Food & Function

PAPER

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Cite this: *Food Funct.*, 2024, **15**, 1899

Melon peel flour: utilization as a functional ingredient in bakery products

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Received 29th November 2023,
Accepted 9th January 2024

DOI: 10.1039/d3fo05268k

rsc.li/food-function

Food by-products are a major concern with a direct impact on the economy, society, and environment. The valorisation of these by-products could be an advantageous approach to face the increase in food waste since it can compromise environmental health and food sustainability. On the other hand, this valorisation would allow the development of new food products with health benefits for the population. *Cucumis melo* L. is a highly consumed fruit all over the world since it has excellent sensory and nutritional qualities, being also a good source of bioactive compounds. However, its peel and seeds are usually discarded. The aim of this study was to evaluate the potential of melon peel flour as a functional ingredient for innovative food products. For that, two different formulations containing melon peel flour were developed (a biscuit and a muffin) by replacing a conventional flour (wheat flour) in different percentages (50% and 100%, respectively). The nutritional composition, total phenolic content, and antioxidant potential of the developed products were studied, showing a high content of fibre, high levels of phenolic compounds and good sensory acceptability. These results show that it is possible to enrich different foods with melon peel flour in order to improve their nutritional properties, contributing to improving public health, simultaneously valorising a usually rejected by-product, reducing food waste and the environmental impact.

Introduction

The large assembly of food by-products that results from fruit production and processing industries is a growing problem that leads to great management difficulties, both at economic and environmental levels. Currently, these by-products are used as fertilizers or for animal feed. However, they have high levels of dietary fibre and bioactive compounds, which gives them the potential to be used for the development/enrichment of food products with improved and beneficial properties for human health.[1,2]

Melon (*Cucumis melo* L.) is a fruit widely consumed around the world, mainly due to its excellent sensory qualities. In addition, it has a rich nutritional composition and is a good source of bioactive compounds.[3] Its global production generates around 8 to 20 million tons per year of by-products, which are currently discarded.[4] Their valorisation meets the priorities established by the Sustainable Development Goals (SDGs) of the United Nations, which aim to promote the use of existing natural resources in a more sustainable and efficient way, meeting the concepts of a circular and green economy.[5]

Currently, society faces major nutritional challenges. It is estimated that the world population will continue to increase exponentially, reaching around 9.8 billion people by 2050.[6] With this growth, the challenge of ensuring that the whole population gets enough safe, nutritious, and healthy food becomes ever-greater.[7] The use of these by-products in the enrichment/development of new food products could also be one of the crucial strategies to combat the hunger and malnutrition that the population faces today.

Bakery products are part of the population's daily diet. However, they are generally nutritionally poor, being rich in saturated fat and sugar and poor in dietary fibre.[8] A sufficient and regular intake of dietary fibre provides many health benefits, reducing the risk of developing several diseases, such as obesity, diabetes, and hypertension, among others.[9–11] The dietary recommendation for dietary fibre intake is 25 g per day, for adults.[12] However, the average daily intake of dietary fibre for the Portuguese population is 16.3 and 19.5 g day^{-1}, for women and men, respectively.[13] To increase the population's intake of dietary fibre, the incorporation of fruit by-products in bakery products has been studied.[14–18]

The objective of this study was to explore the potential use of melon peel flour, evaluating its nutritional composition, antioxidant activity and functional properties. In addition, two

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formulations based on melon peel flour with enhanced nutritional properties and that are organoleptically acceptable were developed.

Materials and methods

Standards and reagents

All chemicals and reagents were purchased from various commercial sources and were of analytical grade. Ultrapure water from the Milli-Q system (Millipore, Bedford, MA, USA) was used.

Melon peel flour preparation

In 2021, the melon samples were collected from melon production and distribution companies (Frutas A. R. Santos, Torres Vedras, Portugal and Planície Verde, Rio Maior, Portugal), mainly discarded fruits, which do not correspond to market needs in terms of size, shape, and/or colour. Initially, the melons were washed under running water, immersed in water with sodium hypochlorite and the melon peels were manually separated and cut into small pieces. After various experiments with temperatures and drying times, to achieve the desired moisture content (<10%), the melon peels were dehydrated in a food dehydrator (Lacor 69523 Pro, Spain) at 50 °C for 18 h. Then, the melon peels were homogenized in a blender (Grindomix GM200, Retsch, Haan, Germany) at 5000 rpm for 1 min and sieved (420 μm) to obtain the melon peel flour, which was subsequently stored under vacuum and protected from light.

Biscuit preparation

Two types of biscuits were prepared (Fig. 1): a control biscuit and a biscuit with 50% melon peel flour instead of wheat flour. Due to the functional properties of melon peel flour, it was only possible to develop biscuits with a 50% replacement. The ingredients and the respective amounts used in both formulations are presented in Table 1. The samples were cooked in a domestic oven (Flama 1548FL, Cesar, Oliveira de Azeméis, Portugal) for 10 min at 200 °C.

Muffin preparation

Two types of muffins were prepared (Fig. 1): a control muffin and a muffin with melon peel flour instead of wheat flour. Several ingredients and several recipes were tested to produce the two types of muffins, being the best ones selected, and used to prepare the samples herein studied. The final formulations (ingredients and amounts) used to produce muffins are presented in Table 2. The muffins were cooked in a domestic oven (Flama 1548FL, Cesar, Oliveira de Azeméis, Portugal) for 15 min at 180 °C.

Fig. 1 Bakery products developed. (A) Control biscuit, (B) biscuit with 50% melon peel flour, (C) control muffin, (D) muffin with 100% melon peel flour.

Table 1 Biscuit formulations

Ingredients (%)	Control biscuit	Biscuit with 50% melon peel flour
Wheat flour	45.46	22.73
Melon peel flour	—	22.73
Sugar	18.18	18.18
Butter	18.18	18.18
Eggs	18.18	18.18

Functional properties

The functional properties of melon peel flour, wheat flour and oat flour were determined. Oat flour is widely used in bakery products and is considered an alternative to wheat flour in the diets of celiac patients. Therefore, its functional properties were determined and compared with melon peel flour, which is gluten-free.

Bulk density. The bulk density of wheat, oat and melon peel flours was determined according to the method described by Wang and Kinsella (1976), with slight modifications. About 10 g of sample were weighed into a 50 mL graduated cylinder. The cylinder was tapped several times on the bench until there was no further decrease in volume. The volume of the compacted sample was recorded, and the bulk density was calculated according to the following equation:[19]

$$\text{Bulk density}\left(\text{g cm}^{-3}\right) = \frac{\text{Weight of sample (g)}}{\text{Volume of sample after tapping }\left(\text{cm}^3\right)}$$

Dispersibility. The dispersibility was determined using the method described by Kulkarni, Kulkarni and Ingle (1991). About 10 g of sample were placed in a 100 mL graduated cylinder and distilled water was added until a volume of 100 mL was reached. The cylinder was vigorously shaken and left for 3 h. The volume of sedimented particles was recorded and the dispersibility was calculated according to the following equation:[20]

$$\text{Dispersibility (\%)} = 100 - \text{volume of settled particle (mL)}$$

Table 2 Muffin formulations

Ingredients (%)	Control muffin	Muffin with 100% melon peel flour
Wheat flour	23.72	—
Melon peel flour	—	18.05
Banana	27.67	29.72
Soya yogurt	19.76	21.23
Eggs	19.76	21.23
Dry yeast	0.79	0.85
Vegetable oil	2.37	2.55
Chocolate	5.93	6.37

Water absorption capacity. To determine the water absorption capacity, 250 mg of sample were weighed into a centrifuge tube and 15 mL of distilled water was added. The sample was stirred and left for 1 h at room temperature. After that, the sample was centrifuged at 3000*g* for 20 min and the supernatant was removed.[21] The residue was weighed, and the water absorption capacity was calculated according to the following equation:

$$\text{Water absorption capacity (g } H_2O \text{ per g of sample)} = \frac{\text{Weight of sediment (g)} - \text{Weight of sample (g)}}{\text{Weight of sample (g)}}$$

Oil absorption capacity. To determine the oil absorption capacity, the same protocol described above was used, using oil instead of distilled water.[21] The oil absorption capacity was expressed as g oil per g of sample and calculated according to the following equation:

$$\text{Oil absorption capacity (g oil per g of sample)} = \frac{\text{Weight of sediment (g)} - \text{weight of sample (g)}}{\text{Weight of sample (g)}}$$

Solubility and swelling power. Solubility and swelling power were determined according to Adegunwa *et al.* (2019), with slight modifications. Briefly, 1 g of sample was weighed into a previously weighed tube and 15 mL of distilled water was added. The mixture was gently stirred for 5 min and then heated in a thermostatic water bath for 40 min. Then, 7.5 mL of distilled water was added, and the mixture was centrifuged at 3000*g* for 20 min. The supernatant was removed and dried at 100 °C until a constant weight was reached. The sediment was weighed, and the solubility and swelling power were calculated according to the following equations:[22]

$$\text{Swelling power (g per g sample)} = \frac{\text{weight of sediment (g)}}{\text{weight of sample (g)} - \text{weight of soluble (g)}}$$

$$\text{Solubility index}(\%) = \frac{\text{Weight of soluble (g)}}{\text{Weight of sample (g)}} \times 100$$

Proximate composition analysis

The melon peel flour, biscuits, and muffins (controls and innovative products) were analysed regarding their content of moisture, ash, total protein, total fat and total dietary fibre. The available carbohydrates and energy values were calculated.[23,24]

For quality assurance purposes, the test material FAPAS® 2496 was analysed with these methods and compared with the assigned values.

The moisture content was determined using a dry air oven (Memmert, Germany), according to the gravimetric method.[25] The ash content was determined by direct incineration of the samples in a muffle furnace (525 ± 25 °C; 20 h) following the official method of AOAC 923.03.[25] The protein content of the samples was determined by the Kjeldahl method, by quantifying the total nitrogen present in the analysed samples and using the block digestion system Foss Tecator 2006 Digestor and a Foss 2200 Kjeltec Auto Distillation unit (Foss, Hilleroed, Denmark).[25] The total fat content was determined by the Soxhlet extraction method (Soxtec ™ 2050, Foss, Hilleroed, Denmark) with acid hydrolysis, using petroleum ether 40–60° as the extraction solvent.[25] The total dietary fibre content was determined using an enzymatic–gravimetric method, according to AOAC 985.29.[25]

Antioxidant activity and total phenolic compounds

Sample extraction. For antioxidant activity evaluation and total phenolic compounds determination, extracts of melon peel flour and biscuits and muffins (controls and innovative products) were prepared. Briefly, 3 g of each sample were mixed with 30 mL of ethanol (90%, v/v) for 10 min at 4500 rpm and then filtered with a 150 mm diameter filter paper (Macherey-Nalgel Gmbh & Co. KG, Germany).

Radical DPPH scavenging activity. Radical DPPH scavenging activity was determined according to the method reported by Albuquerque *et al.* (2016). Briefly, 1 mL of ethanolic sample extract was mixed with 1 mL of DPPH ethanolic solution (0.004% w/v). Then, the mixture was incubated in the dark at room temperature and stirred for 30 min. The absorbance of the mixture and the bleaching of DPPH were measured at 517 nm using a UV-Vis spectrophotometer (Thermo Scientific 300 Evolution, Madison, USA).[26] Trolox was used as a standard with concentrations ranging from 0.5 to 14 μg mL^{-1}. The results were expressed in mg of Trolox equivalents (TE) per 100 g of sample through the interpolation of the calibration curve of Trolox. All analyses were performed in triplicate.

Ferric reducing antioxidant power assay. Ferric reducing antioxidant power was determined according to the method described by Thaipong *et al.* (2006). The working solution was prepared by mixing 25 mL of acetate buffer (300 mM, pH 3.6), 2.5 mL of HCl solution (40 mM) of TPTZ (2,4,6-tripyridyl-*s*-triazine) (10 mM) and 2.5 mL of $FeCl_3 \cdot 6H_2O$ solution (20 mM). Then, this solution was incubated in a water bath at 37 °C for 10 min. In a glass tube, 0.15 mL of the ethanolic sample extracts were added to 2.85 mL of the working solution. The mixture was kept at room temperature and protected from light for 30 min. After the reaction, the absorbance of the samples was monitored in a UV/Vis spectrophotometer at 593 nm (Thermo Scientific Evolution 300, Madison, USA).[27] A calibration curve was prepared with Trolox as a standard, whose concentrations varied between 2 and 105 μg mL^{-1}. All analyses were performed in triplicate and the results were expressed in mg of TE per 100 g of sample.

Total phenolics. The total phenolic content was determined according to the method reported by Song *et al.* (2010), with some modifications. Briefly, 0.5 mL of ethanolic sample extracts were reacted with 2.5 mL of the Folin–Ciocalteu reagent (0.2 M) for 4 min in the absence of light. Then, 2.0 mL of sodium carbonate aqueous solution (7.5%, w/v) was added. The mixture was stirred and incubated in a water bath (40 °C, 60 min). Then, the mixture was centrifuged (10 min, 3000 rpm), and the absorbance of the upper phase was read at

760 nm, using a UV/Vis spectrophotometer (Thermo Scientific Evolution 300, Madison, USA).[28] Gallic acid was used as the standard reference and the results, expressed in mg of gallic acid equivalents (GAE) per 100 g of sample, were obtained through the interpolation of the calibration curve (2 to 90 µg mL^{-1}). All analyses were performed in triplicate.

Sensory evaluation

The development of a new food product needs to consider sensory aspects and consumer acceptance. A hedonic test was used to evaluate the acceptability of the biscuit and muffin developed. 40 untrained panellists evaluated the acceptability of foods about their appearance, colour, odour, texture, taste, and overall acceptability (evaluation taking into account all analysed parameters) using the seven-point hedonic scale method ranging from 1 (disliked it very much), 4 (neither liked nor disliked it), to 7 (liked it very much). The panellists were also asked about their purchase intention (intention to purchase the product if commercially available) through the options "certainly would not buy it", "probably would not buy it", "might or might not buy it", "probably would buy it" and "certainly would buy it".

Statistical analysis

The statistical analyses of data were performed using Microsoft Office Excel® 2010. Results are expressed as mean ± standard deviation (SD). Values presented in the tables are the average values of three individual samples (n = 3). For multiple comparisons of normally distributed data, parametric one-way analysis of variance (ANOVA) followed by the Tukey test was used. A value of $p < 0.05$ was considered significant.

Results and discussion

Functional properties

The functional properties of food are extremely important as they help to characterise the structural quality, nutritional value, and consumer acceptability.[29] The functional properties of the wheat, oat and melon peel flours are presented in Table 3. Melon peel flour had a lower bulk density value (0.46 ± 0.01 g cm^{-3}) than wheat and oat flours. This result is similar to the bulk density (0.40 ± 0.00 g cm^{-3}) reported by Farida *et al.* (2022).[30] However, it is lower than the values reported by Adegunwa *et al.* (2019) for plantain and watermelon rind composite flour (0.52–0.75 g cm^{-3}).[22] The bulk density (g cm^{-3}) of flour is measured without the influence of any compression and depends on the particle size and moisture content.[31,32] Higher bulk densities are desirable to reduce storage and transport costs, as this is an indication that the flour has a lower space requirement. On the other hand, flours with lower bulk densities may be advantageous in the preparation of weaning food formulations.[33]

The hydration properties of dietary fibres are related to several factors such as the chemical structure of the constituent polysaccharides, porosity, and particle size, among others.

Table 3 Functional properties of wheat, oat and melon peel flours

Parameters	Wheat flour	Oat flour	Melon peel flour
Bulk density (g cm^{-3})	0.75 ± 0.02^a	0.60 ± 0.01^b	0.46 ± 0.01^c
WAC (g H_20 per g sample)	1.75 ± 0.08^c	2.93 ± 0.15^b	14.34 ± 0.49^a
OAC (g oil per g sample)	4.83 ± 0.29^a	4.78 ± 0.19^a	5.00 ± 0.43^a
Dispersibility (%)	74.83 ± 0.29^a	58.17 ± 0.76^b	14.67 ± 0.58^c
Solubility (%)	7.75 ± 0.13^b	5.77 ± 0.08^c	15.93 ± 1.06^a
Swelling power (g per g sample)	5.32 ± 0.06^c	6.07 ± 0.01^b	15.01 ± 0.26^a

Values are the average of three individual samples (n = 3), expressed as mean ± standard deviation. Mean values with different superscript letters within a row are significantly different ($p < 0.05$). WAC, water absorption capacity. OAC, oil absorption capacity.

The chemical properties of fibre and its origin (food source) are strongly related to the ability of dietary fibre to retain water. For example, dietary fibre obtained from fruit juice by-products has a higher affinity than those derived from cereals.[34]

Dispersibility of flour measures its ability to be reconstituted in water, and the greater the dispersibility, the better the flour reconstitutes in water. The dispersibility value for melon peel flour was 14.67%, the lowest value of the three flours analysed. However, it is considered high when compared to plantain and watermelon rind composite flour (0.89–1.70%).[22]

The water absorption capacity represents the amount of water that a flour sample can retain after being subjected to an external force (pressure or centrifugation). Melon peel flour obtained the highest value for water absorption capacity (14.34 ± 0.49 g H_2O per g sample), indicating that it has a greater affinity with water. These values are high compared to other flours extracted from fruit by-products like umbu peel flours (3.74–3.95 g H_2O per g) and pequi peel flours (3.74–3.98 g H_2O per g).[35,36] High water absorption values are important for applications such as functional ingredients in bakery products as they prevent water loss during cooking.[30] This parameter is also linked to the flour's ability to produce a viscoelastic dough, which makes it easier to shape and stretch.[29] However, as the water absorption capacity of melon peel flour is high, it is more difficult to obtain a cohesive and uniform dough, as well as to integrate all the ingredients used in a recipe. This can be a challenge when developing foods with high percentages of melon peel flour.

In addition to the water absorption capacity, the oil absorption capacity of the flour is also important and consists of the amount of oil that the flour can retain after being subjected to centrifugation.[34] Although melon peel flour presented the highest value for oil absorption capacity (5.00 ± 0.43 g oil per g sample), no significant differences were found between the values of the remaining flours analysed. The oil absorption capacity of melon peel flour is almost 3 times lower than its water absorption capacity. However, for wheat and oat flours, the opposite was observed. Both flours have a greater absorption capacity for oil than for water. This is in line with Farida *et al.* (2022), who also found a greater water absorption capacity than oil absorption capacity for melon peel flour.

Table 4 Nutritional composition and energy value (per 100 g) for the melon peel flour, biscuits and muffins

Components	Melon peel flour	Control biscuit	Biscuit with 50% melon peel flour	Control muffin	Muffin with 100% melon peel flour
Energy (kJ (kcal))	940 (227)	1946 (464)^{a}	1737 (416)^{b}	1064 (255)^{c}	685 (165)^{d}
Moisture (g)	8.71 ± 0.1	7.17 ± 0.0^{a}	9.25 ± 0.1^{b}	44.3 ± 0.1^{c}	58.6 ± 0.2^{d}
Ash (g)	10.2 ± 0.0	0.49 ± 0.0^{a}	2.97 ± 0.0^{b}	1.81 ± 0.0^{c}	2.76 ± 0.0^{d}
Total protein (g) (NCF = 6.25)	6.91 ± 0.1	7.69 ± 0.2^{a}	7.18 ± 0.0^{a}	6.68 ± 0.2^{b}	7.91 ± 0.1^{b}
Total fat (g)	0.51 ± 0.0	19.5 ± 0.0^{a}	18.9 ± 0.1^{b}	11.7 ± 0.2^{c}	7.23 ± 0.1^{d}
Available carbohydrates (g)	23.7 ± 2.2	63.6 ± 0.4^{a}	47.0 ± 0.8^{b}	26.0 ± 0.1^{c}	10.5 ± 0.8^{d}
Total dietary fibre (g)	50.0 ± 2.0	1.53 ± 0.3^{a}	14.7 ± 0.6^{b}	9.56 ± 0.5^{c}	13.0 ± 0.6^{d}
Salt (g)	3.67 ± 0.0	0.14 ± 0.0^{a}	0.99 ± 0.1^{b}	0.12 ± 0.0^{c}	0.64 ± 0.0^{d}

Values are average of three individual samples (n = 3), expressed as mean ± standard deviation. Mean values with different superscript letters within a row are significantly different ($p < 0.05$). NCF, nitrogen conversion factor.

High oil absorption capacity is desired in baked foods, as fat can act as a flavour retainer and improve the flavour of the food.[37,38] Both the water and oil absorption capacities of flour depend on many factors related to proteins (amino acid composition, conformation, surface polarity, hydrophobicity), which may justify the found differences.[38]

The swelling power of flours refers to their ability to absorb water and increase in volume. It is an important property that affects the quality and functionality of flours in various applications. Flours with high starch content generally have a greater swelling capacity, especially when there is more branched amylopectin. The constituents of starch varies greatly depending on the plant source from which it is derived, which may explain the differences in the swelling capacity of flour from different (plant) sources and different species.[29] The swelling power of melon peel flour was 15.01 ± 0.26 g g^{-1} sample, higher than the values observed for wheat and oat flour. Melon peel flour has a high swelling power compared to banana peel flour (3.62–7.34 g g^{-1} sample) and cassava flour (10.32–12.04 g g^{-1} sample).[39,40] Adegunwa *et al.* (2019) found that temperature has an influence on increasing the swelling power of plantain and watermelon rind composite flour.[22] Abou-Arab *et al.* (2017), who studied the effect of drying methods (microwave-drying, solar-drying and air oven-drying), observed that all the methods studied increased the swelling capacity of the citrus peel powder compared to the fresh sample.[41]

The solubility of melon peel flour was 15.93%, a lower value than that obtained by Farida *et al.* (2022) (22.65%). Its solubility is considered low compared to values obtained for plantain and watermelon rinsed composite flour (22.85–27.49%) and for pequi peel flours (16.7–19.8%), but high compared to plantain flour (6.93%).[22,36,42]

Proximate composition

The results regarding the nutritional composition of the melon peel flour are presented in Table 4. With the results obtained, it is possible to verify that the main constituents of the melon peel flour are dietary fibre and available carbohydrates, 50 and 24 g per 100 g, respectively. Melon peel flour can be considered a good source of dietary fibre, due to its high content. This result also indicates that the melon peel flour produced can be nutritionally better than wheat and whole wheat flour, when comparing their dietary fibre contents (3 and 10.6 per 100 g, respectively).[43] This is because, generally, the peel of the fruit has higher levels of dietary fibre than the pulp or grains.

On the other hand, the dietary fibre content of melon peel flour can also be considered high compared to other fruit peel flours, namely pomegranate peel flour (17.53 g per 100 g), pequi peel flours (39.79–43.32 g per 100 g), and prickly pear peel flour (33 g per 100 g).[16,36,44] Regarding the protein content obtained for melon peel flour (6.91 g per 100 g), it is considered low when compared to wheat and whole wheat flour (12 and 15.1 gper 100 g, respectively).[43] However, when compared with other fruit peel flours, it appears that melon peel flour has higher values than prickly pear peel flour (3.58 g per 100 g), pequi peel flours (3.25–3.26 g per100 g), pumpkin peel flour (3.68 g per 100 g) and pomegranate peel flour (0.70 g per 100 g).[16,18,36,44] Furthermore, melon peel flour had a lower fat content than wheat and whole wheat flours (1.7 and 2.73 g per 100 g, respectively), pumpkin peel flour (3.53 g per 100 g) and prickly pear peel flour (2.12 g per 100 g). However, compared to pequi peel flour (0.17–0.32 g per 100 g) and pomegranate peel flour (0.40 g per 100 g), it is slightly higher.[16,18,36,43,44] It also has a low moisture content (8.71 g per 100 g), as recommended, since high levels contribute to a greater proliferation of microorganisms and chemical reactions, making preservation difficult.[45]

Table 4 also shows the results of the nutritional composition of the biscuits and muffins (controls and innovative products) developed. The control biscuit is characterized by its poor nutritional quality, namely due to its low dietary fibre (1.53 ± 0.3 g per 100 g) and high available carbohydrate contents (63.6 ± 0.4 g per 100 g). By replacing wheat flour with 50% melon peel flour, the dietary fibre content increased to 14.7 ± 0.6 g per 100 g. Since the dietary reference intake for adults for fibre is 25 g day^{-1}, one portion of the innovative biscuit (35 g) can contribute to 21% of the recommended needs, while the biscuit control only contributes to 2% of the recommended needs. Moreover, according to Regulation (EC) No. 1924/2006 on nutrition and health claims, the developed biscuit can be considered high in fibre (>6 g per 100 g).[46]

For the developed muffin, the same was observed. The full replacement of wheat flour by melon peel flour increased the fibre content from 9.56 ± 0.5 g per 100 g to 13.0 ± 0.6 g per 100 g. Therefore, the muffin developed can be considered high in fibre according to the same regulation (>6 g per 100 g).[46] Furthermore, one portion of the developed muffin (48 g) can contribute to 25% of the recommended needs. In addition to dietary fibre, replacing wheat flour with melon peel flour allowed an increase in protein content from 6.68 ± 0.2 g per 100 g (control muffin) to 7.91 ± 0.1 g per 100 g (muffin with 100% melon peel flour), and the reduction in energy value from 255 kcal (control muffin) to 165 kcal (muffin with 100% melon peel flour).

Antioxidant activity

Antioxidant activity was determined using two different methods: 2,2-diphenyl-1-picrylhydrazyl (DPPH$^•$) and ferric reducing antioxidant power (FRAP) assays. The results obtained for the melon peel flour, biscuits, and muffins (controls and innovative products) are shown in Table 5.

The DPPH$^•$ assay is considered a standard colorimetric method, easy to apply and routinely used to evaluate the free radical scavenging potential of an antioxidant molecule.[47] In the DPPH$^•$ method, melon peel flour had an antioxidant potential of 246.8 ± 10.98 mg TE per 100 g. The incorporation of melon peel flour into the biscuits allowed a ∼5-fold increase in their antioxidant potential (from 10.2 to 53.3 mg TE per 100 g). In the case of the developed muffin, no significant differences ($p < 0.05$) were observed between the antioxidant potential of the control and the innovative muffin (Table 5).

The FRAP assay has been widely used in food science. Compared to other assays that only measure free radical inhibition, the FRAP assay directly measures antioxidants in a sample.[48] This assay measures the reduction, by antioxidants, of the ferric ion binding complex (Fe^{3+}) to the ferrous complex (Fe^{2+}), in an acidic medium.[49] For this assay, the content obtained for melon peel flour was 7490.8 ± 189.0 mg TE per 100 g. Similar to what was observed with the DPPH$^•$ method, the incorporation of melon peel flour into the biscuit also allowed an increase of approximately 5 times in antioxidant power, resulting in a content of 1727.7 mg TE per 100 g for the biscuit developed. For the muffin with melon peel flour, an increase in its antioxidant power was also observed, resulting in a food product with 1475.1 mg TE per 100 g.

Many studies associate the accumulation of free radicals with some diseases, such as cancer and neurodegenerative and cardiovascular diseases. Antioxidants are compounds that can prevent and stabilize damage caused by these free radicals by donating electrons to damaged cells. Although biological systems have innate antioxidant defense mechanisms, these may be inefficient. Therefore, a dietary intake of antioxidants is very important to help protect cells from damage caused by free radicals.[50,51]

Total phenolic compounds

The total phenolic content of melon peel flour and the developed bakery products (controls and innovative products) are presented in Table 5. Melon peel flour presented a value of 1709.6 mg GAE per 100 g, for the total phenolic content, a value higher than those reported by Farida *et al.* (2020), 694.78–1271.39 mg GAE per 100 g.[30] The content obtained in this study is very similar to that of prickly pear peel flour (1710 mg GAE per 100 g) reported by Parafati *et al.* (2020) and is higher than those of pomegranate peel flour (1387 ± 3.04 mg GAE per 100 g) and pumpkin peel flour (93.40 ± 0.69 mg GAE per 100 g).[16,44,52] However, our values are lower compared to those reported by Feizy *et al.* (2020) for watermelon peel flour (2473.45 mg GAE per 100 g).[53]

In the case of the developed biscuit, the utilization of melon peel flour promoted a total phenolic content of 456.5 ± 28.0 mg GAE per 100 g. This incorporation allowed a ∼3-fold increase in the content of phenolic compounds. Concerning the developed muffin, a total phenolic content of 712.7 ± 57.0 mg GAE per 100 g was obtained. By replacing wheat flour by melon peel flour, a 1.7-fold increase in the total phenolics was observed.

Phenolic compounds are secondary metabolites produced by plants, whose intake has been associated with a reduction in the incidence of some diseases such as cancer, diabetes, and cardiovascular diseases.[54–56] Interest in phenolic compounds has been increasing over time, and epidemiological studies that suggest a relationship between the consumption of foods rich in phenolic compounds and disease prevention highlight the importance of a diet rich in these types of compounds.

Sensory evaluation

Sensory analysis is extremely important for the food industry and can be used, for example, in the development of new pro-

Table 5 DPPH radical scavenging activity, FRAP assay and total phenolic content of the melon peel flour, biscuits and muffins

	Melon peel flour	Control biscuit	Biscuit with 50% melon peel flour	Control muffin	Muffin with 100% melon peel flour
DPPH$^•$ (mg TE[a] per 100 g)	246.8 ± 10.98	10.2 ± 0.39^a	53.3 ± 2.73^b	39.8 ± 3.73^c	43.5 ± 2.38^c
FRAP (mg TEA per 100 g)	7490.8 ± 189.0	323.7 ± 63.8^a	1727.7 ± 89.7^b	1049.9 ± 60.4^c	1475.1 ± 87.2^d
Total phenolics (mg GAE[b] per 100 g)	1709.6 ± 162.7	147.3 ± 7.6^a	456.5 ± 28.0^b	412.1 ± 32.4^c	712.7 ± 57.0^d

Values are average of three individual samples (n = 3), expressed as mean ± standard deviation. Mean values with different superscript letters within a row are significantly different ($p < 0.05$). [a] TE, Trolox equivalents. [b] GAE, gallic acid equivalents.

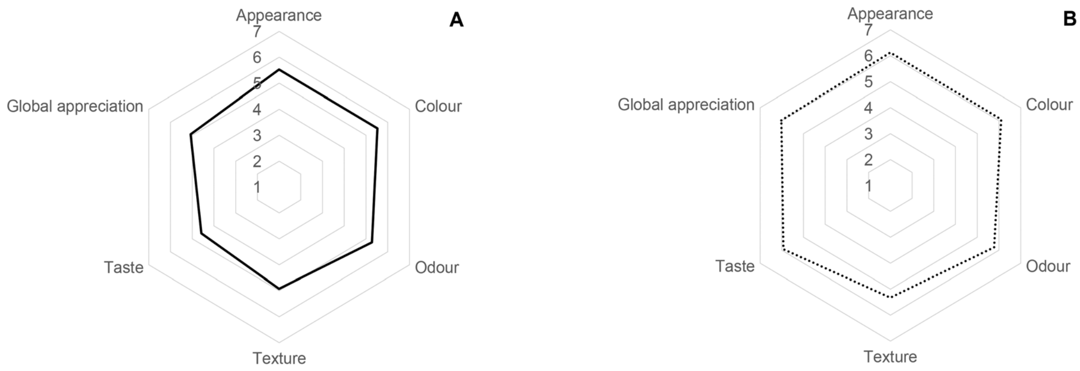

Fig. 2 Sensory evaluation of the (A) muffins and (B) biscuits developed.

ducts, reformulation of products already established on the market, and identification of consumer preferences for a particular product, among others. The sensory analysis scores for appearance, colour, odour, texture, taste and overall acceptability of enriched muffins and biscuits obtained from a panel of untrained tasters are shown in Fig. 2.

Regarding the results obtained for the muffin developed, most panellists gave a rating of 6 "liked it" to the attributes of appearance, colour, and odour. On the other hand, the texture and flavour were classified with the score 5 "like it slightly", by 43% and 35% of the panellists, respectively. The flavour parameter obtained the lowest rating (4.6). This may be related to the fact that no added sugars were used in its formulation. In the case of the biscuit, most of the panellists assigned a score of 6 "liked it" to all evaluated parameters. The appearance and colour of the biscuit were the parameters that most pleased the panellists, with 65% answering "liked it". The colour of the food product has a vital role in sensory analysis for consumers. Through the score attributed by the panellists to this parameter, the use of green-peel melons in the formulations, which gives a slightly greenish tone to the biscuits, may not constitute a rejection factor for consumers.

The results obtained for the overall acceptability were quite satisfactory, in the case of the biscuit developed with 50% melon peel flour, since 53% of the participants classified it as 6 "liked it" and 12 participants classified it as "liked it very much". On the other hand, the overall acceptability of the muffin with 100% melon peel flour was classified with a score of 5 "liked it slightly". However, the number of individuals who "liked it" and "liked it very much" was 8 and 5, respectively. It should be noted that the muffin is entirely made from melon peel flour, without the use of any other type of flour. In this sense, the results obtained also seem to be quite satisfactory.

The results described above agree with the results obtained for the question related to the purchasing potential of the developed products. The biscuit recorded the best scores with 53% of panellists responding that they "probably would buy it" and 35% responding that they "certainly would buy it". Regarding the muffin, 15 of the 40 tasters described that they "might or might not buy it" and 10 tasters responded that they "probably would buy it".

In general, the results obtained by the sensory analysis were quite satisfactory for both developed products based on melon peel flour, with a slight preference among the tasters for the biscuit enriched with 50% melon peel flour.

Conclusions

The melon peel flour has a very interesting nutritional composition. It can be considered rich in dietary fibre and a good source of total phenolic compounds. The integration of high quantities of melon peels in food products allowed the development of two formulations high in dietary fibre and rich in phenolic compounds, contributing to enhancing their nutritional quality. Given the importance of dietary fibre for health and its high content in melon peel flour, the use of this by-product is an excellent option to enrich food products with dietary fibre and contribute to increasing their intake. It was possible to develop a muffin using only melon peel flour, without wheat flour, without added sugar, lactose-free and gluten-free, which was well accepted by the tasters. With these good results, it is believed that this flour could be a potential option to replace wheat flour, increasing the supply of this type of product for the population looking for healthier options and individuals who are gluten intolerant. This work also demonstrates that it is possible to reduce the economic, social and environmental impacts of these by-products that are until now discarded, contributing to a more sustainable production in the food industry, improving public health and meeting the Sustainable Development Goals of the United Nations.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

This work was financially supported by the Foundation for Science and Technology (FCT) under the projects Food4DIAB (EXPL/BAA-AGR/1382/2021) and UIDB/50006/2020 and by AgriFood XXI I&D&I project (NORTE-01-0145-FEDER-000041) co-financed by the European Regional Development Fund (ERDF), through the NORTE 2020 (Programa Operacional Regional do Norte 2014/2020). Rita C. Alves thanks FCT for the CEECIND/01120/2017 contract.

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