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Physicochemical and phytochemical analysis of three melon fruit (canary melon, watermelon, and muskmelon) peels, and their valorization in biscuits development

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Introduction: Melons are highly sought after worldwide due to their exquisite and delectable taste. However, the peels of these fruits, which are rich in phytochemicals and sustainable components for innovative culinary formulations, are often discarded as waste.

Methods: This study explored the phytochemistry and valorization of three melon fruit, i.e., canary melon (*Cucumis melo*, var. Fonzy), watermelon (*Citrullus lanatus*, var. Augusta), and muskmelon (*Cucumis melo*, var. Cantaloupe), peels in food applications by incorporating into wheat flour biscuits. Peels of fruits were separated, dried and powders were extracted with 70% ethanol.

Results and discussion: Comparing the muskmelon fruit peel to the peels of the other two fruits, the muskmelon fruit peel had the significantly ($p < 0.05$) high ash (8.36%), fiber (12.06%), fat (1.21%), protein (5.02%), mineral contents (Mg 233, Ca 364, K 1605, Fe 49.72, and Zn 2.39 mg/100 g), total phenolic content (167.49 mg GAE/100 g), total flavonoid content (79.16 mg QE/100 g) and total antioxidant activity (56.92 mg Trolox equivalent/100 g). Results of the antimicrobial experiments of three melon peels showed that extracts from all peels showed enough antimicrobial activities, nearly comparable to the reference drugs (ampicillin and nystatin), which still showed the highest inhibition zones. Among three extracts, highest zone of inhibition against three bacterial species, i.e., *Bacillus cereus* (12.03 mm), *Escherichia coli* (10.02 mm), and *Streptococcus aureus* (18.08 mm), and fungal species, i.e., *Candida albicans* (8.09 mm), *Aspergillus niger* (7.06 mm), and *Mucor meihi* (7.02 mm) was exhibited by muskmelon peel extract. Moisture, ash, fat, fiber, minerals, phenolics, flavonoids, and antioxidant activities of biscuits were increased as a result of incorporating peel flours. Correlation showed TPC and TAA were highly correlated in watermelon (10%; 1). Using principal component analysis, adding 5% canary watermelon peel powder to biscuits improved their healthful and active elements while maintaining sensory features. Baking with 10% muskmelon or watermelon peel powder boosted nutrition and antioxidant activity. After the control, biscuits fortified with 5% melon peel powder exhibited significantly ($p < 0.05$) high sensory scores. These findings highlight the value of melon peels as sustainable ingredients, promoting waste reduction and enhancing the dietary and functional benefits of food products.

KEYWORDS

melon peel, ethanolic extracts, phytochemicals, biscuits, valorization, antimicrobial properties, antioxidant activity

1 Introduction

The need to extract bioactive substances with advantageous features in the food business could satiate the growing global need for functional foods. On the other side, fruit by-product valorization has also been recognized as an essential action to lessen the detrimental impacts of food waste on the environment, as well as to recover added value compounds and provide new sources of income (Gómez-García et al., 2020). Melon waste byproducts are inexpensive and sustainable sources of valuable bioactive substances. Their usage in the food sector may prove beneficial in the development of pharmaceutical meals that can reduce the population's economic potential. These days, the fruit and vegetable sectors generate a lot of byproducts with significant economic potential (Rico et al., 2020). Fruits and vegetables include a higher percentage of peels among their by-products, which make up between 25 and 60 percent of their weight. These byproducts have an intriguing chemical makeup, which makes them suitable for usage in food products (Rico et al., 2020; Zhao et al., 2023). Melon (*Cucumis melo*, L.) is one of the fruit crops in the Cucurbitaceae family that is widely grown around the world. The quality of melon is characterized by its sweetness, pleasant flavor, and high nutritional content (Kubola and Siriamornpun, 2011; Liu et al., 2023; Zhao et al., 2023). Cucurbitaceae fruits contain substantial amounts of carotenoids and phenolic compounds, which exhibit strong antioxidant activity (Hafeez, 2024). Therefore, they serve as a valuable reservoir of phytochemicals. Additionally, it has been demonstrated that the different fruit constituents within this family exhibited varying levels of antioxidant activity (Kubola and Siriamornpun, 2011). According to recent stats from FAO, in Pakistan, 2.7 lac tons of Cucurbitaceae fruits, including melons, were produced in 2019, with global production of these fruits, predicted to be above 23 million tons (Hussain et al., 2022; FAO, 2019). While, this worldwide production of melons was found to be increased to 28.56 million tons in 2022 (FAO, 2023). Melons often have high water content of 90–97%. These are renowned for their remarkable thirst-quenching and moisturizing qualities. Due to the presence of vitamins (C, B group, and K), minerals (K, Fe, Cu, Fe, and Mg), carotenoids, phenolics, and fiber, melons are the fruit that are nourishing (Tadakod et al., 2022). Melons are a large and varied family of sweet, fresh fruits, with hundreds of different types, including hybrid melons, while peels of these fruits are thought to be byproducts of food processing, with encouraging nutrients (Ganji et al., 2019; Çağındı et al., 2023).

Watermelon [*Citrullus lanatus*, (Thunb) Matsum. and Nakai], is a member of the Cucurbitaceae family and only grows in hotter regions of the world. Humans consume the watermelon's pulp, seeds, and juice, but the rind, which makes up 30% of the fruit overall, is usually discarded as waste without being processed or recycled in any way (Hasanin and Hashem, 2020). Due to the huge amounts of biomass waste produced by global production, which reached 100 million tonnes in 2019, of which one third (rind) is abandoned as waste, watermelon peel has been identified as a promising source of bioactives (Méndez et al., 2023). According to the FAOSTAT, in 2022 the world produced 100 million metric tons of watermelon (FAO, 2023). Watermelon peel is a good source of minerals, antioxidants, and natural polyphenols (Feizy et al., 2020). Each of these substances possesses therapeutic qualities that can be used to cure and prevent disease (Zia et al., 2021). In some places, watermelon rinds are eaten raw, stir-fried, stewed, pickled, or cooked with sugar to make jam. Regarding the application of dried watermelon rind as a component in baked goods, a number of writers have documented its use in bread, cakes, cookies, and noodles (Al-Sayed and Ahmed, 2013; Shivapour et al., 2020; Capossio et al., 2022; Ashoka et al., 2021; Olaitan et al., 2017; Awad, 2017; Pires et al., 2023). Similarly, an imperative horticultural crop grown in many shares of the world is the muskmelon (*Cucumis melo*, L). It may also be found in desert regions and is grown in nations with temperate climates in Europe, Asia, and Africa (Silva et al., 2020). The muskmelon, which has a nettled rind, is consumed as a table fruit, however its rind is discarded as waste (Manchali and Murthy, 2020). Its creamy flesh has a musky flavor and is pale yellow-orange in color (Sangamithra and Ragavi, 2019). In terms of production, muskmelons rank fourth in the world, behind oranges, bananas, and grapes (Aguayo et al., 2004; Gómez-García et al., 2020). Fundo et al. (2018) have reported muskmelon peel, as compared to the edible flesh, to be a good source of fibers, minerals, and bioactive compounds. Similarly, Vella et al. (2019) have also declared muskmelon peel to be high in polyphenols and antioxidant activity. But unfortunately, there have been no food products developed through the incorporation of muskmelon peel flour.

Cucurbitaceae fruit peels contain dietary fibers that have been shown to slow down the digestion of starch, aiding in the treatment of diet-related illnesses including diabetes (Bai et al., 2020; Gómez-García et al., 2020). Compared to the pulp, which is the major component of Cucurbitaceae fruit that is often ingested, the peels of these fruits contain a substantial quantity of fiber, protein, minerals, and carbohydrates (Hussain, 2023; Ho et al., 2016). Cucurbitaceae fruits peel flour is known for its high mineral and dietary fiber content, and adding it to food products has enhanced their nutritional and cooking properties (Freitas et al., 2020). Dietary chips developed from watermelon rind flour were found acceptable and nutritional (Hema Prabha et al., 2021). Development of composite flours, rich in nutritional contents, using wheat flour and flours from fruits byproducts is gaining importance nowadays (Ogo et al., 2021). Imoisi et al. (2020) developed bread from composite flours containing different proportions of watermelon and wheat flours. Due to the ease of preparing, storing and consuming, wheat flour biscuits have become very popular as a snack meal. Biscuits are a preferred option for consumers of all ages due to their simplicity in preparation, convenience of consumption, portability, and prolonged shelf life (Ashoka et al., 2021; Krajewska and Dziki, 2023). However, they are typically made only using a combination of butter, sugar, and wheat flour. This suggests that they are high in calories, but are deficient in dietary fiber and beneficial bioactive substances. At the moment, a sizable part of consumers showed awareness of the connection between poor nutrition and the rise of diet-related illnesses. As a result, individuals are looking for nutrient-dense functional foods that could have a positive impact on their physiologies (Al-Sayed and Ahmed, 2013).

Finding creative and sustainable uses for fruit leftovers is becoming more popular, especially in recent years, as a strategy to reduce waste and advance circular economy principles (Rico et al., 2020). Flours from melon peels could be valuable components in the creation of food items that are functional, due to their advantageous characteristics (Saleh and Ali, 2020). The form, color, and hardness of the bakery product could alter as a result of this enrichment procedure. It can also impact the senses of odor, taste, and appearance, possibly resulting in a drop in overall quality. As a result, it is critical to establish the appropriate level of each addition, while taking consumer acceptance and health into account (Al-Sayed and Ahmed, 2013; Hussain, 2023). While there have been several research studies conducted on various plants belonging to the Cucurbitaceae family, data are scarce regarding the chemical composition of the peels of these fruits and the conversion of these waste materials into beneficial food products. Keeping in view the problems created as a result of waste generated due to the consumption and processing of different melon fruits and vegetables, and the universal demand for functional food products loaded with plant-based phytochemicals, the objectives of current investigations were to explore the peels of three melon fruits (watermelon, muskmelon, and canary melon) for presence of phytochemicals, and antioxidant, and antimicrobial activities. Further, the conversion of these waste peels into useful powders to incorporate in wheat flour for the development of nutritional biscuits, and then to assess the physical, chemical, and sensorial variations in the developed formulated biscuits were also among the objectives of this study.

2 Materials and methods

2.1 Fruit materials sample collection

Three melon fruits (F1 hybrid), watermelon (*Citrullus lanatus*, var. Augusta), muskmelon (*Cucumis melo*, L. var. Cantaloupe), and canary melon (*Cucumis melo*, L. var. Fonzy) for investigations of their peels, were manually harvested from the fields having optimal growing and environmental conditions, when they were fully developed and ripened. ICI Pakistan seeds company provided the seeds for cultivation of these fruits. Subsequently, the fruits were transported to the Department of Food Science and Nutrition at the University of Sargodha for botanical identification. The identification process was conducted by Prof. Dr. Abdul Ghani, an expert botanist from the botany department. During the harvesting process, we took into account the uniformity of size, color, shape, and weight. The harvested samples were then precooled for a time period of almost 3 h to eliminate any residual heat from the field. Then the fruits were immediately transferred to laboratory for experiments where, they were stored in a dark location at a temperature ranging from 20 to 25°C until being tested. Watermelon fruits were round having smooth blackish green rind, with deep red flesh and 6 ± 0.1 kg weight. Muskmelons having 1.5 ± 0.1 kg weight each, were spherical, having greenish skin with longitudinal stripes and orange colored flesh. Canary melons were elongated with bright yellow peel and pale green to white inner flesh, having 1.5 ± 0.1 kg weight of each fruit. The fruits were manually washed, measured, and peeled; the rinds were then diced into 1 cm^3 pieces for further processing and analysis. As the fruits selected for this study are normally cultivated in the Pakistan, and have not been listed in the endangered plants, so there were no strict regulations/guidelines for their use in research. However, for the collection of cultivated fruits, all methods were carried out in accordance with relevant national and international guidelines/legislations/regulations.

2.2 Chemicals, reagents, raw materials, and microorganism strains

The Sigma-Aldrich chemicals company (St Louis, MO, USA) provided all the reagent-grade chemicals used in this study project, and were included acetone, aluminum chloride, sodium hydroxide, 2,2-diphenyl-1-picrylhydrazyl (DPPH), sodium nitrite, the Folin-Ciocalteau reagent, sodium carbonate (Na_2CO_3), the gallic acid ($C_7H_6O_5$), sodium nitrite, and phosphate buffer (pH 7.2 and 7.4), potassium ferric cyanide, trichloroacetic acid (TCA), and ferric chloride. Instruments included were grinder, analytical balance, shaker, vortex mixer, centrifuge, and freezer. Glassware and accessories included were conical flasks (100–200 ml), falcon tubes (15–50 ml), baskets, funnels, graduated cylinder, pipettes, filter paper, spatula, mask, gloves, paper envelops, shopping bags, plastic bottles, and beakers, which were available in scientific laboratory of University. Bacterial and fungal strains for antimicrobial activities were obtained from the Department of Biotechnology, University of Sargodha.

2.3 Preparation of fruit peel powders

Melon peels were rinsed with distilled water after being cleaned with tap water. To preserve the sample, the fruit peels were immersed in 0.2% sodium metabisulphite for 15 min. Then, these sliced peels were dried in a microwave oven (NT-30, Nasan, Shanghai China) using 800 W power at 100°C (until uniform moisture content is achieved for each sample), by following the procedure earlier adopted by Hussain et al. (2021, 2024). The pieces of dried peel were then ground using a stainless-steel grinder and sieved through a 0.5 mm diameter plastic sieve and kept in an airtight container on the shelf in the laboratory.

2.4 Development of ethanolic extracts from fruit peels

Ethanolic extracts of powdered melon peels were prepared according to the guidelines provided by Hussain et al. (2021). In short, 2 g of each powder was dissolved in 20 ml of solvent (70% ethanol and 30% water), and was kept in an orbital shaker (LOS B11, Iran Scientific, Iran) overnight at room temperature. Then the P8 uneven filter was used to filter the extracts by gravity filtration, and a 0.45 μm filter was used for vacuum filtering process. To achieve the 20 ml final stock solution at a concentration of 2 mg/ml, the 0.04 ml extracts were dispersed at 40°C in a rotary evaporator and then reconstituted in 19.96 ml ethanol once more. The finished crude extracts were kept in a laboratory refrigerator in airtight glass bottles. A graphical overview of the study has been drawn in Figure 1.

2.5 Determination of antimicrobial activities of melon peel extracts

Antimicrobial activities of ethanolic extracts of melon peels were tested against three different bacterial species (*Bacillus cereus*, *Escherichia coli*, and *Streptococcus aureus*) and three different fungal species (*Candida albicans*, *Mucor meihi*, and *Aspergillus niger*) using the agar well diffusion assay, by following the guidelines of Neglo et al. (2021) and Barbero-López (2021). The pure cultures of these pathogens were collected from the Microbiology Laboratory, Department of Biotechnology, University of Sargodha. Tested bacterial and fungal strains were streaked over Muller-Hinton agar and Malt extract agar plates, respectively. Agar wells were created using a sterile cork-porer. After that, 100 μl of each melon peel extract and reference antimicrobial drugs (ampicillin and nystatin), at doses of 100 μg/ml, were then added. The samples were then incubated for 24 h at 37°C for bacteria and 72 h at 30°C for fungi. The diameter of each treatment's inhibitory zone was then measured in mm.

2.6 Development of peel powder incorporated biscuits

Different treatments of biscuits were made by adding three melon peels flours at varying percentages, such as 5 and 10% of each, and they were then compared to the control biscuits developed with 100% wheat flour by following the procedure used by Ertaş and Aslan (2020). The biscuit dough was prepared using the standard method American Association of Cereal Chemists (AACC) 10.54.01, in a Brilliance (BDM-2792, Pakistan) laboratory mixer set to 125 rpm for 10 min using the standard formulation: 100 g (14% moisture content) of wheat flour, 80 g of shortening, 80 g of powdered sugar, 4 g of sodium metabisulphite, 2 g of salt, and 2 g of milk powder. There were seven different treatments of biscuits made: one control (100% wheat flour), and six other treatments with two different proportions of three melon peels flours (5 and 10%). Using a stainless-steel roller dough was sheeted to 0.5 mm thickness, cut out with a dough cutter that had a 50 mm diameter, and then baked for 20 min at 170°C on stainless steel metal pans.

2.7 Proximate composition of peel powders and developed biscuits

The generated biscuits and powdered melon peels were subjected to proximate analyses for moisture, protein, ash, fat, and fiber

FIGURE 1
Graphical overview of the work.

contents, in accordance with the protocols outlined by AAAC. Following the required modifications, the AACC's technique no. 8-01 was used to determine the ash, method no. 46-12 for protein, method no. 30-10 for fat, method no. 32-10 for fiber, and method no. 44-11 for moisture. The total carbohydrate content of three melon fruit peel powders and developed biscuits were calculated by difference through adopting the below given formula, as described by Ho et al. (2016).

$$\left[\begin{array}{l}\text{Carbohydrate}\,(\%)\\ \quad = 100\% - \%\left(\text{moisture} + \text{crude protein} + \text{crude fat} + \text{ash}\right)\end{array}\right].$$

2.8 Minerals analysis of melon peel powders and developed biscuits

Mineral analyses were completed after wet digestion of 2 g of each peel powder and different biscuits formulations, using a 9:2:1 mixture of nitric, perchloric, and sulfuric acid, by following the procedure given by Sadiq et al. (2022), with slight modifications. While potassium (K) was examined using a Corning 400 Flame photometer, magnesium (Mg) and calcium (Ca) were evaluated using the EDTA method. Atomic Absorption Spectroscopy (AAS) was used to measure iron (Fe) and zinc (Zn) using a conventional air-acetylene flame (AOAC, 1990; AOAC, 2005). The analysis was done in triplicates and the results were given as mean, the standard deviation (SD), and dry weight (DW).

2.9 Total phenolic content of peel powders, and developed biscuits

The Folin–Ciocalteu colorimetric method, as described by Hussain et al. (2021), was used to determine the TPC of the fruit peel samples and developed biscuits. In a nutshell, 20 ml of sample were combined with 1.57 ml of water, 100 ml of Folin–Ciocalteu reagent, and 300 ml of 7% Na_2CO_3 were added to the mixture after 6 to 8 min. For 2 h, the mixes were maintained at room temperature in the dark. UV–VIS spectrophotometer (4,001/4, ThermoFisher Scientific, USA) was then used to measure the absorbance at 765 nm. The results are presented as mg GAE/100 g of the dry weight of the peel.

2.10 Total flavonoid content of peel powders, and developed biscuits

Ethanolic extracts were used to determine the TFC present in melon fruit peels and biscuits containing different levels of these peel powders, through colorimetric assay by following the guidelines from the procedure adopted by Hussain et al. (2021). Briefly, 0.5 mL aliquots of the diluted solution were obtained and placed in 15 mL polypropylene conical tubes together with 2 mL of double distilled water and 0.15 mL of 5% $NaNO_2$. After 15 min, 1 mL of 1 M NaOH was added. After well blending, the reaction solution was held for a further 15 min. TFC was calculated using the quercetin standard curve and represented as mg QE/100 g of dry weight using a VIS spectrophotometer (UV-1900i, Shimadzu, Japan) detecting absorbance at 510 nm in triplicate.

2.11 Total antioxidant activity of peel powders, and developed biscuits

According to the methodology adopted by Aryal et al. (2019), with certain adjustments, the total antioxidant activity (TAA) of melon peels powders and developed biscuits samples, was assessed using the DPPH method. Based on an estimation of the stable 1,1-diphenyl-2-picrylhydrazyl radicals' ability to scavenge free radicals, the antioxidant capacity of the samples was assessed. By detecting the drop in absorbance at 517 nm, the DPPH scavenging ability was assessed spectrophotometrically using a spectrophotometer (Biochrom, Libra S22, and England). Each reaction was performed in triplicate to find out the means values of TAA, which were presented as mg Trolox equivalent/100 g dry weight.

2.12 Sensory evaluation of the developed products

The developed products were evaluated sensory-wise using a nine-point hedonic scale, as was found in the experiments of Ashoka et al. (2021). Briefly, a panel of 65 semi-trained participants (35 males and 30 females), who were familiar with the qualities of baked goods, rated the sensory quality features of different treatments. The training was conducted in compliance with ISO International Standards ISO 8586:2023 (ISO, 2023) for the product-oriented sensory panel. Using a questionnaire, the same institute's 65 interested staff members in good health were first chosen. Subsequently, they underwent a battery of screening tests, including the basic flavor identification exam, the scent descriptive test, the matching test, the texture descriptive test, the taste intensity ranking test, and the color intensity ranking test. Further, explaining in detail, the samples were given codes before serving to the evaluators, which were then served to the semi-trained panel members under standard laboratory conditions of temperature and relative humidity, while the distilled water bottles were also provided for rinsing purposes in between testing. The products were rated on a 9-point hedonic scale (1–9, lowest and highest approval, respectively) for their color, texture, flavor, taste, and overall acceptability. Obtained results were taken as means along with standard deviations.

2.13 Statistical analyses of the obtained results

The tests for each analysis were performed in triplicate to find out the three values, which were then presented as means and standard deviations. The statistical analysis was conducted using the one-way ANOVA approach, through SPSS 8 Statistics, by IBM, Chicago, USA. Using Duncan's multiple-range test, the mean values were separated with a level of significance as $p < 0.05$. For statistical analysis, guidelines from Steel et al. (1997) were used, for bivariate Pearson correlation (BPC) with a significance level of $p < 0.01$ and for the Principal Component Analysis (PCA).

3 Results and discussion

3.1 Proximate composition of selected fruits peels powders

As presented in Table 1, muskmelon peel powder exhibited the highest contents of fiber, ash, protein, and fat whereas in watermelon peel powder, the moisture and carbohydrate content were found highest. From this comparative analysis of three melon peels, it was observed that peels of all melons are good source of ash, fiber, and carbohydrate content. Some amounts of fat and protein are also present in the peels, which are normally considered as waste streams. Fruits of Cucurbitaceae family are good sources of ash, fat, fiber and carbohydrate contents, and different parts of these fruits contain varying contents of phytochemicals (Bai et al., 2020). Hasanin and Hashem (2020) reported that watermelon peel waste contains high value of nutrients. The result of proximate composition of these three melon fruit peels were in line with the earlier findings of the Abdulaali and George (2020). While comparing the chemical composition of two melon peels, Al-Sayed and Ahmed (2013) reported that watermelon rinds had values of moisture, ash, fat, protein, and carbohydrates as 10.61, 13.09, 2.44, 11.17, and 56.00%, respectively. The chemical composition of the watermelon peel powder determined in current experiments was found in line with those given by Ashoka et al. (2021), with a slightly higher levels of protein, ash and fiber. A similar composition of watermelon rind flour was also provided by Gbaa et al. (2019), reporting that differences in cultivar., specie, cultivation conditions and maturity stage affect the chemical composition of the fruits and their peels. Sadiq et al. (2022) also reported higher ash and fiber contents in peel of watermelon, as compared to flesh and seeds. Comparatively high contents of ash, fat, fiber, protein, and carbohydrates in the peel of watermelon were reported by Ho et al. (2016), possibly due to the difference in the cultivar or agroclimatic conditions. The presence of ash, fat, fiber, protein, and carbohydrates in melon peel powders was also reported by Mallek-Ayadi et al. (2017), providing comparatively high values of moisture, fat, protein, and carbohydrates, as compared to the current findings.

The proximate composition of the peels of seven tropical fruits was examined by Morais et al. (2017), who discovered that the melon and watermelon peels had high ash contents, along with the widest range of minerals. In dry weight of watermelon peel, Feizy et al. (2020) measured crude fat (0.92 g/100 g), crude fiber (24.00 g/100 g), and protein (6.77 g/100 g), and these results supported the presence of fiber, protein, and fat contents in watermelon peel powder, as was reported in our study. Different watermelon types investigated may have produced different results for various physicochemical attributes. Along with being a source of amino acids, protein also affects the organoleptic qualities of food. Fruit has a low crude protein value since they are not good sources of protein, but the presence of protein in peels of melons even in small amounts was a positive indication of current investigations. Current results were also in line with the findings of Chaudhary et al. (2021), when they discovered that the reducing sugar levels in a watermelon peel sample were 25.80 g/L, the total amount of carbs was 92.90 g/L, the total amount of lipids was 3.40 g/L, and the total amount of protein was 3.90 g/L. Watermelon fruit peel waste could prove a good source of nutritional components, according to Rahim et al. (2022). The watermelon peel had the highest moisture, ash, and fiber concentrations of the three different fruit peels.

Manchali and Murthy (2020) reported the main components of muskmelon, which were fiber, minerals, vitamins, carbs, and lipids. Muskmelon offers a good amount of energy, protein, and low fat, which is typically recommended for a calorie-restricted diet, just like any other member of the cucurbit family. Shahidan et al. (2022) found, in comparison to the flesh and seed, the muskmelon peel had the highest carbohydrate content (67.48%), and appreciable amounts of fiber, ash, and other bioactives. According to Sangamithra and Ragavi (2019), the chemical composition of the muskmelon fruit peel is more affected by the fruit's ripeness when it is harvested. As the fruit is full of the beneficial nutrients and therapeutic qualities, its peel is also a good source of ash, fiber, and minerals.

3.2 Minerals composition of selected peel powders

Table 2 lists the minerals that make up the three peel powders that were chosen; canary melon, watermelon, and muskmelon. Iron, calcium, potassium, magnesium, and zinc contents were all evaluated as part of the analysis. With substantially greater levels of magnesium (233 ± 1.10 mg/100 g), calcium (364 ± 2.19 mg/100 g), potassium (1,605 ± 3.30 mg/100 g), iron (49.72 ± 0.08 mg/100 g), and zinc (2.39 ± 0.05 mg/100 g) than the other two peel powders, muskmelon peel powder had the highest mineral content. The remarkable mineral concentration of muskmelon peel powder points to the possibility of it serving as a rich source of important minerals. Canary melon peel powder also provided significant mineral contributions although it was significantly less than muskmelon peel powder. Watermelon melon peel powder had the lowest mineral concentration among the three peel powders, except Fe. Watermelon peel powders nevertheless contribute nutritious value to food compositions despite having a reduced mineral concentration.

Genetic variations, environmental factors, and developmental stages may be responsible for the variability in mineral concentration among

TABLE 1 Proximate composition of selected fruits peels powders.

Peels powders	Proximate composition (%)					
	Moisture	Ash	Fat	Fiber	Protein	Carbohydrates
Canary melon peel	7.15 ± 0.05b	7.04 ± 0.05b	0.99 ± 0.01b	8.73 ± 0.02b	4.78 ± 0.05b	62.48 ± 0.03b
Watermelon peel	8.06 ± 0.07a	6.12 ± 0.03c	0.62 ± 0.02c	7.59 ± 0.06c	4.07 ± 0.02c	65.95 ± 0.05a
Muskmelon peel	6.82 ± 0.04c	8.36 ± 0.06a	1.21 ± 0.05a	12.06 ± 0.09a	5.02 ± 0.04a	54.47 ± 0.02c

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 3$) ± SD.

TABLE 2 Minerals composition of selected peel powders.

Peels powders	Mineral elements (mg/100 g)				
	Mg	Ca	K	Fe	Zn
Canary melon peel	192 ± 0.20b	351 ± 0.90b	1,490 ± 1.30b	41.50 ± 0.03c	1.86 ± 0.04b
Watermelon peel	173 ± 0.60c	320 ± 0.13c	1,414 ± 1.11c	46.20 ± 0.04b	1.12 ± 0.02c
Muskmelon peel	233 ± 1.10a	364 ± 2.19a	1,605 ± 3.30a	49.72 ± 0.08a	2.39 ± 0.05a

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 3$) ± SD.

TABLE 3 Analysis of the total phenolic contents (TPC) total flavonoid contents (TFC) and total antioxidant activity (TAA) of the dried peels extracts.

Peels extracts	Polyphenols assessment		
	TPC (mg GAE/100 g)	TFC (mg QE/100 g)	TAA (mg Trolox equivalent/100 g)
Canary melon peel	98.69 ± 0.14c	35.17 ± 0.09c	30.92 ± 0.04c
Watermelon peel	145.39 ± 0.06b	63.98 ± 0.03b	44.34 ± 0.07b
Muskmelon peel	167.49 ± 0.04a	79.16 ± 0.05a	56.92 ± 0.05a

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 3$) ± SD. TPC, total phenolic contents; TFC, total flavonoid contents; TAA, total antioxidant activity; GAE, gallic acid equivalent; QE, quercetin equivalent.

the peel powders. These elements have an impact on the distribution and accumulation of minerals in fruit peels (Kyriacou et al., 2018). Nutritional advantages are provided by the high mineral content, especially in muskmelon and watermelon peel powders. The minerals magnesium, calcium, potassium, iron, and zinc are necessary for a variety of physiological activities, such as enzyme activation, muscular contraction, bone health, and immune system control. These peel powders could offer a convenient and natural solution to increase mineral intake in culinary preparations. Their inclusion in food compositions can significantly enhance the final goods' overall nutritional profile and mineral makeup (Rahim et al., 2022; Silva et al., 2020; Tikent et al., 2023). The mineral composition of the peels of seven tropical fruits was examined by Morais et al. (2017), who discovered that the canary melon and watermelon peels had the widest range of mineral contents and the highest concentrations of calcium and potassium. The presence of high amounts of important minerals in melon peel was also strongly confirmed by Mallek-Ayadi et al. (2017), validating the present findings regarding the mineral composition of canary melon peel powder. The findings of Fundo et al. (2018) also confirmed the presence of macro and micro minerals in significantly high amounts in muskmelon peels.

Manchali and Murthy (2020) reported muskmelon to be a good source of essential minerals, which could be found in different quantities in different parts of the fruits. In another similar study, providing in-line results, Silva et al. (2020) reported that the peel of *Cucumis melo* contains more calcium and magnesium than the peels of an avocado, pineapple, and banana. Investigations of Ashoka et al. (2021) were found in line for the mineral contents found in the watermelon peel flour. According to the data provided by Sadiq et al. (2022), watermelon peels are a rich source of minerals like Mg, Ca, K, P, Fe, and Zn. Rahim et al. (2022), when examining the mineral content of banana, orange, and watermelon peels, reported that the latter has the highest concentrations of Zn, Na, K, and P, validating the current study outcomes. Feizy et al. (2020) presented a study to assess the chemical composition of watermelon peel, which included minerals to be abundant. Their findings revealed that watermelon peels include sodium (53.59 mg/100 g), potassium (2,074 mg/100 g), calcium (468 mg/100 g), copper (0.59 mg/100 g), iron (12.08 mg/100 g), magnesium (164.48 mg/100 g), zinc (0.91 mg/100 g), and phosphorus (107 mg/100 g). Peels of all studied melons could prove to be a good source of minerals in food formulations developed through the incorporation of powdered peels.

3.3 Total phenolic contents, total flavonoid contents, and total antioxidant activity of the dried peels extracts

Data provided in Table 3 presents the differences in the amounts of TPC, TFC, and TAA of three melon peels. Muskmelon peel presented the highest values of TPC, TFC, and TAA, followed by watermelon peel, whereas canary melon peel presented the lowest values. The antioxidant properties of plant materials are assumed to be caused by phenolic compounds and ascorbic acid found in plants, which are able to scavenge free radicals. These compounds can lower the concentration of free or singlet oxygen, provide free radicals with one atom of hydrogen, induce the quenching of free radicals, and obstruct the removal of hydrogen thus retarding the oxidation process (Martemucci et al., 2022). When organic solvents and water are combined, both hydrophilic and lipophilic molecules become soluble in the mixture, increasing the extraction's efficiency (Singh et al., 2016).

Singh et al. (2016) compared peel and flesh portions of four melon varieties, i.e., watermelon, muskmelon, ash gourd, and pumpkin and findings revealed that peel of muskmelon exhibited higher phenolic and flavonoid contents than pulp, validating the results of the current study that peels of all melons have a high range of phytochemicals, capable of rich medicinal properties. They concluded that many of the chemicals in melon fruits have antioxidant effects. According to Manchali and Murthy (2020) muskmelon peels have high contents of phenolics, flavonoids, and carotenoids, the agents responsible for the high antioxidant properties of this fruit. Muskmelon peel, according to Shahidan et al. (2022), has the potential to be employed as a novel source of natural antioxidants for food and nutraceutical items because it contains the highest number of phenolic acids compared to the seed and flesh.

Al-Sayed and Ahmed (2013) compared phytochemicals present in the rinds of two melon peels and provided results are in line with current ones, confirming the higher contents of phenolics in watermelon rind, as compared to the melon rind. Further antioxidant activity of watermelon rind was also higher than melon rind, and vanillin, coumaric acid, chlorogenic acid, and 4-hydroxybenzoic acid were the main phenolic acids in these fruits' peels. There were 2473.45 mg of gallic acid equivalent/100 g of total phenolic components calculated in watermelon peel extracts by Feizy et al. (2020). Further, these authors conducted several chain reactions to examine the antioxidant capacities of watermelon seed and peel extracts, such as the total antioxidant capacity (TAC), reducing power, metal chelating, sequestration of hydroxyl radicals, superoxide, and DPPH tests, and the oxygen reactive antioxidant capacity (ORAC) test. TAC's ascorbic acid equivalent, reducing power, ability to scavenge DPPH activity, and total ORAC value for peel extract were, in that order, 88.7 mg/g, 17.1, 30.1%, and 19.49 (mmol Trolox/100 g). According to Naguib and Tantawy (2019) watermelon peel had 120.83 ± 0.038 g of phenolic compounds per g of dry weight. The hydroethanolic extract's polyphenol concentration was found to be 203.1 ± 7.17 mg GAE/100 g dry extract. These findings contrast with ours due to differences in the analytic method and melon type. Neglo et al. (2021) reported lower TPC in peels of watermelon, when compared with the results of the current study, which might be due to differences in extraction techniques and cultivars used for the study. Melon peel extracts developed by Rolim et al. (2018), in a manner similar to our experiments, and their phenolic and flavonoid compounds, and antioxidant activity were assessed. The varied types of extracts employed, as well as differences in the variety and maturity stage, may explain why the values of phenolic and flavonoid contents and antioxidant activities discovered in their research were much lower than those determined in the current experiments.

3.4 Antimicrobial activities of selected peel extracts against selected bacterial and fungal species

The results of the antimicrobial activity of selected fruit peel extracts against bacterial and fungal strains are shown in Table 4, in comparison to the standard antibacterial and antifungal drugs ampicillin and nystatin, respectively. Ampicillin and nystatin, as commonly used antibiotics, showed the most significant zone of inhibitions against all the tested bacterial and fungal strains, showing their strong antimicrobial properties. Additionally, the antibacterial activities of three extracts from melon peels were found to be similar to those of the reference medication (ampicillin). The results of the antimicrobial activities of selected fruit peel extracts revealed varying levels of effectiveness against the tested fungal and bacterial strains. Among the three fruit peel extracts, the muskmelon peel extract exhibited the highest antimicrobial activities, followed by the watermelon peel extract, while the canary melon peel extract demonstrated the lowest antimicrobial activities. These variations in antimicrobial activities could be attributed to differences in the phytochemical composition of the fruit peels (Kyriacou et al., 2018). Muskmelon and watermelon peels have been reported to contain different bioactive substances such as phenolics, flavonoids, and tannins, which possess antimicrobial properties (Neglo et al., 2021). The investigated bacterial and fungal strains' growth may be inhibited by these substances working individually or together synergistically (Odelade and Oladeji, 2020; Athanasiadis et al., 2023). Ali et al. (2024), using nystatin as reference antifungal drug, showed strong antifungal activities of watermelon peel extracts. On the other hand, the relatively weaker antimicrobial activity of the canary melon peel extract could be attributed to its lower concentration of antimicrobial compounds (phenolics and flavonoids) compared to the other fruit peels, as can be seen from Table 3. Additionally, variations in the phytochemical composition among different melon varieties might also contribute to the differences in antimicrobial activities (Kyriacou et al., 2018), which could also be verified from the results of Table 3. The scientific study conducted by Neglo et al. (2021) provided in line findings on the antibacterial properties of watermelon extracts derived from the peel, pulp and seeds. The peel extracts, as also showed in the present study, exhibited a more pronounced zone of inhibition against all bacterial species compared to the extracts from the seeds and pulp. When comparing the antimicrobial potential of different fruits peel extracts Singh et al. (2016) also provided supportive results for the current findings as muskmelon peel extracts, among other fruits peels, exhibited significantly higher zone of inhibitions against all bacterial and fungal species. The study provides evidence that fruit peel extracts possess antimicrobial characteristics, indicating their potential as natural sources of antibacterial compounds. Integrating these extracts into food products or creating topical treatments could provide alternate methods for managing and preserving such food products. Additional investigation is required to locate and isolate the precise bioactive components responsible for the observed antimicrobial

TABLE 4 Antimicrobial activities of selected fruits peels extracts against selected bacterial and fungal species.

Peels extracts	Antimicrobial activities (Zone of inhibition mm)					
	Bacterial strains			Fungal strains		
	Bacillus cereus	*Escherichia coli*	*Streptococcus aureus*	*Candida albicans*	*Aspergillus niger*	*Mucor meihi*
Canary melon peel	9.07 ± 0.05d	7.05 ± 0.05d	10.06 ± 0.02d	5.05 ± 0.01d	4.09 ± 0.02d	6.04 ± 0.05c
Watermelon peel	10.07 ± 0.02c	8.02 ± 0.03c	16.03 ± 0.04c	7.08 ± 0.01c	5.06 ± 0.02c	5.09 ± 0.02d
Muskmelon peel	12.03 ± 0.03b	10.02 ± 0.04b	18.08 ± 0.06b	8.09 ± 0.02b	7.06 ± 0.03b	7.02 ± 0.01b
Ampicillin (Antibacterial reference drug)	19.04 ± 0.07a	17.05 ± 0.02a	20.05 ± 0.06a	-	-	-
Nystatin (Antifungal reference drug)	-	-	-	16.01 ± 0.02a	15.06 ± 0.05a	14.06 ± 0.04a

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 3$) ± SD.

activities in fruit peels. Additionally, exploring the mechanism of action and conducting *in vivo* studies would provide a better understanding of their possible uses in the pharmaceutical and food industries.

3.5 Proximate composition of developed product

Table 5 presents the outcome of the proximate analysis of the biscuits fortified with different melon peel powders at 5 and 10% incorporation levels, compared to the control biscuits that were developed without any peel powder. The control biscuits exhibited a moisture content of 8.15 ± 0.05%, which was significantly lower than the biscuits fortified with melon peel powders. The incorporation of 5% peel powder resulted in an increased moisture content of 9.67 ± 0.04% for canary melon peel powder biscuits, while the 10% incorporation level further increased it to 10.11 ± 0.07%. These findings suggest that the addition of melon peel powders influenced the moisture retention of the biscuits, potentially contributing to improved texture and shelf stability (Fradinho et al., 2015). The ash content, which contributes to the mineral content of the biscuits, was found to be significantly higher in the biscuits fortified with melon peel powders, compared to the control. The highest ash content was found in biscuits fortified with 10% muskmelon peel 5.86 ± 0.03%. Overall results indicate that the ash content of the biscuits was significantly influenced by the type and level of melon peel powder incorporated. The fat content of the biscuits ranged from 23.95 ± 0.07% in the control biscuits to 24.88 ± 0.90% in biscuits fortified with 10% muskmelon peel powder. There was a slight but statistically significant rise in the fat contents, observed in the biscuits fortified with melon peel powders, especially at the higher incorporation level.

Fiber content of the biscuits was significantly subjective by the adding up of melon peel powders. The control biscuits contained 0.52 ± 0.04% fiber, while the biscuits fortified with 10% canary melon peel had 4.82 ± 0.02%. The highest fiber content (6.69 ± 0.06%) were present in biscuits developed with 10% muskmelon peel powder. These results indicate that the addition of all melon peel powders significantly enhanced the fiber content of the biscuits, which is beneficial for promoting digestive health. The protein content of the biscuits ranged from 6.02 ± 0.03% in biscuits fortified with 5% watermelon peel powder to 7.25 ± 0.04% in the control biscuits. The differences in protein content were statistically significant, suggesting that the addition of melon peel powders had a significant impact on the protein content of the biscuits, as it was decreased. All types of biscuits made with three different melon peel powder substitution (5 and 10% levels) had a significantly ($p < 0.05$) greater carbohydrate content than the control, with watermelon peel powder incorporated biscuits showing the highest values. Similar findings were found by Ho and Che Dahri (2016) and Al-Sayed and Ahmed (2013) when watermelon peel powder was integrated into noodles and cakes, respectively, and the results showed a higher fiber and carbohydrate content than the control.

Consumers who are concerned about their health seek food items that are low in sugar and fat, while high in fiber and ash, thus contributing fewer calories. Proximate analysis of the biscuits fortified with melon peel powders revealed alterations in their nutritional composition compared to the control biscuits. Mai et al. (2022) reported that cookies supplemented with watermelon peel flour would enhance the nutritional status of consumers. Similar findings were also found in the results of Gbaa et al. (2019), when an improved chemical profile of watermelon rind-added mumu was observed. The incorporation of melon peel powders led to increased moisture content, which could be attributed to the hygroscopic nature of the peel powders. This moisture retention property could contribute to improved texture and extended shelf life of the biscuits. The higher ash content in melon peel powder biscuits indicates an increased mineral content, which could be beneficial for consumers, as minerals play essential roles in various physiological processes. Krajewska and Dziki (2023) incorporated melon peel, with a significant difference between the use of 5, 10, and 15% in the product, the increase in ash concentration was particularly noticeable during this experiment. The variation in ash content among the different melon varieties suggests that the mineral composition of the peels differs, potentially providing diverse nutritional benefits.

The slight increase in fat content in the biscuits fortified with melon peel powders suggests a minor contribution from the peel powders. However, it's crucial to understand that the overall fat content remained within an acceptable range. In an experiment, Gómez-García et al. (2022) found that melon peels flour positively impacted the gut microbiota diversity and promoted the production of short-chain fatty acids. Thus, the slightly increased fat content of biscuits incorporated with melon peel flour could be considered health promoting in the present study. The significant increase in

TABLE 5 Proximate composition of developed product.

Treatments plan	Incorporation levels	Proximate composition (%)					
		Moisture	Ash	Fat	Fiber	Protein	Carbohydrates
Control	0%	8.15 ± 0.05f	0.94 ± 0.02f	23.95 ± 0.07e	0.52 ± 0.04 g	7.25 ± 0.04a	40.29 ± 0.02 g
Canary melon peel powder	5%	9.67 ± 0.04d	3.85 ± 0.02d	24.37 ± 0.70c	3.89 ± 0.06d	6.49 ± 0.02d	44.38 ± 0.04f
	10%	10.11 ± 0.07c	4.75 ± 0.04c	24.69 ± 0.80b	4.82 ± 0.02c	6.75 ± 0.06c	46.30 ± 0.04e
Watermelon peel powder	5%	10.48 ± 0.02b	2.98 ± 0.07e	23.98 ± 0.50d	3.05 ± 0.08f	6.02 ± 0.03f	56.54 ± 0.05b
	10%	10.79 ± 0.03a	3.80 ± 0.02d	24.01 ± 0.80d	3.62 ± 0.05e	6.25 ± 0.05e	57.15 ± 0.06a
Muskmelon peel powder	5%	8.78 ± 0.03e	5.05 ± 0.02b	24.71 ± 1.05b	5.86 ± 0.05b	6.79 ± 0.04c	54.67 ± 0.02d
	10%	9.60 ± 0.02d	5.86 ± 0.03a	24.88 ± 0.90a	6.69 ± 0.06a	6.98 ± 0.05b	55.68 ± 0.05c

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 3$) ± SD.

dietary fiber content in melon peel powder biscuits highlights the potential of these biscuits as a source of dietary fiber, which is known for its beneficial effects on digestive health and satiety. The fiber content varied depending on the melon variety and incorporation level, indicating that the peel composition influenced the dietary fiber content of the biscuits. Hema Prabha et al. (2021) worked on making dietary chips from watermelon peel that were fortified with composite flour and reported that the protein content of the resulting chips was significantly high. However, in present study the protein content of the biscuits remained relatively consistent, indicating that the addition of melon peel powders did not substantially affect the protein content of the final product, as wheat flour itself is good source of protein as compared to the protein contents of melon peel flours (Table 1). Developed nutritional meat product by Freitas et al. (2020), through the incorporation of peel flour from pumpkin, was found high in ash, fiber and important minerals, which also strengthened current findings. Results in line with the current ones were also found when Saleh and Ali (2020) developed nutritional biscuits using relatively higher levels of pumpkin peel powder and observed increments in ash and fiber contents of the developed biscuits. The alterations in the biscuits made with melon, watermelon, and muskmelon peel flour suggest possible nutritional improvements, especially in terms of enhanced dietary fiber and mineral content.

3.6 Minerals analysis of the developed product

Melon peels have high mineral content compared to other portions of the fruit, with high levels of calcium, magnesium, and potassium (Ertaş and Aslan, 2020). Table 6 displays the findings for the mineral content of the biscuits developed with different levels of three melon peel powders. Minerals like Ca and Mg, which affect the bones' structural makeup; K, which affects blood pressure; Fe, which is a component of hemoglobin and myoglobin; and Zn, which affects how carbs, fats, and proteins are metabolized, all have significant positive effects on health (Chakrabarty et al., 2019; Ali, 2023). Compared to the control biscuits sample, the addition of melon peel powder increased the values for Ca, Mg, K, Zn, and Fe. This is because all three types of melon peel powders are found to be good source of minerals (Table 2). According to Ertaş and Aslan (2020) the melon peel powder has 25 times as much calcium, 10 times as much magnesium, 6.8 times as much potassium, and 2.35 times as much iron as wheat flour. Among the three types of melon fruits, muskmelon peel flour has the highest mineral value followed by canary melon and watermelon (Table 2). And same was the case with the biscuits. Biscuits made from muskmelon peel flour have minerals in higher amounts than biscuits made from canary melon peel flour and watermelon peel flour. The incorporation of melon peel powders in biscuit formulations offers a valuable opportunity to enhance the mineral composition of the final product.

These findings for mineral contents of different melon peels fortified biscuits were in line with those given by Ashoka et al. (2021), when they determined the mineral composition of biscuits in which different levels of watermelon peel flour were added, and minerals in all these biscuits were significantly higher than found in the biscuits developed with 100% wheat flour. Hussain (2023) determined Zn and Fe contents in 100% wheat flour biscuits and reported values not much different from those of control biscuits in the present study. Bhol et al. (2016) investigated the effect of pomegranate whole fruit bagasse powder on the mineral contents of the bread. An increase in the mineral contents (calcium, copper, iron, potassium, magnesium, phosphorus, and zinc) was observed for the 15% substitution level of pomegranate whole fruit bagasse powder in bread. High ash contents in non-wheat flours, especially that of peels and pomaces from fruits, vegetables and plants have been found positively related to the high content of minerals in incorporated products. Melon peel can be regarded as an excellent option for the development of innovative functional foods because it is a strong source of minerals and phenolic compounds, according to Silva et al. (2020). This will help to enhance sustainability throughout the food chain. In conclusion, the addition of melon peel powders significantly increased the trace element composition, including Mg, Ca, K, Fe, and Zn, in the developed biscuits. These findings support the utilization of melon peels as a valuable ingredient for enhancing the mineral content of food products and promoting their nutritional value.

3.7 Total phenolic contents, total flavonoid contents, and total antioxidant activity of developed products

Table 7 presents the results of the analysis of total phenolic contents (TPC), total flavonoid contents (TFC) and total antioxidant activity (TAA) of the developed products fortified with different melon peel powders at 5, and 10% incorporation levels, compared to the control biscuits. The TPC for the control biscuits was 5.79 ± 0.04 mg GAE/100 g, TFC 2.98 ± 0.03 mg QE/100 g, and TAA 2.73 ± 0.05 mg of Trolox equivalents (TE) per 100 g. When compared to the control biscuits, the formulated biscuits' TPC, TFC, and TAA significantly increased as a result of the addition of melon peel powders. Biscuits fortified with 10% muskmelon exhibited the highest TPC of 33.71 ± 0.10 mg GAE per 100 g, and these results can be justified by the highest TPC of muskmelon peel powder (Table 3). The overall results indicate that the addition of melon peel powders significantly enhanced the phenolic content of the biscuits. Similarly, the TFC of the biscuits fortified with melon peel powders significantly increased as compared to the control. Biscuits fortified with 5% canary melon peel powder exhibited TFC values of 5.26 ± 0.02 mg QE per 100 g. At the 10% incorporation level, the TFC further increased to 6.62 ± 0.03 mg QE per 100 g. On the other hand, the highest recorded value of TFC was 12.18 ± 0.02 mg QE per 100 g, in biscuits developed with 10% muskmelon peel powder, possibly due to the high TFC contents in the muskmelon peel powder as shown in Table 3. Zhang et al. (2021) detected different phenolics and flavonoids in melon peels, which validates the increase of phenolics and flavonoids in the biscuits developed with higher proportions of melon peel powder. Providing results just in line with the current ones, an increment in TPC of cakes and noodles fortified with watermelon peel powder was also reported by Awad (2017) and Ho and Che Dahri (2016), respectively.

The antioxidant activity of the biscuits, as indicated by the TAA, also increased with the incorporation of melon peel powders. Biscuits fortified with 10% muskmelon gave the highest antioxidant activity of 24.62 ± 0.15 mg TE per 100 g, as among the three peel powders the muskmelon peel powder exhibited the highest TAA

TABLE 6 Minerals analysis in developed product.

Treatments plan	Incorporation levels	Mineral composition (mg/100 g) in developed product				
		Mg	Ca	K	Fe	Zn
Control	0%	23.87 ± 0.06 g	27.36 ± 0.05 g	55.29 ± 0.06 g	1.89 ± 0.02 g	1.02 ± 0.01 g
Canary melon peel powder	5%	36.35 ± 0.02d	42.52 ± 0.15d	83.35 ± 0.20d	4.07 ± 0.03f	1.52 ± 0.03d
	10%	40.05 ± 0.03c	47.34 ± 0.20c	94.68 ± 0.50b	4.50 ± 0.04e	1.78 ± 0.04c
Watermelon peel powder	5%	28.97 ± 0.08e	31.89 ± 0.13f	70.82 ± 0.50f	5.14 ± 0.06d	1.29 ± 0.02f
	10%	25.41 ± 0.07f	36.39 ± 0.14e	77.19 ± 0.60e	5.62 ± 0.08c	1.40 ± 0.02e
Muskmelon peel powder	5%	45.30 ± 0.12b	48.73 ± 0.16b	84.60 ± 0.50c	5.84 ± 0.10b	2.01 ± 0.02b
	10%	49.18 ± 0.20a	54.79 ± 0.10a	103.43 ± 0.30a	6.48 ± 0.06a	2.15 ± 0.03a

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 3$) ± SD.

TABLE 7 Analysis of the total phenolic contents, total flavonoid contents, and antioxidant activity of developed products.

Treatments plan	Incorporation levels	Polyphenols assessment in developed product		
		TPC (mg GAE/100 g)	TFC (mg QE/100 g)	TAA (mg Trolox equivalent/100 g)
Control	0%	5.79 ± 0.04 g	2.98 ± 0.03 g	2.73 ± 0.05 g
Canary melon peel powder	5%	16.59 ± 0.06f	5.26 ± 0.02f	13.49 ± 0.07f
	10%	19.93 ± 0.30e	6.62 ± 0.03e	15.21 ± 0.08e
Watermelon peel powder	5%	22.52 ± 0.07d	8.92 ± 0.03d	19.04 ± 0.10d
	10%	27.48 ± 0.30c	10.03 ± 0.04c	21.51 ± 0.16c
Muskmelon peel powder	5%	28.14 ± 0.80b	10.73 ± 0.05b	22.70 ± 0.12b
	10%	33.71 ± 0.10a	12.18 ± 0.02a	24.62 ± 0.15a

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 3$) ± SD. TPC, total phenolic contents; TFC, total flavonoid contents; TAA, total antioxidant activity; GAE, gallic acid equivalent; QE, quercetin equivalent.

(Table 3). The overall results indicate that the addition of melon peel powders significantly enhanced the antioxidant activity of the biscuits. Bakery products developed with 100% straight grade wheat flour normally lack high concentrations of phytochemicals, thus limiting their use as antioxidant sources. An increase in the TPC, TFC, and antioxidant activity of breads fortified with watermelon peel powder was also witnessed by Pires et al. (2023), validating the current results. Hussain et al. (2021) performed the phytochemical analysis of different formulations of biscuits and determined their TPC, TFC, and DPPH free radical scavenging activities, the results for control biscuits were very much similar to the findings of current research work. Peels of melon and watermelon have loads of high levels of bioactive compounds, which can be recovered through different technologies to develop valuable multipurpose food products (Rico et al., 2020). Melon fruit demonstrated to have sufficient polyphenols in its different parts (Gómez-García et al., 2020). The higher TPC, TFC, and TAA in the biscuits fortified with melon peel powders indicate their potential as a source of antioxidants. Providing results in line with current ones, Mai et al. (2022) reported increased antioxidant activity and phenolic contents in biscuits developed with 10% watermelon peel powder. Ganji et al. (2019) reported that melon has the highest level of antioxidant activity in its peel, which means that peels of melon fruits of different varieties could possess sufficient amounts of natural antioxidant compounds. The observed increase in TPC, TFC, and TAA in the biscuits fortified with melon peel powders can be attributed to the peels' inclusion of bioactive substances such as phenolics and flavonoids.

3.8 Pearson correlation coefficient between total antioxidant activity and phenolic composition (TPC and TFC)

According to Pallant (2020), the results obtained for the biscuit control show that there is a moderate correlation (0.590) between the TPC and TFC. There is a weak negative correlation between TPC and TAA (−0.131), whereas the correlation between TFC and TAA shows a strong negative trend (−0.877). These results demonstrate the weak interference of TPC active compounds; especially TFC in TAA (Table 8). As for various other types of biscuits, we found that TPC and TFC are highly positively correlated in 10% muskmelon peel powder (0.980) and 10% watermelon peel powder with 0.828. Whereas TPC and TFC are highly negatively correlated in 5% watermelon peel powder (−0.785), 10% canary melon peel powder (−0.761) and 5% muskmelon peel powder (−0.621). The correlation between the bioactive compounds was very weak in 5% canary melon peel powder (−0.189). We discovered a very substantial correlation between TPC and TAA in 10% canary melon peel powder (1). Watermelon peel powder (10%; correlation coefficient 0.999), canary melon peel powder (5%; 0.774), and muskmelon peel powder (5%; correlation coefficient 0.683) came next. However, the correlation between TPC and TAA is very poor (or nonexistent) in muskmelon peel powder (10%; −0.541), and particularly in watermelon peel powder (5%; −0.892). In terms of TFC intervention in TAA, watermelon peel powder 5 and 10% exhibited a significant positive connection (0.980 and 0.854, respectively), while canary melon peel powder (5%) showed a medium correlation (0.475) and muskmelon peel powder (5%) had a moderate association (0.149). The TFC intervention in TAA was extremely negative (non-existent) for 10% canary melon peel powder and 10% muskmelon peel powder (−0.756 and −0.699, respectively; Table 8). To summarize, if we want to boost the TAA of biscuits by raising TPC and TFC, we should include 10% watermelon peel powder as an ingredient. To boost the TAA of biscuits by increasing TPC, we can add canary melon peel powder at 5 and 10% level, as well as muskmelon peel powder at 5% level. However, if we wish to increase the TAA of biscuits by raising their TFC, we can do so by adding 5 and 10% watermelon peel powder. Present results were found in conformance when Chikh-Rouhou et al. (2021) reported a strong correlation between bioactive contents of melons with the antioxidant activity of these fruits, while reporting TFC to have a strong correlation with TAA. In line findings were also reported by Ahmed et al. (2021) when a linear relationship was determined between antioxidant activity values and TPC and TFC of melon fruits, and a strong to moderate correlation between polyphenols and antioxidant activity of these fruits was observed, confirming that RPC and TFC contribute to the TAA of the melons and its by-products.

Principal Component Analysis (PCA), as seen in Figure 2, accounts for 86.259% of the overall variance. Specifically, component 1 explains 43.265% of the variance, while Component 2 explains 42.994%. Component 1 in rotated space exhibits a very high positive correlation with carbohydrate (0.884), moisture (0.880), TAA (0.817), Fe (0.810), TPC (0.783), and TFC (0.765). It also shows a substantial negative correlation with texture (−0.860), color (−0.761), taste (−0.758), overall acceptability (−0.746), protein (−0.739), and finally flavor (−0.623). Component 2 exhibits a very significant positive correlation with Fat (0.991), Mg (0.976), Ca (0.964), Zn (0.956), fiber (0.878), K (0.860), and ash (0.850). The regression analysis (Figure 2) shows that various kinds of biscuits are scattered and separated from the control biscuits. As a result, their components and composition vary in terms of bioactive substances (TPC and TFC), antioxidant activity (TAA), macronutrients (carbohydrates, lipids, fibers, and proteins), and minerals (iron, magnesium, calcium, potassium, zinc, and ash). As a consequence, the sensory properties of these biscuits vary greatly. Protein content influences the sensory evaluation of biscuits positively, while carbohydrate and moisture have a negative effect. The addition of canary watermelon peel powder, particularly 5%, to biscuits increases their nutritional and active content while remaining closest to the control biscuit in terms of sensory qualities. The results clearly revealed the effect of each type and quantity of peel powder added to the biscuit components on nutritional benefits, antioxidant activity, and sensory advantages. These findings were in line with the previous results of Šovljanski et al. (2022), when they performed a principal component analysis of the melon peel extracts and showed the variation and occurrence of several phytochemicals in the peel extracts, which have potent antioxidant and antimicrobial effects.

3.9 Sensory evaluation of developed products

A nine-point hedonic scale was used for sensory evaluation of the produced biscuits, with semi-trained panelists offering scores for color, taste, flavor, texture, and overall acceptability. The control biscuits without any melon peel powder received the maximum scores for all sensory parameters, as has been presented in Table 9. The color was rated as 8.11 ± 0.02, taste as 8.07 ± 0.05, flavor as 7.74 ± 0.04, texture as 7.90 ± 0.03, and overall acceptability as 7.99 ± 0.05. These high scores indicate that the control biscuits were well-received by the panelists and were considered favorable in terms of sensory attributes. Biscuits fortified with 5% canary melon peel powder received slightly lower scores when compare to the control. The color of the 5% canary melon peel powder biscuits was rated as 7.65 ± 0.03, taste as 7.20 ± 0.04, flavor as 7.68 ± 0.02, texture as 7.12 ± 0.05, and overall acceptability as 7.18 ± 0.03. Although these scores were slightly lower than those of the control biscuits, they still indicated a positive level of acceptance from the panelists. At the 10% incorporation level of canary melon peel powder, the sensory scores decreased further. The large amount of polyphenol in fruit peels, which causes their mild bitterness and acidity, may be responsible for this decline in taste value (Ertaş and Aslan, 2020). Higher levels of melon peel powder had a more noticeable impact on sensory attributes, resulting in decreased acceptance compared to the control and 5% incorporation level.

For watermelon peel powder, the 5% incorporation level received scores of 7.52 ± 0.05 for color, 7.06 ± 0.04 for taste, 7.27 ± 0.04 for flavor,

TABLE 8 Pearson coefficient correlation results for phenolic compounds and antioxidant activity.

	Bivariate Pearson correlation coefficient		
	TPC/TFC	TPC/TAA	TFC/TAA
Canary melon peel powder (5%)	−0.189	0.774	0.475
Watermelon peel powder (5%)	−0.785	−0.892	0.980
Muskmelon peel powder (5%)	−0.621	0.683	0.149
Canary melon peel powder (10%)	−0.761	1	−0.756
Watermelon peel powder (10%)	0.828	0.999	0.854
Muskmelon peel powder (10%)	0.980	−0.541	−0.699
Control	0.590	−0.131	−0.877

Pearson correlation analysis with a significance level of $p < 0.01$, Where TPC, total phenolic contents; TFC, total flavonoid contents; TAA, total antioxidant activity.

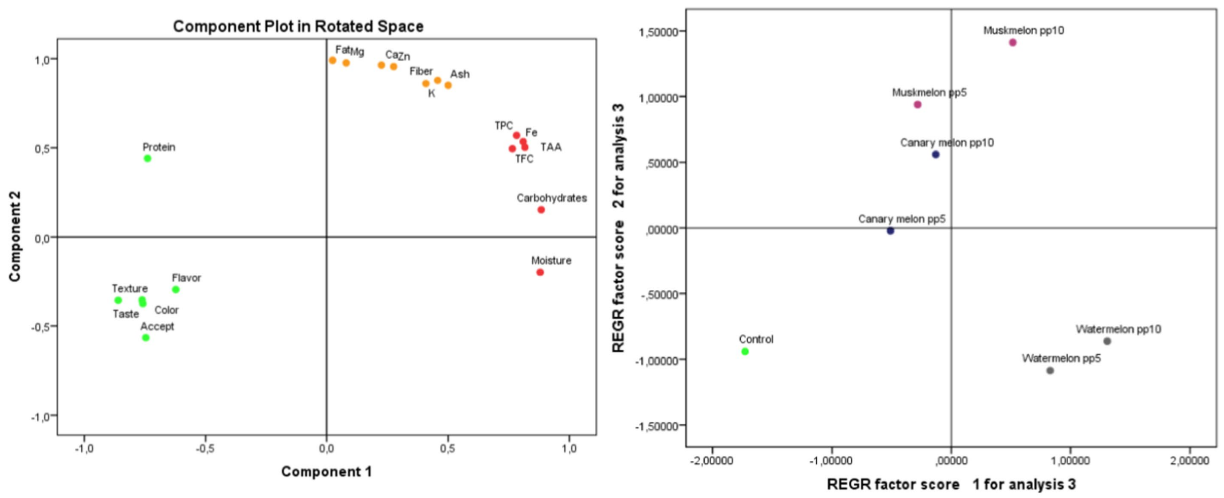

FIGURE 2
Principal component analysis (PCA) based on the different study results (bioactive compounds, antioxidant activities, physicochemical parameters, minerals and sensory evaluation) in the different biscuits. pp: peel powder; 5: 5%; 10: 10%; TPC; total phenolic contents; TFC: total flavonoid contents; TAA: total antioxidant activity; accept: acceptability.

TABLE 9 Sensory evaluation of biscuits.

Treatments plan	Incorporation levels	Sensory parameters				
		Color scores	Taste scores	Flavor scores	Texture scores	Overall acceptability scores
Control	0%	8.11 ± 0.02a	8.07 ± 0.05a	7.74 ± 0.04a	7.90 ± 0.03a	7.99 ± 0.05a
Canary melon peel powder	5%	7.65 ± 0.03b	7.20 ± 0.04c	7.68 ± 0.02a	7.12 ± 0.05b	7.18 ± 0.03b
	10%	6.86 ± 0.03d	6.24 ± 0.05e	7.62 ± 0.11ab	6.75 ± 0.02c	6.57 ± 0.15c
Watermelon peel powder	5%	7.52 ± 0.05c	7.06 ± 0.04d	7.27 ± 0.04c	7.11 ± 0.03b	7.09 ± 0.02b
	10%	6.11 ± 0.03e	6.34 ± 0.06e	7.59 ± 0.03ab	6.30 ± 0.04e	6.60 ± 0.07c
Muskmelon peel powder	5%	7.53 ± 0.03c	7.43 ± 0.03b	7.49 ± 0.03b	7.06 ± 0.03b	7.16 ± 0.04b
	10%	6.14 ± 0.03e	6.27 ± 0.05e	7.26 ± 0.04c	6.54 ± 0.02d	6.10 ± 0.02d

Values in a row or column with similar alphabetic letter are statistically non-significant, whereas with different alphabetic letters are significant ($p < 0.05$), while the data show the means ($n = 65$) ± SD.

7.11 ± 0.03 for texture, and 7.09 ± 0.02 for overall acceptability. These scores indicate that the watermelon peel powder biscuits at 5% incorporation level were generally well-accepted by the panelists, although slightly lower than the control. At the 10% incorporation level of watermelon peel powder, the sensory scores further decreased, which depicted that the higher level of watermelon peel powder negatively affected the sensory attributes and overall acceptability of the biscuits. These results were in line with those of Mai et al. (2022), when acceptable biscuits were developed with different levels of watermelon peel powder. Regarding muskmelon peel powder, the 5% incorporation level received scores of 7.53 ± 0.03 for color, 7.43 ± 0.03 for taste, 7.49 ± 0.03 for flavor, 7.06 ± 0.03 for texture, and 7.16 ± 0.04 for overall acceptability. These scores indicate a positive level of acceptance from the panelists. At the 10% incorporation level of muskmelon peel powder, the sensory scores further decreased, which depicted that the higher level of muskmelon peel powder negatively affected the sensory attributes and overall acceptability of the biscuits (Table 9).

The texture, mouthfeel, flavor, and appearance of an item may be compromised if the proportion of different flours is changed to minimize the calories or to find out other technological advantages (Ho and Che Dahri, 2016). The panelists gave the control biscuits highest scores for color, taste, flavor, texture, and overall acceptability, and at the same time they also gave the biscuits fortified with melon peel powders at 5% incorporation levels higher marks for these sensory parameters. The decrease in sensory scores with higher incorporation levels suggests that there may be a threshold beyond which the presence of melon peel powder starts to negatively affect the sensory attributes of the biscuits. Cookies developed by incorporation of watermelon peel flour were equally liked by the consumers as the control cookies (Olaitan et al., 2017). According to the results of Ashoka et al. (2021), 10% watermelon peel flour was found suitable for developing good quality cakes. This reported high level of watermelon peel flour suitable for cake production was possibly due to the reason that cakes contain higher levels of moisture than biscuits, and higher fiber of watermelon peel flour might have retained more moisture in the cakes.

Abdulaali and George's (2020) research presented positive results about the sensory characteristics of biscuits supplemented with melon peel powder. Specifically, they observed that a 5% fruit peel and pulp content of Cucurbitaceae fruit was appropriate for producing biscuits of acceptable sensory quality. Up to a 4% level of pumpkin peel flour (another fruit of the Cucurbitaceae family), was proven to be a potential ingredient for producing meat products without any negative modifications in the sensory characteristics (Freitas et al., 2020). Saleh and Ali (2020) reported that a further higher level (20%) of pumpkin peel flour also produced good quality biscuits with optimum sensory features. Further, acceptance of biscuits at a higher level of peel flour was possibly due to another member of the same family (pumpkin vegetable) used in that study. Sharaf et al. (2015) added potato peel extract at various concentrations in biscuits and reported that biscuits with 0.5 and 1% potato peel showed acceptable organoleptic properties. The use of orange seed powder in the creation of nutritious biscuits was deemed acceptable, when level of replacement was up to 5%, as reported by Hussain et al. (2023) suggested the enrichment of bakery products from powders of different plant-based materials, as a source of bioactives. During the enrichment of wheat flour with non-wheat flour, compromised sensory features of developed products are obvious, which occur due to interaction among the ingredients such as fat, fiber, protein, and other enzymes, affecting the rheological and baking properties of the dough. To cover these drawbacks, the appropriate selection of the level of replacement of these plant-based powders is very crucial to develop good quality acceptable bakery goods.

4 Conclusion

Melon fruits, including muskmelon, canary melon, and watermelon, are highly valued fruits worldwide due to their exquisite flavor, hydrating properties, and abundance of antioxidants and phytochemicals. However, the disposal of melon by-products, such as peels, as waste presents an opportunity for their valorization and the extraction of bioactive compounds. By incorporating melon fruit peel powders into biscuits, we can add value to the final products. The utilization of melon fruit by-products not only reduces food waste but also promotes sustainability and the development of novel functional foods. Comparing the muskmelon fruit peel to the peels of the other two fruits, the muskmelon fruit peel had the highest mineral content, phenolic content, flavonoid content, and antioxidant activity. Peels from canary melons and watermelons, however, also contained these bioactives. The research therefore showed that these fruit peels are an excellent source of phytochemicals that can be extracted using the right solvent. It was also discovered that followed by ampicillin and nystatin, the muskmelon peel demonstrated the highest antimicrobial activities against both bacterial and fungal strains, respectively. The addition of three melon fruit peel powders to biscuits resulted in positive alterations in their proximate composition, including increased moisture, ash, fat, and dietary fiber content. Furthermore, the biscuits fortified with peel powders showed significantly greater total phenolic, total flavonoid, and antioxidant activity when compared to the control biscuits. Although control biscuits got the highest sensory scores, however, a 5% level of replacement of all three melon peel powders with wheat flour was also found acceptable in terms of sensory acceptability of biscuits. After reviewing the Principal Component Analysis (PCA) and Pearson Correlation coefficient (PCC) findings, we can see that adding 10% of watermelon peel powder to biscuits increases their TAA by increasing TPC and TFC. By raising the TPC, canary melon peel powder (10 or 5%) and muskmelon peel powder (5%) can increase the TAA of the biscuits. Adding watermelon peel powder (5 or 10%) to biscuits increases their TFC, which in turn increases their antioxidant activity. Hence, depending on the type and percentage of peel powder used, there are numerous possibilities for boosting the nutritional quality and antioxidant capacity of biscuits through the use of different melon peel powders. These results suggest that powders from watermelon, muskmelon and canary melon peels, can increase the nutritional content and antioxidant qualities of food products. So, these peels' powders can be used to create food products with significant nutritional value.

5 Recommendations

The peels of different fruits might be regarded as a possible source of numerous antioxidant compounds, which are now not utilized but could have applications in various industrial sectors. Reutilizing fruit peels as a source of antioxidants can lead to measurable economic benefits and contribute to the reduction of environmental pollution caused by the fruit and vegetable industries. It is important to consider both economic (extraction profitability) and environmental (waste management and pollution avoidance) concerns. Various waste products of Cucurbitaceae fruits can be employed as novel ingredients in bakery foods, because of their nutrient-rich composition. To turn waste materials into high-value products, different pharmaceutical foods could be prepared using varying ratios of peel flours, from melon, watermelon, and muskmelon. Incorporating melon peels fosters innovation, and diversification within the food industry while offering possible health advantages to consumers. Additional study is required to explore, and isolate the specific bioactive compounds, through implementing different drying and extraction conditions, and their potential health implications, thus expanding our understanding and utilization of melon peels in various food formulations. Further, work on physical and rheological characteristics of flours from different melon peels, their functional behaviors, and storage stability with microbial studies, is also suggested.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

AH: Conceptualization, Methodology, Writing – original draft. SL: Conceptualization, Methodology, Writing – original draft. AT: Software, Methodology, Conceptualization, Writing – review & editing. KE: Supervision, Validation, Writing – review & editing. MA: Software, Writing – review & editing. SP: Formal analysis, Software, Writing – review & editing. MB: Formal analysis, Writing – review & editing. RM: Funding acquisition, Investigation, Writing – review & editing. ON: Investigation, Writing – review & editing. BE: Validation, Visualization, Writing – review & editing. SY: Resources, Writing – review & editing. HF: Validation, Visualization, Writing – review & editing. NF: Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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