Original article

Major physicochemical and antioxidant changes during peach-palm (*Bactris gasipaes* H.B.K.) flour processing

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Major physicochemical and antioxidant changes during peach-palm (*Bactris gasipaes* H.B.K.) flour processing.

Abstract – Introduction. Several studies have demonstrated that food processing affects nutrients such as bioactive compounds, protein, starch, fat, fiber, minerals and antioxidant capacity. Our study examined how heat changes the physicochemical composition and antioxidant capacity of peach-palm fruit (*Bactris gasipaes* H.B.K.) during flour production. **Materials and methods**. Five commercial batches of fruit were assessed for total contents of phenolic compounds and carotenoids, and hydrophilic oxygen radical absorbance capacity (H-ORAC). The fruit was then cooked and eventually processed into flour. **Results and discussion**. No significant changes were found for contents of fat, protein, starch and dietary fiber during flour production. Cooked peach-palm fruit is a source of Mg, Mn, Cu and K, with 100 g of fruit containing between 5% and 13.5% of the recommended daily intake. Cooking also increased carotenoids by 17%, thus helping to compensate for the 28% loss during drying. No stage of processing affected polyphenol contents or H-ORAC. **Conclusion.** Because of its high bioactive compound content, peach-palm flour shows potential for use in the development of functional foods.

Costa Rica / *Bactris gasipaes* / fruits / processing / drying / proximate composition / carotenoids / polyphenols / antioxidants

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Principales modifications physico-chimiques et antioxydantes au cours de la fabrication de farine de pejibaie (*Bactris gasipaes* H.B.K.).

Résumé – Introduction. Plusieurs études ont montré que la transformation des aliments affectait les nutriments tels que les composés bioactifs, protéines, amidon, graisses, fibres, minéraux, et la capacité antioxydante. Notre étude a examiné comment la chaleur modifiait la composition physico-chimique et la capacité antioxydante des fruits de pejibaie (*Bactris gasipaes* HBK) au cours de la production de farine. **Matériel et méthodes**. Cinq lots commerciaux de fruits ont été évalués pour leur contenu total en composés phénoliques et caroténoïdes, et leur capacité hydrophile d'absorption des radicaux oxygénés (H-ORAC). Les fruits ont ensuite été cuits et éventuellement transformés en farine. **Résultats et discussion**. Aucun changement significatif n'a été trouvé quant au contenu des fruits en matières grasses, protéines, amidon et fibres alimentaires durant la production de farine. Le fruit de pejibaie cuit est une source de Mg, Mn, Cu, et K, dont 100 g de fruits contiennent entre 5 % et 13,5 % de l'apport quotidien recommandé. La cuisson a permis également d'augmenter de 17 % la teneur en caroténoïdes, ce qui contribue à compenser la perte de 28 % observée lors du séchage. Aucune étape de la transformation n'a affecté les teneurs en polyphénols ou la valeur de H-ORAC. **Conclusion**. En raison de sa haute teneur en composés bioactifs, la farine de pejibaie est potentiellement intéressante à utiliser pour le développement d'aliments fonctionnels.

Costa Rica / *Bactris gasipaes* / fruits / traitement / séchage / composition globale / caroténoïde / polyphénol / antioxydant

1. Introduction

Recent studies have demonstrated that many traditional foods contain components that may benefit health. The intake of these components, present in fruits and vegetables, inversely correlates with the incidence of degenerative diseases such as diabetes, cardiovascular diseases, coronary heart diseases, macular degeneration, certain cancers, and age-related cataracts [1–5]. Even so, deficiencies of micronutrients such as iron affect one-third of the world's population [3]. Research on deficiencies and the positive properties of these compounds has led to recommendations for increased consumption of fruits and vegetables rich in bioactive compounds [3].

Antioxidant compounds in foods include vitamins, minerals (*e.g.*, Se and Zn), natural pigments (carotenoids and anthocyanins), tocopherols, and other plant compounds. These compounds can slow down or prevent the oxidation of organic molecules by reducing chemical reactions involving oxygen. They can neutralize the oxidative action by scavenging reactive oxygen species (ROS) and reactive nitrogen species (RNS), or preventing their generation [6, 7].

Although the tropics produce numerous edible fruits, their consumption is limited, despite their high contents of bioactive compounds. Low availability, lack of investment, and poor knowledge of production systems or conservation issues are related to the low use of tropical fruits for direct consumption or by food-processing industries [3].

In food technology, controlling free radicals is important for preventing oxidation and the development of rancidity. Lipid peroxidation gives rise to chemical compounds that cause unpleasant aromas and flavors, which can be prevented by using antioxidants such as carotenoids [8]. Likewise, polyphenols — compounds that have proven antioxidant activity — influence the quality of beverages by imparting bitterness or astringency, significantly affecting texture and mouth feel [9]. Thus, food processing may play an important role in preserving and enhancing the bioavailability of bioactive compounds [10].

However, microwaving, blanching, boiling, deep-frying and baking usually result in substantial losses of carotenoids [11]. Applying or removing heat can also transform fruits and vegetables by changing their content of bioactive compounds and their antioxidant capacity [12]. Such effects suggest that the contents of bioactive compounds will also change in peach-palm fruit when it is processed into flour.

Bactris gasipaes H.B.K. is also known as *pejibaye* in Costa Rica, *chontaduro* in Venezuela, *pibá* in Panamá, *pupunha* in Brasil, and peach-palm in English-speaking countries [13]. Native to the American tropical rainforests, this palm produces abundant fruit that is nutritionally probably the most balanced of the tropical fruits. A promising source of antioxidant compounds such as carotenoids and polyphenols [13–15], the fruit also has high nutritional value in terms of high fiber and β-carotene contents; high starch and fat levels, and therefore high energy content [16]; high mineral contents (*e.g.*, Se and Zn); and low sodium and sugar levels [17].

The fruit thus represents a highly interesting opportunity [7, 14] for exploiting its nutritional composition and high acceptability to prevent major diseases caused by, for example, vitamin A deficiency, which affects the Costa Rican population [18]. Yet, despite its nutritional qualities, peach-palm fruit is underused.

To promote peach-palm fruit as a regular component of the diet, ways must be found to develop stable products such as flour that conserve the fresh fruit's nutritive value. Such products must also be easily stored and sold at accessible prices. Peach-palm flour is an excellent product from which a wide range of products can be developed and marketed [14].

The physicochemical characteristics of peach-palm fruit have already been described [3, 10, 18], but its characterization should be expanded to include contents of bioactive compounds. Components such as carotenoids and fiber define peach-palm fruit as a functional food [10, 18]. These findings must be complemented by determining the fruit's antioxidant capacity.

Our study examines the changes in physicochemical composition and bioactive compound contents (Zn, carotenoids, polyphenols and dietary fiber) that occur in peach-palm fruit when it undergoes processing into flour. Such processing involves the critical steps of cooking and drying; that is, heat treatment.

2. Materials and methods

2.1. Raw material

Five batches of 60 kg of fruit each were harvested in Tucurrique, Costa Rica (9°59'40" N; 83°36'14" W) from a random selection of different palms and bunches growing in a plantation located 703 m above sea level, with an average temperature of 23 °C. The individual fruits themselves were selected according to color (orange to red), ensuring that both scratches and microbiological deterioration were absent.

2.2. Processing of peach-palm fruit

Peach-palm flour was processed at a pilot level, as described by Rojas-Garbanzo *et al.* [14]. Each batch was cleaned and disinfected with a solution of 100 mg sodium hypochlorite (NaClO)·L^{-1} for 15 min. The fruit was then cooked in boiling water for 30 min, cooled, and peeled and deseeded manually. After slicing (0.25-mm thick slices), the fruits were dried at 72 °C to a 10% moisture content in a conventional oven, milled (0.084-cm mesh opening), and vacuum-packed into aluminum bags to prevent deterioration before analysis.

2.3. Reagents

Reagents were obtained from J.T. Baker (México) as follows: sulfuric acid, boric acid, sodium and potassium hydroxides, methanol, acetone, ethyl ether and hexane, all at reagent grade. Other reagents, obtained from Sigma-Aldrich Co., LLC (St. Louis, MO, USA), were α-amyloglucosidase (EC 3.2.1.3), glucoxidase, glucose, sodium carbonate, gallic acid, Folin–Ciocalteu reagent, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), sodium fluorescein, 2,2′-azobis (2-amidinopropane) dihydrochloride (AAPH), monobasic and dibasic sodium phosphates, and Total Dietary Fiber Kit TDF-100A (heat-stable α-amylase, amyloglucosidase and protease).

2.4. Chemical analysis

2.4.1. Chemical composition

Moisture, fat, protein, dietary fiber, ash, soluble solids, total acidity and pH contents were determined by using standard AOAC methods; that is, 920.151, 991.20, 920.152, 985.29, 940.26, 932.12, 942.15 and 981.12, respectively [19]. The minerals P, Ca, Mg, K, S, Na, Fe, Cu, Zn, Mn and B were analyzed by atomic absorption spectrophotometry, as described by Jones *et al.* [20]. Nitrogen was analyzed by dried combustion as described by Schweizer *et al.* [21]. Starch content was determined as described by Southgate [22].

2.4.2. Total carotenoid content

Carotenoids were extracted from 5-g samples according to methods described by Schiedt and Liaaen-Jensen, and Rojas-Garbanzo *et al.* [14, 23]. The analysis was conducted with a UV-visible spectrophotometer (Shimadzu UV-1700 PharmaSpec, Kyoto, Japan), using a wavelength of 450 nm. Total carotenoid content was calculated, using an extinction coefficient of 2500 for a 1% n-hexane solution, and expressed as micrograms (μg) of β-carotene equivalents per gram (dry weight).

2.4.3. Preparation of the acetone extracts for total polyphenol content and antioxidant capacity

The acetone extracts were prepared according to Georgé *et al.* [7]. Samples (3 g) of peach-palm fruit were homogenized with 20 mL of acetone solution (at 70/30 of distilled water) in a 25-mL Erlenmeyer flask covered with aluminum foil. The mixture was then gently agitated for 10 min in a magnetic agitator and ultrasonic bath, and transferred to a 50-mL volumetric flask, filtering it through a Whatman No. 41 filter paper.

2.4.4. Total polyphenol content

Total polyphenols were determined, using the Folin–Ciocalteu spectrophotometric method as described by Georgé *et al.* [7]. Gallic acid was used as the standard, and ascorbic acid and reducing sugar interferences were eliminated by using OASIS® cartridges (Waters Corporation, Milford, MA, USA). Absorbance was measured with a UV-visible spectophotometer (Shimadzu UV-1700 PharmaSpec, Japan), using a wavelength of 765 nm against a reagent blank. The polyphenols were quantified, using the external calibration curve of gallic acid with a linearity range of 10–80 mg gallic acid Eq·L^{-1}. Good correlation was obtained ($r^2 = 0.9996$), reporting the concentration of total polyphenols as milligrams (mg) of gallic acid equivalent (GAE) per 100 g (dry weight).

2.4.5. Hydrophilic antioxidant capacity

Hydrophilic oxygen radical absorbance capacity (H-ORAC) was determined as described by Huang *et al.* [24]. The assays were conducted on a spectrofluorometer (Synergy HT, BioTek Instruments, Inc., Winooski, VT, USA), using fluoroscein as an indicator of peroxyl radical damage. The excitation wavelength was set at 493 nm and emission wavelength at 515 nm. The H-ORAC was expressed as micromoles (µmol) of Trolox equivalents (TE) per gram (dry weight), using an external calibration curve of Trolox (4.0-32.3 µmol TE·L^{-1}) with good correlation ($r^2 = 0.9993$).

2.4.6. Color

Color was determined with a HunterLab colorimeter (2° standard observer angle and illuminant C; Hunter Associates Laboratory Inc., Reston, VA, USA). Color was expressed as L^*, a^* and b^* values. The parameters *hue* (h^*), *chroma* (c^*) and total color difference (ΔE^*) were obtained, as described by Gonnet [25]: $h = \tan^{-1}(b^* / a^*)$;
$c = [(a^*)^2 + (b^*)^2]^{1/2}$;
$\Delta E^* = [(\Delta L^*)^2 + (\Delta c^*)^2 + (\Delta h^*)^2]^{1/2}$.

2.4.7. Statistical analysis

To evaluate the effects of different stages of flour production on the physicochemical composition, bioactive compounds and antioxidant capacity of peach-palm fruit, five replications were performed. The study followed a randomized complete block design, with three treatments (raw and cooked peach-palm fruit, and peach-palm flour). Significant differences between treatments were determined by performing an ANOVA ($\alpha = 0.05$) and Tukey's test, using JMP 4.1 software (SAS, Cary, NC, USA). Data were expressed as the mean ± standard deviation.

3. Results and discussion

3.1. Effects of flour production on physicochemical composition

3.1.1. Macronutrients

After cooking, moisture content increased significantly by 5% (*table I*). Peach-palm fruit was in direct contact with water, which softened cell walls, facilitating water transfer to the pulp [13]. This allowed carbohydrates such as starch, cellulose and hemicellulose to absorb water during cooking [26]. Moisture content in raw and cooked peach-palm pulp was therefore significantly different ($p > 0.05$) at (56 ± 5) g·100 g^{-1} and (59 ± 4) g·100 g^{-1}, respectively.

The flour, however, was dried to a final moisture content of (13 ± 3) g·100 g^{-1}, to comply with the standard CODEX STAN 152-1985 for wheat flour [27]. As expected, drying decreased the moisture content of peach-palm flour by 78%. Low moisture content allows long shelf life, as both microbiological growth and deterioration from enzymatic reactions are less likely to occur [28].

Fat, protein, ash and starch contents were not significantly affected by cooking and drying during flour production. These results differ from those of Fernández *et al.* and Clement [26, 29], who reported fat content as decreasing by more than 20% during cooking. The melting point of fatty acids is

Table I.

Changes in the physicochemical composition (g·100 g^{-1} dry weight) during the production of peach-palm flour (average of five samples).

Component	Moisture	Fat	Protein	Starch	Dietary fiber	Ash	Soluble solids	Acidity[1]	pH
Raw	56 ± 5 b	14 ± 3 a	5.0 ± 1.1 a	70 ± 4 a	11± 1a	1.8 ± 0.1 a	4.6 ± 0.3 b	0.23 ± 0.10 a	5.3 ± 0.6 a
Cooked	59 ± 4 a	13 ± 3 a	5.0 ± 1.1 a	68 ± 4 a	12 ± 1a	1.8 ± 0.1 a	4.6 ± 0.4 b	0.13 ± 0.05 a	5.6 ± 0.6 a
Flour	13 ± 3 c	13 ± 2 a	5.0 ± 1.0 a	67 ± 7 a	10 ± 1a	1.78 ± 0.03 a	14 ± 3 a	0.16 ± 0.04 a	6.1 ± 0.2 a

Means in the same column with different letters are significantly different ($p < 0.05$).

[1] Expressed as citric acid equivalents per 100 g of dry weight.

40 °C, with the fatty acids transferring, as a surface layer, to water [26]. In our study, fat content did not change ($p > 0.05$) during flour production; the configuration of fatty acids may have changes [13].

Protein content did not change after cooking and drying ($p > 0.05$). Peach-palm fruit, being fruit, was expected to have a low content of this constituent. Even so, the values for both fruit and flour showed an interesting nutritional level at (5.0 ± 1.0) g·100 g^{-1} (dry weight)[1]. Although this level is lower than in legumes such as pea, chickpea, lentil and bean [ranging from (17 to 30) g·100 g^{-1} dw] [30], world protein requirements are such that it continues to be a global issue, with heightened concerns about food security and protein malnutrition [30]. Peach-palm fruit can therefore function as a supplementary food towards achieving the daily recommended protein intake.

Cooked peach-palm fruit is a traditional snack. A serving of two cooked peach-palm fruits (peeled and seeded), with an average mass of 50 g, can supply about 4.3% of a person's daily protein needs, according to the FDA[1]. This fruit also has the advantage of supplying eight of the ten amino acids that are essential in the adult diet [17].

The starch content of cooked peach-palm fruit was (68 ± 4) g·100 g^{-1} dw, not being significantly different ($p > 0.05$) to that of flour (*table I*). Keeping starch content constant is essential for products where starch influences sensory characteristics.

Soluble solids, total acidity and pH variables were not significantly affected by the cooking process ($p > 0.05$). Such results enable these components to be used as quality control parameters during peach-palm flour production.

3.1.2. Micronutrients

The results obtained when producting peach-palm flour showed that heat treatment had no significant effect ($p > 0.05$) on the flour's mineral content (*table II*). This is an attractive feature because this flour would be used as raw material for several products such as bread, biscuits, cakes and pastas. In such products, where combination of components in product formulation can reduce mineral contents, peach-palm flour would be a good vehicle by which to add micronutrients, thereby enriching the Costa Rican diet.

In our study, peach-palm fruit presented both macro-minerals (K, P, Mg and Ca) and micro-minerals (Fe, Cu, Zn, Mn and B). However, in general, the mineral content profile of Costa Rican peach-palm fruit differs from that of the peach-palm fruit of the Colombian rainforests. According to Leterme *et al.*, the Colombian fruit presented higher contents of Ca, Mg, S, Zn and Na, but fruits from both regions presented similar contents of P, K, Mn, Fe and Cu [3].

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[1] FDA. 21 CFR 101.9 Nutrition labeling of food. DRAFT 2011-04-28. http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=101.9, 2009.

Table II.
Changes in the mineral content during the production of peach-palm flour (average of five samples).

• Macronutrients

Peach palm fruit	N	P	Ca	Mg	K	S	Na
	(g·100 g^{-1} dry weight)						
Raw	0.79 ± 0.02 a	0.078 ± 0.005 a	0.032 ± 0.005 a	0.042 ± 0.005 a	0.65 ± 0.06 a	0.10 ± 0.01 a	Not detected
Cooked	0.83 ± 0,.17 a	0.078 ± 0.004 a	0.028 ± 0.004 a	0.042 ± 0.004 a	0.66 ± 0.06 a	0.11 ± 0.01 a	Not detected
Flour	0.86 ± 0.21 a	0.074 ± 0.005 a	0.026 ± 0.005 a	0,042 ± 0,004 a	0.66 ± 0.04 a	0.10 ± 0.01 a	Not detected

• Micronutrients

Peach palm fruit	Fe	Cu	Zn	Mn	B
	(mg·kg^{-1} dry weight)				
Raw	13.40 ± 1.34 a	3.80 ± 1.30 a	3.20 ± 0.45 a	3.20 ± 1.10 a	1.60 ± 0.55 a
Cooked	14.60 ± 1.67 a	4.20 ± 1.79 a	3.60 ± 0.89 a	3.80 ± 0.84 a	2.20 ± 0.35 a
Flour	15.40 ± 1.67 a	4.60 ± 0.55 a	3.20 ± 0.45 a	3.60 ± 0.89 a	2.00 ± 0.71 a

Means in the same column with different letters are significantly different ($p < 0.05$).

According to Blanco *et al.*, who analyzed peach-palm from the same region, cooked Costa Rican fruits presented a sodium (Na) content of (9.1 ± 0.6) mg·100 g^{-1} (dw) [18], whereas the results from our study showed no content for this mineral. These authors also reported K at (0.549 ± 0.005) g·100 g^{-1} (dw), Mg at (16.6 ± 4.1) mg·100 g^{-1} (dw), and Fe at (0.8 ± 0.0) mg·100 g^{-1} (dw). These concentrations were lower than those of our study: K, (0.66 ± 0.06) g·100 g^{-1} (dw); Mg, (0.042 ± 0.004) g·100 g^{-1} (dw); and Fe, (14.60 ± 1.67) mg·kg^{-1} (dw). The differences may have resulted from the varieties of peach-palm used, and their climatic, soil and environmental conditions [13, 17]. This hypothesis is supported by results obtained by Yuyama *et al.* [17], who reported lower Mg, Zn and Fe contents, but similar Ca content, and a higher K content compared with those of our study.

The recommended daily intake (RDI) of minerals, as suggested by the FDA[1], is much higher than the levels found in 100 g of cooked peach-palm fruit (*table III*). Technical regulations suggest that nutrient contents may be declared when these contribute at least 5% of the RDI per 100 g [31]. If a serving of two cooked peach-palm fruits were to be presented as a final product, the label would declare contributions to RDI only for Mg (5%), Mn (8%), Cu (9.5%) and K (13.5%).

Even so, taking into account all the minerals found in peach-palm fruit, this fruit can supplement other foods in the Costa Rican diet to provide the minimum RDIs for minerals.

3.2. Effects of flour processing on bioactive compound content

In many fruits and their products, thermal treatment either reduces or increases bioactive compounds such as carotenoids, polyphenols or dietary fiber [2, 3, 5, 9, 18, 32, 33].

Table I.
Nutritional value of cooked and peeled peach-palm fruit (traditional method of consumption) according to the Recommended Daily Intake (RDI)[1].

• Macronutrients

Nutritional value	N	P	Ca	Mg	K	S	Na
	(g·100 g^{-1} fresh weight)						
Traditional method of consumption (TWC)	0.34	0.03	0.01	0.02	0.27	0.04	Not detected
	(g·100 g^{-1} or fresh weight)						
Recommended daily intake (RDI)[1]	–	1.0	1.0	0.4	2.0	–	0.5
Contribution (%)	–	3.0	1.0	5.0	13.5	–	0

• Micronutrients

Nutritional value	Fe	Cu	Zn	Mn	B
	(mg·100 g^{-1} fresh weight)				
Traditional method of consumption (TWC)	0.6	0.17	0.15	0.16	0.09
	(mg·kg^{-1} fresh weight)				
Recommended daily intake (RDI)[1]	18.0	2.0	15.0	2.0	–
Contribution (%)	3.3	9.5	1.0	8.0	–

3.2.1. Dietary fiber

Dietary fiber was not affected by flour production. Cooked fruit and flour had high dietary fiber contents [(12 ± 1) g·100 g^{-1} and (10 ± 1) g·100 g^{-1} (dw), respectively]. This attribute provides health benefits such as reducing low-density triglycerides and cholesterol and preventing constipation [33]. Because of its high dietary fiber content [(5.0·100) g^{-1} (fw)], cooked peach-palm fruit may be considered as a food source of this compound [31].

3.2.2. Total carotenoid content

Total carotenoid content was significantly affected ($p < 0.05$) by cooking and drying (*figure 1*). Carotenoid content increased by 17% from raw to cooked peach-palm fruit, probably because cooking softens both the cell walls and macromolecules such as fatty acids and proteins that encapsulate carotenoids, thus making them more available [13]. According to Miglio *et al.*, cooking in water preserves antioxidant compounds, especially carotenoids, and releases them from the food as the heat disrupts protein-carotenoid complexes [34].

Figure 1.
Changes in carotenoid content during the production of peach-palm flour ($n = 5$). Different letters or numbers indicate significant differences after heat treatment steps at $p < 0.05$.

The level of increase in carotenoid content for cooked peach-palm fruit is important because it governs the bioavailability of bioactive compounds. Carotenoid availability in fruit depends on the associations occurring between proteins or lipids and carotenoids [28]. The efficiency of absorption of carotenoids in the diet is affected by several factors; for example, the amount of carotenoid ingested; how the food is processed or cooked; the presence of other dietary ingredients that may stimulate (*e.g.*, type and amount of dietary fat) or inhibit (fiber) absorption; matrix effects, and interactions between carotenoids, etc. [35].

The effects of cooking on carotenoid content in peach-palm fruit shown in this study differ from the results reported by Jatunov *et al.* [13]. These authors used fruits from six different varieties. Immersing the fruits in boiling water for 30 min showed no effects. Our results also differed from those of Rojas-Garbanzo *et al.*, who reported a 23% decrease in carotenoid content in heat-treated peach-palm fruits [14]. However, the cultivars these authors used also differed from those of our study. Overall, we found cooking to increase carotenoid availability, thus helping to compensate for the carotenoids lost during drying.

The total carotenoid content in peach-palm flour decreased by 28% compared with cooked fruit. Carotenoids may have been reduced through enzymatic and oxidation reactions, and molecules degraded through prolonged heat treatment (3 h) [11]. The total decrease (15%) in carotenoid content from raw fruit to flour was not significant ($p > 0.05$).

According to Rojas-Garbanzo *et al.*, peach-palm fruit has at least nine carotenoids with provitamin A activity, all of which are significantly affected by cooking and drying with hot air [14]. Because the bioavailability of carotenoids can increase after cooking (through release from macromolecules) [13], the amount of carotenoids present in the flour reinforces the idea of peach-palm fruit being a functional food, as it is a source of antioxidants and provitamin-A compounds.

Peach-palm flour and cooked fruit, respectively, presented a total carotenoid content of (123 and 79) µg of β-carotene Eq·g^{-1} (fw). Cooked peach-palm fruit has a higher carotenoid content than other fruits such as banana cv. 'Comprida', guava, mango cv. 'Rosa', melon cv. 'Japonés', papaya cv. 'Hawaii', and watermelon (µg), with (10.62, 42.98, 24.98, 23.97, 46.39 and 40.09) µg of β-carotene Eq·g^{-1} (fw), respectively [36], These colored fruits are frequently consumed by the population.

Peach-palm fruit may be compared with other fat-rich fruit such as dabai (*Canarium odontophyllum* Miq.), which is another underused fruit found in tropical rainforests and eaten by indigenous people. Although peach-palm fruit must be cooked before being eaten and dabai can be eaten fresh, the peach-palm fruit presented a higher total carotenoid content at 79 µg of β-carotene Eq·g^{-1} (fw) *versus* 55.5 µg for dabai [5].

Carotenoid release during processing is evident in the changing pulp color of peach-palm fruit. Several studies have previously correlated color with carotenoid content of different fruits and vegetables. Thus, color represents a rapid estimate of the amount of this pigment [13] present in the fruit. Raw peach-palm fruit is light orange, turning deep orange when cooked. The color parameters (*table IV*) showed a significant increase in red (a^*), which was enhanced from 17 in raw fruit to 27 in cooked peach-palm fruit, and yellow (b^*), which increased from 53 to 71. These color changes result from the increased exposure of carotenoids after cooking, which generates more intense reds and yellows. Luminosity (L^*) declined significantly ($p < 0.05$) from 75 to 61.

Color changes are explained by the softening of cell walls, which led to increased levels of those carotenoids with 9 to 11 conjugated double bonds such as all-*trans*-β-carotene and lycopene [11, 14, 28]. Carotenoids with more conjugated double bonds are able to express more color. According to Rojas-Garbanzo *et al.*, lycopene, the carotenoid with the highest conjugated double bonds, is also present

Table IV.
Color characteristics of peach-palm fruit at successive steps of flour processing (average of five samples).

Color parameter	*a**	*b**	*L**	°Hue	Chroma
Raw	17 ± 2 c	53 ± 4 b	75 ± 1 a	72 ± 1 a	56 ± 4 b
Cooked	27 ± 2 a	71 ± 5 a	61 ± 5 c	69 ± 1 b	76 ± 5 a
Flour	24 ± 2 b	69 ± 5 a	69 ± 3 b	71 ± 1 a	73 ± 5 a

Means in the same column with different letters are significantly different ($p < 0.05$).

ΔE* (total color difference value) = 25 between raw and cooked peach-palm fruit, and ΔE* = 8 between cooked fruit and flour.

in peach-palm fruit [14]. The authors reported an increase of 6% for this carotenoid after cooking. This explains the changes in color obtained in our study.

The hue angle significantly ($p < 0.05$) dropped in value after cooking but, after drying, the hue angle increased again. This explains the initial light orange color in raw peach-palm fruit, which is less than 90º, and the strong orange color in cooked fruit as carotenoids increased, generating the deeper red color. Increased hue angle after drying means a weaker red color, which is linked to reduced carotenoid content [13].

The chroma value (*i.e.*, color intensity) rose significantly after cooking and is not affected by drying. Because the raw peach-palm fruit's light orange color turned deep orange when cooked and processed into flour, increased chroma value was expected (*table IV*). Cooked peach-palm fruit has an intense orange color that is linked to higher carotenoid content.

The total color difference value (ΔE*) between raw and cooked peach-palm fruit was 25, while cooked fruit differed from flour by 8. These differences in color were perceptible to the human eye, as ΔE* values were higher than 5 [25].

3.2.3. Total polyphenol content

The effect of heat treatment on total polyphenol content was also evaluated; this is the first time that polyphenols have been reported in peach-palm fruit processing. Cooking and drying had no significant effect ($p > 0.05$), with cooked fruit and flour presenting a total polyphenol content of (70 ± 4) mg GAE·100 g^{-1} and (63 ± 2) mg GAE·100 g^{-1} (dw), respectively (*figure 2*).

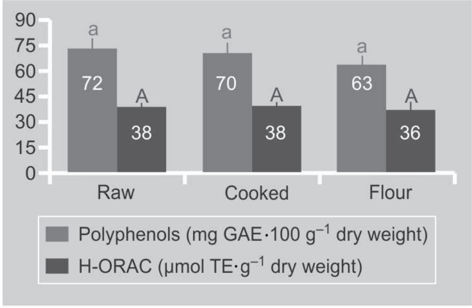

Figure 2.
Changes in polyphenol content and hydrophilic antioxidant capacity during the production of peach-palm flour ($n = 5$). Different letters indicate significant differences after heat treatment steps at $p < 0.05$.

These results are surprising, as cooking and drying, that is, heat treatment, were expected to reduce total polyphenol contents [32]. Other factors that may also induce rapid deterioration of antioxidant compounds are enzymatic reactions and oxidation [32], and exposure to light and oxygen during peeling and slicing.

To explain why the polyphenol content in the peach-palm fruits we studied was not affected, it is necessary to examine the polyphenol profile during flour production. The constant values for polyphenol content during flour production could be attributed to the formation of phenolic compounds in an intermediate state of oxidation by enzymatic or chemical reactions that generates molecules able to stabilize the π-electron system in the aromatic ring, leading to high antioxidant properties [32].

Compared with avocado [667 mg GAE·100 g^{-1} (dw)], raw and cooked peach-palm fruit presented a lower polyphenol content than that of other lipophilic-component-rich food [36]. Despite low total polyphenol contents, peach-palm fruit can be considered as an alternative source of this type of antioxidant compound.

The polyphenol content of another traditional fruit from Costa Rica – the tropical highland blackberry (*Rubus adenotrichus*) – is also affected by heat treatment (blanching). Even so, the final product (*i.e.*, juice) presented higher polyphenol content than cooked peach-palm fruit [(5050 ± 1) mg GAE·100 g^{-1} (dw)] [37].

3.3. Effects of flour processing on hydrophilic antioxidant capacity

Hydrophilic antioxidant capacity was not affected by peach-palm flour production; that is, no significant differences appeared after cooking and drying (*figure 2*). When food is exposed to drastic heat treatment such as cooking and drying, sources of antioxidant activity, which include hydrophilic compounds such as polyphenols, vitamin C, Se and Zn, and lipophilic compounds such as carotenoids, may be either generated or lost [3, 5, 12, 32].

If they are generated, oxygen radical absorbance capacity (ORAC) values may be enhanced, giving stability to the final product [32]. The behavior of each antioxidant compound during peach-palm flour production must be discovered to determine if heat affects its antioxidant activity or if its behavior results from the generation of intermediate compounds with such characteristics [32].

Compared with other fruits, the antioxidant capacity of cooked peach-palm fruit [36 μmol TE·g^{-1} (dw)] is lower than that reported for fruits such as blueberries, blackberries and cranberries, the values for which range between (90 and 160) μmol TE·g^{-1} (dw). At the same time, its antioxidant capacity is higher than for other fruits traditionally consumed such as watermelon, melon and mango, the values for which range from (16 to 24) μmol TE·g^{-1} (dw) [38]. Compared with legume flours, peach-palm flour had a similar antioxidant capacity to cannellini-bean flour [38 μmol TE·g^{-1} (dw)], but a lower value than that of pinta-bean flour [96 μmol TE·g^{-1} (dw)] [39].

For each stage, antioxidant capacity is underestimated because H-ORAC is an analysis that includes only hydrophilic components. It does not take into account the antioxidant activity of lipophilic compounds such as carotenoids [7]. To know the total antioxidant potential of peach-palm fruit, the lipophilic antioxidant capacity must also be determined.

4. Conclusions

The thermal processes – specifically cooking and drying – used to produce flour did not affect the principal physicochemical compounds (fat, protein, starch and dietary fiber) of peach-palm fruit. The nutritional and energy values of starch and fat remained very high in cooked fruit and flour.

The peach-palm fruit is rich in bioactive compounds, with significant antioxidant capacity. It may be considered as a functional food because of its high carotenoid and dietary fiber contents. The total carotenoid content of traditionally cooked peach-palm fruit was higher than those reported for other tropical fruits such as banana, mango, melon and papaya. Peach-palm flour can also be used as an ingredient, rich in bioactive compounds, for functional food formulation.

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Principales cambios físico-químicos y antioxidantes en la fabricación de harina de pejibaye (*Bactris gasipaes* H.B.K.).

Resumen – Introducción. Varios estudios han demostrado que el procesamiento de alimento tiene un efecto sobre nutrientes como compuestos bioactivos, proteína, almidón, grasa, fibra, minerales y sobre la capacidad antioxidante. En nuestro estudio se analiza como el calor cambia la composición físico-química y la capacidad antioxidantes durante el procesamiento de la harina de pejibaye (*Bactris gasipaes* H.B.K.). **Material y métodos**. Cinco lotes de fruta disponible comercialmente fueron analizados para determinar el contenido total de polifenoles y carotenoides; así como la capacidad hidrofilia de absorción de radicales de oxígeno (H-ORAC). Posteriormente, la fruta se cocinó y se procesó para obtener la harina. **Resultados y discusión**. No se encontró diferencia significativa en el contenido de grasa, proteína, almidón y fibra dietética durante la producción de la harina. La fruta de pejibaye cocinado es una fuente de Mg, Mn, Cu, y K; 100 g de fruta cocinada contiene entre 5% y 13.5% de la ingesta diaria recomendada. La cocción aumenta el contenido de carotenoides en un 17% lo que compensa el 28% de pérdida que se da durante el secado. Las etapas de procesamiento de harina de pejibaye no afectan el contenido de polifenoles ni el valor de H-ORAC. **Conclusión**. Dado el alto contenido de compuestos bioactivos, la harina de pejibaye representa una alternativa potencial para el uso en el desarrollo de alimentos funcionales.

Costa Rica / *Bactris gasipaes* / frutas / procesamiento / secado / composición aproximada / carotinoides / polifenoles / antioxidantes