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Nutritional and technological properties of pulp and peel flours from different mango cultivars

Maiqui IZIDORO[1,2], Magali LEONEL[1*], Sarita LEONEL[1,2], Nathalia Aparecida Barbosa LOSSOLI[1,2], Hebert Teixeira CÂNDIDO[1,2], Patrícia Graosque Ulguim ZÜGE[2], Jaciene Lopes de Jesus ASSIS[3]

Abstract

Global mango production generates significant agricultural and industrial waste, including non-standard fruits and peels. Herein, flours obtained from the immature fruits of four mango cultivars (Haden, Keitt, Parwin, and Tommy Atkins) were characterized for their physicochemical properties with the goal of valorization as an ingredient in functional food products. Regardless of cultivar, the peel flours represented excellent sources of fiber, with notable calcium, magnesium, manganese, carotenoids, and antioxidant contents as well as high percentage of large particles and good water retention capacity. Pulp flours exhibit high starch content, light color, and fine granulometry. The mango cultivars strongly interfered with the differentiation of the mango peel and pulp flours. The results presented herein show that understanding the characteristics of flours obtained by processing different parts of the fruits of various cultivars can produce composite mango flours with different nutritional and technological properties, expanding their possible uses in food products and driving sustainable agricultural production in terms of efficient crop waste management.

Keywords: proximate composition; minerals; carotenoids; microstructure; technological properties.

Practical Application: Mango flours can be used as functional flours in food formulations. Mango peel flours have the potential to be used as sources of dietary fiber, and can contribute to increased bioactive compounds and minerals intake. Pulp flours can be used in the development of gluten-free products to increase their nutritional value.

1 Introduction

Mangoes are widely produced and consumed fruits that are enjoyed worldwide. The world production of mangoes, mangosteens, and guava in 2020 was 54.83 million tons, with 72.5% of the production located in Asia. India is the largest producer worldwide (24.7 million tons) while Brazil is the largest producer in South America (2.13 million tons) (Food and Agriculture Research of United Nations, 2022). The isolated Brazilian mango production in 2020 was 1.57 million tons, cultivated over an area of 72,000 ha with the states of Pernambuco, Bahia, Minas Gerais, and São Paulo producing the vast majority (Instituto Brasileiro de Geografia e Estatística, 2022).

The mango fruit is a drupe with different shapes (round, oval, elliptical, and heart-shaped), consisting of skin (epicarp), pulp (mesocarp), and seed kernels (endocarp). The fruits vary in size (3–26 cm length; 1.5–10 cm width) and weight (132–702 g) according to cultivar and growing conditions (Silva et al., 2014).

Most mango is sold as fresh fruit, but mango agro-industrialization generates several highly appreciated products including juices, nectar, jellies, and ice creams. The Brazilian domestic market for mangoes is unattractive because of its low profit margin and not all producers have access to export markets, which are more profitable and feature high demand and favorable exchange rate scenarios. In 2021, Brazil exported 244,840 tons of fruit (Hortifruti Brasil, 2022).

To improve the domestic Brazilian mango market, varietal diversification must be achieved to obtain better yields and expand growing regions, as well as to reduce post-harvest losses and limit agro-industrial residues. A large number of unsuitable fruits for the fresh market, together with those discarded in industrial operations represent significant economic and environmental losses (Serna-Cock et al., 2016; Castro-Vargas et al., 2019; Wall-Medrano et al., 2020; Safdar et al., 2022).

The production of flour from fruits that do not reach commercial quality is an alternative method to reduce post-harvest losses (Amorim et al., 2022). The production of mango flour reduces free water, resulting in an increased time-to-market and concentrating health-promoting nutrients. Green mango fruits represent a promising source of vitamins, essential minerals, bioactive compounds, proteins, dietary fiber, and starch (Oak et al., 2019; Patiño-Rodríguez et al., 2020; Gupta et al., 2022).

The functional flour market, which includes fruit flours, has grown considerably due to consumer awareness of health benefits and lifestyle changes that promote consumption of gluten-free and vegan products. According to Industry ARC™ (2022), the market for functional flours is estimated to reach US$82.7 billion by 2027, growing at a CAGR of 7.3% (2022–2027).

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[1] *Centro de Raízes e Amidos Tropicais – CERAT, Universidade Estadual Paulista – UNESP, Botucatu, SP, Brasil*
[2] *Departamento de Horticultura, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista – UNESP, Botucatu, SP, Brasil*
[3] *Embrapa Mandioca e Fruticultura, Cruz das Almas, BA, Brasil*
*Corrresponding author: magali.leonel@unesp.br

Varietal diversification in mango orchards is an approach for sustainable production. Mango fruits have a high nutritional value and there are large losses of non-standard fruits in orchards that can be used for industrial processing, promoting increased profitability for mango growers and reducing the generation of agricultural waste. This study aimed to characterize the production of peel and pulp flour of four mango cultivars to identify characteristics that may contribute to the production of functional mango flours, adding value to the agro-industrial sector.

2 Materials and methods

2.1 Mango cultivars

Mango fruits belonging to Tommy Atkins, Parwin, Keitt, and Haden cultivars were harvested from the orchard in the São Manuel Experimental Farm of São Paulo State University, São Manuel City, São Paulo State, Brazil (22°44'28"S and 48°34'37"W, 740 m a.s.l.). The climate according to the Köppen-Geiger's classification system is Cfa, humid subtropical climate, mesothermic, with rainfall concentrated from November to April (summer), mean annual rainfall of 1376.70 mm, and average temperature of the hottest month >22 °C. The soil in the experimental area is classified as dystrophic Typic Hapludox (Soil Survey Staff, 2014).

2.2 Peel (MPeF) and pulp mango (MPuF) flours production

From each cultivar, approximately 50 kg of fruit at maturity stage 2 were harvested from 10 mango trees. For flour production, 10 kg of fruit were randomly separated for each process, totaling four repetitions. The fruits were washed in water, sanitized (hypochlorite solution 200 ppm, 15 min), and rinsed in chlorinated water. The pulp and peel were manually separated using sanitized knives. The peel and pulp were dried in an oven under air circulation (55 °C) for 24 h. After cooling to room temperature (22 °C) for 1 h, the materials were disintegrated using a knife mill. Samples were stored at room temperature in tightly sealed plastic containers.

2.3 Proximate composition of mango flours

The methodologies of the Association of Official Analytical Chemists (2012) were used to evaluate the proximate composition of the mango flours. Moisture (method 934.06), ash (method 923.03), lipids (method 923.05), fiber (method 920.86), total sugars (method 968.28), and starch (method 996.11) were determined.

2.4 Minerals

The mineral contents of the prepared mango flours were determined following the methodologies described by Malavolta et al. (1997). The N concentration was determined via sulfur digestion and subsequent distillation in a semi-micro Kjeldahl steam distiller. The P, K, Ca, Mg, Cu, Fe, Mn, and Zn contents were determined via nitroperchloric digestion with subsequent atomic emission spectrometry with argon plasma.

2.5 Carotenoids, acid ascorbic, and antioxidant activity

Analysis of total carotenoid content in mango flours was analyzed according to the method described by Lichtenthaler & Buschmann (2001), with some modifications, using 80% acetone as a standard. Measurements were recorded using a spectrophotometer at wavelengths of 470, 646, and 663 nm and the results expressed in µg/g.

To determine the levels of ascorbic acid in mango flour, an extraction solution was prepared (15 g metaphosphoric acid: 40 mL acetic acid: 3.7 mL concentrated sulfuric acid: 450 mL water). Subsequently, approximately 2 g of the sample was weighed, mixed with 25 mL of the extractor solution in test tubes, and maintained at 22 °C in a water bath with agitation for 1 h. After this period, the tubes were centrifuged for 10 min and the supernatants collected. The sedimented residue was mixed with 10 mL of extraction solution, vortexed, centrifuged twice for 5 min, and the supernatants were recovered. To quantify the ascorbic acid content, the extract was titrated using indophenol dye (50 mg dye, 42 mg $NaHCO_3$, and 200 mL water) until the pink color persisted for 15 s (Sogi et al., 2013).

The total antioxidant activity was determined by capturing the radical $ABTS^+$ (Re et al., 1999). The decrease in absorbance was measured after 6 min of reaction at 734 nm and the results were calculated using a Trolox standard curve and expressed as µmol Trolox g^{-1} flour.

2.6 Microstructure

The microstructural characteristics of the prepared mango flours were analyzed by scanning electron microscopy (SEM; FEG-MEV; JEOL model 7500F), as described by Mesquita et al. (2016).

2.7 Technological properties

The color of the mango flours was analyzed using a colorimeter (MINOLTA, CR-400), using the parameters L*, a*, and b* represented by the CIE_{65} (Commission International Illuminant) model. Color parameters were L^* (darkness/lightness), a^* (greenness/redness), and b^* (blueness/yellowness), chroma (c*), corresponding to the radius, representing color intensity, and hue angle (h), representing color tone .

For granulometric analysis of the flours, 100 g of sample was weighed and placed in a sieve shaker equipped with an adjusted rheostat composed of four sieves with openings of different diameters (0.85, 0.60, 0.425, and 0.25 mm) and a pan. The equipment was agitated for 10 min, and the fractions were retained on each sieve.

The water-holding capacity (WHC) and oil-holding capacity (OHC) were determined as described by Wang et al. (2015).

2.8 Statistical analysis

Statistical analysis was performed using the Statistica software (version 12.0; StatSoft Inc., USA). Results were submitted to the analysis of variance (ANOVA) and Tukey test, adopting a level of significance of 5%. Results are expressed as the mean ± standard deviation. Principal component analysis (PCA) was performed using covariance matrices (XLSTAT -Addinsoft, New York, USA)

3 Results and discussion

3.1 Proximate composition

The proximate composition values of the mango flours are listed in Table 1. Flour moisture is directly linked to the product quality and stability during storage. The two mango flours (MPeF and MPuF) exhibited moisture contents of <11%, lower than the maximum content of 15% established in the Brazilian quality standards (Brasil, 2005).

The mango pulp flours had a higher moisture content than the peel flours for all cultivars, in agreement with the report by Abdul Aziz et al. (2012) for flours obtained from unripe mango fruits. This is likely related to the higher initial moisture content of the mango pulp.

Flours obtained from 'Tommy Atkins' cultivar had higher moisture contents, likely due to the higher lipid levels compared to other cultivars. A higher lipid content prevents water from breaking the hydrophobic barrier formed by lipids, requiring longer drying times than flours with lower lipid contents (Reis et al., 2018).

For both mango pulp and peel flours, carbohydrates (total sugars and starch) represented the main fraction of the dry matter, followed by fiber, protein, ash, and lipids, except for the 'Haden' mango peel flour, which had the highest fiber content (Table 1).

Ash values differed significantly in relation to the fruit parts between the cultivars. The flours obtained from 'Keitt' fruit processing showed higher levels of ash. Independent of cultivar, the mango peel flours contained higher ash contents (2.78–3.89%) than the pulp flours (1.92–3.61%), indicating that the mango peels contained higher levels of minerals than the pulp.

The lipid levels in the flours differed between cultivars and fruit parts, with levels ranging from 1.14 to 1.38% in pulp flours and from 1.11 to 2.68% in peel flours. The flours obtained from the 'Keitt' variety had the lowest levels of lipids, showing lower levels than the 1.6 to 3.7% in dry matter reported by Marçal & Pintado (2021). The lower lipid content in flours is favorable for prolonging shelf life, as flours with higher levels are prone to enzymatic oxidation that produces free fatty acids that contribute to rancidity. These processes can cause changes in the flour color, reduced texture and taste, odor generation, and nutritional changes (Vinutha et al., 2022).

The pulp flours protein contents ranged from 2.88 to 3.50% and in the peel flours from 2.85 to 4.35%, with the 'Keitt' flours significantly lower than the others. Proteins play important roles in human health, are indispensable for growth and development, regulate physiological functions, and maintain pH homeostasis (Amagliani et al., 2017). Thus, the flour protein content can be a factor in their valorization as food ingredients. However, it is important to consider that in starchy products, protein interactions with starch interferes with rheological properties and digestibility (Lu et al., 2022).

The flours obtained from the mango fruit peels had higher fiber contents (35.23 to 43.16%) than the pulp flours (8.33 to 17.59%), with differences between the cultivars. The Haden cultivar differed from the others in terms of its peel flour exhibiting the highest content of dietary fiber, while its pulp flour showed the lowest level of dietary fiber.

Patiño-Rodríguez et al. (2020) observed similar average fiber contents for mango pulp flour (11.75 ± 0.01 g/100 g) obtained from the mango fruit "Ataulfo". Mango peel has been identified in other studies as a sustainable fiber source for the food industry, with variations from 35.5 to 78.3% total fiber (d.b), 11.2 to 28% soluble fiber, and 23.5 to 50.3% insoluble fiber (Abdul Aziz et al., 2012; Sánchez-Camargo et al., 2019).

Mango flours can be considered products with a high content of dietary fiber because they present levels a value twice as high than 3 g/100 g of fiber in their compositions (Brasil, 2012).

Unripe mango fruits are sources of starch and pectin, and during ripening increased concentrations of mono-and disaccharides

Table 1. Proximate composition of mango peel flour (MPeF) and mango pulp flour (MPuF).

		Haden	Keitt	Parwin	Tommy Atkins
Moisture (%)	MPeF	4.80 ± 0.06^{Cb}	5.59 ± 0.03^{Bb}	5.79 ± 0.02^{Bb}	7.85 ± 0.05^{Ab}
	MPuF	8.85 ± 0.02^{Ba}	9.94 ± 0.04^{Aa}	9.89 ± 0.06^{Aa}	10.39 ± 0.03^{Aa}
		% (dry basis)			
Ash	MPeF	$3.82 \pm 0.02A^{a}$	3.89 ± 0.02^{Aa}	1.93 ± 0.01^{Cb}	2.78 ± 0.04^{Ba}
	MPuF	1.92 ± 0.03^{Cb}	3.61 ± 0.02^{Aa}	3.09 ± 0.01^{Ba}	2.02 ± 0.03^{Cb}
Lipids	MPeF	1.61 ± 0.04^{Ca}	1.11 ± 0.02^{Da}	2.68 ± 0.03^{Aa}	2.02 ± 0.02^{Ba}
	MPuF	1.35 ± 0.12^{Ab}	1.14 ± 0.13^{Ba}	1.23 ± 0.14^{Bb}	1.38 ± 0.04^{Ab}
Protein	MPeF	4.35 ± 0.03^{Aa}	3.85 ± 0.02^{Aa}	4.04 ± 0.06^{Aa}	3.79 ± 0.02^{Aa}
	MPuF	3.50 ± 0.06^{Ab}	3.88 ± 0.13^{Aa}	3.10 ± 0.15^{Ab}	3.45 ± 0.04^{Aa}
Fiber	MPeF	43.16 ± 0.24^{Aa}	35.23 ± 0.32^{Ba}	38.99 ± 0.41^{ABa}	42.10 ± 0.63^{Aa}
	MPuF	8.33 ± 0.22^{Cb}	11.08 ± 0.11^{Bb}	13.19 ± 0.11^{Bb}	17.59 ± 0.12^{Ab}
Total sugars	MPeF	9.71 ± 0.12^{Bb}	10.36 ± 0.22^{Aa}	9.12 ± 0.11^{Bb}	10.68 ± 0.09^{Aa}
	MPuF	10.61 ± 0.14^{Aa}	10.84 ± 0.12^{Aa}	10.38 ± 0.08^{Aa}	9.17 ± 0.06^{Bb}
Starch	MPeF	37.85 ± 0.86^{Bb}	46.56 ± 0.31^{Ab}	43.24 ± 0.51^{Ab}	39.31 ± 1.02^{Bb}
	MPuF	74.29 ± 0.28^{Ba}	80.45 ± 0.25^{Aa}	69.01 ± 0.26^{Ca}	66.39 ± 0.49^{Ca}

Values are expressed as mean ± standard deviation (n = 4). For each component same capital letter and lower case in the row indicate no significant difference at $p < 0.05$ according to the Tukey´s test.

are often observed, with sucrose, fructose, and glucose as major constituents of the ripe fruits (Maldonado-Celis et al., 2019; Lebaka et al., 2021). Total sugar and starch content analyses of the mango flours showed differences between the cultivars for the two flour types, with variations from 9.12 to 12.36% for total sugars and 37.85 to 44.56% for starch in the peel flours. Pulp flours differed by the highest levels of starch (66.01 to 71.3%). The lower starch content in peel flour is due to the starch content in the peel, which is transitory starch that is biosynthesized in the chloroplasts of the fruit peels (Patiño-Rodríguez et al., 2020).

The market for gluten-free products is growing, flours as raw materials in gluten-free products is necessary to expand the product range and enrich the nutrient content. Comparing the mango flours with those obtained from rice, corn, oats, buckwheat, chickpeas, tiger nuts, and plantain (Culetu et al.,2021), the ash contents of Haden and Keitt mango peel flour and Parwin pulp flour were like those of chickpea flour, which had the highest value (3.55% d.b). The fiber content of mango peel flour exceeded that of tiger nut flour (35.42% d.b.), and those of mango pulp flours were like those of amaranth, quinoa, and buckwheat flours (9.01, 9 .39 and 10.69% d.b., respectively). The mango flour protein content was like that of plantain flour (2.91% d.b.), while the starch content of the mango peel flours was similar to that of the flours from chickpea (39.52% d.b.) and gram (dried chickpeas; 45.74% d.b.). The starch content of the mango pulp flours was comparable to those of the flours obtained from rice (82.58% d.b.), banana (78.54% d.b.), corn (72.52% d.b.), and oat (72.53% d.b.).

3.2 Minerals

Minerals are important for proper biological function, and including fruit flours in food products can help diversify the diet and minimize micronutrient deficiency risk. As reported in other studies, mango flours are composed of considerable mineral contents (Sabino et al., 2015, Diomande et al., 2021).

It was observed that the peel flours (MPeF) exhibited higher levels of total minerals than the pulp flours (MPuF), except for the 'Keitt' flours, which did not show differences by flour type in P, N, Zn, and Cu, and the pulp flour of this cultivar had the highest Fe content (Table 2).

Potassium was found at the highest level in mango flours (MPeF and MPuF) with the peel flour of the 'Keitt' cultivar presenting the highest content and the peel flour of the 'Tommy Atkins' cultivar the lowest level. Mango peel flours also contained considerable levels of manganese, with significant variations between the cultivars and particularly high levels in the Haden cultivar flour.

Diomande et al. (2021) analyzed the mineral content of mango peel flour on a dry basis from four cultivars, showing that potassium was most prevalent (1549.43 to 1883.65 mg/100 g), followed by calcium (910.33 to 1204.45 mg/100 g) and magnesium (164.87 to 257.46 mg/100 g). The peel flours of cultivars Keitt and Kent had the highest levels of iron (2.21 and 2.08 μg/100g) and the Amélie and Brooks cultivar flours had the highest levels of zinc (0.51 and 0.44 μg/100g).

Kelte et al. (2020) reported average contents of 7.82, 1.32, and 2.18 mg kg^{-1} of Fe, Mn, and Zn, respectively, for corn flour. Araújo et al. (2008) analyzed minerals in 54 wheat flour samples consumed in Brazil and reported ranges from 0.89 to 7.15 mg g^{-1} for phosphorus, 0.76 to 3.16 mg g^{-1} for potassium, 0.19 to 0.51 mg g^{-1} for magnesium, 0.11 to 1.96 mg g^{-1} for calcium, 1.00 to 2.80 μg g^{-1} for copper, 10.5 to 146.6 μg g^{-1} for iron, 3.9 to 14.7 μg g^{-1} for manganese and 5.1 to 13.9 μg g^{-1} for zinc.

Table 2. Minerals contents of mango flours (dry basis).

		Haden	Keitt	Parwin	Tommy Atkins
			g kg^{-1}		
P	MPeF	1.78 ± 0.05^{Aa}	1.01 ± 0.03^{Ca}	1.53 ± 0.04^{Ba}	1.50 ± 0.04^{Ba}
	MPuF	0.71 ± 0.02^{Cb}	0.92 ± 0.02^{Ba}	1.10 ± 0.01^{Ab}	0.89 ± 0.02^{Bb}
K	MPeF	11.24 ± 0.33^{Ba}	13.80 ± 0.41^{Aa}	7.68 ± 0.23^{Cb}	5.72 ± 0.17^{Db}
	MPuF	9.24 ± 0.26^{Cb}	10.36 ± 0.28^{Bb}	10.64 ± 0.32^{Aa}	11.08 ± 0.31^{Aa}
Ca	MPeF	3.15 ± 0.09^{Aa}	2.19 ± 0.07^{Ba}	2.13 ± 0.06^{Ba}	2.91 ± 0.09^{Aa}
	MPuF	0.76 ± 0.02^{Bb}	0.63 ± 0.02^{Cb}	0.60 ± 0.01^{Cb}	1.17 ± 0.03^{Ab}
Mg	MPeF	1.44 ± 0.04^{Aa}	1.36 ± 0.02^{Aa}	0.92 ± 0.03^{Ba}	1.01 ± 0.03^{Ba}
	MPuF	0.56 ± 0.02^{Bb}	0.44 ± 0.01^{Cb}	0.45 ± 0.01^{Cb}	0.68 ± 0.02^{Ab}
N	MPeF	5.1 ± 0.14^{Ba}	4.02 ± 0.12^{Ca}	5.05 ± 0.15^{Ba}	6.04 ± 0.16^{Aa}
	MPuF	4.03 ± 0.12^{Ab}	4.05 ± 0.12^{Aa}	3.99 ± 0.11^{Ab}	4.01 ± 0.11^{Ab}
			mg kg^{-1}		
Fe	MPeF	16.2 ± 0.48^{Aa}	9.2 ± 0.27^{Cb}	12 ± 0.35^{Ba}	2.2 ± 0.52^{Da}
	MPuF	7.4 ± 0.22^{Bb}	14.2 ± 0.41^{Aa}	5.4 ± 0.15^{Cb}	1.1 ± 0.03^{Db}
Mn	MPeF	30.48 ± 0.91^{Aa}	19.28 ± 0.58^{Ba}	13.12 ± 0.39^{Ca}	10.15 ± 0.30^{Da}
	MPuF	5.07 ± 0.15^{Bb}	9.12 ± 0.27^{Ab}	4.06 ± 0.12^{Bb}	9.21 ± 0.28^{Ab}
Zn	MPeF	9.08 ± 0.25^{Aa}	6.1 ± 0.17^{Da}	7.06 ± 0.20^{Ca}	8.08 ± 0.23^{Ba}
	MPuF	6.1 ± 0.17^{Bb}	6.13 ± 0.14^{Ba}	7.04 ± 0.18^{Aa}	6.12 ± 0.16^{Bb}
Cu	MPeF	1.01 ± 0.02^{Ab}	0.98 ± 0.01^{Aa}	0.95 ± 0.01^{Ab}	0.96 ± 0.01^{Ab}
	MPuF	2.02 ± 0.04^{Ba}	1.01 ± 0.01^{Ca}	1.97 ± 0.05^{Ba}	2.95 ± 0.06^{Aa}

Values are expressed as mean ± standard deviation (n = 4). For each mineral same capital letter and lower case in the row indicate no significant difference at $p < 0.05$ according to the Tukey´s test.

Sodium, calcium, phosphorus, magnesium, and potassium are macro minerals with recommended daily intakes for adults of >100 mg/day. Iron, copper, zinc, iodine, and manganese are trace elements, and their recommended daily intake is <100 mg (Prashanth et al. 2015). The results of the pulp and mango peel flours showed excellent mineral profiles compared to traditional flours. Thus, the inclusion of these flours in food formulations can contribute to increased mineral intake.

3.3 Total carotenoids, ascorbic acid, and antioxidant activity

Carotenoids are tetraterpene pigments responsible for the yellow, orange, red, and purple colors of fruits and have important functions in plant physiology and human health, with positive effects in terms of antioxidation and prevention of vitamin A deficiency (Liang et al., 2020).

The fruits of mango cultivars are differentiated by their peel and pulp color at different stages of maturation, and the levels of chlorophyll, anthocyanins, and carotenoids influence these colors. The mango peel flours had higher total carotenoid levels than the pulp flours (Table 3). The peel flour of the Tommy Atkins cultivar was distinguished by its high content of total carotenoids, and the content of total carotenoids in the pulp flour of the 'Keitt' was >55% higher than those observed in the other flours.

Ellong et al. (2015) reported that total carotenoids of unripe mango cultivars Bassignac, Green, Julie, and Moussache ranged between 276.17 and 2,183 µg/100 g in fresh matter and doubled in mature fruits. In their study of different mango cultivars during fruit ripening, Ranganath et al. (2018) observed a significant increase in carotenoid content in unripe fruits, <5 µg/g of fresh matter.

Ruales et al. (2018) reported 14.47 µg/g (dry weight) of total carotenoids in mango pulp and Abdul Aziz et al. (2012) observed 96.91 and 56.46 µg/g (dry weight) in green peel and green pulp mango flours. The lower levels observed herein may be due to inherent differences in cultivars, cultivation locations, and fruit maturation stages.

Ascorbic acid performs several immunological-related biological functions, including collagen formation, iron absorption, nitrosamine inhibition, and antioxidant activity (Castillo-Velarde, 2019).

The mango flours differed in ascorbic acid content, with the peel and pulp flours of the 'Parwin' presenting the highest levels. Pulp flours from the Haden and Keitt cultivars had higher levels of ascorbic acid than their respective peel flours (Table 3). The levels of ascorbic acid in mango peel flour were higher than those reported by Sogi et al. (2013) in dried mango peel powder (68.49 to 84.74 mg/100 g d.b), and lower than that reported by Rosário et al. (2022) in passion fruit albedo flour (377.36 mg/100g).

Variations in ascorbic acid contents in the pulps of mango cultivars were reported by Manthey & Perkins-Veazie (2009) in the context of growing location and harvest date. The authors observed 15.5 to 29.6 mg/100 g FW for 'Tommy Atkins', 23.6 at 38.8 mg/100 g FW for 'Haden', and 17.9 to 33.4 mg/100 g FW for 'Keitt'.

Regardless of mango cultivar, the peel flours showed higher antioxidant activity than the pulp flour, with the 'Parwin' flours showing a higher ability to scavenge free radicals. Abdul Aziz et al. (2012) also observed that mango flour samples obtained from peels showed strong scavenging effects when compared to the mango pulps.

The possibility of developing novel products from mango derivatives and increasing functionality with the inclusion of peel flour was studied by Rubiano-Charry et al. (2019). The authors observed that the addition 1% of mango peel powder to dehydrated mango pulp snacks increased the vitamin C content up to 28% as well as the bioactive and total antioxidant capacity up to 64%.

3.4 Microstructure

Micrographs of the mango flours are shown in Figure 1. The morphological observation of the mango flours by scanning electron microscopy showed cell wall fragments, starch with protein adhered to granule surfaces, and aggregated granules, likely due to damage during flour milling. In both types of flour, regardless of the cultivar, the starch granules adopted a predominantly round shape.

Lagunes-Delgado et al. (2022) reported that mango starch isolated from juice and dry flour presented round and semi-spherical shapes, without starch aggregation in the juice, unlike mango flour.

3.5 Technological properties

Significant differences were observed among the mango flours for all color parameters (Table 4). The luminosity (L*) of

Table 3. Total carotenoids, total phenolics, acid ascorbic and antioxidant activity.

		Haden	Keitt	Parwin	Tommy Atkins
Total carotenoids (µg/g)	MPeF	35.5 ± 0.21^{Ca}	41.6 ± 0.18^{Ba}	46.7 ± 0.11^{Ba}	55.2 ± 0.46^{Aa}
	MPuF	4.2 ± 0.02^{Bb}	11.5 ± 0.17^{Ab}	4.95 ± 0.16^{Bb}	4.67 ± 0.13^{Bb}
Acid ascorbic (mg/100 g)	MPeF	99.0 ± 4.19^{Bb}	103.6 ± 2.9^{Bb}	136.4 ± 7.7^{Aa}	97.4 ± 3.23^{Ba}
	MPuF	118.2 ± 4.1^{Ba}	120.2 ± 3.1^{Ba}	129.4 ± 8.7^{Aa}	102.9 ± 4.6^{Ca}
Antioxidant activity (µmol Trolox/g)	MPeF	362.3 ± 1.4^{Ba}	315.7 ± 1.4^{Ba}	576.4 ± 1.6^{Aa}	218.7 ± 0.5^{Ca}
	MPuF	45.2 ± 0.9^{Ab}	31.68 ± 0.2^{Bb}	48.84 ± 0.6^{Ab}	34.62 ± 0.2^{Bb}

Values are expressed as mean ± standard deviation (n = 4). For each component same capital letter and lower case in the row indicate no significant difference at p < 0.05 according to the Tukey´s test.

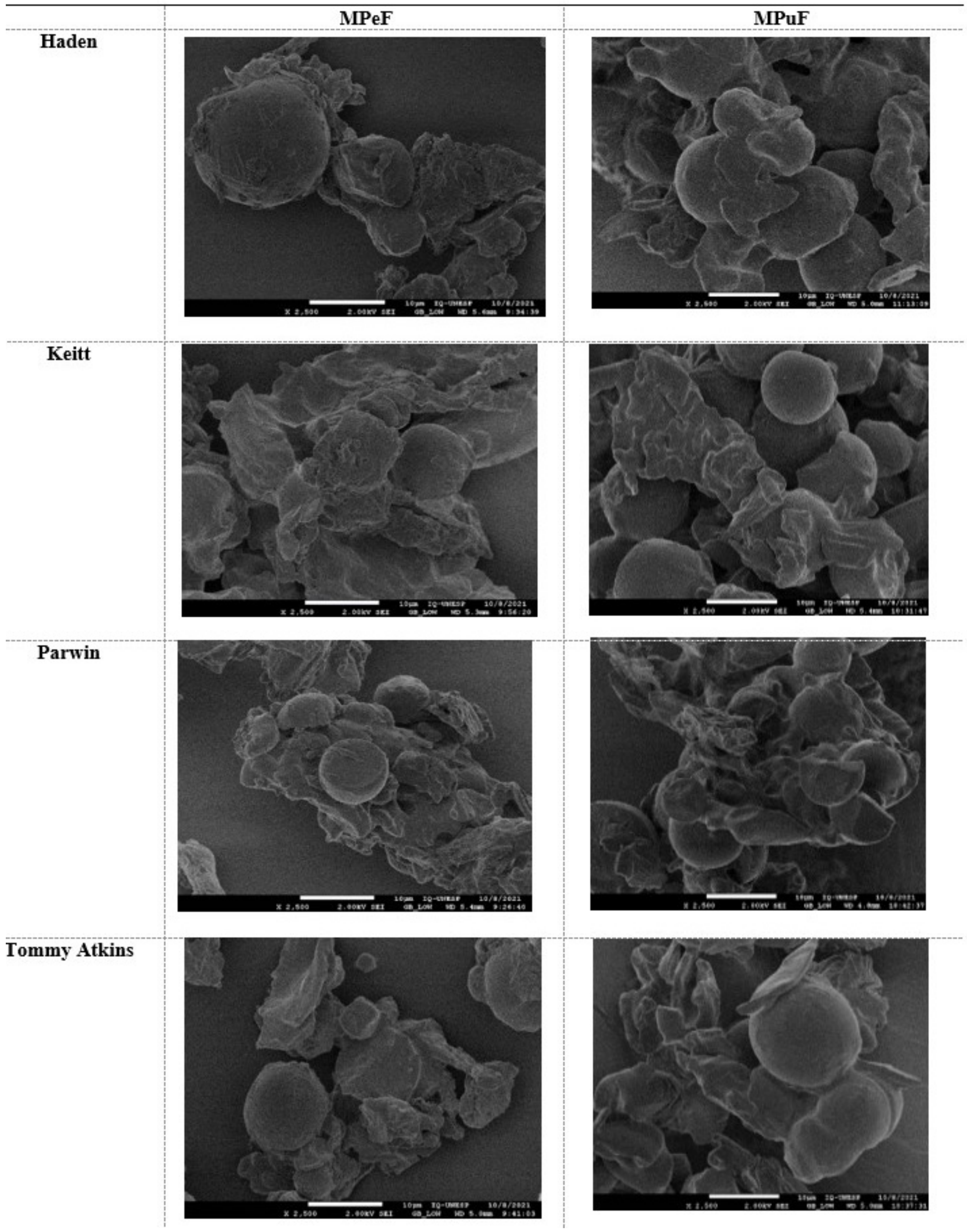

Figure 1. Scanning electron microscopy images of mango peel flour (MPeF) and pulp (MPuF) at 2500 × magnification.

the mango peel flours ranged from 61.34 to 71.15, lower than that of the flours produced from the pulp with L* values ranging from 71.31 to 81.98.

The color intensity (Chroma) ranged from 15.36 to 20.76 with the 'Keitt' mango peel and 'Parwin' mango pulp flours as the least pigmented. All mango flours exhibited a hue above 70°, that is, they were yellowish and likely influenced by carotene concentration. Abdul Aziz et al. (2012) reported 22.91 and 33.88 of chroma, and 91.87 and 95.62 of hue for the pulp and peel flours of unripe mango fruits, showing yellowish flours more pigmented than those herein, likely due to the intrinsic characteristics of the processed cultivar.

The granulometric analysis of the flours showed that the mango peel flours contained a higher percentage of large particles than the pulp flours (Table 4). The sum of the flour particles retained in the sieves 0.85 to 0.25 mm ranged from 71.57 to 80.3% for peel flours and from 64.91 to 76.83% for pulp flours, with 'Haden' and 'Tommy Atkins' mango pulp flours showing higher percentage of smaller particles (≤0.25mm).

Granulometry is a quality control parameter for flour. Particle size can determine the homogeneity of the product and specific characteristics of the flour. Products with smaller particles absorb proportionally more water than those containing larger particles (Assis et al., 2019).

Table 4. Color parameters, granulometry, water-holding capacity, and oil-holding capacity of mango flours.

		Color			
		Haden	Keitt	Parwin	Tommy Atkins
L*	MPeF	71.15 ± 0.83^{Ab}	61.96 ± 0.93^{Cb}	65.59 ± 1.20^{Bb}	61.34 ± 0.34^{Cb}
	MPuF	81.98 ± 0.13^{Aa}	71.31 ± 0.32^{Ba}	80.94 ± 0.12^{Aa}	81.73 ± 0.26^{Aa}
a*	MPeF	1.14 ± 0.07^{Ab}	0.55 ± 0.01^{Bb}	0.45 ± 0.01^{Bb}	-0.25 ± 0.02^{Cb}
	MPuF	3.48 ± 0.03^{Ca}	5.91 ± 0.03^{Aa}	4.58 ± 0.05^{Ba}	2.80 ± 0.03^{Ca}
b*	MPeF	18.66 ± 0.12^{Aa}	15.36 ± 0.04^{Bb}	18.74 ± 0.27^{Aa}	19.69 ± 0.35^{Aa}
	MPuF	19.43 ± 0.29^{Ba}	19.68 ± 0.33^{Aa}	16.46 ± 0.10^{Cb}	20.57 ± 0.46^{Aa}
Chroma	MPeF	18.69 ± 0.12^{Aa}	15.36 ± 0.04^{Bb}	18.74 ± 0.27^{Aa}	19.69 ± 0.35^{Aa}
	MPuF	19.73 ± 0.29^{Aa}	20.54 ± 0.32^{Aa}	17.08 ± 0.11^{Bb}	20.76 ± 0.45^{Aa}
Hue angle	MPeF	86.50 ± 0.19^{Ba}	87.95 ± 0.03^{Aa}	88.62 ± 0.01^{Aa}	89.27 ± 0.04^{Aa}
	MPuF	79.84 ± 0.06^{Ab}	72.80 ± 0.34^{Bb}	74.44 ± 0.06^{Bb}	82.25 ± 0.08^{Ab}
		Granulometry (% flour retained)			
0.85 mm	MPeF	6.64 ± 0.25^{Ba}	6.19 ± 0.20^{Ba}	9.22 ± 0.33^{Aa}	9.29 ± 0.42^{Aa}
	MPuF	1.11 ± 0.04^{Cb}	5.89 ± 0.19^{Aa}	3.30 ± 0.12^{Bb}	2.85 ± 0.09^{Bb}
0.60 mm	MPeF	12.09 ± 0.46^{Aa}	10.87 ± 0.35^{Ba}	10.75 ± 0.38^{Ba}	12.44 ± 0.44^{Aa}
	MPuF	6.51 ± 0.25^{Bb}	9.59 ± 0.31^{Aa}	10.05 ± 0.36^{Aa}	7.37 ± 0.26^{Bb}
0.425 mm	MPeF	23.23 ± 0.88^{Ba}	25.97 ± 0.83^{Aa}	24.65 ± 0.89^{Ba}	27.66 ± 0.97^{Aa}
	MPuF	22.33 ± 0.85^{Aa}	22.22 ± 0.71^{Ab}	22.39 ± 0.81^{Ab}	12.08 ± 0.42^{Bb}
0.25 mm	MPeF	38.34 ± 1.15^{Aa}	28.91 ± 0.92^{Bb}	26.96 ± 0.97^{Bb}	22.18 ± 0.77^{Cb}
	MPuF	38.41 ± 1.46^{Ba}	40.03 ± 1.28^{Ba}	41.09 ± 1.48^{Aa}	42.61 ± 1.51^{Aa}
Pan	MPeF	19.7 ± 0.74^{Bb}	28.06 ± 0.89^{Aa}	28.42 ± 1.02^{Aa}	28.43 ± 0.99^{Ab}
	MPuF	31.64 ± 1.20^{Ba}	22.27 ± 0.71^{Cb}	23.17 ± 0.83^{Cb}	35.09 ± 1.23^{Aa}
		Water and Oil retention (g/g)			
WHC	MPeF	4.29 ± 0.01^{Ba}	4.44 ± 0.01^{Aa}	4.18 ± 0.01^{Ca}	4.46 ± 0.01^{Aa}
	MPuF	3.26 ± 0.02^{Cb}	3.51 ± 0.03^{Bb}	3.35 ± 0.03^{Cb}	3.64 ± 0.02^{Ab}
OHC	MPeF	1.26 ± 0.01^{Ba}	1.24 ± 0.02^{Ba}	1.25 ± 0.03^{Ba}	1.37 ± 0.01^{Aa}
	MPuF	1.21 ± 0.01^{Aa}	1.20 ± 0.01^{Aa}	1.22 ± 0.02^{Aa}	1.18 ± 0.02^{Aa}

WHC = Water-holding capacity; OHC = oil-holding capacity. Values are expressed as mean ± standard deviation (n = 4). For each component, same capital letter and lower case in the row indicate no significant difference at $p < 0.05$ according to the Tukey´s test.

The water retention capacities of the mango flours ranged from 3.26 to 4.46 g/g with the mango peel flours showing higher water retention, which is justified by the higher concentration of fibers (Table 4). This is likely due to the higher fiber content and higher percentage of larger particles present in the peel flour. The high water-holding capacity is an important property for the use of mango peel flours as ingredient in meat products, breads, and cakes.

The oil retention of mango flours ranged from 1.18 to 1.37 g/g, with the 'Tommy Atkins' peel flour showing the highest retention. These retention capacities were similar to those reported in other studies with fruit flours: 1.18 to 1.27 g/g for buriti flour (Resende et al., 2019); 1.76 g/g for orange flour (Wang et al., 2015); and 1.23 to 1.35 g/g for pequi flour (Leão et al., 2017). Flours with a higher oil absorption rate act as flavor retainers and improve the sensation and taste of food.

3.6 Principal component analysis (PCA)

PCA was used herein to visualize the variations in the characteristics of the flours obtained from the mango peel (MPeF) and pulp (MPuF), accounting for >70% of the variation in the two flour types (Figure 2).

For mango peel flours (Figure 2A) PC1 and PC2 contributed 40.48% and 34.57% of the variance, respectively. Regarding the PC1 component, fiber, total sugars, lipids, carotenoids, Zn, Ca, Fe, N, Cu, WHC, and OHC were located in Quadrants 1 and 2. On the opposite side (Quadrants 3 and 4), PC2 reflects the granulometry, starch, ash, Mn, and Mg characteristics that contributed to the differentiation of MPeF from 'Haden'. Potassium, ascorbic acid, and antioxidant activities differentiated MPeF from 'Keitt'. Carotenoids contributed to the differentiation of the 'Tommy Atkins' flour.

In the PCA of mango pulp flours (Figure 2B), the overall PCA provided 70.54% of the cumulative variance, while PC1 and PC2 accounted for 40.37% and 30.17% of the variance, respectively. PC1 was reflected in Quadrants 1 and 2 and was composed of factors that contributed to the differentiation of the 'Tommy Atkins' flours. Combined with the vectors in the same direction, the data indicated a positive correlation of color parameters with moisture, WHC, and K. In PC2, the carotenoids, starch, and ash contents contributed to the differentiation of pulp flour from the Keitt cultivar. Antioxidant activity, ascorbic acid, total sugars, OHC, Zn, and Cu contributed to the similarity in pulp flours from the cultivars Parwin and Haden.

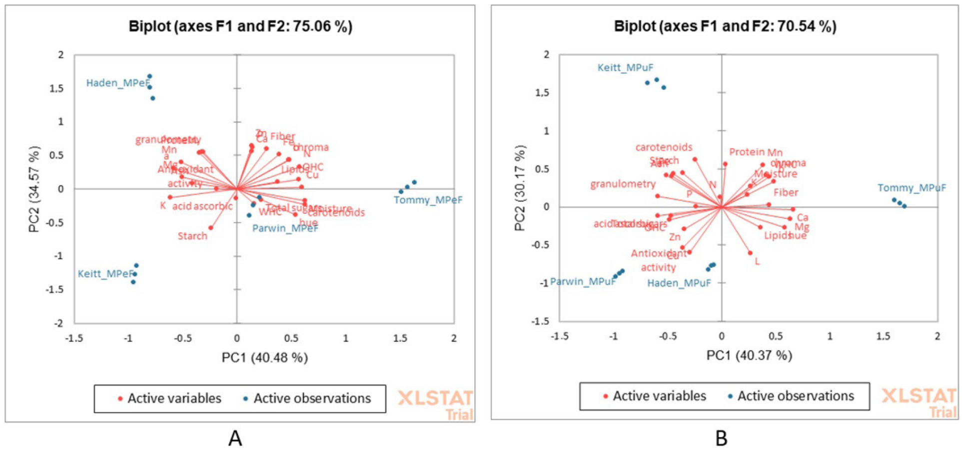

Figure 2. PCA analysis of mango flours physicochemical characteristics. (A) mango peel flours (MPeF), and (B) mango pulp flour (MPuF).

4 Conclusions

Peel flours are sources of fiber and can be used as a vector to increase the intake of minerals, carotenoids, and ascorbic acid. Pulp flours contain high levels of starch and can be used in the development of gluten-free products to increase their nutritional value. The differences between the composition of peel and pulp flours in the same cultivar can enhance the possibilities of flour mixtures and contribute to the valorization of peels as co-products. Differentiating cultivars as raw materials for obtaining fruit flours contributes to strengthening varietal diversification in the agro-industrial chain of mangoes. The results presented herein contribute to the promotion of the production of flour from non-standard fruits and mango processing residues, contributing to sustainable development and health promotion.

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