thirst (Asfaw, 2022). In 2020, about 101 million t of watermelon were produced on a total *area* of 3.05 million ha globally, with Asia contributing 81% of the total production (Assefa et al., 2020; Morales et al., 2023).

In Bangladesh, watermelon cultivation has become a more popular and profitable agribusiness in recent years due to its relatively higher yield per unit area among the different kinds of fruits grown in the country (Rabbany et al., 2013).

Commercially, watermelon with good quality is always preferred by consumers, with external quality attributes of watermelon, such as shape, weight, and rind and flesh colors, being important preference components in consumer purchases of the fruit (Kyriacou et al., 2018). In addition to the external quality factors, consumers also consider internal quality features such as the fruit's sugar and nutritional contents (Musacchi and Serra, 2018). As a nutrient-dense, low energy food, watermelon provides vital nutrients and contributes to the overall fruit intake in the human diet (Fulgoni and Fulgoni, 2022). Its flesh contains a large amount of water, which is approximately 93% of the total weight of the flesh (Liu et al., 2018) and also contains micronutrients such as vitamins, minerals, amino acids (citrulline and arginine), lycopene and bioactive compounds (Manivannan et al., 2020; Rico et al., 2020). Generally, watermelon rind is treated as agricultural waste and discarded after consuming the attached flesh, causing environmental issues and biomass loss (Xiaofen and Ramirez, 2022). Though the rind is not as juicy as the flesh, it is edible and has many health benefits due to the presence of the important amino acid citrulline, along with fiber, minerals and phenolic compounds (Mohan et al., 2016; Ashoka et al., 2022). In addition, the rind has been studied for utilization as an ingredient in products including pickle, candy and cheese (Mohamed et al., 2013). Hence, it would be advantageous to capture the nutritional potential of the rind and create commercial value, rather than limiting it to agricultural waste.

The economic and nutritional values of watermelon that have been recognized have created the opportunity to develop and commercialize new varieties combining high fruit yield and quality (Yang et al., 2016). Nowadays, changes in human population patterns have led to increasingly smaller families and, as a consequence, a preference for smaller fruits, such as the mini watermelon weighing 2–4 kg (Barnes et al., 1994). In addition, consumers having low incomes prefer small-to-medium-sized fruits rather than large fruits because of the lower price of the former, as well being easy to handle and occupying less space in a refrigerator (Sari et al., 2016). Therefore, watermelon production has ultimately shifted from big fruits to small-sized fruits having desirable quality attributes (Tegen et al., 2021). In Bangladesh, where watermelons enjoy significant popularity, this particular type has the potential to mirror the trends seen in other countries, indicating a promising future (Sarker et al., 2017).

To date, various studies in different countries have explored the nutritional composition and bioactive compounds of watermelon genotypes (Choudhary et al., 2015; Singh et al., 2018; Tlili et al., 2023). However, it is recognized that factors such as genotypic variability, agricultural practices, environmental conditions and harvesting and post-harvest techniques, can influence the concentrations of bioactive compounds and nutrients in watermelons (Choudhary et al., 2015; Nadeem et al., 2022). Therefore, it is crucial to characterize various watermelon genotypes for these substances to determine their nutritional value. In Bangladesh, research on watermelon has been mainly centered on the yield and its determinants, with little available published scientific information on the nutritional status and bioactive profile of the watermelon genotypes grown under agro climatic conditions. Hence, the present study was designed to assess the fruit quality of mini watermelon genotypes in terms of their proximate composition and bioactive compounds for selecting promising genotypes to be used for future watermelon breeding programs in Bangladesh.

Materials and Methods

Experimental site

The experiment was conducted at the Department of Horticulture, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur-1706, Bangladesh during February to August 2022. This experimental area is in the agro-ecological zone Madhupur Tract (AEZ 28) (24°09°N; 90°26°E; 8.4 m above sea level), with the mean temperature in the range 28–32°C in the summer season, whereas in the winter season it falls below 20°C and the annual rainfall is in the range 1,000–1,500 mm. The soil is a clay loam in texture and acidic in nature with a pH of around 5.8 (Khan et al., 2023).

Plant material

The seeds of the two varieties and three lines of mini watermelon were collected from the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur-1701, Bangladesh and the Lalteer Seed Limited Dhaka. Bangladesh, respectively and were denoted by different accession numbers: W_1 (BARI watermelon-1), W_2 (BARI watermelon-2), W_3 (L-32468), W_4 (L-32236) and W_5 (L-32394).

Experimental design and crop management

Fresh, healthy, mature seeds were soaked in water for 3 hr and sown in February 2022 in 10.16 cm × 12.7 cm polythene bags using three seeds each with garden soil and compost mix (1:1). At the three-to-four true leaf stage, the seedlings were transferred to the main research field following a randomized complete block design (RCBD) replicated thrice. The unit plot size was 4 m × 2 m, accommodating seven plants in each plot following a spacing of 1 m ×1 m. The plants at their subsequent growing stages were fertilized with appropriate doses of manures and fertilizers following the Fertilizer Recommendation Guide of Bangladesh (Ahmmed et al., 2018). Intercultural operations such as weeding, irrigation, mulching, trellising, pheromone trap setting and pesticide and fungicide spraying were carried out as required.

Fruit harvest and data collection

Five fully matured, ripe fruits per genotype were randomly harvested in August 2022. Maturity was assessed by the presence of a dried tendril, yellow ground spot and a hollow sound when the fruit was tapped (Correa et al., 2020). Harvested fruits were immediately taken to the laboratory and determined for their fruit physical and nutritional quality traits.

Determination of fruit physical attributes

Fruit appearance was judged visually based on fruit shape, rind pattern and flesh color, while flesh texture was assessed by mouth feel according to Goda (2007). The cross sections of the fruits of the studied genotypes are presented in Fig. 1. Fruit length was measured from the blossom end to the stem end, while fruit diameter was measured across the fruit in the middle portion. Rind thickness was estimated from the flesh to the outer rind of the fruit and measured at the midway point between the blossom and stem end on each side. The weight of each fruit was determined using a top pan electric balance.

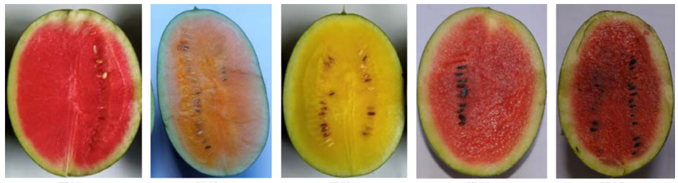

Fig. 1 Cross sections of representative fruit sample of five studied mini watermelon genotypes

Proximate composition

For proximate composition estimation, each fruit was prepared by washing with tap water and drying with paper towels. The total soluble solids (TSS) content of the flesh was analyzed using a hand refractometer (Model Atago N1; Japan) with values being presented as °Brix. The total and reducing sugar contents in the flesh and rind of watermelon were estimated according to the procedure described by Somogyi (1952). The β-carotene contents of the examined genotypes were assessed following the methodology outlined by Nagata and Yamashita (1992). Vitamin C as ascorbic acid was determined using a titration method described by Elgailani et al. (2017). The mineral contents (Na, K, Ca, Mg, Fe) were analyzed using an atomic absorption spectrophotometer in accordance with the procedures outlined by Association of Official Analytical Chemists (1984) and Morshed et al. (2021).

Bioactive compounds

Determination of bioactive compounds was carried out in accordance with the standard methods using methanolic extracts of flesh and rind samples (Mohammed et al., 2020).

The total phenolic content (TPC) was quantified spectrophotometrically using the Folin-Ciocalteu procedure (Mohammed et al., 2020), with some modifications. During analyses, 0.5 mL of methanolic extract was mixed with 2.5 mL of the Folin-Ciocalteu reagent and 2 mL of 7.5% sodium carbonate. Then, the resultant mixture was incubated at 30°C for 1 hr in the dark, followed by measuring absorbance at 760 nm using a spectrophotometer (PD-303 UV Spectrophotometer; APEL Co., Japan) against a methanol blank. Different concentrations of gallic acid were used to calculate the standard curve and results were expressed as milligrams of gallic acid equivalent (GAE) per 100 g of fresh weight.

Determination of the total flavonoid content (TFC) was carried out using the aluminum chloride colorimetric method (Pourmorad et al., 2006), with some modifications. In brief, 100 µL of methanolic extract at an appropriate dilution was mixed with 100 µL of 10% (weight per volume) $AlCl_3$ and 100 µL of 1M potassium acetate. Then, the mixture was incubated at room temperature in the dark for 40 min, followed by the measurement of absorbance at 420 nm using the spectrophotometer against a methanol blank. Total flavonoid was quantified from the quercetin standard calibration curve and expressed as milligrams of quercetin equivalent (QE) per 100 g fresh sample.

Statistical analysis

All analyses were performed in triplicate following a RCBD and the average mean data were evaluated based on analysis of variance tests and the means were compared based on a Duncan's multiple range (DMRT) test to determine the significant differences ($p < 0.05$ using the R software (version 4.0; R Core Team, 2020). In addition, correlation matrix, cluster analysis, principal component analysis (PCA) and biplot analysis were performed using the GGally, agricolae, Factoextra and Corrplot packages in the R software.

Results and Discussion

Fruit physical attributes

The quality of fruit is a major aspect from the point of view of consumers which is determined by both physical and biochemical properties. Physical properties include the size, shape and color of the fruit which prompt immediate preference in the market as visual attractions (Usharani et al., 2022). Table 1 reveals that the studied mini watermelon genotypes had noticeable variations in fruit morphological characteristics such as fruit shape, rind and flesh color, and flesh texture. In terms of fruit shape, it was found different among the mini watermelon genotypes. Three different types of fruit shapes were noticed during evaluation: round (W_1), oval (W_2 and W_4) and oblong (W_3 and W_5). Watermelon fruit shape can be elongated, oval, round or oblong based on the fruit length-to-width ratio (Lou and Wehmer, 2016).

Divergent rind colors, ranging from light to dark green (solid or striped) and yellow (Gusmini and Wehner, 2007; Dou et al., 2018) and patterns in watermelon are preferred by consumers, making them commercially important, with considerable emphasis being to their esthetic value (Kayesh et al., 2013). In the present study, fruits of the W_1, W_2 and W_3 genotypes had blackish, light and dark green rind, respectively, while the remaining two genotypes (W_4 and W_5) showed a combination of deep and light green color (light green with dark green stripe).

Watermelon flesh color is another vital appearance quality closely associated with consumer preference (Yuan et al., 2021). Watermelon flesh colors include coral red, scarlet red, canary yellow, orange and white. These different colors of watermelon not only provide visual diversity but are important from a nutritional perspective, as they are based on the carotenoid composition and content (Song et al., 2023). Among the tested genotypes, fruits of the W_1, W_4 and W_5 genotypes had red flesh, with a yellow color in W_2, whereas W_3 had yellowish orange flesh. The different types and contents of carotenoids contribute to this variation in flesh color of watermelon (Song et al., 2023).

Fruit flesh texture properties, especially flesh firmness, influence sensory quality and affect the taste, flavor and the shelf life of ripened watermelon fruit (Gao et al., 2020; Sun et al., 2020). During the current evaluation, a juicy, compact flesh texture was recorded in the W_2, W_3 and W_5 genotypes, while crispy and sandy compact flesh characteristics were noticed for the W_1 and W_4 genotypes, respectively.

Table 1 Fruit morphological attributes of five studied mini watermelon genotypes

Genotype	Fruit shape	Rind color	Flesh color	Flesh texture
W_1	Round	Blackish green	Red	Crispy
W_2	Oval	Light green	Yellow	Juicy compact
W_3	Oblong	Dark green	Yellowish orange	Juicy compact
W_4	Oval	Light green with dark green stripe	Red	Sandy compact
W_5	Oblong	Light green with dark green stripe	Red	Juicy compact

W_1 = BARI watermelon-1; W_2 = BARI watermelon-2; W_3 = L-32468; W_4 = L-32236; W_5 = L-32394

The physical traits of the studied mini watermelon fruits showed significant variation in terms of size, rind thickness and weight (Table 2). Fruit length, along with diameter, is a good indicator of better-quality watermelons. In the present study, fruit lengths were in the range of 15.06–22.09 cm and the significantly longest fruit was produced by the W_5 genotype, whereas the W_1 genotype produced the shortest (15.06 cm) which was not significantly different from the W_2 and W_4 genotypes. The maximum fruit diameter (12.93 cm) was recorded for the W_5 genotype followed by W_1 while fruit of W_2 had the minimum diameter (9.59 cm) that was not significantly different from the W_3 genotype. Sari et al. (2016) reported that in 38 mini watermelon lines, the fruit lengths and diameters were in the ranges 14.53–23.67 cm and 11.71–17.94 cm, respectively, which was consistent with the present results.

Rind thickness in watermelon fruits is an important feature for packaging as fruits with a very thin rind require greater care in transport to the final destination and have a shorter shelf life, which are both undesirable characteristics for both the trader and the final consumer (Rouphael et al., 2010). The present study revealed that the thickest rind (1.57 cm) was in the W_1 genotype, while the thinnest (0.74 cm) was in the W_4 genotype. The range in rind thickness in the present study was greater than reported by Sari et al. (2016).

Fruit weight in watermelon production is an important descriptor of fruit type, although it can also be considered as a yield component (Gusmini and Wehner, 2007). The average fruit weight of the studied genotypes in the present study was in the range 2.16–3.79 kg and the lightest fruit (2.16 kg) was harvested from the W_3 genotype, while the other genotypes produced fruits that were not significantly different in weight, with W_4 having heavier fruit (3.79 kg). However, this finding was inconsistent with Sari et al. (2016), who reported that the fruit weight remarkably varied (1.21–3.59 kg) among mini watermelon lines.

Proximate composition

The fruits of the different mini watermelon genotypes were significantly ($p < 0.01$) different in terms of nutritional abundance. Flesh sweetness is one of the prime internal as well as eating quality determining factors of fresh watermelon fruit which is related to the TSS (Yativ et al., 2010; Yau et al., 2010; Liu et al., 2013). By international standards, fruit can be classified according to a refractometric index when measured at the midpoint of the fruit in the equatorial section. Any watermelon with ≥ 8°Brix at the center of the flesh is sufficiently ripe and considered good internal quality, while that with 10°Brix is of very good internal quality (Kyriacou et al., 2018). Among the genotypes, W_1 was the sweetest, with the highest TSS content (10.79°Brix), whereas W_4 had the lowest value (9.08°Brix), which was not significantly different from W_5 (Fig. 2). Hence, the W_1, W_2 and W_3 genotypes with TSS values above 10°Brix in the present study could be considered as fruits with very good internal quality. Sari et al. (2016) reported TSS values in the range 6.74–11.45°Brix in their mini watermelon lines; the present results were also within that range. However, Jonathan et al. (2007) reported TSS values in the range 10.6–12.0°Brix in 26 seedless mini watermelon varieties, which were higher than the observations in the present study.

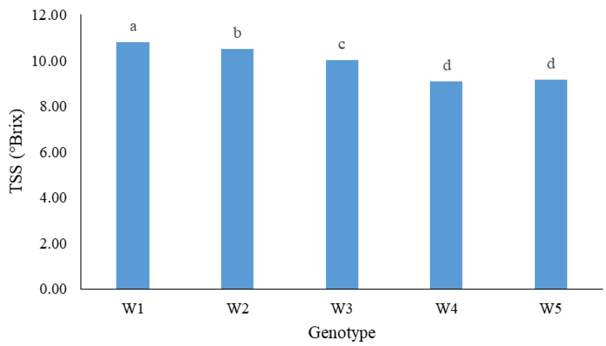

Fig. 2 Total soluble solid content (TSS) of different mini watermelon fruits, where columns with the same lowercase letter above them (s) are not significantly different at $p < 0.01$, error bars indicate SD, W_1 = BARI watermelon-1, W_2 = BARI watermelon-2, W_3 = L-32468, W_4 = L-32236 and W_5 = L-32394

Table 2 Fruit length, diameter, rind thickness and fruit weight of mini watermelon genotypes

Genotype	Fruit length (cm)	Fruit diameter (cm)	Rind thickness (cm)	Average fruit weight (kg)
W_1	15.06 ± 0.59^{c}	11.77 ± 0.89^{ab}	1.57 ± 0.04^{a}	3.19 ± 0.48^{a}
W_2	15.11 ± 1.48^{c}	9.59 ± 0.55^{c}	0.96 ± 0.04^{c}	3.15 ± 0.67^{a}
W_3	18.37 ± 0.22^{b}	10.19 ± 0.20^{c}	1.27 ± 0.11^{b}	2.16 ± 0.17^{b}
W_4	17.33 ± 2.54^{bc}	11.52 ± 0.11^{b}	0.74 ± 0.92^{d}	3.79 ± 0.19^{a}
W_5	22.09 ± 0.36^{a}	12.93 ± 0.81^{a}	0.88 ± 0.04^{c}	3.26 ± 0.57^{a}

W_1 = BARI watermelon-1; W_2 = BARI watermelon-2; W_3 = L-32468; W_4 = L-32236; W_5 = L-32394

Data presented as means ± SD of three replications (n = 5) in each column followed by same lowercase superscripts are not significantly different at $p <$ 0.05 based on Duncan's multiple range test using the R software (R Core Team, 2020).

The sugar contents in flesh and rind samples of the watermelon fruit varied significantly ($p < 0.01$) among the five genotypes (Table 3). The W_2 genotype performed well, with the maximum values of total sugar (18.95 mg/100 g) and reducing sugar (17.33 mg/100 g) contents in its flesh. In contrast, the W_3 genotype contained 8.95 and 5.01 mg/100 g of total and reducing sugar contents, respectively, which were the minima for all the flesh samples. In addition, the rind of the W_5 genotype contained the maximum amounts of total sugar (17.33 mg/100g) and reducing sugar (9.16 mg/100g) contents, whereas W_4 had the minimum sugar contents (3.80 mg/100 g and 1.99 mg/100 g for total and reducing, respectively). The present values for the reducing sugar content of the flesh were lower than those reported by Soumya and Rao (2014).

Carotenoids such as β-carotene, are an important dietary source of *vitamin A* (Marjorie, 2012; Tang, 2012). Generally, a higher beta carotene content would increase the nutritive value of fruit (Venkatesan et al., 2016). Analysis of variance revealed significant ($p < 0.01$) differences among the five genotypes regarding the β-carotene content in the fruit flesh and rind (Table 4). The β-carotene content in the flesh and rind of the tested mini watermelons fluctuated in the ranges 0.03–0.17 mg/100 g and 0.01–0.23 mg/100 g, respectively, with the W_3 genotype enriched with the highest amount in both the flesh (0.17 mg/100 g) and rind (0.23 mg/100 g). In contrast, the flesh of the W_5 genotype had the least amount (0.03 mg/100 g) of β-carotene, whereas the rind of W_4 contained the lowest amount (0.01 mg/100 g), which was not significantly different from the W_1 genotype. Quite similar values in watermelon flesh (0.1–2.1 mg per kg fresh weight) were obtained by Tlili et al. (2011). Furthermore, the present results were lower than those of Tlili et al. (2023) who recorded the β-carotene level in watermelon cultivars in the rage 1.54–10.39 mg per kg fresh weight.

Ascorbic acid is an active form of vitamin C that can impart a sour taste and its amount varies in different species of fruits and vegetables (Soumya and Rao, 2014; Manchali et al., 2021). It is of great importance from a nutritional viewpoint due to its antioxidant property (Dhillon et al., 2019). The estimated value of vitamin C was the highest in the flesh (32.85 mg/100 g) and rind (29.70 mg/100 g) of the W_5 and W_1 genotype, respectively (Table 4), whereas the lowest amounts were in the fruit of the W_2 genotype (10.40 mg/100 g in the flesh and 10.46 mg/100 g in the rind). These findings concurring with those reported by Tlili et al. (2023) who recorded total vitamin C in the watermelon flesh in the range 113.43–241.16 mg/kg fresh weight. The observed variability might be ascribed to genotypic differences, applied agricultural practices, degree of maturation at harvest and post-harvest handling (Leskovar et al., 2004; Tlili et al., 2011).

Table 3 Total and reducing sugar content of various mini watermelon genotypes

Genotype	Total sugar content (mg/100 g)		Reducing sugar content (mg/100 g)	
	Flesh	Rind	Flesh	Rind
W_1	12.32 ± 0.08^c	10.61 ± 0.39^b	7.18 ± 0.20^c	3.62 ± 0.39^d
W_2	18.95 ± 0.45^a	11.06 ± 0.30^b	9.24 ± 0.42^a	7.52 ± 0.16^b
W_3	8.95 ± 0.61^d	8.97 ± 0.64^c	5.01 ± 0.11^e	4.42 ± 0.14^c
W_4	12.10 ± 1.01^c	3.80 ± 0.31^d	5.63 ± 0.38^d	1.99 ± 0.06^e
W_5	15.35 ± 0.52^b	17.33 ± 0.58^a	8.42 ± 0.10^b	9.16 ± 0.17^a

W_1 = BARI watermelon-1; W_2 = BARI watermelon-2; W_3 = L-32468; W_4 = L-32236; W_5 = L-32394
Data presented as mean ± SD of three replications ($n = 5$) in each column followed by same lowercase superscript are not significantly different at $p < 0.01$ based on Duncan's multiple range test using the R software (R Core Team, 2020).

Table 4 Contents of β carotene and vitamin C in flesh and rind of mini watermelon fruits

Genotype	Content of β-carotene (mg/100 g)		Vitamin C (mg/100 g)	
	Flesh	Rind	Flesh	Rind
W_1	0.15 ± 0.00^b	0.02 ± 0.00^d	15.19 ± 0.04^d	29.70 ± 0.57^a
W_2	0.06 ± 0.00^c	0.07 ± 0.00^c	10.40 ± 0.03^e	10.46 ± 0.09^d
W_3	0.17 ± 0.00^a	0.23 ± 0.01^a	18.46 ± 0.02^b	16.03 ± 0.03^c
W_4	0.14 ± 0.00^b	0.01 ± 0.01^d	15.63 ± 0.06^c	16.14 ± 0.22^c
W_5	0.03 ± 0.00^d	0.14 ± 0.01^b	32.85 ± 0.25^a	20.24 ± 0.52^s

W_1 = BARI watermelon-1; W_2 = BARI watermelon-2; W_3 = L-32468; W_4 = L-32236; W_5 = L-32394.
Data presented as mean ± SD of three replications ($n = 5$) in each column followed by same lowercase superscript are not significantly different at $p < 0.01$ based on Duncan's multiple range test using the R software (R Core Team, 2020).

Dietary mineral elements are crucial for good and balanced human nutrition. They support a wide variety of bodily functions such as building and maintaining healthy bones and teeth, keeping the muscles in shape and improving the functions of the heart and brain (Jéquier and Constant, 2010). Table 5 shows that there was significant ($p < 0.01$) variability in the mineral contents among the five mini watermelon genotypes. The Na content varied within the ranges 0.02–0.10% for the flesh and 0.04–0.10% for the rind of the mini watermelon fruits. The significantly highest content of Na (0.10%) in the flesh was noted in the W_4 genotype and the lowest value was recorded in the W_3 genotype (0.02%). The rinds of both the W_3 and W_6 genotypes had the highest amounts of Na (0.10%). Conversely, the least Na content was recorded in the rind of the W_2 genotype which was not significantly different from the W_1 genotype.

The maximum K contents of the flesh and rind (1.39%) were in the W_4 and W_3 genotypes, respectively, whereas the minimum levels were in both the flesh (0.67%) and rind (1.03%) of the W_1 genotype.

Again, among the genotypes, the maximum percentage of Ca in the flesh (0.28%) was in the W_2 genotype, which was not significantly different from the W_4 genotype, while the minimum amount (0.16%) was in the W_1 and W_3 genotypes. On the other hand, the fruit rind with the highest content of Ca (0.28%) was in the W_5 genotype and the least value (0.15%) was detected in the W_4 genotype, which was not significantly different from the W_1 genotype.

In addition, the results showed that fruit with the maximum content of Mg in its flesh was harvested from W_5, followed by the W_3 genotype, whereas the minimum level (0.28%) was observed in W_1, which was not significantly different from the W_2 genotype. However, the fruit rinds with the highest (0.38%) and lowest (0.2%) amounts of Mg belonged to the W_3 and W_1 genotypes, respectively. Feizy et al. (2020) recorded values of 468.00 ± 0.12 mg/100 g, 164.48 ± 0.20 mg/100 g, 2,074.00 ± 10.00 mg/100 g and 53.59 ± 0.10 mg/100 g of calcium, magnesium, potassium and sodium, respectively, in watermelon rind, which were nearly similar to the values in the present study.

Bioactive compounds

Fruits produce a wide array of secondary metabolites, which perform essential physiological and biochemical functions, as well as being of the utmost importance in fruit quality from the point of view of consumer acceptability, affecting the color, appearance and the flavor and influencing fruit nutritional characteristics (Sanchez-Ballesta et al., 2022). Flavonoids and phenolic acids are the most important groups of secondary metabolites and bioactive compounds in plants (Kim et al., 2003).

Phenolic compounds have gained much attention due to their antioxidant activities and free radical scavenging abilities, with potential beneficial implications for human health (Soumya and Rao, 2014). With respect to the TPC, there were significant ($p < 0.01$) differences among the watermelon genotypes (Table 6). The TPC values were greatest in the flesh of W_3 (107.08 mg GAE/100 g) and in the rind of the W_1 genotype (89.74 mg GAE/100 g), while the lowest contents were in the flesh of the W_4 (8.44 mg GAE /100 g) and the rind of the W_5 (5.76 mg GAE/100 g) genotypes. These results were comparable to the findings of Tlili et al. (2023), who reported the TPC in the flesh of watermelon cultivars varied in the range 79.55–243.51 mg GAE/kg fresh weight. Additionally, the amount of TPCs in the peel measured by Feizy et al. (2020) was 2,473.45 mg GAE/100 g. The variation in the phenolic content was probably due to the different degrees to which the biosynthetic pathways of these compounds were affected during ripening and also might be due to genetic and environmental factors (Kolayli et al., 2010).

Table 5 Mineral contents of flesh and rind of different mini watermelon genotypes fruits

Genotype	Na (%)		K (%)		Ca (%)		Mg (%)	
	Flesh	Rind	Flesh	Rind	Flesh	Rind	Flesh	Rind
W_1	0.05±0.00^{d}	0.05±0.00^{c}	0.67±0.00^{e}	1.03±0.01^{d}	0.16±0.00^{c}	0.16±0.01^{d}	0.28±0.04^{c}	0.20±0.00^{e}
W_2	0.07±0.00^{c}	0.04±0.00^{c}	1.30±0.00^{c}	1.13±0.01^{c}	0.28±0.00^{a}	0.20±0.01^{c}	0.31±0.00^{c}	0.34±0.01^{b}
W_3	0.02±0.00^{e}	0.10±0.00^{a}	1.09±0.00^{d}	1.37±0.01^{a}	0.16±0.01^{c}	0.23±0.01^{b}	0.36±0.01^{ab}	0.38±0.01^{a}
W_4	0.10±0.00^{a}	0.06±0.01^{b}	1.39±0.00^{a}	1.16±0.01^{b}	0.27±0.00^{a}	0.15±0.01^{d}	0.35±0.01^{b}	0.31±0.01^{c}
W_5	0.08±0.00^{b}	0.10±0.01^{a}	1.33±0.00^{b}	1.15±0.01^{bc}	0.23±0.01^{b}	0.28±0.01^{a}	0.39±0.00^{a}	0.25±0.01^{d}

W_1 = BARI watermelon-1; W_2 = BARI watermelon-2; W_3 = L-32468; W_4 = L-32236; W_5 = L-32394.
Data presented as mean ± SD of three replications ($n = 5$) in each column followed by same lowercase superscript are not significantly different at $p < 0.01$ based on Duncan's multiple range test using the R software (R Core Team, 2020).

Flavonoids are phenolic compounds having free radical scavenging activity and are linked to multiple health benefits, including antioxidant, anti-carcinogenic and anti-inflammatory properties (Rocha et al., 2005). It is well-known that flavonoids contribute to the nutritional value and food quality in terms of modifying color, taste, aroma and flavor (Panche et al., 2016). As depicted in Table 6, the maximum TFC values were in the flesh of W_3 (18.37 mg QE/100 g) and rind of the W_5 genotype (17.17 mg QE/100 g). In contrast, the minimum amounts were recorded in the W_1 genotype (14.87 mg QE/100 g in the flesh and 14.01 mg QE/100 g in the rind). These differences in the TFC might have been due to the different genotypes of the watermelons that were analyzed.

Multivariate analysis

Pearson's correlation matrix was used to investigate the interrelationships among the 25 studied variables related to mini watermelon fruit quality (Fig. 3A). This analysis revealed that fruit size (length and diameter) had a very weak correlation with fruit weight, indicating that the fruit weight of a melon did not increase with an increase in its fruit length and breadth. Fruit size exhibited a moderate-to-strong correlation with vitamin C but had almost no correlation with β-carotene, suggesting that an increase in size promoted the vitamin C content in watermelon, not the β-carotene content. Among the biochemical and bioactive compounds, the TSS and TPC had strong negative correlations with fruit size and weight, respectively. This indicated a reverse association between fruit size and the levels of TSS and TPC in the watermelon. However, TFC had a very weak positive and sugar content showed almost no correlation with fruit morphology. Mineral contents in the fruit flesh had weak-to-moderate correlations with fruit size, except for Na and Mg, which were strongly positively correlated with fruit weight and fruit length, respectively. Fruit size (length and diameter) had moderate-to-strong positive correlations with all the physio-chemical, functional and mineral properties of the rind, except for TPC, vitamin C and Mg contents. Rind thickness, as well as fruit weight, had very weak or no correlation with the studied rind properties. Such diversified relationships among the fruit physical and biochemical properties displayed the wide variability among the genotypes.

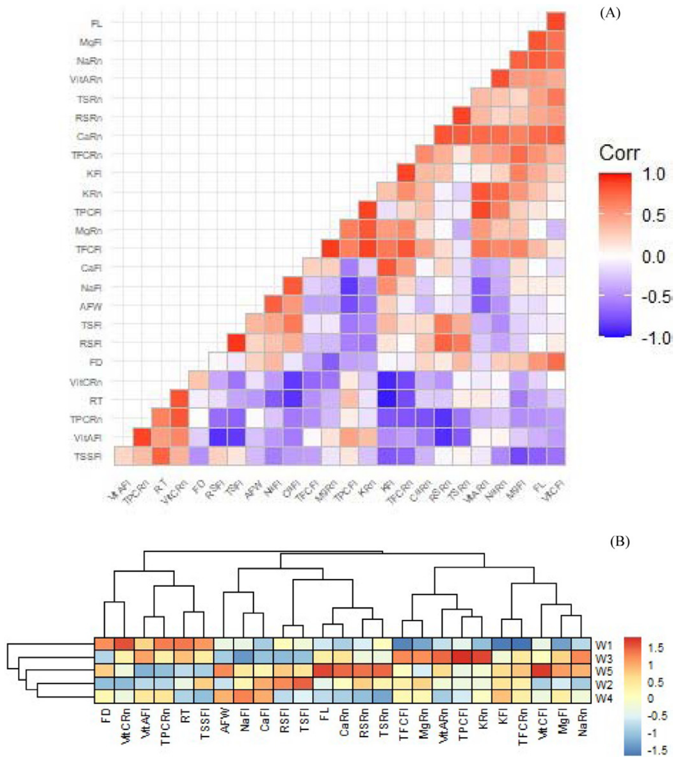

Fig. 3 (A) Correlation coefficients for variables related to fruit morphological and nutritional quality in mini watermelon; (B) distribution of 25 variables into two major clusters based on Heatmap. Here, FL = Fruit length, FD = Fruit diameter, RT = Rind thickness, AFW = Average fruit weight, VitAFl = β-carotene of flesh, VitCFl = Vitamin C of flesh, TSSFl = TSS of flesh, TFCFl = Total flavonoid content of flesh, TPCFl = Total phenol content of flesh, RSFl = Reducing sugar of flesh, TSFl = Total sugar of flesh, NaFl = Na of flesh, KFl = K of flesh, CaFl = Ca of flesh, MgFl = Mg of flesh, VitARn = β-carotene of rind, VitCRn = Vitamin C of rind, TSSRn = TSS of rind, TFCRn = Total flavonoid content of rind, TPCRn = Total phenol content of rind, RSRn = Reducing sugar of rind, TSRn = Total sugar of rind, NaRn = Na of rind, KRn = K of rind, CaRn = Ca of rind, MgRn = Mg of rind

Table 6 Total phenolic content (TPC) and total flavonoid content (TFC) of flesh and rind of mini watermelon genotypes fruits

Genotype	TPC (mg GAE/100 g)		TFC (mg QE/100 g)	
	Flesh	Rind	Flesh	Rind
W_1	15.81 ± 0.08^d	89.74 ± 0.51^a	14.87 ± 0.14^d	14.01 ± 0.11^c
W_2	20.96 ± 0.20^b	13.82 ± 0.27^d	17.26 ± 0.04^b	16.55 ± 0.60^b
W_3	107.08 ± 0.58^a	55.48 ± 0.55^c	18.37 ± 0.03^a	16.69 ± 0.15^b
W_4	8.44 ± 0.13^e	61.27 ± 0.28^b	17.06 ± 0.06^c	16.62 ± 0.64^b
W_5	18.87 ± 0.16^c	5.76 ± 0.47^e	16.99 ± 0.06^c	17.17 ± 0.18^a

W_1 = BARI watermelon-1; W_2 = BARI watermelon-2; W_3 = L-32468; W_4 = L-32236; W_5 = L-32394; GAE = gallic acid equivalent; QE = quercetin equivalent.

Data presented as mean ± SD of three replications (n = 5) in each column followed by same lowercase superscript are not significantly different at $p < 0.01$ based on Duncan's multiple range test (DMRT) using the R software (R Core Team, 2020).

A heatmap with a dendrogram cluster that was prepared using the 25 studied dependent variables depicted two main clusters (Fig. 3B). Cluster 1 consisted of variables such as fruit diameter, vitamin C (rind), β-carotene (flesh), TPC (rind), rind thickness and TSS that were closely related to each other. Cluster 2 contained the other variables that were further grouped into two sub clusters. Average fruit weight, fruit length, Na (flesh), Ca (flesh and rind), reducing sugar and total sugar contents (flesh and rind) formed sub cluster 1, while TFC (flesh and rind), Mg (flesh and rind), K (flesh and rind), TPC (flesh), β-carotene (rind), vitamin C (flesh) and Na (rind) were in sub cluster 2.

Principal component analysis (PCA) simplifies the wide range of data by transforming the number of correlated variables into a smaller number of variables. As observed, the first two principal components (PC 1 and PC 2) explained 64.8% of the pattern variations. Among the variables, TPC (flesh and rind), β-carotene (rind) and K content (rind) were strong, with total sugar content (rind) and fruit diameter contributing les, while the rest of the parameters were intermediate in their contributions (Fig. 4A).

As seen in Fig. 4B, rind thickness, average fruit weight, TSS, β-carotene of flesh, vitamin C and TPC of the rind were positively correlated, considering PC1, while PC2 was positively correlated with fruit length, rind thickness, TSS, vitamins, TPC, TFC, flesh Mg and rind minerals. Among these variables, rind thickness, TSS, β-carotene (flesh), vitamin C (rind) and TPC (rind) were commonly found as positive loading factors in both dimensions. Therefore, these variables contributed the most, indicating differences among the genotypes and the importance of selecting the proper genotype to provide high-quality fruit values.

The PCA-biplot placed the five mini watermelon genotypes in five distinct positions (Fig. 4C), with W_1 and W_3 locate on the positive sides of dimension 1 and dimension 2, respectively. Among the remaining three genotypes, W_2 and W_4 were positioned very near to each other showing close statistical similarity. These PCA findings were further clarified by cluster dendrogram analysis, showing that the five watermelon genotypes were grouped into two main clusters where Cluster 1 contained only the W_1 genoytype distinctfor the other genotypes and Cluster 2 could be further divided into two sub clusters, with the W_3 genotype in one subcluster and remaining three genotypes in the other sub cluster (Fig. 4D).

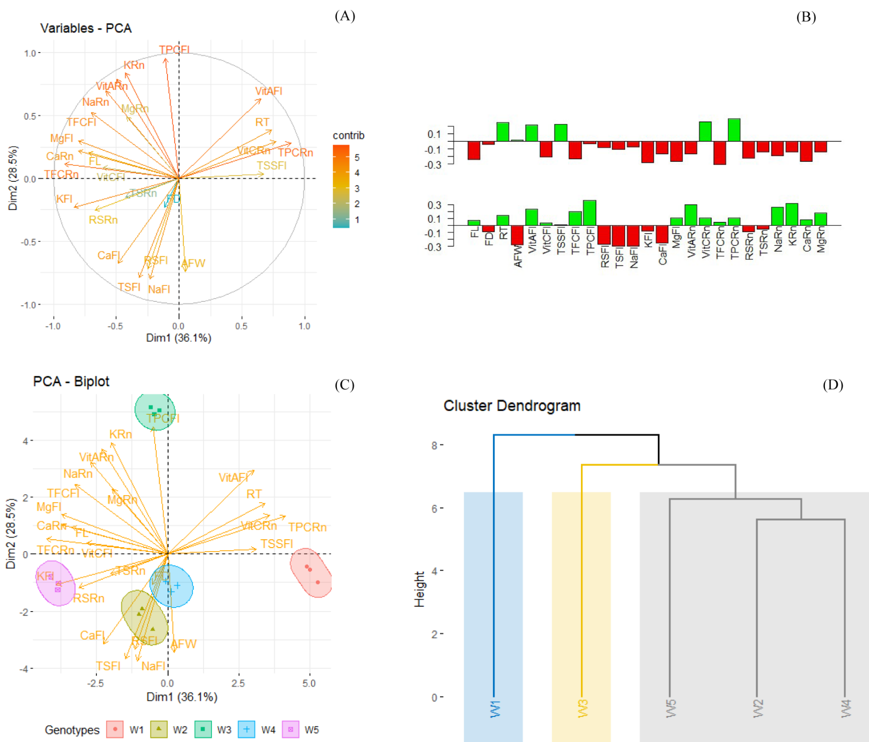

Fig. 4 Principal components analysis (PCA) of variables showing their major contributions; (B) factor loadings for first two principal components (PC1 and PC2); (C) PCA-biplot analysis representing performance of genotypes regarding quality parameters; (D) cluster dendrogram categorizing accessions according to similarities

The results of this comparative study indicated that the W_1 and W_3 genotypes showed promise in terms of fruit quality. Therefore, they could be grown to meet the market demands for mini watermelons regarding good quality fruit and they could assist breeders and other researchers in mini watermelon improvement. However, the rind of both the W_1 and W_5 genotypes could be considered as promising functional ingredients for food and industrial usage as potential sources of bioactive compounds.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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