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Technological potential of mango by-products for industrial applications in Brazil

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Abstract

In the industrial processing of mangoes, large amounts of peels and seeds are generated, which can cause environmental damage if not properly managed. However, these by-products possess high added value due to the potential technological applications of their components. This study evaluated the yield of by-products and the chemical composition of three mango varieties commonly processed in Brazilian industries (Palmer, Tommy Atkins, and Ubá). The Ubá mango showed a lower pulp yield (69.3%), but its soluble solids content (15.7 °Brix) was significantly higher than that of Tommy Atkins (11.5 °Brix). Ubá mango kernel flour presented lower luminosity and a less yellowish tone but achieved a much higher flour yield. The peel flours of all the three varieties contained high levels of pectin (13.6% dry basis). Although the protein content in the kernels was similar across varieties (6.2% dry basis), Ubá mango kernel flour exhibited the highest lipid content (12.0% dry basis) and starch concentration (48.6% dry basis), highlighting its greater technological potential for industrial applications.

Keywords: *Mangifera indica*; mango industrialization; waste; added value; kernel flour.

Practical Application: This study evaluates the yields and chemical composition of by-products from peels and seeds of mango varieties commonly processed in Brazilian industries, highlighting their potential applications in industrial processing

1 INTRODUCTION

India is the world's largest mango producer, accounting for 38.19% of global production, surpassing Brazil, which is the seventh largest producer, with 3.25% of the total quantity (Gazzola et al., 2020). According to data from Instituto Brasileiro de Geografia e Estatística (IBGE, 2024), Brazil produced 1,758,118 tons of mangoes in 2023.

The global processed mango products market is estimated to be worth USD 16.55 billion. Different varieties of mangoes, such as Alphonso, Tommy Atkins, Kent, and Palmer, are cultivated in diverse climates. The secondary processed mango product segment holds the largest share of the market, including juices, fruit bars, candies, jellies, jams, pickles, and fruit-based cosmetics containing mango extracts (Grand View Research, 2018).

The mango consists of three parts: the endocarp (seed), which contains a kernel surrounded by a tegument; the exocarp (peel); and the mesocarp (pulp). Mango residues account for approximately 30–60% of the total weight of the fruit, depending on the species. The mango seed represents about 20–60% of the weight of fruits from different varieties, while the peel accounts for 15–20% of the fruit's weight (Choudhary et al., 2022 Conceição; et al., 2024; Dukare et al., 2022).

Utilizing by-products such as peels and seeds has been proposed as a viable alternative for maximizing the use of mangoes. Peels and seeds are rich in bioactive compounds, allowing for the production of peel flour (rich in fiber) and kernel flour (high in resistant starch and oil), which are typically used without additional processing (García-Mahecha et al., 2023). Some applications of these by-products include using kernel starch as a thickener in dairy drinks (Silva et al., 2013) and kernel flour for preparing cereal bars (Gomes, 2017). Mango peels are also a source of pectin (Matharu et al., 2016), and the oil extracted from the kernel can be blended with palm oil to replace cocoa butter in the formulation of chocolate and confectionery products (Jahurul et al., 2014).

The chemical composition of mango pulp, peels, and seeds can be influenced by factors such as variety, soil and climate conditions, and the cultural treatments applied during production (Simões et al., 2020). Researchers have examined the chemical composition and yield of mango by-products from different regions, revealing varying results depending on the production conditions (Kaur et al., 2023). Therefore, evaluating the technological potential of mango by-products from different varieties must take into account the specific edaphoclimatic conditions under which the mangoes are grown.

The goal of this study is to assess the differences in by-product yields and chemical compositions of peels and seeds from different mango varieties typically processed in Brazilian industries (Ubá, Tommy Atkins, and Palmer). The study aims to maintain consistency in cultivation conditions related to soil, climate, and cultural treatments, to gather insights into the technological potential of the by-products of each variety processed in the industry.

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1.1 Relevance of the work

This study evaluates the differences in by-product yields and the chemical composition of peels and seeds from mango varieties commonly processed in Brazilian industries, under cultivation conditions standardized for soil, climate, and crop management practices. The objective is to assess the technological potential of these by-products, highlighting their applicability in industrial processing.

2 MATERIAL AND METHODS

2.1 Raw material

The fruits were harvested from a commercial plantation located in the municipality of Laranja da Terra, ES (19°53′56″S, 41°3′25″W), under standardized soil, climatic conditions, and cultural practices adopted for the production of three mango varieties (Tommy Atkins, Palmer, and Ubá). According to the Köppen-Geiger classification, the climate is Aw-type (tropical rainy, with a dry winter season), with an average annual temperature of 23.8°C and average annual rainfall of 1,050 mm (Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural [INCAPER], 2020). The soil is classified as *Latossolo Vermelho Distrófico Argissólico* (Cunha et al., 2016). The fruits were harvested at the ripe stage and standardized for mass (g), length (cm), diameter (cm), and skin color, according to the typical characteristics of each mango variety.

A total of 60 samples of each variety were washed under running water, sanitized by immersion in a 100 ppm sodium hypochlorite solution for 10 min, rinsed with distilled water, and dried with paper towels. The mangoes were stored in a cold room (Climasul, Brazil) at 12°C and 90% relative humidity (RH) (Figure 1) until processing. The pulp, peel, and seeds were separated, weighed, and stored in polyethylene packaging in a freezer (Consul, Brazil) at −18°C for subsequent chemical analyses.

2.2 Physical characterization of the fruit

The fruits were weighed individually on a semi-analytical balance (Gehaca, BG 2000, Brazil), and the results were expressed in grams. The shape and size were determined by measuring the diameter (cm) with a manual caliper in three positions on the fruit: the equatorial region and the midpoints of the upper and lower parts, as well as the length from the apex to the peduncle.

Peel color was measured at three equidistant points on each side of the fruit using a Hunter colorimeter (MiniScan Spectrophotometer Plus, HunterLab, USA) with a D65 illuminant and a 10° observation angle. The device was calibrated with black and white reflective plates, and results were expressed in the CIE Lab* color space.

2.3 Determining the yield of pulp, peel, and seeds

The peel, seed, kernel, and seed coat were manually separated using a stainless steel knife. Pulp residues adhering to the peel and seed were removed by scraping to quantify the total pulp content.

The mass (g) of the peel, seed, and pulp was measured on a semi-analytical balance (Gehaca, BG 2000, Brazil). The mass of the seed coat and kernel was determined after cutting the seed with stainless steel scissors. The yield of pulp and co-products from peels and seeds (g 100 g^{-1} fruit) was calculated in relation to the fruit mass.

The yield of flour from the peel and kernel fractions, relative to fruit mass, was calculated based on a mass balance, considering the proportion of each component and its dry matter content (Association of Official Analytical Chemists [AOAC], 2005), and assuming a final dry matter content of 90% in the flour (Equation 1), according to Talma et al. (2019).

$$Y_f = \left(\frac{F_{comp} * X_{dm}}{DM_f}\right) \qquad (1)$$

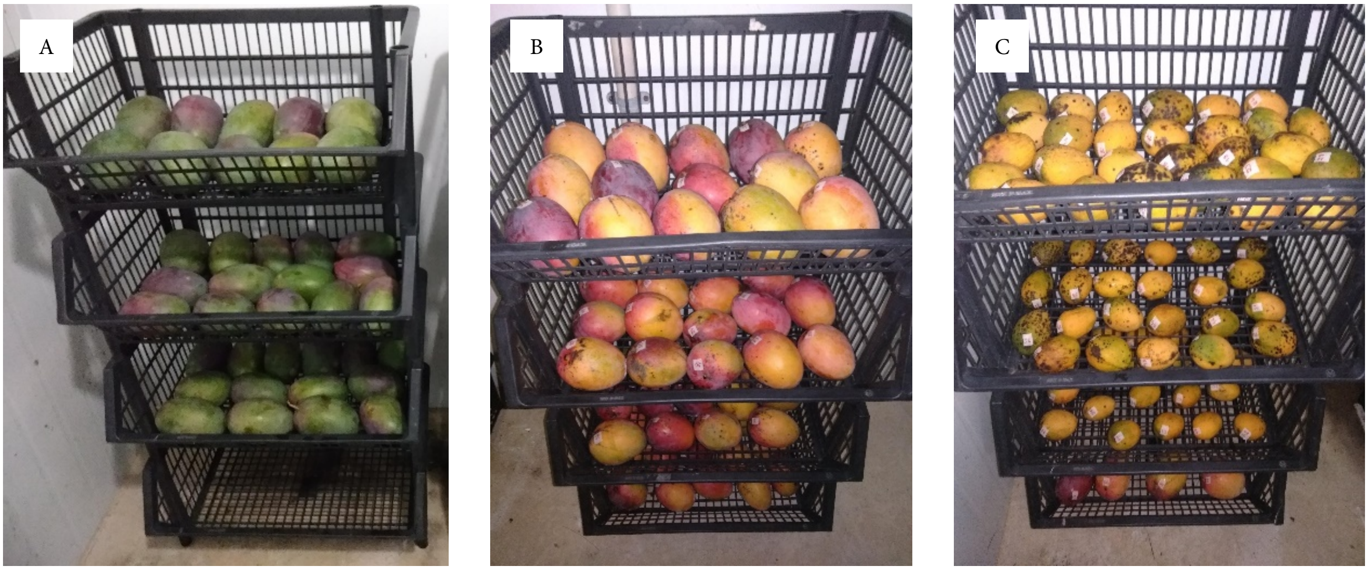

Figure 1. Mango varieties stored at 12 °C and 90% relative humidity: (a) Palmer, (b) Tommy Atkins, and (c) Ubá.

where Y_f = Yield of flour from peel or seed components, % (g 100 g^{-1} fruit); F_{comp} = Proportion of each component, % (g 100 g^{-1} fruit); X_{dm} = Dry matter content of each component, % (g 100 g^{-1} material); DM_f = Final dry matter content in the flour, % (g 100 g^{-1} dry material).

2.4 Moisture characterization of the co-products and total soluble solids of the pulp

The peel and seed samples from each fruit were thawed and cut into small pieces, while the pulp was homogenized using a blender (Turratec, TE 102, Brazil). Triplicate samples of 1 g were weighed on an analytical balance (Gehaca, AG 200, Brazil) and dried in an oven (Quimis, Q317M32, Brazil) at 105°C for 24 h (AOAC, 2005). After cooling and weighing, the moisture and dry matter contents were determined (g 100 g^{-1} samples).

The total soluble solids (TSS) content (°Brix) was determined in triplicate using homogenized pulp samples from each fruit with a digital refractometer (Atago, PAL-1, Japan).

2.5 Obtaining mango co-product flours

The samples of peels, teguments, and kernels were thawed and processed in a tray dryer (Pardal, Brazil) at 50°C for 24 h. The dried samples were ground in an analytical mill (Quimis, Brazil) and sieved through a 50-mesh sieve to standardize the flour. All analyses were performed in triplicate, using five replicates composed of samples from 12 fruits.

2.6 Characterization of flour moisture and color

The flours were analyzed for moisture content as described in Section 2.4, and the results were expressed as % (g 100 g^{-1}). Color was measured using a Hunter colorimeter (MiniScan Spectrophotometer Plus, HunterLab, USA), with results expressed in the CIE L*, a*, b* system. Measurements were taken in a crystal cuvette (40 × 60 mm) attached to a black opaque cup (65 × 75 mm), following the methodology described by Talma et al. (2019).

2.7 Lipid content of the flours

Lipid analysis was performed based on the Bligh and Dyer method, with adaptations. A 1 g portion of the sample (Gehaca analytical balance, AG 200, Brazil) was mixed with 10 mL of chloroform, 20 mL of methanol, and 8 mL of distilled water. After mechanical stirring (Norte Científica, NA 3600, Brazil), 10 mL of chloroform and 10 mL of 15% sodium sulfate were added, stirred for 2 min, and left to stand to allow phase separation. Then, 15 mL of the lipid fraction in chloroform was combined with 1 g of anhydrous sodium sulfate to remove residual moisture. After manual stirring, the liquid phase was filtered through filter paper, and 5 mL of the filtrate was collected in a previously dried and weighed Petri dish, which was kept in an oven (Quimis, Brazil) at 105°C for 4 h. After cooling and reweighing on an analytical balance (Gehaca, AG 200, Brazil), lipid content was determined using Equation 2.

$$C_L = \frac{(Pf - Pi) * 4 * 100}{m} \tag{2}$$

where C_L = Lipid content (% db); P_f = Final weight of the plate (g); P_i = Initial weight of the plate (g); Weight 4 = Correction factor for the chloroform volume; m = flour mass (g, db).

2.8 Protein content of the flours

Protein analysis was performed based on the Kjeldahl method (AOAC, 2005), with adaptations. Flour samples (0.5 g), weighed on an analytical balance (Gehaca, AG 200, Brazil), were placed in a test tube with 1 g of catalytic mixture and 7 mL of reagent-grade sulfuric acid. The mixture was digested in heating blocks (Tecnal, TE 007A, Brazil), initially at 50°C, and then gradually heated and maintained at 350°C for 1 h. After cooling, 7 mL of distilled water and three drops of phenolphthalein indicator were added. The solution was then distilled in a nitrogen distiller (Marconi, MA 036 plus, Brazil) using a 50% sodium hydroxide solution. A 75 mL aliquot of distillate was collected in a 125 mL Erlenmeyer flask containing 20 mL of 4% boric acid, four drops of methyl red, and two drops of bromocresol green. The distillate was titrated with 0.1 N hydrochloric acid until the endpoint (pink coloration). Protein content in the flour was calculated according to Equation 3.

$$C_P = \frac{K * 0{,}0014 * 100 * V * N_P}{m} \tag{3}$$

where C_P = Protein content (% db); K = Correction factor for the HCl solution; Weight 0.0014 = Conversion factor for N_2 content in the sample; V = Volume of 0.1 N HCl solution used in the titration (mL); N_P = Nitrogen to protein conversion factor (6.25); m = flour mass (g, db).

2.9 Total sugar and starch content of the flours

Total sugar analysis was performed based on the Lane-Eynon method (AOAC, 2005). Flour samples (2 g) were homogenized with 40 mL of distilled water and 2 mL of concentrated hydrochloric acid, and incubated in a water bath at 60°C for 1 h. After cooling, the solution was neutralized with 40% sodium hydroxide and transferred to a 50 mL volumetric flask containing 2 mL of 15% potassium ferrocyanide and 2 mL of 30% zinc acetate. The flask was filled to volume with distilled water, mixed thoroughly, and allowed to stand for 30 min. The solution was then filtered through filter paper and used to titrate a heated mixture of 5 mL Fehling A and 5 mL Fehling B with 40 mL of distilled water, until the endpoint indicated by the color change of 1% methylene blue. The total sugar content was calculated according to Equation 4.

$$TS\,(\%) = \frac{FC}{2} * 50 * 100/(V * P) \tag{4}$$

where TS = total sugar content (g 100 g^{-1} db), FC = Fehling solution titer, V = volume used in titration (mL), P = sample weight (g).

The same protocol was applied for starch analysis, except that the flour solution in an acidic medium was autoclaved at 120°C for 30 min. Starch content was calculated according to Equation 5.

$$\text{Stc}\ (\%) = \left[\left(\frac{\text{FC}}{2} * 250 * 100/(\text{V} * \text{P})\right) - \text{TS}\right] * 0.90 \tag{5}$$

where Stc (%) = Starch content (g 100 g^{-1} db), FC = Fehling solution titer, V = volume used in titration (mL), P = sample weight (g), TS (%) = Total sugar content (g 100 g^{-1}), 0.90 = glucose to starch conversion factor.

2.10 Fiber content of the flours

The non-enzymatic gravimetric method (AOAC 920.86/ AACC 32.10), with adaptations, was used for fiber determination. Bags made of TNT fabric were pretreated by immersion for 15 min in a 20% neutral detergent solution heated to 90°C, washed by immersion in hot distilled water (2–3 times), and neutralized with 30–40 mL of pure acetone. The bags were dried in a tray dryer (Pardal, Brazil) at 55°C for 24 h, placed in an oven (Quimis, Q317M32, Brazil) at 105°C for 2 h, and cooled in a desiccator for 1 h. Flour samples (0.5 g), weighed on an analytical balance (Gehaca, AG 200, Brazil), were placed in the bags, sealed, and incubated in glass tubes containing 30 mL of 8 M urea solution and four drops of thermostable amylase, heated in a water bath at 90°C for 5 min, and left at room temperature for 4 h. The bags were then digested in a fiber digester (Tecnal, TE 149, Brazil) under reflux with 3 L of neutral detergent solution and four drops of amylase enzyme for 60 min. Subsequently, they were washed by immersion in hot distilled water (2–3 times, 30 s each), dried, and cooled in a desiccator. The bags were weighed on an analytical balance to determine fiber mass. The dry residue was further analyzed for ash content (AOAC, 2005) after incineration in a muffle furnace (Quimis, Q318M, Brazil) at 550°C for 4 h. Fiber content was calculated according to Equation 6.

$$\text{C}_{\text{FT}} = \left(\frac{\text{Pf}}{\text{m}} * 100\right) - \text{C}_{\text{ash}} \tag{6}$$

where C_{FT} = fiber content in the flour (g/100 g^{-1}, db), C_{ash} = ash content in the fibers (g/100 g^{-1}), P_f = fiber dry mass (g), m = flour mass (g, db).

2.11 Pectin content of the flours

Pectin was extracted according to Talma et al. (2019) The flour was suspended (1:50 w/v) in 25 mL of distilled water and mixed with 25 mL of 1 mol L^{-1} nitric acid, previously heated to 80°C in a water bath (Precision Reciprocal Shaking Bath Model 50, Thermo Scientific, USA), stirred for 40 min, and cooled in an ice bath. The solution was filtered, combined with three volumes of ethanol, and stored at 4°C for 15 h (overnight). After centrifugation (Sorvall Legend RT Centrifuge, Thermo Scientific, USA) at 4500 rpm for 40 min, the pellet was washed with cold acetone and centrifuged again at 4500 rpm for 20 min. The pectin was dried in a forced-air oven at 37°C for 5 h and weighed on an analytical balance. The yield was expressed relative to flour mass (dry basis), normalized to 100 g.

2.12 Ash content of the flours

Ash content of the flours was determined according to the AOAC methodology. Approximately 5 g of sample (Gehaca, AG 200, Brazil) was weighed into a porcelain crucible (previously dried in a muffle furnace at 550°C, cooled, and stored in a desiccator). The samples were carbonized over a Bunsen burner and incinerated in a muffle furnace (Quimis, Q318M, Brazil) at 550°C for 4 h until light ash was obtained. The temperature was then reduced to 150°C, and the crucibles were cooled in a desiccator and weighed to determine ash mass. The results were expressed according to Equation 7.

$$\text{Ac} = \frac{\text{As}}{\text{Ms}} * 100 \tag{7}$$

where A_c = Ash content of the flour (%, db), A_s = Ash mass of the sample (g), M_s = Mass of the sample (g, db).

2.13 Statistical analysis

The experiment was conducted in a completely randomized design (CRD), with 60 replicates for yield analysis of the components of the three mango varieties, and five replicates of composite samples of 12 fruits for the chemical analysis of the flours of each fruit component (by-product), performed in triplicate. The results were processed using STATISTICA software, version 7.0, and analyzed by analysis of variance (ANOVA). Mean comparisons were performed using Tukey's test at the 5% significance level.

3 RESULTS AND DISCUSSION

3.1 Physical characteristics of different mango varieties

The physical measurements of the fruits are presented in Table 1. Palmer mangoes showed the highest average fruit mass and length, whereas Tommy Atkins mangoes exhibited the highest equatorial diameter values. Ubá mangoes had significantly smaller length, width, and weight compared with Tommy Atkins and Palmer mangoes.

Fruit size and weight can be influenced by soil and climatic conditions, as well as by cultural practices adopted in cultivation. According to Oliveira et al. (2013), Ubá mangoes are small, oblong–oval fruits, ranging from 92.3 g to 160.8 g. Silva et al. (2009) reported average weights of 135.6 g for Ubá mangoes, 521.1 g for Tommy Atkins, and 678.6 g for Palmer. In the evaluation of 67 Ubá mango accessions of industrial interest, Rufini et al. (2011) observed variability in fruit mass (91.5–182.25 g), seed mass (8.25–21.0 g), and longitudinal and transverse diameters, with averages of 71.58 mm and 56.66 mm, respectively.

As shown in Table 1 and Figure 1, Ubá mangoes are characterized by the highest luminosity values (CIE L*) and a more yellowish tone (CIE b*). Palmer mangoes display a greener hue, as indicated by the negative CIE a* values, whereas Tommy Atkins mangoes exhibit a redder hue, reflected in their higher CIE a* values.

In the study by Silva et al. (2009), the yellow color indices (CIE b*) were lower than those obtained in the present study, with values of 33.4 for Ubá, 17.0 for Tommy Atkins, and 13.9 for Palmer. Carvalho (2021) reported that Palmer mangoes had lower luminosity (CIE L* = 30.67), a higher red index (CIE a* = 13.73), and a lower yellow index (CIE b* = 13.35). According to Costa et al. (2017), during the ripening of Tommy Atkins mangoes, luminosity (CIE L*) ranges from 31.34 to 39.47; the CIE a* parameter increases from –5.94 at 35 days after flowering to 8.49 at 135 days; and the yellow hue (CIE b*) reaches values of about 20 during this period.

Table 1. Physical characterization of three mango varieties (Palmer, Tommy Atkins, and Ubá) harvested at the ripe stage on a commercial farm in Laranja da Terra, Espírito Santo, Brazil.

Physical characteristics		Varieties		
		Palmer	Tommy Atkins	Ubá
Weight		549.23 ± 13.53^{a}	509.77 ± 8.19^{b}	118.89 ± 2.47^{c}
(g)		9.0 ± 0.1^{a}	9.0 ± 0.1^{a}	5.4 ± 0.1^{b}
Width	Upper half	7.9 ± 0.1^{b}	8.1 ± 0.1^{a}	4.6 ± 0.1^{c}
(cm)	Bottom half	7.3 ± 0.1^{a}	7.0 ± 0.1^{b}	4.1 ± 0.1^{c}
Length		13.1 ± 0.1^{a}	11.5 ± 0.1^{b}	7.5 ± 0.1^{c}
(cm)	CIE L*	47.08 ± 0.51^{c}	54.76 ± 0.84^{b}	62.36 ± 0.36^{a}
Peel	CIE a*	−0.18 ± 0.81^{c}	17.79 ± 1.01^{a}	6.98 ± 0.33^{b}
color	CIE b*	22.21 ± 0.79^{c}	33.55 ± 1.03^{b}	53.59 ± 0.44^{a}

CIE: Commission Internationale de l'Éclairage. Color space coordinates means followed by the same letter in a row do not differ significantly according to Tukey's test at the 5% probability level. Data are expressed as mean ± standard deviation.

3.2 Yield of pulp, peel, and seed

The quantification of pulp yield and by-products from the three mango varieties is presented in Table 2.

The Tommy Atkins variety showed the highest pulp yield, with lower proportions of peel and seed. In contrast, the Ubá mango had the lowest pulp and total by-product yields but the highest proportions of peel, seed, and kernel, highlighting its potential for co-product utilization (Table 2). The seed of the Ubá mango accounted for 14.45% of the fruit mass, whereas that of the Tommy Atkins mango represented 7.81%.

According to Oliveira et al. (2013), Ubá mango fruits contain between 64.34 g and 107.15 g of pulp, approximately 13.48 g to 29.90 g of peel, and 15.7 g to 30.4 g of kernel, values similar to those obtained in the present study. Here, peel and seed residues were carefully scraped to remove as much adhered pulp as possible.

In an evaluation of the performance of a mango pulping machine, Wurlitzer et al. (2019) reported yields of 75.5% pulp, 11.7% peel, and 10% seed for Tommy Atkins mangoes, while Palmer mangoes yielded 77.5% pulp, 8.1% peel, and 9.3% seed. In the present study, peel and seed yields for these varieties were lower, likely due to manual scraping to remove adhered pulp (Table 2). Silva et al. (2009) also observed lower pulp yield (61.2%) and higher seed (15.6%) and peel yields (23.3%) for Ubá mangoes compared with Tommy Atkins and Palmer varieties.

Table 2. Mass (g), moisture content (g 100 g^{-1}), yield of fruit components (g 100 g^{-1} wb), and flour yield (g 100 g^{-1}) of peel, tegument, and kernel from three mango varieties (Palmer, Tommy Atkins, and Ubá) harvested at the ripe stage on a commercial farm in Laranja da Terra, Espírito Santo, Brazil.

Fruit content	Varieties		
	Palmer	T Atkins	Ubá
Pulp (g)	445.09 ± 12.18^{a}	427.50 ± 7.27^{a}	82.93 ± 2.36^{b}
Peel (g)	41.98 ± 1.06^{a}	24.21 ± 0.81^{b}	10.00 ± 0.30^{c}
Seed (g)	46.68 ± 1.06^{a}	39.65 ± 0.65^{b}	16.96 ± 0.38^{c}
Tegument (g)	13.52 ± 0.38^{a}	13.38 ± 0.29^{a}	6.24 ± 0.13^{b}
Kernel (g)	32.61 ± 0.79^{a}	25.38 ± 0.47^{b}	9.77 ± 0.25^{c}
Yield of pulp (g 100 g^{-1} wb)	80.74 ± 0.29^{b}	83.81 ± 0.23^{a}	69.26 ± 0.67^{c}
Yield of peel (g 100 g^{-1} wb)	7.74 ± 0.16^{b}	4.77 ± 0.15^{c}	8.56 ± 0.28^{a}
Yield of seed (g 100 g^{-1} wb)	8.58 ± 0.14^{b}	7.81 ± 0.10^{c}	14.45 ± 0.32^{a}
Yield of tegument (g 100 g^{-1} wb)	2.47 ± 0.04^{c}	2.64 ± 0.05^{b}	5.30 ± 0.10^{a}
Yield of kernel (g 100 g^{-1} wb)	6.00 ± 0.13^{b}	5.00 ± 0.07^{c}	8.19 ± 0.24^{a}
Moisture of pulp (g 100 g^{-1})	85.35 ± 0.11^{b}	86.82 ± 0.10^{a}	82.78 ± 0.08^{c}
Moisture of peel (g 100 g^{-1})	83.34 ± 0.10^{a}	80.43 ± 0.09^{b}	77.59 ± 0.12^{c}
Moisture of tegument (g 100 g^{-1})	46.91 ± 0.08^{a}	44.77 ± 0.11^{b}	34.41 ± 0.10^{c}
Moisture of kernel (g 100 g^{-1})	44.17 ± 0.09^{b}	46.11 ± 0.09^{a}	43.17 ± 0.10^{c}
Total soluble solids in pulp (°Brix)	16.89 ± 0.16^{a}	11.49 ± 0.15^{c}	15.70 ± 0.18^{b}
Yield of peel flour (g 100 g^{-1} fruit)	1.44 ± 0.28^{b}	1.03 ± 0.24^{c}	2.10 ± 0.57^{a}
Yield of tegument flour (g 100 g^{-1} fruit)	1.46 ± 0.17^{c}	1.62 ± 0.26^{b}	3.79 ± 0.57^{a}
Yield of kernel flour (g 100 g^{-1} fruit)	3.73 ± 0.66^{b}	2.99 ± 0.33^{c}	4.91 ± 0.79^{a}

Means followed by the same letter in a row do not differ significantly according to Tukey's test at the 5% probability level. Data are expressed as mean ± standard deviation.

The Ubá mango was further characterized by the lowest moisture content in pulp, peel, tegument, and kernel (Table 2). Wurlitzer et al. (2019) reported 81.48% moisture in Tommy Atkins pulp and 85.85% in Palmer pulp. Carvalho (2021) found 73.19% moisture in Palmer peel, while Silva et al. (2009) reported 64.78% moisture in Tommy Atkins kernel. In contrast, Lima et al. (2019) recorded 55.6% moisture in Palmer kernel.

The pulps of Palmer and Ubá mangoes had higher TSS values, favoring their suitability for industrial processing (Table 2). The TSS content of Ubá mangoes ranges from 16.0 to 19.0 °Brix (Benevides et al., 2008).

Among the three varieties, the peels and kernels of Ubá mangoes provided the highest flour yields (Table 2). The kernel flour yield (4.91%) was more than double the peel flour yield (2.10%), underscoring the relevance of developing technologies for the valorization of these co-products.

3.3 Characterization of peel and seed co-products: color attributes and chemical composition

The color, moisture, and chemical composition of flours obtained from the co-products of the three mango varieties are presented in Table 3. Peel and kernel flours from Palmer mangoes exhibited the highest luminosity values (CIE L*). In contrast, Ubá mango kernel flour showed lower luminosity and a slightly less yellowish hue (CIE b*). For Tommy Atkins mango kernel flour, Gomes (2017) reported lower values of CIE L* (62.33), CIE a* (2.53), and CIE b* (17.41).

Peel flours were characterized by higher moisture content than kernel flours across all the three varieties (Table 3). This difference may be attributed to the water-retention capacity of the chemical constituents present in each material. Izidoro et al. (2023) also reported higher moisture content in Tommy Atkins peel flour (7.85%) compared with Keitt (5.59%) and Haden (4.80%) varieties.

Kernel flours showed higher lipid contents than peel flours in all varieties (Table 3). Notably, the lipid content of Ubá mango kernel flour was 54.6% higher than that of Palmer mango kernel flour.

According to Vieira et al. (2009), Ubá mango kernel flour contains 12.18% ether extract, whereas Ramos et al. (2021) reported lower lipid values in Tommy Atkins kernels (6.34%), differing from the findings of Gomes (2017) (9.01%) and Láscaris et al. (2020) (11.17%). The lowest lipid values in peel flours were reported by Rybka et al. (2018) for Tommy Atkins (2.05%) and Palmer (1.5%) mangoes. Such discrepancies in the chemical composition of the same variety highlight the importance of standardizing production conditions. Mwaurah et al. (2020) noted that lipid content in mango kernels ranges from 8.15 to 25.57%, values comparable to those of soybeans and cotton seeds (18–20%).

Protein content was generally higher in kernel flour than in peel flour across the varieties, except for Ubá mango (Table 3). Kernel flours averaged 6.16% protein, representing approximately 50% of the value found in wheat flour (Abdelaleem &

Table 3. Color parameters and contents of moisture (%), lipids (g 100 g^{-1} db), proteins (g 100 g^{-1} db), total sugars (g 100 g^{-1} db), starch (g 100 g^{-1} db), fiber (g 100 g^{-1} db), pectin (g 100 g^{-1} db), and ash (g 100 g^{-1} db) in flours from peel, tegument, and kernel of three mango varieties (Tommy Atkins, Palmer, and Ubá) harvested at the ripe stage on a commercial farm in Laranja da Terra, Espírito Santo, Brazil.

	Tommy Atkins			**Palmer**			**Ubá**		
	Peel	**Kernel**	**Tegument**	**Peel**	**Kernel**	**Tegument**	**Peel**	**Kernel**	**Tegument**
CIE L*	53.15 ± 0.07^{bC}	63.43 ± 0.09^{bB}	69.84 ± 0.19^{bA}	54.38 ± 0.07^{aC}	65.60 ± 0.07^{aB}	73.11 ± 0.07^{aA}	52.24 ± 0.09^{cC}	60.64 ± 0.13^{cB}	69.05 ± 0.13^{cA}
CIE a*	7.20 ± 0.17^{bA}	3.96 ± 0.11^{bC}	5.12 ± 0.12^{aB}	6.45 ± 0.06^{cA}	4.47 ± 0.06^{aB}	3.53 ± 0.05^{bC}	8.76 ± 0.08^{aA}	3.71 ± 0.08^{bC}	4.90 ± 0.10^{aB}
CIE b*	27.67 ± 0.06^{bA}	21.62 ± 0.06^{bB}	21.94 ± 0.07^{cB}	26.78 ± 0.12^{cA}	22.03 ± 0.10^{aB}	22.36 ± 0.09^{bB}	29.81 ± 0.11^{aA}	20.32 ± 0.11^{cC}	22.96 ± 0.08^{aB}
Moisture (%)	7.31 ± 0.23^{bA}	5.98 ± 0.52^{aB}	3.99 ± 0.25^{aC}	9.97 ± 0.35^{aA}	5.23 ± 0.33^{bB}	3.98 ± 0.30^{aC}	7.34 ± 0.22^{bA}	5.09 ± 0.38^{bB}	3.76 ± 0.37^{aC}
Lipids (% db)	3.68 ± 0.26^{bB}	8.69 ± 0.18^{bA}	0.39 ± 0.03^{bC}	4.78 ± 0.40^{aB}	7.78 ± 0.38^{cA}	0.28 ± 0.05^{bC}	4.85 ± 0.33^{aB}	12.03 ± 0.30^{aA}	0.85 ± 0.15^{aC}
Proteins (% db)	5.15 ± 0.04^{bB}	6.26 ± 0.11^{aA}	2.83 ± 0.40^{aC}	4.90 ± 0.36^{cB}	6.05 ± 0.21^{aA}	2.49 ± 0.30^{aC}	6.18 ± 0.13^{aA}	6.18 ± 0.17^{aA}	2.63 ± 0.24^{aB}
Total sugars (% db)	21.23 ± 0.24^{bA}	6.34 ± 0.40^{aB}	4.75 ± 0.65^{bC}	30.41 ± 0.69^{aA}	6.10 ± 0.39^{aB}	6.00 ± 1.00^{aB}	19.12 ± 1.16^{cA}	4.91 ± 0.32^{bB}	5.41 ± 0.67^{abB}
Starch (% db)	10.06 ± 0.46^{bC}	44.31 ± 0.45^{bA}	15.41 ± 0.55^{aB}	7.08 ± 0.55^{cC}	48.08 ± 0.55^{aA}	14.91 ± 0.71^{aB}	11.20 ± 0.69^{aC}	48.62 ± 0.66^{aA}	14.59 ± 0.80^{aB}
Fibers (% db)	41.93 ± 2.43^{aB}	33.02 ± 3.21^{aC}	75.12 ± 2.48^{aA}	39.47 ± 3.22^{bB}	23.81 ± 3.99^{cC}	74.43 ± 2.62^{aA}	38.46 ± 2.21^{bB}	26.22 ± 1.20^{bC}	75.03 ± 2.20^{aA}
Pectin (% db)	14.26 ± 1.34^{a}	nd	nd	13.09 ± 0.61^{a}	nd	nd	13.52 ± 0.23^{a}	nd	nd
Ashes (% db)	4.17 ± 0.18^{bA}	2.17 ± 0.13^{aB}	1.36 ± 0.12^{aC}	4.51 ± 0.14^{aA}	2.64 ± 0.13^{aB}	1.21 ± 0.18^{bC}	3.06 ± 0.26^{cA}	2.06 ± 0.07^{bB}	1.39 ± 0.19^{aC}
Sum of chemical components (% db)	100.48	99.79	99.86	104.24	99.69	99.79	96.39	100.02	99.9

nd: not determined. Data are represented with standard deviations. In each line, the means followed by the same lowercase letters for the same material among different varieties, and the same capital letters among different materials for the same variety, indicate no significant difference by the Tukey test at $p \leq .05$

Al Azab, 2021). According to Mwaurah et al. (2020), mango kernels may contain 6.0–13% protein, including essential amino acids important for human nutrition. Similarly, Abdalla et al. (2007) found a high essential amino acid content (32.1 g 100 g^{-1} protein), exceeding Food and Agriculture Organization of United Nations (FAO, 1993) reference levels. Vieira et al. (2009) reported 4.39% protein in Ubá mango kernels. For Tommy Atkins mangoes, Izidoro et al. (2023) found 3.79% protein in peel flour, while Rybka et al. (2018) observed only 0.82%. In kernel flour, Gomes (2017) reported 5.37% protein, and Ramos et al. (2021) found 6.81%, with lower values in peel flour (3.92%).

Peel flours contained more total sugars than kernel flours in all the three varieties, with Ubá mango exhibiting the lowest sugar contents in both peel and kernel (Table 3). This suggests that sugars accumulate preferentially in the peel during ripening. Izidoro et al. (2023) reported an average of 10.52% total sugars in the peel of Keitt and Tommy Atkins mangoes, compared with 9.42% in Haden and Parwin mangoes.

Starch content also differed between peel and kernel components. Ubá mango kernels had particularly high starch levels, while Palmer mango peels had the lowest (Table 3). Starch represented approximately half of the chemical composition of Ubá and Palmer kernels, supporting their potential use as starch sources in food applications. In Indian mangoes, starch content in kernels ranged from 47.45% to 59.06%, with 97.8% purity (Sonthalia & Sikdar, 2015). Digestibility studies further indicated that more than 70% of this starch is resistant to digestion, a valuable property for developing foods targeting individuals with diabetes (Mwaurah et al., 2020).

Ash content was higher in peels than in kernels across all varieties, especially in Palmer mangoes, while Ubá mangoes had the lowest values (Table 3). Higher ash levels likely reflect mineral content associated with structural cell wall components and pigments in the peel. Izidoro et al. (2023) reported ash content of 2.78% in Tommy Atkins peel flour, lower than that of Haden and Keitt mangoes (3.86% on average). In kernels, Mwaurah et al. (2020) found ash contents ranging from 0.26 to 4.69%, indicating their potential as a mineral source in functional foods.

Peel flours were also characterized by high pectin content, averaging 13.6% across the three varieties (Table 3), whereas kernels contained only trace amounts. Depending on extraction conditions and mango varieties, peel may contain 5–11% pectin (Wongkaew et al., 2020). Oliveira et al. (2018) reported values ranging from 18.8 to 32.1% in Ubá mango peels, depending on the extraction method.

Teguments were characterized by high fiber content, with no significant differences among varieties. Kernels had the lowest fiber contents, particularly in Ubá mangoes (Table 3). Peel flours had higher fiber levels than kernel flours in all the three varieties. Rybka et al. (2018) found 19.3% acid detergent fiber and 21.2% neutral detergent fiber in Tommy Atkins peel flour, compared with 16.4 and 21.7%, respectively, in Palmer peel flour. In kernel flour from Tommy Atkins mangoes, Ramos et al. (2021) reported 25.8% insoluble dietary fiber, 11.6% soluble dietary fiber, and 39.15% available carbohydrates. For peel flour, they reported 36.7, 17.3, 19.4, and 39.1%, respectively. Vieira et al. (2009) found that Ubá mango kernel flour contained 29.65% neutral detergent fiber and 70.0% total carbohydrates.

4 CONCLUSIONS

All the three mango varieties presented high pulp yields, ranging from 69.3% in Ubá mangoes to 83.8% in Tommy Atkins mangoes. Ubá mangoes showed the highest yields of peels (8.6 g 100 g^{-1} fruit) and seeds (14.5 g 100 g^{-1} fruit), as well as the highest production of peel flour (2.1 g 100 g^{-1} fruit) and kernel flour (4.9 g 100 g^{-1} fruit).

The kernel flour from the three varieties was rich in starch, with the highest value observed in Ubá mangoes (48.4% db), which also exhibited the highest lipid content (12% db). The peel flour from all varieties proved to be a good source of pectin (13.6% db on average).

Therefore, the by-products of Ubá mangoes, in addition to presenting the highest yields of peel and kernel flours, also show greater technological potential due to the elevated starch and lipid contents in kernel flour and the relevant pectin content in peel flour, making this variety particularly advantageous for by-product valorization.

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