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Pretreatment and drying of Peruvian Criollo mango peel and effect content of bioactive compounds and antioxidant activity

Noemí León-Roque[1]*, Yoella Ramos Yajahuanca[1], Angela Tocas Silva[1], César Monteza Arbulú[1], Jimy Oblitas[2]

[1]Universidad Pedro Ruiz Gallo, Lambayeque, Lambayeque, Perú
[2]Universidad Privada del Norte, Cajamarca, Perú
*Corresponding author, e-mail: nleonr@unprg.edu.pe

Abstract

Revaluation of Criollo mango peels for use in the food industry would generate an environmentally sustainable impact on the circular economy. This research seeks evaluation temperature (T) and time (t) of mango peel pre-cooking (PMP) and effect of drying on the concentration functional compounds (CFC). For this, a 2^2-type experimental design with a central point was implemented to evaluate the effects temperature (80, 89, and 98 °C) and time (5, 12.5, and 20 min) on the PMP the Criollo variety. The analyses performed included quantification total polyphenols (TP), total flavonoids (TF), antioxidant capacity (AC), and vitamin C (VC). This study, the effect conventional drying at three temperatures (45, 55, and 65 °C) was evaluated over 10 hours. The main findings study indicated that, after optimization to maximize CFC, the best values were obtained PMP of temperature and time, with 80 °C and 5 minutes, respectively. During the drying process, it was observed that, under the temperatures examined, there was no significant change in most of the samples. This study serves as a starting point for reevaluating Criollo mango skins through implementation circular economy and their application in products such as cookies made with mango peel.

Keywords: antioxidant capacity, Criollo mango, flavonoids, HPLC, vitamin C

Introduction

Mango (*Mangifera indica L.*) is a fruit that is widely recognized globally and has significant economic importance. This tropical and subtropical fruit, native to India, is distinguished by its attractive color, juicy flavor, and fascinating aroma (Jiménez-López et al. 2020; Song et al. 2025). Peru ranked as the fifth largest supplier worldwide and the third largest in Latin America, with exports reaching US$408.6 million (MIDAGRI, 2025). In addition, the country exports fresh mangoes of improved varieties, such as Kent, Edward, Haden, and Tomy Atkins, as well as Criollo, from various regions of Peru (León-Roque et al. 2023).

In mango processing, the peels become waste, accounting for between 15 and 20% of the total fruit weight, depending on the genotype (Serna-Cock et al. 2016; Kaur and Srivastav 2018). However, recent research has revealed that this component of the fruit contains a considerable number of bioactive compounds, such as polyphenols, flavonoids (León-Roque et al. 2023; Saborirad et al. 2024; Tripty et al. 2025), and vitamin C (Ocampo et al. 2020). These phytochemicals, present in mango by-products, have been shown to have beneficial health effects (Wall-Medrano et al. 2020; Sorrenti et al. 2023).

Mango peels have been reported to contain gallic acid, catechins, and mangiferin, a distinctive polyphenol found in mangoes (Hu et al. 2023). As Kučuk et al. (2024) and Abdelmontaleb et al. (2025) have mentioned, mango peels are exceptional waste products that could contribute to the sustainable development of high-value products for various applications. Additionally, mango peels have been reported to have antioxidant activity (Sai-Ut et al. 2015; Shirahigue and Ceccato-Antonini, 2020), anti-inflammatory (Knödler et al. 2008), antibacterial (Chun-Yung et al. 2018), and

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antimicrobial (Shirahigue and Ceccato-Antonini, 2020) properties, showing that the use of mango peels can be an economical way to improve the problem of waste disposal for companies that use mangoes in their various processes, adding value to food industry by-products as ingredients for new foods with healthier diets and a more sustainable circular economy (Tripty et al. 2025).

Another technological problem identified is presence of bitter flavors in the peels, a problem that can be improved through heat pretreatment. In line with the above, one of the most promising strategies for reusing mango peels is to convert them into powder. However, the dehydration process leads to the loss of bioactive compounds (Marçal and Pintado 2021).

Using mango peels in food processing provides producers with an additional source of income and reduces waste (Rojas et al. 2020). However, despite the existence of health-promoting compounds, extracting these with minimal losses remains challenging. The objective of this research is therefore to evaluate the effect of pre-cooking time and temperature of mango peels on these compounds, as well as the impact of drying. These compounds are important for the food industry.

Materials and methods

Reagents

Standard gallic acid, Folin Ciocalteu's phenol reagent, quercetin 3-glucoside analytical standard, aluminum chloride anhydrous powder, (±) 6-Hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox) were purchased from Sigma-Aldrich; the ascorbic acid standard, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), from Merck; HPLC-grade methanol and analytical-grade ethanol were purchased from Supelco. In addition, ultrapure water was used in the procedure.

Samples

The Criollo variety mango, from the district of Jayanca, was purchased at the Moshoqueque wholesale market, located in the José Leonardo Ortiz district, in the province and city of Chiclayo, Lambayeque, Peru. The fruits were transferred to the laboratory of the School of Chemical Engineering and Food Industries at the Pedro Ruiz Gallo National University of Lambayeque. Mangoes with a uniform yellow peel and an advanced degree of ripeness, without signs of disease or mechanical damage, were selected (Figure 1-A). Mangoes with green spots on the peel were stored until they turned completely yellow. Subsequently, the peels were separated, placed in airtight bags, and frozen at -20°C in an ultra-freezer until the time of treatment.

Pre-treatment of mango peels

One hundred grams of mango peel frozen at -20°C was weighed into a beaker and covered with distilled water. According to the center point factorial design, eight treatments with three replicates were prepared for pre-cooking, with factor 1 being temperature (80, 89, and 98 °C) and factor 2 being cooking time (5, 12.5, and 20 minutes) (see **Table 1**).

The pre-cooked samples were separated into two parts: one part to obtain mango peel pulp (Figure 1– B) and the other for the drying process (**Figure 1** – C).

Obtaining pre-cooked mango peel pulp: In accordance with the treatments established in Table 1, the pre-cooked peels were pulped in a food processor, hermetically sealed, and frozen at -20°C. They were then stored until extraction and analysis.

Pre-cooked peel drying process: The procedure was carried out at temperatures of 45 °C, 55 °C, and 65 °C in a 60-tray food dehydrator, with a constant duration of 10 hours. The sample was ground, and the resulting

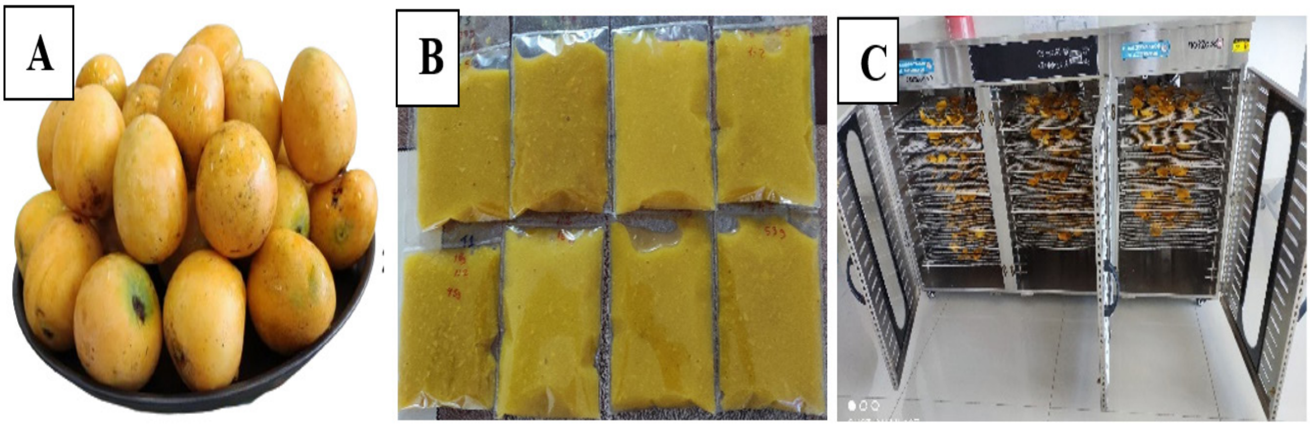

Figure 1. (A) Criollo mango fruit; (B) pre-cooked mango peel pulp; (C) pre-cooked mango peel drying at 45, 55, and 65°C for 10 hours.

Table 1. Design of experiments: 2^2 with central point.

	Coding		Variable	
	Temperature (°C)	Time (min)	Temperature (°C)	Time (min)
Treatment 1	–1	–1	80	5
Treatment 2	1	–1	98	5
Treatment 3	–1	1	80	20
Treatment 4	1	1	98	20
Treatment 5	0	0	89	12.5
Treatment 5	0	0	89	12.5
Treatment 5	0	0	89	12.5
Treatment 5	0	0	89	12.5

flour was stored at 20 °C in airtight containers until it was subsequently extracted and analyzed.

The physical properties of Criollo mango peel were determined, and analyses of pH, titratable acidity, and soluble solids were performed. Before pretreatment, the moisture content of the treatments was determined according to the design established in Table 1. The moisture content of mango peel flour was determined after drying at 45 °C, 55 °C, and 65 °C.

Preparation of extracts from pre-cooked mango peel pulp

To prepare the extracts, 2 g of pre-cooked frozen mango peel pulp was used, together with 4 ml of a 72% ethanol solution, a treatment optimized for Criollo mangoes by León-Roque et al. (2023), with certain modifications regarding the treatments of 80, 89, and 98 °C cooking temperatures and 5, 12.5, and 20 minutes of cooking time, respectively. They were stirred for 89.9 minutes in an orbital shaker at room temperature. Subsequently, centrifugation was performed at 4000 xg at 4 °C for 10 minutes. The supernatants were then filtered through a 0.22 µm PTFE filter before undergoing TP, TF, and AC analysis by spectrophotometry and VC analysis by HPLC.

Preparation of extracts from pre-cooked mango peel flour

0.2 g of pre-cooked mango peel flour was weighed and extracted in 4 ml of 72% ethanol solution from the optimized treatment for Criollo mango by León-Roque et al. (2023), following the same procedure as in the previous item.

Determination of total phenolic content (TPC)

The TPC of the extracts was measured using the Folin-Ciocalteu colorimetric method (Singleton et al. 1999), varying the reagent concentration, alkalinity, and temperature to reduce the time required to reach a steady state. This method was adapted by Magalhães et al. (2010) with some modifications, and the absorbance was read in a UV-Vis spectrophotometer at 765 nm. Gallic acid was used as a standard concentration ranging from 0 to 1000 ppm. TPC was expressed as milligrams of gallic acid equivalent (mg GAE)/100 g of sample d.w., with the equation of the line $y = 0.0005x - 0.0033$ and $R^2 = 0.9978$.

Determination of total flavonoid content (TFC)

The TFC was determined using the method based on the aluminum chloride colorimetric assay (Shraim et al., 2021), with modifications: 600 µL of the extract was mixed with 2580 µL of solution A (1800 µL of 5% sodium nitrite and 24 mL of ultrapure water). The mixture was left to stand for 5 minutes, and 180 µL of 10% aluminum chloride was added. It was left to stand for 1 minute and, finally, 2520 µL of solution B (12 mL of 1 M NaOH with 14.4 mL of ultrapure water) was added. Finally, the absorbance was measured at a wavelength of 415 nm in a UV-Vis spectrophotometer. TFC was estimated using a calibration curve with quercetin as the standard (from 0 to 500 ppm) and expressed as milligrams of quercetin equivalents (mg QE)/100 g of sample d.w., with the equation of the line $y = 0.002x - 0.0178$ and $R^2 = 0.9994$.

Determination of antioxidant capacity (ABTS)

The antioxidant capacity of ethanolic extracts of mango pulp and pre-cooked mango peel flour was evaluated. It should be noted that most foods contain a mixture of hydrophilic and lipophilic compounds that may be in free form or bound to other macromolecules, so there is no solvent or mixture of solvents that can solubilize all the antioxidant compounds present in them (Zhang et al. 2020).

In this study, the antioxidant capacity was evaluated according to Re et al. (1999) with slight modifications and measured using the ABTS (2,2'-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid)) radical scavenging method. A 7 mM ABTS solution and a 2.45 mM potassium persulfate solution were prepared. Both solutions were mixed at a 1:1 ratio in an Erlenmeyer flask covered with aluminum foil in a dark environment. The mixture was incubated for 16 hours at 25 °C in the dark. After this time, 2 mL of the ABTS* radical and 100 mL of absolute ethanol were added to a 250 mL Erlenmeyer flask, and the absorbance was measured at 734 nm. Next, the ABTS* radical was added dropwise until an absorbance of 0.70 ± 0.02 was reached. Then, a 50 µL aliquot of pretreated Criollo mango pulp extract and peel flour or Trolox standard was added, along with 1000 µL of the ABTS* radical. After allowing the mixture to stand for 6 minutes, readings were taken with a UV-Vis spectrophotometer at 734 nm. A 500 ppm Trolox stock solution was prepared as a standard. For the calibration curve from 0 to 250 mg/L, data were expressed as μmol TEAC/g FW, using the equation y = -0.0021x + 0.559 with R^2 of 0.996.

Vitamin C by HPLC

The concentration of vitamin C was quantified using HPLC-DAD (Hitachi LCK-2020), with ascorbic acid (AA) as the standard. A stock solution of 500 ppm and a calibration curve from 0 to 250 ppm were prepared by dissolving it in the phase B solution. The equation of the line was y = 60116x - 56850, and R^2 = 0.9999.

The detection of chromatographic peaks by HPLC-DAD was performed at a wavelength (λ) of 254 nm. Separation was performed on a 5 μm Shim-pack GIST C18 column, with dimensions of 150 x 4.6 mm, at a flow rate of 0.5 mL/min, an injection volume of 10 μL, and a temperature of 30 °C. A mixture of methanol and water (80/20 v/v, solvent B) was used as the mobile phase for 10 minutes. The extracts were filtered with a 0.45 μm syringe filter and placed in a 2 mL vial in the autosampler. The data was processed using LabSolutions software.

Statistical Analysis

Precooking as a pretreatment for Criollo mango peel samples was evaluated using a two-level factorial design with center point: cooking temperature (F1: 80, 89, and 98 °C) and cooking time (F2: 5, 12.5, and 20 min). The runs were evaluated using eight treatments with three replicates; the design is shown in Table 1. Design Expert software was used to generate response surfaces and contour plots, keeping one variable constant in the second-order polynomial model.

The effect of drying temperatures of 45, 55, and 65 °C for 10 hours was also evaluated in both treatments for the variables TP, TF, AC, and VC. R software was used to perform comparisons based on Tukey's test.

Results and discussion

Evaluation of pre-cooking as a pretreatment for Criollo mango peel

Figure 2 shows the percentages of pulp, seed, and peel of the Criollo mango. The peel represented 18.4%, a rate similar to that reported by León-Roque et al. (2023) in a study conducted with the same mango variety.

The physical-chemical composition of mango peel (pH, soluble solids, and titratable acidity) has not been studied extensively. **Table 2** shows values similar to those reported by Vu et al. (2023) for the pH of mango puree (4.73 ± 0.33) and for soluble solids (17.43 ± 0.42 °Bx).

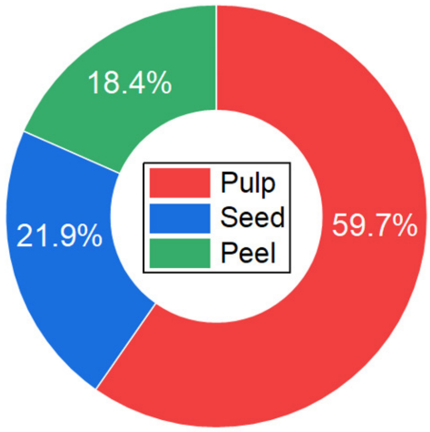

Figure 2. Percentages of pulp, seed and peel of Criollo mango.

Table 2. Physical and chemical composition of mango peel.

	Mean ± SD
pH	4.940±0.0012
Soluble solids (Bx)	21.243±0.886
Titrable acidity	0.171±0.037
Maturity index	128.19±25.78
Precooked shell moisture (%)	80.24±0.41

Values represent mean ± SD (n = 3)

Titratable acidity varies depending on the cultivar and degree of ripeness of the mango and decreases as the fruit ripens.

The moisture content of pre-cooked, dehydrated, and ground mango peel flour at 45 °C was 8.808 ± 0.92; at 55 °C, it was 8.154 ± 1.082; and at 65 °C, it was 6.955 ± 0.886. These values are similar to those reported by Osunrinade et al. (2025), who found 9.38% moisture in mango peel dried at 50 °C in a cabinet dryer.

Figure 3 shows the average values of TP, TF, AC, and VC for the pre-cooked mango peels.

The values obtained in this study are similar to those reported by Serna-Cock et al. (2015) for Criollo, Keitt, and Tommy Atkins varieties. Although they are not as high as those obtained using technologies such as freeze-drying (Fong-in et al., 2025), the values obtained in the process used are acceptable and similar to those reported for other mango varieties, as this technology is still expensive for small producers.

The effect of time (min) and temperature (°C) of pre-cooking mango peel on TP, TF, AC, and VC was evaluated. **Table 3** shows a summary of the statistical analysis performed.

According to Table 3, temperature had a significant effect ($P \leq 0.05$) on TP, TF, and VC, while time only had an impact ($P \leq 0.05$) on vitamin C concentration. **Figure 4** shows the response contours of the interactions between time and temperature, where it can be seen that the highest concentrations of TP, TF, AC, and VC are

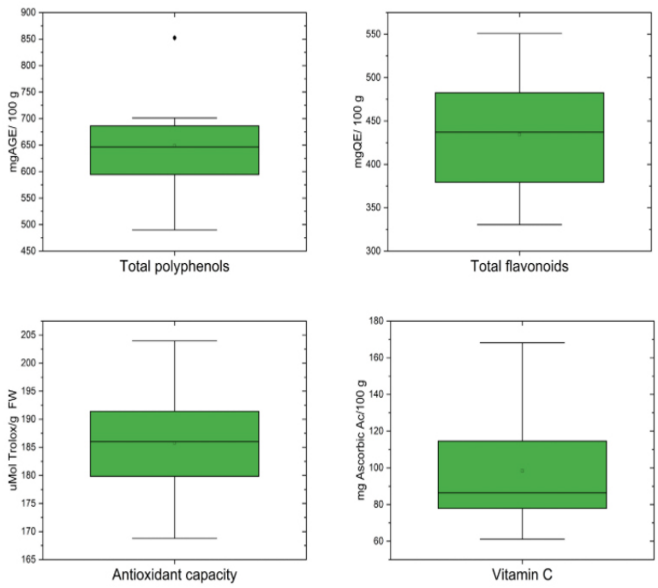

Figure 3. Average values of total polyphenols (TP), total flavonoids (TF), antioxidant capacity (AC) and vitamin C (VC).

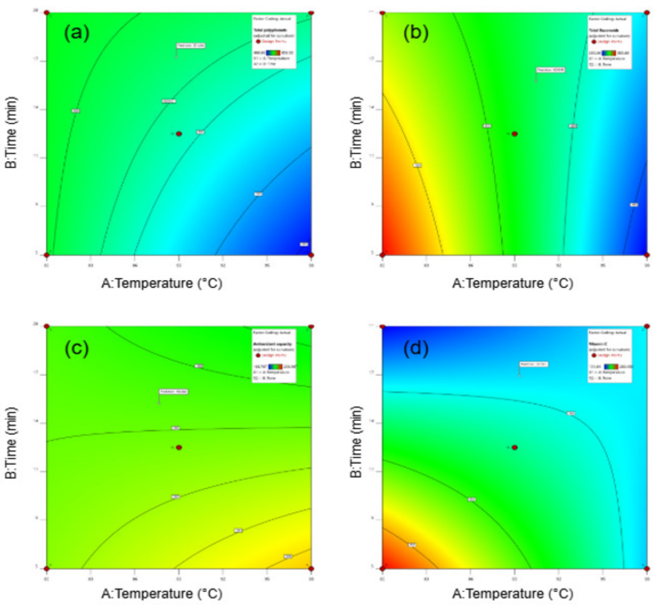

Figure 4. Response contours of the effect of time and temperature (a) total polyphenols, (b) total flavonoids, (c) antioxidant capacity and (d) vitamin C.

found in areas close to the minimum values of the heat treatment (80 °C) to which they were subjected.

A projection of optimal values was performed, as shown in Figure 5, where it can be seen that TF and VC obtain maximum values according to the minimum values used, which were 80 °C and 5 minutes. This optimization was determined using the desirability function, which yielded a value of 0.81.

Evaluation of the peel flours obtained

In order to observe the impact of the temperature

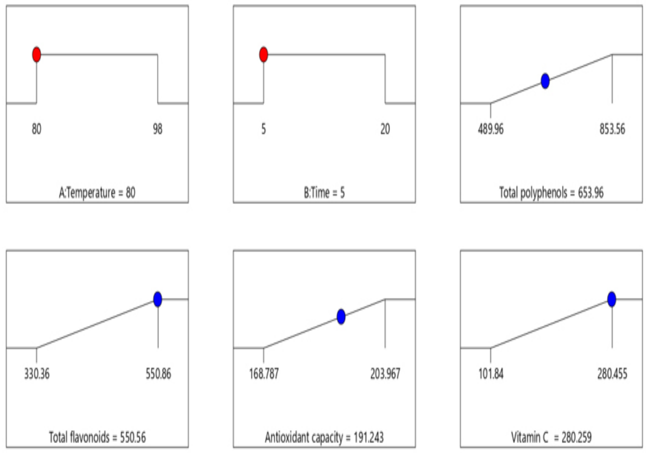

Figure 5. Projection of optimal values

used in the drying process (45 °C, 55 °C, and 65 °C), a comparison was made between the five combinations of parameters used in the pulp extraction process. Figure 6 shows the analysis of a multiple comparison according to Tukey's model, where it can be seen that there are only effects of temperatures in treatments 3 and 5 for TPC and in treatments 2, 4, and 5 for TFC; the rest of the parameters did not undergo significant changes ($P \leq 0.05$). A study by Akther et al. (2023) reveals that cabinet drying offers better conditions for TPC and AC quality.

The values obtained show that the inclusion of Criollo mango peel can improve various foods when used as a supplement. In fact, there are already references to the use of dried mango peel powder in various products, such as its incorporation into soft cheese and its assessment as a natural preservative through direct fortification (Abdelmontaleb et al. 2025), its incorporation into sourdough to produce functional breads with improved nutritional value (Chulibert et al. 2024), and its incorporation into corn extrudates, which demonstrated greater overall acceptability and an increase in total phenolic content of approximately fourteen times (Fontes-Zepeda et al., 2023), among others. All of this leads to improved sensory characteristics and acceptability, minimizes agro-industrial waste, and results in a product with added value

The pre-cooked mango peel flour that presented the highest TPC was dried at 45 °C, with values ranging from 33.61 ± 0.240 to 79.53 ± 0.24 mg GAE/g. Similar values were reported by Tripty et al. (2025) of 64.4 ± 0.26 mg GAE/g, as well as by Kaur B., Srivastav P.P. (2018), of 60.5 mg GAE/g. The highest TFC corresponds to drying at 45 °C, ranging from 10.30 ± 0.06 to 27.49 ± 0.07 mg QE/g. Similar values were also reported by Tripty et al. (2025) of 10.7 ± 0.11 mg QuE/g DW, and Ocampo et al. (2020) of 3.2 to

Table 3. Efecto del tiempo y temperatura de precocción de la cáscara de mango sobre los compuestos bioactivos

Source	Total polyphenols (TP)	Total flavonoids (TF)	Antioxidant capacity (AC)	Vitamin C (VC)
	P-value	P-value	P-value	P-value
A-Temperature	0.0488*	< 0.0001*	0.8175	0.0023*
B-Time	0.154	0.5543	0.0888	< 0.0001*
AB	0.2195	0.0066	0.2445	< 0.0001*

* significant

21.6 mg catechin/g in peels from 13 mango genotypes.

According to Osunrinade et al. (2025), mango peel had a significant impact, as it showed higher AC in noodles with mango peel. In this study, the highest AC values were obtained at a lower pre-cooking temperature of 80°C. The optimal values were projected at 80°C for five minutes (**Figure 5**).

For vitamin C, values of 0.73 to 1.25 mg ascorbic acid per gram of precooked mango peel flour at 45 °C drying were obtained, according to values reported by Ocampo et al. (2020). In peels of 13 mango genotypes, the vitamin C content ranged from 4.55 to 6.40 mg/g. This is because the peels in this study were precooked and then subjected to drying at 45 °C, 55 °C, and 65 °C. Drying at the lowest temperature yielded the highest values, but these are lower than those reported by Ocampo et al. (2020).

Conclusion

Pre-cooked, dried, and ground Criollo mango peel flour is a promising alternative for the revaluation of this by-product, which exhibits bioactive compounds and antioxidant activities in concentrations that could make its use as an ingredient in the food industry viable. The main findings indicated that, after optimization to maximize the concentration of functional compounds, values of 80°C and 5 minutes were the most suitable for pre-cooking pretreatment. Likewise, during drying, it was observed that, based on temperatures studied, there was no significant change in most of the samples. This study provides an initial basis for revaluing the skins of Criollo variety of mangoes, which has not been the subject of a more extensive study compared to the most widely consumed mango varieties.

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