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Effect of turmeric flour on the sensory properties, antioxidants and antidiabetic activity of a spicy fruit sauce

Efecto de harina de *Curcuma longa* en las propiedades sensoriales, actividad antioxidante y antidiabética de salsa picante de fruta

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ABSTRACT

Keywords:
α-glucosidase
Charapita chili
Mangifera indica
Solanum sessiliflorum

Peru is one of the largest exporters of turmeric. In this sense, it is important to use turmeric in new products for national consumption to achieve its revalorization with other national resources, such as mango, cocona, and charapita chili of Amazonian origin. Due to the growing interest in functional foods, the aim of this study was to evaluate the effect of the addition of turmeric (*Curcuma longa* L.) flour (TF) to a spicy fruit sauce (SFS), in the sensory rating, total phenolic compounds (TPC), and antioxidant activity. A factorial experiment design of two factors was carried out: TF content (6, 7, 8, and 9%) and type of fruit (mango and cocona). The proximal composition was determined, and spectrophotometric methods were used to measure the TPC, total curcuminoids, and antioxidant activity: DPPH, FRAP, and ABTS; the colorimetry method was used to measure the color of the samples; and atomic absorption spectroscopy was used to measure the mineral content. The antidiabetic activity was determined for the optimized sample. The optimal SFS was mango-based with 8% TF, with 5.01±0.23 mg curcuminoids g^{-1}, 4.29±0.13 mg GAE g^{-1}, and a higher flavor rating (4.39). The antioxidant capacity DPPH, FRAP, and ABTS was: 15.01±2.38, 14.59±0.04, and 42.01±2.11 µmol TE g^{-1}, respectively; and the α-glucosidase inhibition test resulted in IC_{50} of 69.81±9.42 µg mL^{-1}. In conclusion, TF provides TPC, curcuminoids, antioxidants, and antidiabetic activity. This suggests possible future applications of TF in the development of functional food with antioxidant and antidiabetic effects.

RESUMEN

Palabras clave:
α-glucosidasa
Ají Charapita
Mangifera indica
Solanum sessiliflorum

El Perú es uno de los mayores exportadores de cúrcuma fresca. En ese sentido, es importante emplear la cúrcuma en nuevos productos de consumo nacional para lograr su revalorización junto a otros recursos nacionales, como el mango, cocona y ají charapita de origen amazónico. Dado el creciente interés en alimentos funcionales, este estudio tuvo como objetivo evaluar el efecto de la adición de harina de *Curcuma longa* L (HC) en una salsa picante (SP), analizando la calificación sensorial, compuestos fenólicos (CFT) y actividad antioxidante. Se realizó un diseño experimental factorial de dos factores: HC (6, 7, 8 y 9%) y tipo de fruta (mango y cocona). Se determinó la composición proximal, se usaron métodos espectrofotométricos para los CFT, curcuminoides totales y la actividad antioxidante: DPPH, FRAP y ABTS, se usó un colorímetro para medir el color de las muestras, y el espectrofotómetro de absorción atómica para medir el contenido de minerales. A la muestra optimizada se le determinó la actividad antidiabética. La SP óptima fue la de mango con 8% de HC, con 5,01±0,23 mg curcuminoides g^{-1} y 4,29±0,13 mg GAE g^{-1}. La capacidad antioxidante DPPH, FRAP y ABTS fue :15,01±2,38, 14,59±0,04 y 42,01±2,11 µmol TE g^{-1}, respectivamente y la prueba de inhibición de la α-glucosidasa resultó en IC_{50} de 69,81±9,42 µg mL^{-1}. En conclusión, la HC aporta CFT, curcuminoides, actividad antioxidante y antidiabética. Esto sugiere posibles aplicaciones de la harina de cúrcuma en el desarrollo de productos alimenticios funcionales dirigidos a efectos antioxidantes y antidiabéticos.

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Turmeric (*Curcuma longa* L.) is a plant commonly used in many countries, especially in Asia; its rhizome is used as a spice to flavor or color foods and dishes. In 2022, Peru exported 2,734,764 tons of turmeric (*Curcuma longa*), 80.9% fresh, 15.9% in powder, and 3.2% in juice and coloring presentations, among others (CIEN 2023).

It is used in traditional Indian medicine to treat anorexia, cough, diabetic wounds, urinary tract infections and liver disorders, and it also has a similar action to insulin (Mohanty et al. 2004). Likewise, Seclén (2015) mentions that diabetes is a public health problem in Peru, especially for middle-aged people, since approximately a quarter of the adult population of Peru has a higher risk of diabetes.

Slowing glucose absorption by inhibiting the activities of carbohydrate digestive enzymes is considered an effective treatment for diabetes mellitus type 2 (Perez 2016). Tshiyoyo et al. (2022) evaluated the ability of curcumin, and rosmarinic acid to inhibit α-amylase, α-glucosidase and hepatic lipid accumulation. Although several synthetic drugs have been used to treat diabetes, efforts are needed to develop new effective inhibitors against α-amylase and α-glucosidase. Metformin is the most prescribed and recommended drug for type 2 diabetes mellitus because of its better tolerability, pleiotropic benefits, and cost-effectiveness. However, it has secondary effects such as abdominal distension, flatulence, bloating and the possibility of diarrhea (Chaudhary et al. 2024).

The incorporation of fresh *Curcuma longa* or its extract into food matrices provides phenolic compounds and a notable antioxidant capacity. In this regard, Awaeloh et al. (2025) developed gluten-free extruded snacks based on green banana and rice flour enriched with turmeric microcapsules, observing an increase in antioxidant activity while maintaining high sensory acceptability. Similarly, Modi and Sahota (2024) optimized a fermented beverage with fresh turmeric using a response surface methodology. Hutachok et al. (2023) evaluated macaroni fortified with turmeric and green tea extract, which not only has high antioxidant activity but also demonstrated hypolipidemic effects in diabetic rat models by using serum triglyceride levels. These findings support the use of turmeric as a functional ingredient and justify its incorporation into innovative products such as the fruit-based spicy sauce evaluated in this study.

The health benefits of turmeric, including its α-glucosidase inhibitory effects, are well recognized. Although studies have explored its use in food matrices through extracts, microencapsulated forms, and fresh turmeric, there remains a lack of research on the potential antidiabetic and antioxidant effects of new product formulations using turmeric flour in combination with other ingredients, particularly those that have undergone thermal processing. In this study, the inhibition of α-glucosidase of the optimized SFS formulation was demonstrated. At the same time, it contributes to the food sector with a proposal for the productive diversification of turmeric to provide added value to this resource. This study addresses a novel topic, as no prior research was found on the incorporation of turmeric into spicy fruit sauces.

The aim of this study was to assess the impact of turmeric flour (TF) incorporation on the sensory properties, curcuminoid and total phenolic contents, antioxidant capacity, and α-glucosidase inhibitory activity of a spicy fruit sauce.

MATERIALS AND METHODS

Turmeric

Plants of *C. longa L.*, from the Zingiberaceae family, were identified by the Amazonian Herbarium (AMAZ) and registered with code AMAZ 42787. Rhizomes were sown in the Caserío Angel Cárdenas from San Juan, Maynas, Loreto (2'58.954" S, 73°25'46.047" W) at 132 meters above sea level (masl). The humid tropical climate of the area had a temperature range from 20 to 32° C and a rainfall of 2,500 mm per year. In January 2022, 8 months after sowing, the plants with rhizomes at the phenological flowering stage were harvested by digging up. Then, 250 kg of rhizome were washed and sorted. Yellow and orange rhizomes with 5 – 8 cm length and 1.5 – 2 cm diameter were selected and disinfected with 2% sodium hypochlorite for 30 min. They were cut with a steel knife to a thickness of 3 mm to improve the drying process, then dried in a drying chamber with a dehumidifier (25 Pint, Peru) at 30 – 35 °C for 6 days with a drying yield of 10%. Then, dried flakes were ground in an analytical mill (A 11 Basic, IKA, USA), passed through a 500 µm sieve, and retained in a 500 µm sieve (Retsch, Peru). Turmeric flour (TF) was vacuum-packed in polyethylene bags, protected from light, and refrigerated at 5±1 °C until later use.

Chemical reagents

Folin Ciocalteu's phenol reagent (2N), monohydrated gallic acid (≥98.5%, ACS), Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) ≥96%, potassium iodide solution (>99.0%, ACS), and Acetic acid (≥99.7%, ACS) were obtained from Sigma-Aldrich (Canada). Curcumin standard ≥95% (Bio Basic, Canada). The reagents sodium carbonate (≥99.9%), iron trichloride hexahydrate (ACS), calcium standard (in HNO_3 1,000 mg of Ca in 1 L), acetone (≥99.8%, ACS), methanol (≥99.9%, ACS), chloroform (≥99.8%, ACS) and sodium thiosulfate (ACS) were purchased from Merck (USA). The reagent 2,4,6-Tri(2-pyridyl)-1,3,5-triazine 98% was from Alfa Aesar (Germany), and ethanol (99.5%) was from Scharlau (Spain). Deionized water was supplied by the Barnstead water purification system (Barnstead, Model D11911, Germany). Hydrochloric acid ultrapure reagent (32-35%) (J.T. Baker, Canada), iron standard ICP-27N-5 1,000 μg mL^{-1} (Accustandard, EE. UU.), copper standard ICP-15N-5 1,000 μg mL^{-1} (Accustandard, EE. UU.), zinc standard (1,000 mg L^{-1}, Sigma-Aldrich, Canada), sodium standard ICP-54N-5 1,000 μg mL^{-1} (AccuStandard, EE. UU.), magnesium standard ICP-32N-5 1,000 μg mL^{-1} (AccuStandard, EE. UU.), potassium standard ICP-43N-5 1,000 μg mL^{-1} (AccuStandard, EE. UU.)

Experimental design

To formulate the SFSs, a full factorial design was used with the Minitab statistical program (Table 1), with two factors: Type of fruit with two levels: mango and cocona; and the second factor: turmeric flour content with four levels: 6, 7, 8, and 9% turmeric flour. TF was added to the spicy mango (SMS) and cocona (SCS) sauce as established in Table 1.

The effect of the factors on the following response variables was analyzed: Flavor, TCC, TPC, ABTS, FRAP, DPPH. Optimization was calculated by maximizing flavor score, TCC, and TPC.

Table 1. Experimental design of the formulations of spicy fruit sauces and treatment codes.

Experiments	Treatment code (TF)	Blocks	Fruit	Turmeric flour (%)
1	SMS 6%	1	Mango	6
2	SCS 6%	1	Cocona	6
3	SMS 7%	1	Mango	7
4	SCS 7%	1	Cocona	7
5	SMS 8%	1	Mango	8
6	SCS 8%	1	Cocona	8
7	SMS 9%	1	Mango	9
8	SCS 9%	1	Cocona	9
9	SMS 6%	2	Mango	6
10	SCS 6%	2	Cocona	6
11	SMS 7%	2	Mango	7
12	SCS 7%	2	Cocona	7
13	SMS 8%	2	Mango	8
14	SCS 8%	2	Cocona	8
15	SMS 9%	2	Mango	9
16	SCS 9%	2	Cocona	9

Formulation of the spicy fruit sauce

The studies were conducted in the bioactive compounds laboratories of the Instituto Tecnológico de la Producción, Lima-Peru. The supplies were purchased at the Lima wholesale market. The formulation is shown in Table 2.

Table 2. Formulations in percentage (%) of spicy mango sauce (SMS) and spicy cocona sauce (SCS).

Ingredients	SMS (6%)	SMS (7%)	SMS (8%)	SMS (9%)	SCS (6%)	SCS (7%)	SCS (8%)	SCS (9%)
Yellow chili	20	20	20	20	20	20	20	20
Charapita chili	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Turmeric	6	7	8	9	6	7	8	9
Mango	41	40	39	38	0	0	0	0
Cocona	0	0	0	0	31	30	29	28
Vegetal spices	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Pepper	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Garlic	1	1	1	1	1	1	1	1
Salt	3	3	3	3	3	3	3	3
Oil and vinegar	19	19	19	19	19	19	19	19
Water	5.15	5.15	5.15	5.15	15.15	15.15	15.15	15.15

Sensory evaluation

To control the effect of contrast between samples, a balanced incomplete blocks design (Cochran and Cox 1957) was followed for 28 trained panelists, 14 male and 14 females, between 25 and 60 years old. Workers from the Instituto Tecnológico de la Producción participated; they were selected based on their habit of consuming spicy sauce at least three times a week, and for liking the spicy sensation. The test was developed by a professional from the sensory evaluation laboratory. The 5-point hedonic scale was used to evaluate color, smell, flavor, and texture (consistency). The rating of 5, 4, 3, 2, 1 corresponded to "I like it a lot"; "I like it", "I neither like it nor dislike it", "I dislike it", and "I dislike it a lot", respectively. The rating "3" was considered acceptable, and lower ratings were not acceptable.

Each panelist received two samples according to the balanced incomplete block design (5 g per sample). Pieces of white potato measuring 3x3 cm were used as a sample vehicle. Also, a glass of water was provided, as well as a sensory card that the participants were asked to mark according to their liking. The temperature of the sample at the time of serving was 20±2 °C. The evaluation was carried out in duplicate. The data were processed with R software (Studio version 4.3.1).

Color measurement

The colorimetry equipment (Konica Minolta, CM-5 spectrophotometer, Japan) was used with illuminant D65 and a viewing angle of 0° in reflectance mode, expressing the readings in terms of the CIELab color space (L*, a*, b*). Measurements were made of the values, where L represents luminosity (0 = black, 100 = white), a represents red/green (+ value = redness, - value = greenness), and b represents yellow/blue (+ value = yellowness, - value = blue). The Browning Index (BI) of the sauces was calculated using Equation 1 (S Abd El-Baset and Almoselhy 2023). The BI was used in order to measure how much the SFS increases the brown intensity as TF is added. No references were found with measurements of L*, a*, and b* of spicy fruit sauce; for this reason, the coloration was compared with three commercial samples of chili sauce.

$$BI = \frac{100}{0.17}\left(\frac{a + 1.75\,L}{5.645\,L + a - 0.012\,b} - 0.31\right) \quad (1)$$

Chemical analysis

All the chemical analyses were done in duplicate.

Obtaining extracts

In a 2 mL vial, 1 g of SFS sample was weighed and washed with 1 mL of 96 ° ethanol, then placed in a centrifuge (Centrifuge 5415 C, Germany) at 10,000 rpm for 10 min. The supernatant was placed in a tube, and eight similar washes were performed on the sample in the vial. The entire supernatant was then centrifuged in the refrigerated centrifuge (Centrifuge 5804 R, Germany) at 7,500 rpm for 10 min at 5 °C. Finally, it was rooted in a 10 mL vial and stored frozen until further analysis. The extract was used for the chemical analysis of total phenolic content, total curcuminoids, antioxidant activity, and antidiabetic activity.

Determination of total phenolic compounds

Total phenolic content (TPC) was determined using the Folin-Ciocalteu procedure described by Barriga-Sánchez et al. (2021) with modifications. 71 µL of extract was combined with 71 µL of Folin-Ciocalteu, 1,430 µL of 6% (w/v) sodium carbonate, and 2,000 µL of deionized water. The mixture was kept in the dark at room temperature for 1 h. The reading was performed at 750 nm using a Genesys 180 model spectrophotometer (Thermo Scientific, USA), and the results were reported as milligram gallic acid equivalents (GAE) per gram of sauce using a curve generated with standard solutions of 50, 100, 150, 200, and 400 mg L^{-1}.

Determination of total Curcuminoids

The methodology was followed as described by Hazra et al. (2015). A standard solution of 500 µg mL^{-1} of curcumin with methanol was prepared in a 10 mL vial, and from it, a calibration curve with the following concentrations: 5, 10, 15 and 20 µg mL^{-1} in ethanol, the absorbances of the points of the calibration curve were measured in the Genesys 180 model spectrophotometer (Thermo Scientific, USA) at 421 nm, and the SFS sample extracts were also directly measured at 421 nm. The results were expressed in mg curcuminoids g^{-1} SFS.

Antioxidant activity

ABTS assay

The 2-2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical cation scavenging capacity test of SFS was performed according to Prior et al. (2005). A calibration curve was used with Trolox concentrations of 0.1, 0.5, 1.0, 1.5, and 2.0 mM in ethanol. The calibration curve and the sample extracts were measured in the spectrophotometer. The results were expressed in µmol TE g^{-1} SFS.

DPPH

The antioxidant capacity of SFS was determined using the procedure described by Barriga-Sánchez et al. (2021), using the reagent 2, 2-diphenyl-1-picrylhydrazyl (DPPH). For the calibration curve, Trolox was used as a standard, and a calibration curve was prepared from the sample extracts, from 100 µL to 900 µL. After 30 minutes of reaction in the dark, the absorbance was determined in the spectrophotometer at 518 nm. The results were expressed in µmol TE g^{-1} SFS.

FRAP assay

The antioxidant capacity of the spicy fruit sauce was determined using the FRAP assay as described by Barriga-Sánchez et al. (2022). Samples extracts at the appropriate dilution were added to the FRAP reagent (acetate buffer pH=3.6, TPTZ (2,4,6-tripyridyl-s-triazine) and $FeCl_3 6H_2O$ in a ratio of 25:2.5:2.5). The mixture was incubated at 20 °C for 30 min, and the absorbance was measured with the Spectrophotometer at 595 nm. A calibration curve was prepared using 50, 150, 300, 400, 500, and 600 µM Trolox. The results were expressed in µmol TE g^{-1} SFS.

Antidiabetic activity

α-glucosidase inhibition assay

The quantification of α-glucosidase inhibition was determined using the enzymatic hydrolysis of the substrate p-Nitrophenyl-α-D-glucopyranoside (p-NGP) by the action of the enzyme α-glucosidase (α-GLC) that releases p-nitrophenolate and α-D-glucose units, as described by Artanti et al. (2012) and Srianta et al. (2013) with modifications. Acarbose was used as a positive control (10-1,000 µg mL^{-1}). 50 µL of SFS Sample extract was added to a vial with 100 µL of p-NGP (5 mM) and 330 µL of phosphate buffer (pH=6.8); the same was done for acarbose. 20 µL of α-GLC (0.24 U mL^{-1} in phosphate buffer, pH=6.8) was added, and the vials were incubated at 37 °C for 15 min. The reaction was stopped with 500 µL of Na_2CO_3 (0.2 M), and the absorbance was measured at 405 nm. The results were expressed in IC_{50}, units µg mL^{-1}. The criterion to confirm positive antidiabetic activity consisted of comparing the IC_{50} of the sample and acarbose, and the sample must have a lower IC_{50} compared to acarbose.

Characterization of the optimized SFS (SMS 8% TF)

Proximal composition analysis

The proximal composition was determined as described by Barriga-Sánchez et al. (2022).

The moisture content was estimated by the gravimetric method by drying the sample in an oven (Venticell Ecoline, Czech Republic). The ash content was determined by incinerating the dried sample overnight in a muffle furnace (Barnstead, Thermolyne, model 48000, USA). Total nitrogen content was determined by the Kjeldahl method using a Kjeldatherm TZ automated block digester (Germany) and a Buchi K-350 distillation unit (Spain). Fat content was determined by the Soxhlet method using a Buchi E-800 Universal Extractor (Switzerland).

Determination of mineral nutrients

Analyses of calcium, iron, copper, zinc, magnesium, sodium, and potassium were performed with an atomic absorption spectrophotometer (Perkin Elmer, Analyst 800, USA) as described by Barriga-Sánchez et al. (2022).

Viscosity determination

The viscosity was determined with a viscometer (Brookfield viscometer, DV2T, USA), and the spindle 64 was used. The apparent viscosity was determined at 3 rpm at 25 °C for the SMS 8TF and three commercial samples.

Determination of pH value

The pH of each spicy sauce was determined by direct reading, using the potentiometer (Thermo Scientific, Orion VersaStar Pro, Indonesia) with a semi-solid sample electrode (Thermo Scientific Orion 8157BNUMD).

Determination of acidity

A TitroLine TL 7000 automatic titrator (Schott GmbH, Germany) was used for the analysis. First, 0.5 g of sauce was weighed, and 50 mL of 96% ethanol, neutralized with phenolphthalein, was added to the sample. The mixture was then homogenized. Titration was carried out using 0.02 N NaOH. A blank sample, consisting of neutralized ethanol titrated with 0.25 N NaOH, was included, and the volume of NaOH consumed during titration was recorded. Equation (2) was used to calculate the percentage of acetic acid.

$$\text{Acetic Acid}(\%) = \frac{V \text{ x } N \text{ x } F \text{ x } 0.060}{W} \text{ x } 100 \qquad (2)$$

Where V is the volume of NaOH used in titration (mL), N is the normality of NaOH, F is the NaOH factor, W is the weight of the sauce sample (g), and 0.060 is the Milliequivalents of acetic acid.

Determination of consistency

The consistency of SMS 8 TF was determined using a Bostwick consistometer (Cole-Parmer Consistometer, USA) following the method of Juszczak et al. (2013). The consistometer tank was filled, and the gate was opened. The distance traveled after 30 seconds was recorded, and the results were expressed in centimeters per 30 seconds.

Statistical analysis

With the Minitab v.17 statistical program (Minitab, USA), a full factorial experimental design was obtained and the effect of the factors on the sensory evaluation score, TCC, TPC and antioxidant activity was analyzed; a one-way analysis of variance (ANOVA) and Tukey's multiple comparisons test of means were also performed. Previously, the results of the sensory analysis were analyzed by the RStudio 4.3.1 program, and then a factor analysis was performed. A significance level of P<0.05 was used. Results were presented as mean ± standard deviation and calculated using Excel 2016 (Microsoft, USA).

RESULTS AND DISCUSSION

Sensory analysis of the SFS

A sensory acceptable spicy sauce formulation was achieved, successfully masking the unpleasant taste of turmeric.

The attributes color, smell, and texture (consistency), and the spicy sensation, presented ratings higher than "3"; while in the flavor attribute, two of the treatments obtained ratings lower than "3" (Figure 1). The highest flavor scores were obtained by SMS 7% TF and SMS 8% TF (Table 3).

There was a significant effect of the type of fruit on the flavor (P=0.022), color (P=0.044), texture (P=0.029) of the SFS, also of the TF (P=0.017) on the flavor of the SFS (Table 4). There was no significant effect of the addition of TF and the type of fruit on the odor and spicy sensation (Table 4).

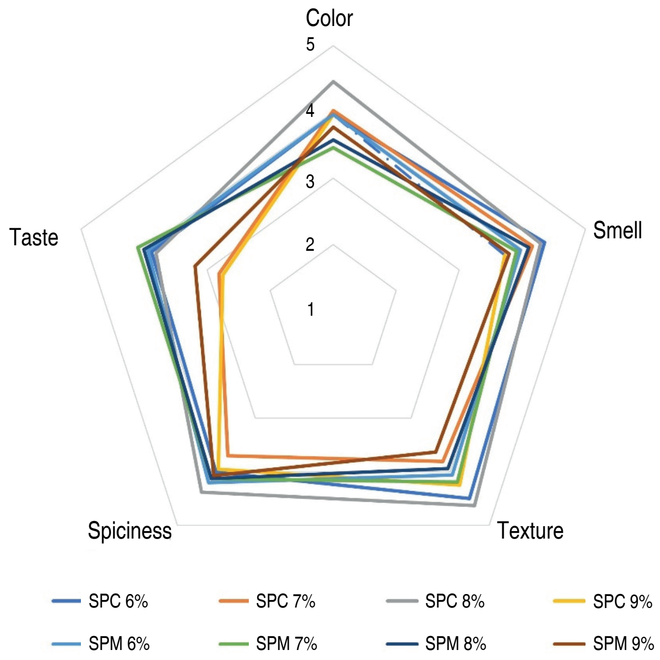

Figure 1. Spicy fruit sauce color, smell, texture, spiciness, and flavor ratings. SCS: spicy cocona sauce, SMS: spicy mango sauce, containing 6%, 7%, 8%, and 9% turmeric flour.

Table 3. Experimental design with results of flavor rating, total curcuminoids (TCC), total phenolic compounds (TPC) of mango (SMS) or cocona (SCS) spicy sauce with 6, 7, 8 and 9% turmeric flour.

Experiments	Treatment (TF)	Flavor	TCC (mg curcumin g^{-1})	TPC (mg GAE g^{-1})
1	SMS 6%	4.11	3.74	2.95
2	SCS 6%	3.86	3.77	3.43
3	SMS 7%	4.48	4.51	3.71
4	SCS 7%	2.98	4.54	4.01
5	SMS 8%	3.61	4.85	4.38
6	SCS 8%	3.98	5.12	4.46
7	SMS 9%	2.98	5.73	4.52
8	SCS 9%	2.86	5.29	4.75
9	SMS 6%	3.77	3.86	2.99
10	SCS 6%	3.89	3.83	3.32
11	SMS 7%	3.77	4.56	3.72
12	SCS 7%	2.64	4.47	3.46
13	SMS 8%	4.39	5.18	4.19
14	SCS 8%	3.64	5.16	4.22
15	SMS 9%	3.39	5.75	4.45
16	SCS 9%	2.64	5.54	4.31

SMS: spicy mango sauce, SCS: spicy cocona sauce.

Table 4. ANOVA of the factorial design of the attributes flavor, color, texture, smell, and spiciness of the Spicy Fruit Sauce.

Attribute		Flavor				Color				Texture			
Source	DF	Adj SS	Adj MS	*F*-Value	*P*-Value	Adj SS	Adj MS	*F*-Value	*P*-Value	Adj SS	Adj MS	*F*-Value	*P*-Value
Model	8	4.38	0.55	4.71	0.028	1.71	0.21	1.95	0.196	1.78	0.22	3.55	0.056
Blocks	1	0.03	0.03	0.27	0.616	0.41	0.41	3.78	0.093	0.18	0.18	2.94	0.130
Linear	4	3.39	0.85	7.30	0.012	0.84	0.21	1.92	0.212	0.87	0.22	3.48	0.072
TF(%)	3	2.39	0.80	6.87	0.017	0.18	0.06	0.55	0.665	0.40	0.13	2.13	0.185
Fruit type	1	1.00	1.00	8.62	0.022	0.66	0.66	6.04	0.044	0.47	0.47	7.56	0.029
2-Way Interactions	3	0.95	0.32	2.74	0.123	0.46	0.15	1.39	0.322	0.72	0.24	3.85	0.064
TF(%)*Fruit type	3	0.95	0.32	2.74	0.123	0.46	0.15	1.39	0.322	0.72	0.24	3.85	0.064
Error	7	0.81	0.12			0.77	0.11			0.44	0.06		
Total	15	5.19				2.48				2.21			

Attribute		Smell				Spiciness			
Source	DF	Adj SS	Adj MS	F-Value	P-Value	Adj SS	Adj MS	F-Value	P-Value
Model	8	0.72	0.09	0.70	0.688	0.56	0.07	0.93	0.547
Blocks	1	0.01	0.01	0.04	0.848	0.00	0.00	0.00	1.000
Linear	4	0.62	0.15	1.19	0.393	0.32	0.08	1.06	0.444
TF(%)	3	0.48	0.16	1.23	0.369	0.26	0.09	1.13	0.399
Fruit type	1	0.14	0.14	1.09	0.332	0.06	0.06	0.82	0.394
2-Way Interactions	3	0.10	0.03	0.26	0.851	0.24	0.08	1.06	0.423
TF(%)*Fruit type	3	0.10	0.03	0.26	0.851	0.24	0.08	1.06	0.423
Error	7	0.91	0.13			0.53	0.08		
Total	15	1.63				1.09			

DF: degrees of freedom; AdjSS: Adjusted Sum of Squares); Adj MS: Adjusted Mean Square; F value: Test statistic and *P* value: Is the probability of observing.

No references were found for sensory evaluation studies on turmeric-based spicy fruit sauces. However, Malomo et al. (2022) conducted a sensory evaluation using a 9-point scale to analyze the attributes of canned African catfish in tomato sauce with the addition of 3 and 4% turmeric. The results show that tomato sauce without turmeric (control) obtained better sensory ratings in the attributes of appearance, taste, texture, aroma, and general acceptability, with scores of 7.20, 6.60, 7.20, 7.33, and 7.27, respectively. They conclude that adding turmeric at 4% caused a decrease in sensory acceptance, to scores of 6.93, 5.40, 6.27, 6.33, and 6.00, respectively; this decrease indicated that turmeric negatively affected the sensory perception of the panelists. Similar results were obtained in this study, as the lowest scores corresponded to the spicy fruit sauce with the highest TF content.

Color determination (L*, a* and b*)

The average values of L* of the SCS were in the range of 55.60 to 58.94, and for the mango, from 53.43 to 54.78; and the a* value of the SCS presented lower values than the SMS, indicating that the cocona hot sauce presented greater clarity than the mango hot sauce. The b* value of the SCS 6% TF presented a greater yellow intensity than the rest of the SFSs. No articles on sauces of this type were found in the bibliography consulted. The color coordinates L* and a* presented values very far from those of commercial hot sauces (Table 5), possibly due to the use of turmeric, which is a natural colorant. The commercial sauces used in the comparison with the sauce in this work do not contain fruit or turmeric but represent the varieties of spicy sauces available in supermarkets in Lima, Peru.

The greater the addition of TF, the higher the BI value, indicating the greater intensity of brown color in the SFSs with 9% TF (Table 5).

Table 5. Color parameters (L, a, b*) and Browning Index (BI) of mango and cocona sauces containing 6%, 7%, 8%, and 9% turmeric flour.

Treatment code	L*	a*	b*	BI
SCS 0%	69.38±0.04^{C}	3.22±0.01^{E}	47.92±0.06$^{B, C}$	3.59±0.02^{G}
SCS 6%	58.94±0.13^{E}	16.33±0.20^{B}	57.96±3.03^{A}	19.40±0.20^{D}
SCS 7%	55.73±0.41$^{F, G}$	16.39±0.84^{B}	52.67±2.17$^{A, B, C}$	20.50±1.11$^{C, D}$
SCS 8%	57.11±0.20$^{E, F}$	17.65±0.25^{A}	54.78±2.10$^{A, B}$	21.47±0.22$^{B, C}$
SCS 9%	55.60±0.47$^{F, G}$	17.77±0.30^{A}	51.56±0.99$^{A, B, C}$	22.14±0.18$^{A, B}$
SMS 0%	64.90±0.01^{D}	5.59±0.01^{D}	50.17±0.01$^{A, B, C}$	6.41±0.01^{F}
SMS 6%	53.98±1.71^{G}	17.04±0.02$^{A, B}$	50.94±4.73$^{A, B, C}$	21.89±0.65$^{A, B, C}$
SMS 7%	53.58±0.17^{G}	17.34±0.31$^{A, B}$	51.11±3.83$^{A, B, C}$	22.41±0.34$^{A, B}$
SMS 8%	54.78±0.14$^{F, G}$	17.60±0.15^{A}	51.90±2.29$^{A, B, C}$	22.25±0.14$^{A, B}$
SMS 9%	53.43±1.11^{G}	18.02±0.08^{A}	48.60±1.70$^{B, C}$	23.26±0.35^{A}
Commercial Chili sauce N° 1	77.32±0.01^{A}	1.02±0.02^{F}	48.03±0.04$^{B, C}$	1.19±0.02^{H}
Commercial Chili sauce N° 2	76.23±0.01$^{A, B}$	4.04±0.02^{E}	45.11±0.02^{C}	4.01±0.02^{G}
Commercial Chili sauce N°3	74.05±0.04^{B}	8.93±0.02^{C}	58.09±0.06^{A}	8.80±0.02^{E}

Tukey test. Different letters in the same column indicate a significant difference (*P*<0.05). Equal letters in the same column indicate no significant difference (*P*>0.05).

Phenolic compounds, total curcuminoids, and antioxidant capacity (ABTS, FRAP, DPPH)

Total Phenolic Compounds (TPC)

The addition of TF had a significant effect on the phenolic compound content of the sauce (Table 6). As shown in Figure 2, increasing the percentage of flour in the SFS formulation led to a rise in TPC content, reaching values between 2.97 and 4.53 mg GAE g^{-1}, values higher than those reported by Guo et al. (2024), who made a spicy Chinese cabbage sauce (0.86 mg GAE g^{-1}); and by Rahman et al. (2024) when evaluating tomato and pumpkin sauce (0.035 to 0.062 mg GAE g^{-1}). In contrast, El Haggar et al. (2023) found higher TPC values (14.8317 mg GAE g^{-1}) in acai sauce, possibly because the latter contained sweet red peppers and pomegranate sauces as main ingredients. No studies of TPC, TCC, or antidiabetic activity in hot sauces with turmeric were found in the literature.

Table 6. Analysis of variance of factorial regression of total curcuminoids (TCC) and total phenolic compounds (TPC) vs % turmeric flour and type of fruit.

		TCC (mg g^{-1})				TPC (mg GAE g^{-1})			
Source	**DF**	**Adj SS**	**Adj MS**	***F*-Value**	***P*-Value**	**Adj SS**	**Adj MS**	***F*-Value**	***P*-Value**
Model	8	7.1512	0.8939	105.4	0.000	4.7022	0.5878	26.700	0.000
Blocks	1	0.0400	0.0400	4.710	0.067	0.1502	0.1502	6.820	0.035
Linear	4	7.0023	1.7506	206.30	0.000	4.4515	1.1129	50.550	0.000
TF(%)	3	6.9890	2.3297	274.54	0.000	4.3826	1.4609	66.360	0.000
Fruit type	1	0.0132	0.0132	1.560	0.252	0.0689	0.0689	3.1300	0.120
2-Way Interactions	3	0.1089	0.0363	4.280	0.052	0.1006	0.0335	1.520	0.291
TF(%)*Fruit type	3	0.1089	0.0363	4.280	0.052	0.1006	0.0335	1.520	0.291
Error	7	0.0594	0.0085	-	-	0.1541	0.0220	-	-
Total	15	7.2106	-	-	-	4.8563	-	-	-

Total curcuminoid content (TCC)

Turmeric from the Peruvian Amazon is a valuable resource characterized by its high content of bioactive compounds, mainly curcuminoids. There was a significant effect (directly proportional) of the addition of TF (*P*=0) on the TCC content of the SFS (Table 6), since as the percentage (%) of flour in the SFS increased, the TCC content increased (Figure 2). The TCC content of this study was in the range of 3.8 to 5.74 mg g^{-1} sample.

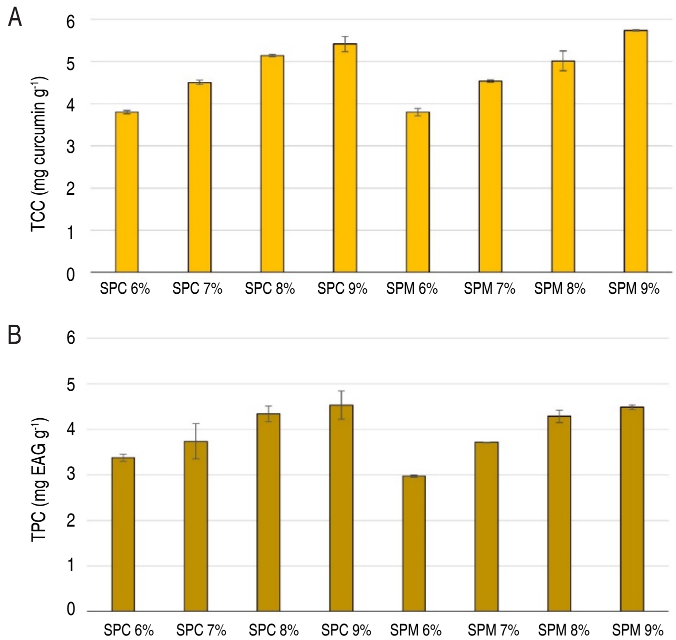

Figure 2. A) Content of total curcuminoids (TCC) and B) Total phenolic compounds (TPC) of spicy fruit sauces of mango (SMS) and cocona (SCS) containing 6%, 7%, 8%, and 9% turmeric flour.

Antioxidant activity

As more TF content is added, the antioxidant activity of FRAP and ABTS increases (Figure 3). In this regard, Barzegar (2012) pointed out that the hydrogen and electron transfer mechanisms explain the antioxidant potential of curcuminoids, which are the mechanisms on which the ABTS and FRAP methods are based, respectively.

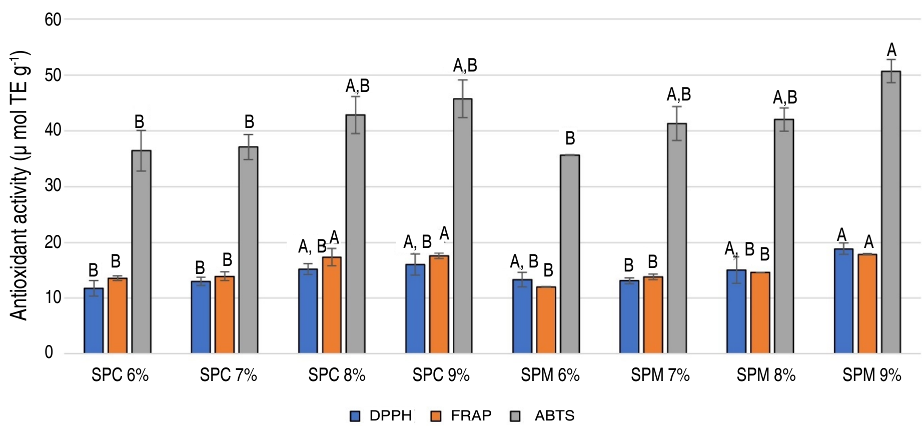

Figure 3. Antioxidant capacity DPPH, FRAP, and ABTS of the SFS, containing 6%, 7%, 8%, and 9% turmeric flour.

The percentage (%) of TF in the SFS formulation had a significant effect on the antioxidant capacity value DPPH (P=0.000), FRAP (P=0.000), and ABTS (P=0.000). As well as the type of fruit (P<0.05) on the antioxidant capacity, FRAP, and ABTS (Table 7). No studies reporting the antioxidant capacity of spicy fruit sauces with turmeric or similar formulations were found in the literature review. The following section discusses studies on antioxidant activity in other sauces. Guo et al. (2024) reported the antioxidant capacity (FRAP) of 360 µmol TE L^{-1} of a fermented spicy Chinese cabbage sauce, a value higher than that reported in this study, possibly due to the different technique and inputs used in its process.

Table 7. Analysis of variance of the factorial regression of antioxidant activity vs % turmeric flour and type of fruit.

		DPPH (µmol TE g^{-1})				FRAP (µmol TE g^{-1})				ABTS (µmol TE g^{-1})			
Source	**DF**	**Adj SS**	**Adj MS**	***F*-Value**	***P*-Value**	**Adj SS**	**Adj MS**	***F*-Value**	***P*-Value**	**Adj SS**	**Adj MS**	***F*-Value**	***P*-Value**
Model	8	75.64	9.46	6.60	0.010	68.03	8.50	16.67	0.000	415.71	51.96	35.37	0.000
Blocks	1	5.54	5.54	3.87	0.090	0.20	0.20	0.38	0.560	48.77	48.77	33.20	0.000
Linear	4	64.27	16.07	11.22	0.000	62.00	15.50	30.38	0.000	337.64	84.41	57.46	0.000
TF(%)	3	59.46	19.82	13.83	0.000	57.69	19.23	37.69	0.000	323.63	107.88	73.43	0.000
Fruit type	1	4.81	4.81	3.36	0.110	4.30	4.30	8.43	0.020	14.02	14.02	9.54	0.020
TF(%)*Fruit type	3	5.83	1.94	1.36	0.330	5.84	1.95	3.81	0.070	29.29	9.76	6.65	0.020
Error	7	10.03	1.43	-	-	3.57	0.51	-	-	10.28	1.47	-	-
Total	15	85.67	-	-	-	71.60	-	-	-	425,99	-	-	-

Park and Byun (2014) developed Bulgogi sauce, with soy and apple puree, with the addition of turmeric concentrate at concentrations of 10, 20, 30, and 40%. The Bulgogi sauce increased the DPPH antioxidant capacity value as the turmeric concentration increased. In this study, the addition was in smaller quantities, but an increase in antioxidant capacity was evident in the SFS with 9% TF compared to those with 6% TF. As shown in Figure 3, both TPC and curcuminoid levels increased significantly with the percentage of TF, which are known contributors to antioxidant activity. Therefore, the greater presence of these bioactive compounds in the samples with 9% TF justifies the higher antioxidant activity observed.

The sauces prepared in this study presented antioxidant activity (ABTS) in the range of 35.66 to 50.69 µmol TE g^{-1}, showing greater capacity for eliminating free radicals than that reported in the acai sauce prepared by Da Silva et al. (2021) (1.00 and 1.10 µmol TE g^{-1}), this variation could be due to the fact that turmeric provides greater antioxidant activity.

Spicy Fruit Sauce optimization

The predicted formulation obtained with the full factorial design, maximizing flavor, TCC, and TPC, was SMS 8% TF (Figure 4); the highest desirability was for flavor and TPC, and the desirability when evaluating TCC was lower.

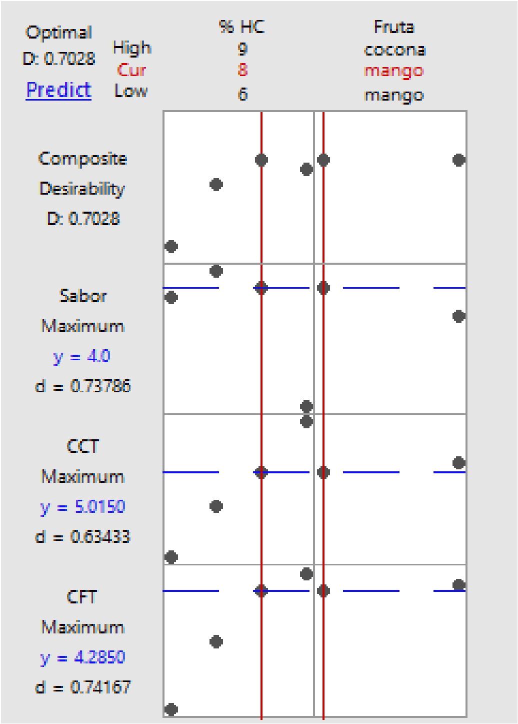

Figure 4. Optimization of spicy fruit sauce formulation.

Antidiabetic activity

The IC_{50} of SMS 8% TF was 69.81±9.42 μg mL^{-1} (IC_{50} of acarbose=415.56±7.20 μg mL^{-1}), indicating antidiabetic activity.) Sabir et al. (2020) found in the ethanolic extract of *C. longa* a greater inhibitory effect on α-GLC (IC_{50}=37.1±0.3 μg mL^{-1}) than in the present work, while Aranda-Ventura et al. (2021) reported a lower inhibition effect on α-glucosidase in ethanolic extract and aqueous extract of *C. longa* (IC_{50} of 81.90 and 171.60 μg mL^{-1}, respectively).

Di Pierro et al. (2015) mention that an overweight person requires consuming *Curcuma longa* at a dose of 800 mg twice a day for 1 month to lose weight and body fat. Likewise, Maithili et al. (2015) conclude that a diabetic patient should consume turmeric in doses of 2 g for 4 weeks to reduce dyslipidemia, LDL, and cholesterol.

Characterization of the optimized SFS (SMS 8% TF)

Proximate composition and mineral nutritional content of the optimal sauce

The proximal composition of the SFS is shown in Table 8, highlighting its mineral nutrient content. The protein and ash content were higher than the cocona hot sauce developed by Terry and Casusol (2018), who reported 1% protein and 3.3% ash. El Haggar et al. (2023) developed a sauce formula as a healthy functional product, with a higher protein content (2.07%) and a lower fat content (0.21%) compared to the present work; with a calcium, magnesium and potassium contribution of 24.53, 5.85 and 68.22 mg 100 g^{-1}, respectively, lower than what was obtained in this study for SMS 8% TF. The opposite was true for copper, iron, and zinc contents (0.85, 1.21, and 1.03 mg per 100 g of the sample, respectively), which were higher than the SMS 8% TF (Table 8).

Table 8. Proximal composition, mineral nutrients, and viscosity of the spicy sauce 8% TF.

Analysis	Component	Values	Commercial Chili sauce N°1	Commercial Chili sauce N°2	Commercial Chili sauce N°3
Proximal composition (g 100 g^{-1})	Moisture	68.11±0.00	-	-	-
	Protein	1.78±0.06	-	-	2.3
	Fat	13.81±0.08	46.6	33.3	26.2
	Saturated fat	1.50±0.01	6.67	5.33	3.2
	Ash	3.67±0.00	-	-	-
Mineral nutrients (mg 100 g^{-1})	Ca	56.87±1.29	-	-	-
	Mg	41.96±2.37	-	-	-
	Na	1185.48±22.57	666.67	733.33	333
	K	295.74±0.96	-	-	-
	Cu	0.24±0.00	-	-	-
	Fe	1.12±0.04	-	-	-
	Zn	0.27±0.01	-	-	-
Viscosity (3 RPM)	-	70500±4946.57^{A}	67550±597.22^{A}	51450±525.99^{B}	42950±191.49^{C}

The values are expressed as the mean ± standard deviation (n = 2).

Commercial sauces 1, 2, and 3 are the most demanded by consumers. The spicy sauce developed in this study exhibited a darker color compared to the commercial ones, while its flavor and consistency were similar to those of commercial sauce N°2.

Commercial sauces 1 and 2 exhibited higher fat and saturated fatty acids content in comparison to the sauce developed in this study.

The product prepared in this work is free of high saturated fat octagon since it presented 1.50±0.01% of saturated fat, which complies with the Peruvian regulations specified by the regulations of the Law for the Promotion of Healthy Eating (Ministerio de Salud del Perú 2017), which establishes that an octagonal symbol is displayed that indicates if the product has a content greater than or equal to 4 g of saturated fat per 100 g of product. However, it does correspond to show an octagon due to its high sodium content.

pH, Acidity, and consistency values

The pH of the sauce was 4.12±0.01, which meets the expected value for the stability of this type of product (Codex standard: pH<4.6). Therefore, the study was conducted using a percentage acidity of 0.53±0.06 acetic acid, at which sensory acceptability was achieved.

The Bostwick consistency in the mango spicy sauce was 2.5 cm per 30 s while the sweet and sour sauces with acai and non-conventional food plants, evaluated by Da Silva et al. (2021), presented 12.7 and 14.5 cm per 30 s of consistency, indicating that SMS is of greater consistency than these sauces, possibly because it has many solids in its formulation.

CONCLUSION

This study contributes to the existing literature of functional foods by providing information related to the antioxidant activity and α-glucosidase inhibition of a product formulated with turmeric flour. Also, it presents a simple technology for the preparation of a fruit-based spicy sauce. The spicy mango sauce with 8% turmeric flour presented the highest sensory score, phenolic compounds, and curcuminoids. This study showed that turmeric flour is a source of bioactive compounds, such as curcuminoids, and has potential antidiabetic properties through α-glucosidase inhibition. Future evaluations of other products using turmeric flour as an ingredient, such as instant soups, and shelf-life studies, and bioavailability of curcuminoids are recommended.

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CONFLICT OF INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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