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ARTÍCULO

Efecto de la cáscara de mango criollo in terms of the quality of a soda cracker

Effect of Criollo Mango Peel on the quality of a soda cracker



CÁSCARA DE MANGO CRIOLLO

GALLETA TIPO SODA

CALIDAD NUTRICIONAL

APROVECHAMIENTO DE SUBPRODUCTOS

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EFFECT OF CRIOLLO MANGO PEEL ON THE QUALITY OF A SODA CRACKER

Effect of Criollo Mango Peel on the Quality of a Soda Cracker

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Discipline:	*[X] Technology Management and Industrial Innovation*

ABSTRACT

Abstract— Cookies are widely accepted and consumed products and serve as a suitable matrix for incorporating ingredients with nutritional and functional value. The purpose of this study was to evaluate the nutritional, functional, and sensory properties of a soda-type cookie made by partially replacing wheat flour with Creole mango (Mangifera indica L.) peel powder. Based on the base formulation (F0), four cookie formulations (F1, F2, F3, and F4) were developed with different levels of wheat flour replacement by Creole mango peel powder (PCM): 12.5%, 15.0%, and 17.5%, respectively. Following an acceptance test, the three best-rated formulations (F2, F3, and F4) were analyzed to determine their physicochemical characteristics, phenolic content, and antioxidant activity using DPPH and ABTS assays. Sensory evaluation of aroma, flavor, color, and texture was conducted using a 5-point hedonic scale.

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The partial replacement of wheat flour with PCM had a significant effect on the physicochemical, functional, and sensory properties of soda crackers. Compared to the control cracker, formulation F4 exhibited higher levels of total dietary fiber, total phenols, and antioxidant activity. As the level of substitution increased, the ratings for attributes such as flavor, aroma, and texture decreased. However, the formulation with the highest acceptability was F3, made with 17.5% PCM. These results indicate that the incorporation of this Creole mango by-product improves the nutritional and functional properties of the cookies without significantly compromising their sensory acceptability.

Therefore, the use of Creole mango peel powder represents a viable alternative for the utilization of agro-industrial byproducts and for the development of functional foods with potential health benefits.

***Keywords*—**antioxidant activity, functional food, phenolic compounds, dietary fiber, cookie.

ABSTRACT (ENGLISH)

Abstract—Cookies are widely accepted and consumed products, providing a suitable matrix for incorporating ingredients with nutritional and functional value. The purpose of this research was to evaluate the nutritional, functional, and sensory properties of a soda-type cracker made by partially substituting wheat flour with powdered native mango peel (Mangifera indica L.). Starting from the base formulation (F0), four cookie formulations (F1, F2, F3, and F4) were developed with different levels of substitution of wheat flour with powdered native mango peel (PCM): 12.5%, 15.0%, and 17.5%, respectively. After an acceptance test, the three best-performing formulations (F2, F3, and F4) were analyzed to determine their physicochemical characteristics, phenolic content, and antioxidant activity using DPPH and ABTS assays. Sensory evaluation of aroma, flavor, color, and texture was performed using a 5-point hedonic scale.

Partial substitution of wheat flour with mango peel powder (MPP) had a significant effect on the physicochemical, functional, and sensory properties of soda crackers. Compared to the control cracker, formulation F4 showed higher levels of total dietary fiber, total phenols, and antioxidant activity. As the level of substitution increased, the ratings for attributes such as flavor, aroma, and texture decreased. However, the formulation with the highest consumer acceptance was F3, made with 17.5% MPP. These results indicate that incorporating this byproduct of the native mango improves the nutritional and functional properties of the crackers without significantly compromising their sensory acceptability.

Therefore, the use of mango peel powder represents a viable alternative for utilizing agro-industrial byproducts and for developing functional foods with potential health benefits.

***Keywords*—**antioxidant activity, cookie, dietary fiber, functional food, phenolic.

INTRODUCTION

The fast-paced lifestyle of today's society has led to consumption patterns characterized by a high intake of ultra-processed foods with low nutritional value, high percentages of saturated fats, refined sugars, and preservatives, and high caloric content [1,2,3,4]. This consumption pattern, coupled with the rapid development of modern society, has increased the number of patients with chronic noncommunicable diseases (NCDs), including obesity, diabetes, cancer, and intestinal diseases, among others [5].

By 2023, the Pan American Health Organization [6] reported that NCDs were claiming the lives of 41 million people each year, accounting for 71% of all deaths worldwide. In Latin America, approximately 5.5 million people die annually from NCDs. It is estimated that between 30 and 40% of cancer deaths are attributable to dietary factors. Furthermore, of the deaths caused by chronic diseases in people under 65, one-third are related to diet [7]. This highlights a connection between diet, nutrient intake, and the development of chronic diseases, primarily due to a lack of consumption of functional foods [8], as demonstrated by various related studies.

In recent years, consumers have shown a growing preference for functional foods, which not only provide nutritional value but also offer added benefits with positive physiological effects on the body [9]. These foods are notable for their high content of antioxidants and dietary fiber [10], in addition to being convenient for easy consumption, storage, and handling [7].

Dietary fiber is considered a group of complex carbohydrates that cannot be digested by the human body; it is associated with micronutrients (vitamin C, vitamin E, Se, Zn, Mg, and Cu) and bioactive compounds, primarily polymeric polyphenols and low-molecular-weight polyphenols. Adequate intake of dietary fiber with antioxidant capacity is associated with a reduced risk of various chronic diseases related to oxidative stress [11, 12, 13]. These include cardiovascular diseases (CVD) [14], myocardial infarction [15, 16], hypertension [5, 15],
, type 2 diabetes [5, 14], and certain types of cancer [5, 14, 15], as well as certain gastrointestinal diseases [16] and serum cholesterol levels [5, 17]; it has also been associated with weight loss [5, 11, 14, 15].

Cookies are widely accepted among all age groups due to the variety of types, shapes, compositions, and nutritional qualities, making them a food in high demand that is highly versatile and inexpensive to produce [17, 19]. In addition to being widely consumed and easy to produce, cookies are considered a source of essential nutrients for humans [7, 4, 18, 20]. It has been observed that their nutritional content increases depending on the raw materials used; therefore, soy flour, wheat germ, legumes, fruits, aqueous extracts, byproducts (hulls, seeds), and non-conventional flours have been incorporated into their formulations. These ingredients help improve not only the protein content [7, 21], but also the dietary fiber content [22, 24, 25, 26, 27], resistant starch [28], and antioxidant components, transforming them into functional foods without affecting their sensory quality [21].

The mango is among the most widely consumed fruits worldwide. The fruit of the common mango (*Mangifera indica L.*) is characterized by its yellow color and reddish base, and it also has firm, uniform flesh. Its peel is the main byproduct of processing [29], accounting for approximately 15 to 20 percent of the total weight of the fresh fruit [1, 35] and is considered a good source of bioactive components such as dietary fiber, compounds with antioxidant activity—including polyphenols [31], carotenoids, vitamin E, and vitamin C—as well as enzymes [29, 30, 35]. Additionally, it is a source of pectin, cellulose, hemicellulose, lipids, and proteins [30]. Therefore, it is believed that incorporating Creole mango (Mangifera indica L.) peel as a partial substitute for wheat flour in soda cracker formulations can improve the product's nutritional and functional properties, due to its fiber and bioactive compound content, without significantly affecting the sensory acceptability of the crackers.

The World Health Organization [32] recommends that adults consume between 25 and 35 grams of dietary fiber daily. However, the Mexican population consumes only 16 to 18 g of dietary fiber per day—that is, just three-quarters of the recommended amount [35, 36]. The objective of this project was to evaluate the physicochemical, functional, and sensory properties of a soda cracker made with partial substitution of wheat flour with powder from the peel of the Creole mango (*Mangifera indica L.)* as a partial substitute for wheat flour, so that it could be considered an alternative for maintaining good health and reducing the risk of developing chronic diseases related to insufficient intake of fiber and bioactive components, thereby making use of the peel of a fruit that has limited commercial scale in the regions where it is produced.

METHODOLOGY

Generative AI Statement

The authors declare that no generative artificial intelligence tools or AI-assisted technologies were used in the drafting of the manuscript, the analysis of the data, or the creation of original content. All work was performed entirely by the authors using conventional methods.

Responsibility

As the author of this manuscript, I assume full responsibility for the veracity and accuracy of the data presented, guaranteeing that all information has been verified using primary sources to prevent the generation of "hallucinations" or fictitious data derived from automated processes. Furthermore, I declare that the analysis was conducted according to criteria of objectivity and neutrality, implementing cross-checking protocols to identify and mitigate potential cognitive or algorithmic biases, thereby ensuring that the conclusions faithfully reflect the observed technical reality without distortions.

Research Design

This research followed a completely randomized experimental design, in which the percentage of wheat flour replaced by Creole mango peel powder was varied to evaluate its effect on the physicochemical and functional properties and sensory characteristics of soda crackers. Starting from a base formulation (F0), several formulations with different substitution levels were developed to compare the treatments using analysis of variance.

The study has an explanatory scope, as it seeks to establish the cause-and-effect relationship between the incorporation of Creole mango powder and changes in the cookies' physicochemical properties, dietary fiber, phenolic compounds, color, and sensory acceptance. Furthermore, it is applied research because it uses scientific knowledge to develop a functional food from an agroindustrial byproduct.

Thus, this design allows us to answer the following research question: What is the effect of partially substituting wheat flour with mango peel powder on the nutritional content, functional benefits, and sensory characteristics of a soda cracker?

Justification of Sampling

This study included three types of samples: 1) experimental cookie samples used for physicochemical and functional analyses, 2) participants who served on the sensory evaluation panel to determine the acceptability of the formulations, and 3) semi-trained judges to evaluate the sensory attributes.

For the physicochemical and functional analyses, four soda cracker formulations were prepared: a control formulation (F0), made with 100% wheat flour, and three formulations with partial replacement of wheat flour with Creole mango (Mangifera indica L.) peel powder at levels of 12.5% (F2), 15% (F3), and 17.5% (F4). Each formulation was prepared in triplicate under controlled processing conditions, constituting the experimental units for the determination of physicochemical characteristics, dietary fiber content, total phenols, and antioxidant capacity (DPPH and ABTS), evaluated under a completely randomized design with independent replicates; this allowed for the control of experimental variability and ensured the reproducibility of the results.

The sensory evaluation to assess the acceptability of the formulations was conducted with a panel of 80 untrained cookie consumers selected through non-probabilistic convenience sampling, due to the accessibility of potential consumers and because one of the objectives of this research was to determine the acceptability of the developed formulations among a population that consumes baked goods. The participants were over 18 years of age and belonged to the TecNM technological community: Instituto Tecnológico Superior de Acatlán de

Osorio, who were regular consumers of cookies as well as baked goods, with no dietary restrictions related to the ingredients used in the formulations, such as gluten or mango intolerance. This sample size allows for statistically representative results regarding the degree of liking and minimizes the natural variability of human responses. The sensory evaluation of flavor, color, aroma, and texture was conducted by a panel of nine semi-trained tasters at 48-hour intervals to avoid sensory fatigue or product recall.

The samples used are considered relevant to achieving the research objectives, as they allowed for the evaluation of the effect of different levels of wheat flour replacement with Creole mango peel powder on the physicochemical, functional, and sensory properties of soda crackers. The inclusion of four replacement levels made it possible to analyze the influence of this functional ingredient on the quality of the crackers.

Methods

Data collection in this study was conducted using standardized sensory and analytical techniques, employing validated instruments widely used in food research to evaluate the sensory, physicochemical, and functional properties of soda-type cookies made with partial substitution of wheat flour with Creole mango (Mangifera indica L.) peel powder.

In the acceptance ranking test, an evaluation sheet designed specifically for the test was used as the recording instrument, on which participants recorded the order of preference assigned to each sample. The samples were presented in random order to minimize biases associated with the order of presentation. Purified water was provided for mouth rinsing between samples to reduce the residual effect of flavors. The validity of this technique is supported by its widespread application in affective sensory analysis and by international guidelines for consumer preference studies.

The acceptability of sensory attributes (flavor, color, aroma, and texture) was determined using a structured five-point hedonic scale (1 = I dislike it very much, 5 = I like it very much). The instrument used was an evaluation form developed specifically for the study, based on descriptors defined during the training of a panel of nine tasters—faculty members and students in the Food Industry Engineering program—who had previously participated in five training sessions, each lasting one hour. During these sessions, reference samples were used to standardize evaluation criteria and improve the reproducibility of responses. The content validity of the instrument was ensured by selecting relevant sensory attributes of the product based on research by other authors, as well as through the consensus-based definition of descriptors during the training. Reliability was enhanced through the prior training of the panel of judges, the evaluation of each sample in triplicate, and the conduct of separate sessions at 48-hour intervals to minimize sensory fatigue and the memory effect.

Crude protein, crude fiber, ash, fat, and moisture were determined using the official methods of the Association of Official Analytical Chemists (AOAC), which are internationally recognized for their reproducibility and precision due to their standardization, thereby ensuring the validity and reliability of the results obtained in this study. Moisture content was determined using a thermobalance in accordance with standard NMX-F-428-1982. Carbohydrate content was determined by difference; this procedure is widely accepted in proximate analysis of foods. The color of the samples was determined using a colorimetric technique with a spectrophotometer (OceanOptics USB 2000). It was operated under

using optical-grade Teflon (PTFE) to calibrate reflectance and perform white balance adjustments, standardize the procedure, and replicate measurements. This ensured data with high analytical validity and statistical reliability for evaluating the effect of partially replacing wheat flour with Creole mango peel powder on the color of soda crackers.

Total, soluble, and insoluble dietary fiber were quantified using the enzymatic-gravimetric method developed by Asp et al. (1983) and subsequently modified by Parra & Meza (2016). Commercial analytical-grade enzymes (α-amylase, pepsin, and pancreatin) from Sigma Aldrich® were used. The validity of this method lies in its international recognition for the determination of dietary fiber in foods, and its reliability is ensured through the use of standardized protocols, certified reagents, and controlled experimental conditions.

The total phenolic compound content in the soda cracker samples was determined using the Folin-Ciocalteu colorimetric method. Measurements were performed using a Multisan FC microplate spectrophotometer and gallic acid (Sigma Aldrich®) as the reference standard for constructing the calibration curve. This method is validated based on its widespread use for the quantification of phenolic compounds in foods. In this study, analytical reliability was verified through the use of certified standards, analytical blanks, and calibration curves with adequate coefficients of determination (R^2= 0.9918).

The antioxidant activity of the cookie sample extracts was evaluated using the DPPH and ABTS assays, widely recognized spectrophotometric methods for demonstrating the ability to scavenge free radicals through the transfer of electrons or hydrogen atoms. Absorbance readings were taken using the Multisan FC microplate spectrophotometer, with Trolox (Sigma Aldrich®) as the reference standard. Both methods exhibit adequate sensitivity, reproducibility, and scientific acceptance for evaluating antioxidant activity in functional foods. The validity of these assays is supported by their widespread use in research on antioxidants in foods, which served as a reference for comparing results; reliability was ensured through the standardization of experimental protocols, the use of certified reagents, and the performance of these determinations under optimal laboratory conditions.

Procedure

This study was conducted at the Food Industries Workshop and the Multifunctional Basic Laboratory of the Food Industry Engineering Program at the National Technological Institute of Mexico, Acatlán de Osorio Campus, as well as at the Natural Products Research Laboratory in the Faculty of Chemical and Biological Sciences at the Autonomous University of Guerrero.

Raw Material

Creole mangoes at maturity stage 3 [35] were collected from backyard orchards in the municipality of Acatlán, Puebla, between May and June 2025. The mangoes were washed with potable water to remove dirt particles. A potato peeler was used to separate the peel from the pulp. The samples were placed in contact with a citric acid solution (5% w/v) [18] and subsequently in a sodium bisulfite solution (1% w/v) to prevent enzymatic browning, as well as the proliferation of molds and yeasts, during the convective drying process [35].

The Creole mango peels were subjected to convective drying with hot air (60°C) in a tray dryer (Aresma, model 100) for 24 hours until a constant moisture content was reached [35, 36], which

was monitored at 60-minute intervals using an analytical balance with an accuracy of ± 0.0001 g, until the final weight after dehydration was reached. Once dehydrated, the peels were ground into a fine powder that passed through a No. 35 sieve with a 500-micron mesh size, resulting in a powder similar to wheat flour. The resulting powders were stored in hermetically sealed polyethylene bags, labeled as PCM (mango peel powder), and kept at room temperature until used in the production of soda crackers.

In addition, all-purpose wheat flour, wheat starch, salt, milk, butter, yeast, and baking powder from commercial brands available on the local market were purchased.

Cookie Formulations

The cookie samples were prepared from doughs containing 10, 12.5, 15, and 17.5% MSC as a substitute for wheat flour. The base formula for the soda cracker used was as follows: 125 g of wheat flour, 60 g of milk, 30 g of butter, 20 g of cornstarch, 3 g of baker's yeast, and 3 g of sodium bicarbonate. In an Oster$^{(MR)}$stand mixer, the milk, melted butter, and solid ingredients were mixed for 6 minutes at a speed of 125 rpm using the dough hook until a smooth, workable dough was obtained. The dough was allowed to rest for 30 minutes. Portions of the dough were rolled out to a thickness of 3.5 mm, cut into 3 x 10 cm rectangles using a pasta wheel cutter, and baked at 170°C for 8–9 minutes. After baking, the cookies were allowed to cool to room temperature and placed in brown paper bags until evaluation.

Evaluation of the Cookies

a) Ranking Test

The soda crackers made using the four formulations were subjected to a ranking test conducted by 60 untrained judges who were regular cracker consumers. They were asked to rank the samples from highest to lowest acceptance based on flavor, with the aim of selecting the most preferred samples [34, 35]. The soda biscuit samples were coded as F1, F2, F3, and F4 and were presented in random order. Each participant was instructed to rinse their mouth with purified water between each sample [4, 3].

b) Acceptability Test (Hedonic Scale)

A sensory evaluation based on attributes was conducted by a panel of nine tasters—comprising students and faculty from the Food Industry Engineering program—on the base formulation and the three formulations that received the highest acceptance in the ranking test. This panel of evaluators underwent five one-hour training sessions: during these sessions, reference samples were presented to enable the panel to achieve optimal evaluation and to develop the descriptors to be assessed in the soda cracker formulations with partial substitution of wheat flour with PCM. Thus, an evaluation form was developed to assess the attributes of flavor, color, aroma, and texture. The samples consisted of soda-type cookies baked one day in advance, which were packaged in brown paper bags and stored at room temperature to preserve their sensory characteristics. The samples were presented on disposable plates, accompanied by water as a rinsing agent and the evaluation form. A 5-point hedonic scale [36] was used, where 1 = I strongly dislike it, 3 = I neither like nor dislike it, and 5 = I strongly like it. This evaluation was conducted in triplicate every 48 hours to avoid sensory fatigue or product recall.

d) Physicochemical Analysis

Official AOAC methods [37] were used to determine the content of crude protein (950.36), crude fiber (950.37), ash (930.22), fat (935.38) and moisture [36, 38, 39, 47, 48, 49, 54, 57] using the rapid thermobalance method (NMX-F-428-1982) [40, 36]. The carbohydrate content was calculated by difference [4, 39, 40].

The color of the cookie surface samples was determined according to the tristimulus color system described by Francis [46] using a spectrophotometer (OceanOptics USB 2000). The X, Y, and Z color coordinates and the CIE coordinates L^*, a^*, b^*, as well as chromaticity (C), which represents the saturation or purity of the color, were calculated directly by OceanViem software version 2.0.19-rc1.

e) Total Dietary Fiber

The total, soluble, and insoluble dietary fiber in the samples was determined using the gravimetric enzymatic method [37, 39, 54], developed by Asp *et al.* [41] and modified by Parra & Meza [42], using alpha-amylase, pancreatin, and pepsin from Sigma Aldrich®.

Extraction

For each formulation in this study, an extract was prepared by mixing 6 g of finely ground cookie sample with 30 mL of 70% (v/v) ethanol. The mixture was stirred for 1 hour at a power of 30 W. The resulting extract was filtered and centrifuged; the supernatant was stored in an amber bottle [39, 53]. An aliquot of these extracts was used to quantify total phenolic content and antioxidant activity.

f) Total phenols

The total phenols in the extracts of the four formulations evaluated were determined colorimetrically [38, 47, 48, 49, 54, 57] using the Folin-Ciocalteu method, as described by Singleton *et al.* [43], with some modifications [37, 39, 54], and Sigma Aldrich® gallic acid as the standard. Aliquots of 0.2 mL of the extract were added to 0.20 mL of Folin-Ciocalteu reagent, followed by the addition of 0.2 mL of a 7.5% (w/v) aqueous sodium carbonate solution. The mixture was stirred and allowed to stand for 30 minutes at room temperature, protected from light. Absorbance at 765 nm was measured using a Multiskan™ FC microplate photometer. A blank sample consisting of water and reagents was used as a reference. The results were expressed as milligrams of gallic acid equivalents per gram of powder (mg GAE/g powder) based on the gallic acid calibration curve using the following equation:

$y = 0.0203\ x + 0.0159$ Equation 1
$R^2 = 0.9918$

g) Antioxidant Activity

The antioxidant capacity of the extracts from the formulations was determined using the DPPH [47, 48, 54, 58] and ABTS [58] assays. For calibration, Trolox from Sigma Aldrich was used as a reference in the assays. All measurements were performed using a Multiskan™ FC microplate photometer.

DPPH

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay was performed using a method described by Blois [59], modified by Brand-Williams *et al.* [45], and further modified by Nanjo *et al.* [60]. Aliquots of 200 µL were taken from each of the cookie sample extracts. These were mixed with 1.0 mL of 0.1 mM DPPH in ethanol (96% v/v). The control samples contained all reagents except the extract. The reaction mixture was shaken until completely homogenized; the mixtures were stored in the dark for 30 min at room temperature, and the absorbance was measured at 517 nm using a microplate reader (Multiskan FC, Thermo Scientific). Antioxidant activity was expressed as IC50 (µg/mL). The values were obtained using linear regression analysis [61]. The percentage of neutralization was calculated based on the decrease in absorbance relative to the control, according to the following equation:

$$\% \text{ Inhibition: } 1 - (A_S / A_0) \times 100 \quad \text{Equation 2}$$

where A_o is the absorbance at 517 nm of the blank control and A_s is the absorbance of the sample preparation. The half-maximal inhibitory concentration (IC_{50}) was defined as the amount of sample required to achieve 50% of the free radical scavenging activity.

Antioxidant Assays

The Trolox equivalent antioxidant capacity (TEAC) assay was performed following the modified methodology described by Re *et al.* [45]. The ABTS·+ assay was performed by mixing 5 mL of ABTS solution (7 mM) with 88 µL of $K_2S_2O_8$ (potassium persulfate) solution (140 µM); the mixture was allowed to stand for 16 h in the dark at room temperature. Subsequently, the absorbance of the radical was adjusted to an OD at 730 nm of 0.7. Five µL of cookie extracts were mixed with 245 µL of the adjusted radical; the mixture was incubated for 30 min in the dark at room temperature and measured at 730 nm. The results were reported as µM Trolox Equivalent (TE)/g dry weight (d.w.).

ABTS

The Trolox-equivalent antioxidant capacity assay was performed following the modified methodology described by Re *et al.* [45]. ABTS+ was prepared by mixing 5 mL of ABTS solution (7 mM) with 88 µL of $K_2S_2O_8$ (potassium persulfate) solution (140 µM) and allowing the mixture to stand for 16 h in the dark at room temperature. Subsequently, the absorbance of the radical solution was adjusted to an OD at 730 nm of 0.7. Five µL of cookie extracts were mixed with 245 µL of the adjusted radical solution; the mixture was incubated for 30 min in the dark at room temperature and measured at 730 nm. The results were reported as µM Trolox Equivalent (TE)/g dry weight (d.w.). Absorbance was measured at 730 nm, and the results were expressed in micromoles of Trolox equivalent per gram of dry matter using the following equation:

$$\% \text{ Inhibition: } [1 - (A_{ABTS+-} - \frac{A_{blank}}{A_(ABTS+-)})] * 100 \quad \text{Equation 3}$$

Where: A_{ABTS+-} is the absorbance of the cationic radical solution at 734 nm, A_{sample} is the absorbance of the reaction mixture with the extract,

Data Analysis Statistical

Analysis

The results were expressed as the mean value of 3 determinations ± the standard deviation. The results of the physicochemical analyses, dietary fiber and total phenol content, antioxidant activity (DPPH and ABTS), as well as the sensory characteristics of the

were subjected to an analysis of variance (ANOVA) using a completely randomized design [36, 39, 49, 50, 51, 57] to determine the existence of significant differences, followed by Tukey's test for comparing means. All analyses were performed using the Minitab statistical software package (Version 17), with a p-value of $\alpha \leq 0.05$ considered a significant effect.

Methodological Limitations

This study has some limitations that should be taken into account when interpreting the results. First, this study was conducted using Creole mango peel from the Mixteca region of Puebla, which is specific to a particular stage of ripeness and season; therefore, the chemical composition of this raw material may differ from that observed in other mango varieties, geographic areas, or growing conditions. This limits the extrapolation of the results to other mango cultivars.

Similarly, the formulations evaluated were restricted to certain levels of partial substitution of wheat flour with Creole mango peel powder; therefore, the observed effects do not represent the behavior of formulations with substitution percentages higher or lower than those studied.

Regarding the sensory evaluation, a possible limitation stems from the size and characteristics of the panel of judges, as well as their level of training. The results reflect the preferences of this specific group and may not be representative of a broader population or, where applicable, of different consumer segments.

Furthermore, the determinations of physicochemical and functional properties were conducted under laboratory conditions using traditional analytical techniques, which may differ from instrumental chemical techniques.

RESULTS

Acceptance of Formulations

Table 1 presents the results of the acceptance rates for soda-type cookie formulations containing 10, 12.5, 15, 17.5, and 20% PCM. Based on these data, the three formulations with the highest scores (F2, F3, and F4) were selected and subjected to physicochemical analyses, including sensory attributes, colorimetry, dietary fiber determination, total phenols, and antioxidant activity (DPPH and ABTS).

Table 1. *Results of the ranking test for cookies with partial substitution of wheat flour with Creole mango peel powder*.

	Formulation				
	F1 10% PCM	**F2 12.5% PCM**	**F3 15.0% PCM**	**F4 17.5% PCM**	**F5 20% PCM**
% Acceptance	46	50	54	61	44

Source: Author's *own work* (2026).

Evaluation of Sensory Attributes

Statistical analysis indicated that there are significant differences among the formulations (p = 0.000) regarding the tasting panel's acceptance level for flavor, aroma, and texture, but not for the color of the cookies (Table 2).

Table 2. *Level of acceptance of sensory attributes of soda-type cookies with partial substitution of wheat flour with Creole mango peel powder*.

	Formulation			
Attribute	**F0**	**F2**	**F3**	**F4**
Color	5,000	3,875 ± 0.500[a]	4,000 ± 0.632[a]	3,500 ± 0.632[a]
Flavor	4.759	4.188 ± 0.834[ab]	4.375 ± 0.719[a]	3.563 ± 0.814[b]
Aroma	4.451	3.938 ± 0.772[a]	3.313 ± 0.602[b]	3.375 ± 0.719[ab]
Texture	4.741	4.500 ± 0.632[a]	4.375 ± 0.500[ab]	3.875 ± 0.619[b]

* Different letters indicate a significant difference, according to Tukey's test at the 95% level.
Source: Author's *own work* (2026).

Physicochemical Properties

Table 3 shows the results obtained for moisture, carbohydrates, crude protein, crude fiber, fat, and ash present in the soda-type cookie formulations with partial substitution of wheat flour with powders. Statistical analyses indicated that, in the soda-type cookies under study, there were significant differences in moisture, protein, crude fiber, ash, and carbohydrate content (p = 0.00), but not in fat content.

Table 3. *Physicochemical properties of soda-type cookie formulations with partial replacement of wheat flour with Creole mango peel powder**.

Property	**Formulation**			
	F0	**F2**	**F3**	**F4**
Moisture	1.783 ± 0.098[c]	4.996 ± 0.005[a]	4.503 ± 0.165[b]	4.500 ± 0.000[b]
Fats	14,091 ± 0.660[a]	14.113 ± 0.792[a]	14.577 ± 0.887[a]	14,940 ± 0.560[a]
Proteins	7,703 ± 0.200[a]	6.700 ± 0.265[b]	6,210 ± 0.212[b]	6,200 ± 0.155[b]
Ash	2,910 ± 0.317[b]	3,346 ± 0.045[a]	3,480 ± 0.075[a]	3,576 ± 0.050[a]
Crude Fiber	0.366 ± 0.005[d]	1.446 ± 0.005[c]	1.580 ± 0.010[b]	1.836 ± 0.005[a]
Carbohydrates	73.07 ± 0.00[a]	69.39 ± 0.00[b]	69.65 ± 0.00[c]	68.948 ± 0.00[d]

* Different letters indicate a significant difference, according to Tukey's test at the 95% level.
Source: Author's *own work* (2026).

Replacing wheat flour with PCM significantly affected the chroma and redness (a^*) but not the lightness (L^*) or yellowness (b^*) of the cookie's surface color (Table 4).

Table 4. *Color of soda-type cookie formulations with partial substitution of wheat flour with Creole mango peel powder**.

Formulation	**C***	**L***	**a***	**b***
F0	23.953 ± 4.86"	45.762 ± 3.40[b]	10.283 ± 3.47"	21.503 ± 4.34"
F2	18.717 ± 1.82[b]	32,687 ± 1.561a	11.746 ± 1.626°	14.526 ± 1.59[b]
F3	25,420 ± 3.01a	42,571 ± 11.48°	11.85 ± 3.73a	22.360 ± 1.89[a]
F4	23.991 ± 2.29" [b]	33.574 ± 0.883°	11.280 ± 0.507"	20.410 ± 1.051[ab]

* Different letters indicate a significant difference, according to the Tukey test at the 95% level.

Source: Author's *own work* (2026).

Dietary Fiber Content, Total Phenols, and Antioxidant Activity

Analysis of variance revealed significant differences in dietary fiber content (Table 5), total phenols, and antioxidant activity (Table 6) with respect to the replacement of wheat flour with PCM ($p < 0.05$).

Table 5. *Dietary fiber content in soda crackers made with partial substitution of wheat flour with Creole mango peel powder**.

Formulation	Total dietary fiber	Dietary dietary Insoluble	Dietary dietary soluble
F0	2.199 ± 0.000	1.445 ± 0.000	0.7534 ± 0.000
F2	5.397 ± 0.204[a]	3.754 ± 0.147[b]	1.642 ± 0.057[b]
F3	5.717 ± 0.189[b]	3.975 ± 0.147[b]	1,741 ± 0.735[a]
F4	6.463 ± 0.181[a]	4.520 ± 0.131[a]	1.939 ± 0.050[a]

* Different letters indicate a significant difference, according to the Tukey test at the 95% level.
Source: Author's *own work* (2026).

Table 6. *Total phenolic content and antioxidant activity of soda-type cookies with partial substitution of wheat flour with Creole mango peel powder**.

Formulations	Total Phenols	DPPH Inhibition (IC50)	ABTS Inhibition (IC50)
F0	168 ±0.050	210 ±0.084	376 ±0.401
F2	1195.1 ± 58.1 c	57.353 ± 1.670 a	90.94 ± 13.73 a
F3	1754.0 ± 30.3 b	51.78 ± 5.49 a	47.39 ± 3.06 b
F4	2120.0 ± 73.7 a	48.08 ± 7.16 a	47.56 ± 8.46 b

* Different letters indicate a significant difference, according to Tukey's test at the 95% level.
Source: Author's *own work* (2026).

DISCUSSION

Evaluation of Sensory Attributes

According to Table 2, as the substitution of wheat flour with PCM increased, the acceptability of these attributes in the cookie formulations decreased compared to the base formulation (F0), which is consistent with findings from previous studies on cookies made with different levels of wheat flour substitution, such as 2.5–10% [54], 5–20% [47], 5–15% [48], and 20–50% [49] of mango peel powder from other varieties, as well as with 10–30% pitahaya peel powder [50], 30–70% guava peel flour [38], and 10–30% plum pomace [48].

The acceptance test results show that, up to a 15% replacement level of wheat flour with PCM, the color, flavor, and texture of the cookies remained at acceptable levels. Above this substitution level, the cookies exhibited a brown color, attributed to enzymatic browning of the PCM [47, 49, 48, 54] as a result of polyphenol oxidase and peroxidase activity
[53] on the polyphenols in the husk. Thus, PCM imparts a dark color to the cookies

, giving the impression of an overbaked product [52]; this could have led the panelists to perceive the product as overbaked, thereby affecting their evaluation. Regarding flavor, the cookies made with more than 15% PCM had a bitter taste. This result is consistent with that reported by Aslam *et al.* [48] for cookies with similar percentages of mango peel substitution and may be related to the high polyphenol content present in this byproduct [49, 47, 48, 54].

As a result of baking, the characteristic mango aroma present in the dough underwent a drastic change due to the thermal degradation of volatile compounds [53], affecting the acceptability of this attribute in the three formulations evaluated. This behavior differs from that reported by Aslam *et al.* [48] and Ajila *et al.* [54] for cookies containing up to 15% mango peel, in which the incorporation of mango peel did improve the perception of this attribute.

The texture of the three soda-type cookie formulations evaluated in this study showed slightly lower acceptability compared to the F0 formulation. The acceptability of this attribute was influenced by the content of mango peel incorporated into the formulations. This behavior is consistent with reports on cookies made with 5–30% peel from other mango varieties [54, 47, 49, 48], 10–30% pitahaya peel powder [50], and 10–30% plum pomace [51], in which certain substitution levels improved the texture compared to the base formulation. However, at substitution levels above 30%, the cookies tended to become harder, which reduced their acceptability.

Physicochemical Properties

The chemical composition of these baked goods varies depending on the percentage of wheat flour substitution; this was observed in cookies made with the peels of other mango varieties [54, 47, 49, 48], guava peels [36], plum pomace [51], and pitahaya peels [50].

The highest moisture content was recorded in the cookies from treatment F2 (4.996%), and the lowest content was found in the control cookies from treatment F0 (1.783%). In this study, the moisture content of the samples increased as the level of wheat flour substitution with PCM increased. This behavior is consistent with the findings reported by Ashous & Gadallah [47], Aslam *et al.* [48], and Bandyopadhyoy *et al.* [49] in cookie formulations made with mango peels from other varieties and in cookies made with plum pomace [51]. The trend toward increased moisture content could be explained by the high dietary fiber content of mango pomace. Due to its high water-absorption capacity, fiber increases the water-retention capacity of the cookies [53], which is reflected in higher moisture content.

Regarding protein content, formulation F2 (12.5% PCM) had the highest value among soda-type cookies with partial wheat flour substitution. However, when compared to the base formulation (F0), all formulations showed lower protein content, which is consistent with reports on cookies made with 5% to 30% mango peel powder from other varieties [47, 48, 49], pitahaya peel powder [50], guava peel powder [36], and plum residue powder [51]. This variation in protein content can be explained by the reduction in wheat flour in the formulations, since it is the main source of protein [58], providing approximately 12% per 100 g, in contrast to the 4.43% reported for PCM [35].

Compared to the cookies in formulation F0, formulations F2 (12.5% PCM) and F4 (17.5%) had the lowest and highest ash content at 3.346% and 3.576%, respectively. The ash content increased as the substitution of wheat flour with PCM increased. These results are consistent with those reported for cookies made with 5 to 30% of peel powder from other varieties of

[49] and guava peel powder [38]. According to Gondim *et al.* [59], this increase can be explained by the fact that fruit peels contain a higher proportion of minerals than their edible parts; therefore, as the content of Creole mango peel powder in the formulations of this study increased, the ash content also rose.

Among the formulations containing PCM, formulation F4 (17.5% PCM) had the highest crude fiber content (1.836%). The fiber content in all the PCM-containing soda cracker formulations was higher than that reported for the control formulation (F0). This behavior can be explained by the fact that wheat flour contributes between 0.5–1% of this nutrient, whereas a content of 15.76% has been reported for Creole mango peel [39]. This increase in fiber is consistent with the findings reported by Ashous & Gadallah (2011) [47], Aslam *et al.* [48], and Bandyopadhyoy *et al.* [49] for cookie formulations containing similar percentages of mango peel, banana peel [57], and plum pomace [51].

The L^*value decreased as the percentage of PCM increased. The control cookie had the highest brightness compared to the cookies containing PCM. There was a tendency for the a^*value to increase as the content of Creole mango peel powder increased. No specific trend was observed in the C* and b^*values when PCM was added. The polyphenol oxidase and peroxidase in the peel exert activity on their polyphenols [54]. As a result of enzymatic browning, the brightness of the cookies tends to decrease, which is consistent with the findings reported by Ajila *et al.* [54] and Ashous & Gadallah [47].

Dietary Fiber Content, Total Phenols, and Antioxidant Activity

The total dietary fiber values found in the three formulations with partial replacement of wheat flour with PCM were higher than those of the base formulation (F0), demonstrating a progressive increase in total, soluble, and insoluble fiber as the percentage of PCM in the formulations increased (Table 5), This is consistent with the findings in cookie formulations containing 5% and up to 20% mango peel powder reported by Ajila *et al.* [54]; according to these authors, during baking, some of the components present in the mango peel may have contributed to the formation of additional dietary fiber. Commercial soda crackers typically provide little dietary fiber, as they are made primarily from refined wheat flour, which loses much of this component during processing. In general, this type of cracker contains between 2.8 and 3.0 g of fiber per 100 g of product.

According to the data presented in Table 6, the total phenolic content of the cookies increased as the incorporation of PCM increased, reaching its highest value in formulation F4 (17.5%), with 2,120 mg AGE/g, which is consistent with values reported for cookies containing similar percentages of mango peel from other varieties [47, 48, 49], pitahaya peel powder [50], banana peel powder [57], and guava peel powder [36]. The incorporation of phenol-rich ingredients, such as fruit byproducts, is used to functionalize baked goods; however, their effectiveness depends on the various stages of the production process, particularly mixing and baking, as both can significantly affect the content and activity of these compounds [47, 49, 54].

In this regard, antioxidant activity increased significantly as the level of substitution with PCM increased. This behavior is consistent with what has been reported for cookies made with similar substitution percentages of mango powders from other varieties [47, 48, 49] as measured by the DPPH assay, as well as for bread enriched with grape seed extract [58], as evaluated by the ABTS assay. This effect can be attributed to the higher polyphenol content provided by the Creole mango peel powders.

CONCLUSIONS

The partial replacement of wheat flour with Creole mango peel powder had a significant effect on the physicochemical, colorimetric, functional, and sensory properties of soda crackers. It was observed that, as the percentage of Creole mango peel powder increased, the protein content decreased, while moisture, fat, and crude fiber increased in the evaluated formulations. Formulation F2 had the highest protein content, while formulation F4 stood out for its higher content of total dietary fiber and total phenols compared to the control cookie, also demonstrating greater antioxidant activity. The partial replacement of wheat flour with Creole mango peel powder contributed to an increase in dietary fiber and phenolic compounds, thereby improving the nutritional and functional value of the baked good.

Regarding sensory characteristics, it was found that as the substitution rate increased, the ratings for attributes such as flavor, aroma, crispness, and texture decreased; however, formulation F3, containing 17.5% Creole mango peel powder, was the most accepted by the tasters, demonstrating that this mango byproduct can be incorporated without significantly affecting the product's sensory acceptability.

The results confirmed that Creole mango (Mangifera indica L.) peel powder can be used as a functional ingredient in the production of soda crackers, offering an alternative for increasing the intake of dietary fiber and bioactive compounds associated with potential health benefits. Thus, its use represents a viable strategy for utilizing agro-industrial byproducts and developing value-added functional foods.

As a direction for future research, it is recommended to conduct an in-depth study evaluating the effect of Creole mango peel powder on the shelf life, oxidative stability, and microbiological behavior of baked goods.

DATA AVAILABILITY STATEMENT

Study Data

The datasets generated and analyzed during this research are available upon reasonable request to the corresponding author. The data include the experimental results obtained from the physicochemical, nutritional, functional, colorimetric, and sensory analyses reported in this article.

Protocol / Code / Questionnaire

The protocols and questionnaire are not publicly deposited in a repository, but may be provided by the corresponding author upon reasonable request, in order to facilitate the reproducibility of the study. No proprietary or restricted computer code was developed.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding this manuscript.

Ethical Approval

Not applicable (no human or animal participants).

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