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# Effects of Foam Mat Drying on the Nutritional, Functional, Antioxidant, and Sensory Properties of Soursop-Based Crisps

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## ABSTRACT

**This study investigates how foaming agents affect the nutritional, antioxidant, physicochemical, and sensory qualities of soursop-based crisps, which are crucial for meeting year-round market demand due to fruit cultivation limitations. Soursop pulp was whipped with varying concentrations of soy proteins (SP6% and SP8%), egg proteins (EP6% and EP8%), and whey proteins (WP6% and WP8%) to create seven treatments, including a control without foaming agents. The samples were then dried at 70°C, and their proximate and phytochemical composition, functional properties, antioxidant activity, and sensory attributes were assessed. Compared to the control, soursop-based crisps made with foaming agents contained higher fat content (1.87–4.15%), with EP10% and WP8% showing high ash content (5.82–6.60%), and WP10% and EP8% having elevated carbohydrate (85.92–87.66%) and protein (2.75–3.88%) levels. EP10% had the highest swelling index (3.03%) and oil absorption capacity (25.33%), while SP8% and SP10% exhibited greater water absorption (61.33–63.67%). Traces of oxalates, phytates, and tannins were found in all samples (<0.6 mg/ml). WP8% and WP10% had the highest flavonoid content (10.16–10.71 mgQE/ml), while SP10%, EP10%, WP8%, and WP10% showed the highest ferric-reducing activity (IC50:0.02–0.03 mg/ml). Most panelists (74% to 100%) favored soursop-based crisps from foam mat drying. In conclusion, foam mat drying affected the nutritional, physicochemical, and sensory properties of soursop-based crisps differently based on the type and concentration of foaming agents used, suggesting the method's potential for long-term fruit preservation.**

**Keywords:** Conventional drying, foam mat drying technology, soursop fruits, nutritional potential, functional properties, and hedonic test.

## INTRODUCTION

Fruits have been an integral part of the human diet for many years and are also considered food supplements, internationally recommended as essential for healthy nutrition and well-being due to their high quantity and quality of water, sugars, vitamins, minerals, and phytochemicals

[1,2]. But a lack of knowledge regarding available fruits, their usage, and nutritional and health implications poses challenges, particularly in addressing micronutrient deficiencies [3]. Nevertheless, a food-based approach, particularly dietary diversification, has the potential to enhance the consumption of micronutrient-rich locally available foods such as fruits, which is crucial in addressing hidden hunger [4]. However, the cultivation of fruits is often restricted to specific seasons and regions, leading to the need for preservation techniques to meet year-round market demand [5].

Soursop (Annona muricate) is a highly sought-after exotic fruit due to its exceptionally pleasant aromatic and juicy flesh. The milky soursop pulp, commonly consumed fresh, can also be utilized in the production of candies, ice creams, beverages, and flavorings. Typically, the quality assessment of soursop is based on visual aspects of the fruit, texture, flavor, and health compounds present [6]. Additionally, parts of the soursop are consumed as a vegetable due to their medicinal properties, which have been demonstrated to have antibacterial, antioxidant, antidiabetic, antitumor, antifungal, antihypertensive, gastroprotective, and anesthetic properties [7]. However, soursop is a highly perishable fruit with a short shelf life, and as a result, there is a need for preservation methods. Processing of soursop into various products not only reduces post-harvest losses but also helps retain the nutritional and phytochemical quality of the processed products [8].

One of the techniques that can be utilized for preserving soursop (fruit) is drying to minimize undesirable reactions while maintaining and enhancing the inherent quality of the starting fruit [9], as drying is a preservation method that involves the removal of water vapor from the surface of food material to its surrounding space, resulting in a dried material with an extended shelf life [10]. However, throughout the drying process, alterations in the composition and texture of food items may occur, such as nonenzymatic browning, reduction in bioactive compounds, or diminished rehydration capacity of the dried food product [11]. Hence, it is crucial to prioritize drying techniques that minimize nutrient loss, preserve texture, and enhance the sensory attributes of the end product while keeping economic costs to a minimum.

Foam-mat drying is a method used for semi-liquid and liquid foods, especially those that are heat-sensitive, viscous, and sticky, and cannot be dried using other techniques such as spray drying [12, 13]. In this process, liquid food material is transformed into foam using surfactant additives, such as foaming agents or foam stabilizers [14]. The foam is then spread out on a sheet or mat and dried using hot air (40-90°C) at atmospheric pressure. Common additives used in foam-mat drying include methyl cellulose, egg white, maltodextrin, and gum Arabic [12]. The concentration of foaming agents and the drying conditions can affect the properties of the foam-mat dried food products.

For example, a study on plum powder found that the concentration of the foaming agent and the whipping duration had a substantial effect on the foam-forming characteristics, and the foam mat drying process retained the antioxidant properties of the plum powder considerably without causing any significant loss [15]. Another study on tomato powder found that the antioxidant activity of the foam-mat dried powder increased with an increase in the foaming agent concentration, while it decreased with an increase in the whipping time [16]. Little

research has been conducted on the effect of various foaming agents (arabic gum, fish gelatin, Portogel®, and albumin) on soursop drying and all these studies have focused on the production of soursop powder [10,17,18]. Further research is needed to investigate the specific effects of other foam mat drying on the processing of other soursop products. The objective of this study was to investigate the effects of foam mat drying on the nutritional, functional, antioxidant, and sensory properties of soursop-based crisps.

## MATERIALS AND METHODS

### Raw Materials and Chemical Acquisition

Ripe green soursop fruits (Annona muricate), weighing approximately 50 kg, were procured from the local market (Main market, Bamenda, Cameroon) and transported to the laboratory of the College of Technology, University of Bamenda. Subsequently, the soursop fruits were manually sorted, washed with clean tap water, and stored at 4°C. All chemicals used in the study are of analytical grade and were obtained from Sigma-Aldrich (United Kingdom).

### Foaming Agents and Stabilizer

The method for preparing foaming agents, such as soy protein (SP), egg protein (EP), and whey protein (WP), at different concentrations was implemented following the procedure outlined by Salahi et al. [19]. The foaming agents were procured from Olam Group Limited (Lagos, Nigeria) and prepared at the concentrations of 8% and 10% (w/v), while carboxymethyl cellulose (CMC) was prepared at the concentrations of 3% and 4% (w/v). The preparation process involved diluting each foaming agent in 100 ml of distilled water and allowing it to stand for 30 minutes. Subsequently, the foaming agent was whipped using an electric hand mixer at maximum speed for 5 min to form the foam, after which the stabilizer (CMC) was added to stabilize the foam.

### Experimental Design for Production of Soursop-Based Crisps

Completely Randomized Design (CRD) was employed as described in Table 1. The soursop fruits, obtained from the local market (Main Market, Bamenda, Cameroon), were peeled and unseeded. The unseeded fruit pulps were blended in a food processor (Braun Multi Quick 1 Hand Blender, 450 Watt, MQ 120, Poland) and packed in sterilized stainless-steel containers, as described by Kandasamy et al. [20]. The soursop pulp was progressively added to the foam and whipped for 10 minutes. After the whipping process, the samples were layered on a tray approximately 1 cm thick and placed in an oven dryer at 70°C until the weight was constant.

**Table 1: Mixture Design for the formulation of soursop-based crisps**

| Sample | Soursop pulp | Foaming agent | Foam stabilizer |
|---|---|---|---|
| | | **Soy protein (SP)** | **Carboxymethyl cellulose** |
| SP8% | 200g | 16g (8%) | 6g |
| SP10% | 200g | 20g (10%) | 8g |
| | | **Egg protein (EP)** | |
| EP8% | 200g | 16g (8%) | 6g |
| EP10% | 200g | 20g (10%) | 8g |
| | | **Whey protein (WP)** | |
| WP8% | 200g | 16g (8%) | 6g |

| | | | |
|---|---|---|---|
| WP10% | 200g | 20g (10%) | 8g |
| Soursop | 200g | - | - |

**Determination of Proximate Composition**

Moisture, crude fiber, and ash content were determined according to AOAC [21]. Crude protein was determined by the Kjeldahl method whereas crude fat was determined by the Soxhlet extraction method. Total carbohydrate was determined as the difference between 100 and the sum of the percentages of the following components: crude proteins, crude fat, ash, and moisture. The total carbohydrate was calculated as followed:

$$\% \text{ total carbohydrate} = (100 - (\%\text{Ash} + \%\text{fibre} + \%\text{fat} + \%\text{protein}))$$

To determine the calorie content, the approach described by Bhattacharjee et al. [22] was utilized, as shown below:

$$\text{Calory content (Kcal/100g)} = (crude\ protein \times 4) + (Total\ carbohydrate \times 4) + (crude\ fat\ \times 9)$$

**Determination of Phytochemical Composition**

**Determination of Oxalate Content:**

The oxalate levels in the samples were determined using the method outlined by Day and Underwood [23]. Each sample, weighing 1 g, was soaked in 75 ml of 1.5 N sulphuric acid for 1 hour, then filtered using No. 1 Whatman filter paper. Subsequently, 25 ml of the filtrate was transferred to a conical flask and titrated hot at about 80–90 °C against 0.1 M potassium permanganate until a persistent pink coloration endpoint was achieved for 15 seconds. The titration value was then used to calculate the oxalate content.

$$\text{Oxalate content (mg/100g)} = \frac{Titre\ value\ \times volume - mass\ equivalent\ of\ KMnO_4\ \times dilution\ factor}{Molar\ equivalent\ of\ KMnO_4\ \times Weight\ of\ sample\ used} \times 100$$

**Determination of Phytate Content:**

The phytate content of samples was assessed using the method of Wheeler and Ferrel [24]. A 4 g of each sample was weighed and soaked in a beaker containing 100 ml of 2% hydrochloric acid for 180 min and then filtered with a No. 1 Whatman filter paper. Afterward, 25 mL of the filtrate was pipetted into a conical flask, followed by the addition of 5 ml of 0.3% ammonium thiocyanate to serve as an indicator and 53.5 ml of distilled water for the solution to yield its proper acidity. The resulting solution was titrated against 5.66 mg per milliliter of standard $FeCl_3$ solution that contained about 1.95 g of iron per milliliter until a brownish-yellow coloration persisted for 5 min. The phytate contents of the samples were calculated from the titre value as follows:

$$\text{Phytate content (mg/100g)} = \frac{Titre\ value\ \times Iron\ equivalent\ \times dilution\ factor}{Weight\ of\ sample\ used} \times 100$$

**Determination of Total Polyphenol Content:**

The impact of the different processing methods, on the total polyphenol content of soursop crisps, was assessed using the Folin-Ciocalteu method [25]. In a test tube of 5 ml volume, 20 µl of a 2 mg/ml extract solution was added, followed by the Folin-Ciocalteu reagent (0.2 ml) and distilled water (2 ml). After 3 min incubation of the solution mixture at room temperature, 1 ml of 20% sodium carbonate solution was added and the mixture was incubated for 20 min under the same conditions. The absorbance of the resulting blue-coloured solution was measured at 765 nm. The total polyphenol content of the extract was calculated from the gallic acid standard curve and expressed as milligrams equivalents of gallic acid per gram of extract.

$$\text{Total phenol content (mg gallic acid/g)} = \frac{Absorbance_{sample} \times Slope_{standard\ curve} \times dilution\ factor}{Weight\ of\ sample\ used}$$

**Determination of Total Flavonoid Content:**

Total flavonoid content was determined as described by Aiyegoro and Okoh [26]. To 0.2 ml of aluminum chloride ($AlCl_3$, 10%) was added 0.2 ml aliquot of an extract followed by the successive addition of 0.2 ml of potassium acetate (CH3COOK, 1 M) and 1.12 ml of distilled water. The whole mixture was well homogenized and incubated at room temperature, and the absorbance was read at 415 nm against the reagent blank 30 minutes later. Quercetin (0–1000 µg/mL) served as a standard, and the results were expressed as mg Quercetin/g dry matter.

$$\text{Flavonoid content (mg Quercetin/g)} = \frac{Absorbance_{sample} \times Slope_{standard\ curve} \times dilution\ factor}{Weight\ of\ sample\ used}$$

**Determination of Tannin Content:**

Tannin was determined as reported by Bainbridge et al. [27]. One gram of sample was introduced into an Erlenmeyer flask and 15 ml of acetone (10% acetic acid) was added. The mixture was vortex for 15 minutes and then filtered and diluted 20 times with distilled water before the assay. A volume of 1 ml of the diluted mixture was added to each test tube coated with aluminum foil to exclude light followed by 3 ml of freshly prepared solution of 4% vanillin in ethanol. After stirring, 1 ml of concentrated HCl was added to each tube which was then allowed to stand at room temperature for 15 minutes, and the absorbance was read at 500 nm against a blank. The tannin content was evaluated using a standard solution of tannic acid (0.1 mg/ml) and the results were expressed in milligrams of tannic acid per gram of solids.

$$\text{Tannin content (mg tannic acid/g)} = \frac{Absorbance_{sample} \times Slope_{standard\ curve} \times dilution\ factor}{Weight\ of\ sample\ used}$$

**Determination of Functional Properties**

**Water and Oil Absorption Capacity:**

These parameters were determined using the method described by Lin et al. [28] and modified by Tambo et al. [29]. One gram of sample was respectively mixed with 10 ml of sunflower oil to determine the oil absorption or 10 ml of distilled water to determine the water absorption. The mixture was incubated in a water bath at 30°C for 30 min. The mixture was centrifuged at 4500 rpm for 15 min. The volume of water or oil absorbed was measured. The WAC and OAC were calculated as follows:

$$\text{WAC/OAC} = \frac{W1-W2}{W1} \times 100$$

Where W1 is water/oil in and W2 is water/oil out

**Bulk Density:**

The bulk density of the flour samples was determined by the method described by Onwuka [30]. The sample (50 g) was weighed into a 100 mL graduated cylinder, then, this was gently tapped at the bottom several times on a laboratory bench, until no further diminution of the sample level. The volume was then recorded. The bulk density was calculated as:

$$Bulk\ density\ (g/ml) = \frac{Weight\ of\ the\ sample\ (g)}{Volume\ of\ the\ sample\ (ml)}$$

**Determination of Swelling Capacity:**

To determine the swelling capacity of the samples, the method outlined by Takashi and Seib [31] was employed, which involves mixing 0.1 g of the sample with 10 ml of distilled water in a centrifuge tube. To ensure the flour stays evenly dispersed, the mixture is continuously stirred in a thermostatic water bath at 80°C for 30 minutes. After this period, the tube is carefully removed and weighed with its contents. To further extract the gel, the sample is centrifuged at 1000 x g for 15 minutes, with the resulting supernatant being discarded. The weight of the sedimented gel is then measured to determine the dry matter content. Using this data, the swelling power can be calculated utilizing the provided formula.

$$Swelling\ capacity = \frac{Weight\ of\ wet\ mass\ of\ sediment}{Weight\ of\ dry\ matter\ in\ the\ gel}$$

**Hydrogen Potential (pH):**

The pH was measured according to AACC 02–52.01 methods [32]. Ten grams of crisps were mixed with 90 ml of distilled water in a beaker, homogenized, and then allowed to sit at room temperature for 30 minutes for pH measurement. The pH of the resulting liquid was determined using a pH meter (Metrohm, Switzerland).

**Determination of Antioxidant Activity**

**Determination Ferric Reducing Antioxidant Power (FRAP):**

The ferric-reducing antioxidant power of soursop-based crisp was assessed following the method of Yildirim [33]. An aliquot of 0.5 ml plant extract (250, 500, 1000, and 2000 µg/ ml) was mixed with 1 ml phosphate buffer (0.2 M, pH 6.6) and 1 ml of 1% aqueous $K_3Fe(CN)_6$

solution, well shaken and incubated at 50°C for 30 min. After incubation, 1 ml of 10% TCA solution was added to stop the reaction, and the mixture was centrifuged at 1000 rpm for 10 min. 1.5 ml of supernatant, 1.5 ml of distilled water, and 0.1 ml of 0.1% $FeCl_3$ solution were added, mixed, and incubated for 10 min and absorbance read at 700 nm. A sample blank, containing all the reagents but no extract was prepared in the same conditions. TBHQ, a powerful ferric reducer was used as a positive control to compare the reducing power of the extracts.

$$\text{FRAP (mg AAE/g)} = \frac{Absorbance_{sample} \times Slope_{standard\ curve} \times dilution\ factor}{Weight\ of\ sample\ used}$$

The IC50 value (g/L) was determined by plotting the percentage inhibition against the inhibitor concentration and using logit regression to interpolate the concentration at which the inhibition is 50%.

**Determination of DPPH-Scavenging Activity:**

The ability of soursop-based crisps to scavenge the DPPH radical was determined according to the method of Braca et al. [34]. A total of 4.5 ml of 0.002% alcoholic solution of DPPH was added to 0.5 ml of different concentrations (250, 500, 1000, and 2000 µg/ml) of samples and standard solutions separately, to have final concentrations of products of 25-200 µg/ml. The samples were kept at room temperature in the dark and after 30 min the absorbance of the resulting solution was measured at 517 nm. The absorbance of the samples, control, and blank were measured in comparison with methanol. The scavenging activity was expressed as the percentage of DPPH radicals scavenged:

$$\text{DPPH radical scavenged (\%inhibition)} = \frac{Absorbance_{reference} - Absorbance_{sample}}{Absorbance_{reference}} \times 100$$

The IC50 value (g/L) was determined by plotting the percentage inhibition against the inhibitor concentration and using logit regression to interpolate the concentration at which the inhibition is 50%.

**Sensory Analysis**

The sensory evaluation of soursop-based crisps dried using foam mat technique involved 50 untrained panelists who participated in hedonic tests. Both male and female panelists were included, and they were screened for eligibility based on several criteria: absence of soursop-related food allergies, not being pregnant or attempting to conceive, refraining from driving within 2 hours after the sensory test, and being at or above the legal age of 21 (the legal age of majority in Cameroon). Approval for the research was obtained from the Department of Nutrition, Food and Bioresource, College of Technology, University of Bamenda, Bambili, Cameroon. Before the experiments, participants were required to review an information sheet and provide written consent to the researchers.

The sensory evaluation involved assessing the appearance, aroma, taste, and sweetness of the crisps using a 9-point rating scale ranging from "extremely unpleasant" to "extremely pleasant." Overall acceptability was also evaluated using the same scale. Each sample, anonymized with 3-digit codes, consisted of 30 grams placed on a plate. To prevent taste interference, participants took a three-minute break and drank water between tastings.

### Statistical Analysis

Data obtained in this study was entered in Microsoft Excel 2016 sheets and statistically evaluated using the Statistical Package for Social Science (SPSS) version 27 and expressed in terms of mean ± standard deviation. One-way ANOVA (Analysis of Variance) coupled with Tukey test was used to compare different soursop-based crisps in terms of nutritional, phytochemical, antioxidant, and sensory properties. Discriminant sensory analysis was conducted to compare soursop-based crisps. Differences between comparable sets of results were considered significant at $p<0.05$.

## RESULTS

### Proximate Characterization of Soursop-Based Crisps

The moisture content of soursop-based crisps (SC) varied from 5.33% to 9.92% (Table 2). SC made with egg proteins 8% exhibited the lowest water content, while SC 10% had the highest. When the samples were compared to the control, EP8% and WP10% exhibited similar moisture content, while the remaining samples showed higher levels. The findings also indicated that an increase in foaming agent concentration led to a decrease in moisture content, except for SC made with egg proteins, where the opposite was observed.

The fat content of the soursop-based crisps ranged from 1.87% to 4.15% (Table 2). SC made with whey proteins 10% exhibited the lowest content, whereas SC made with soy protein 8% had the highest content. A significant decrease was observed as the concentration of foaming agents increased, except when using egg proteins as a foaming agent. These fat contents were statistically greater than that of the control.

The protein content found in soursop-based crisps varied from 2.60% to 4.60% (Table 2). These contents were not statistically different from that of the control used ($p \geq 0.05$) except for EP10% which presented the highest protein contents. This suggested the concentrations of foaming agents were marginal to cause a significant increase in protein content.

The fiber content of the soursop-based crisps varied from 0.47% to 1.99% (Table 2). All crisps were relatively low in fiber compared to the control ($p < 0.05$). However, among themselves, EP10% and WP8% had the highest levels, while EP8%, SP10%, and WP10% had the lowest contents.

The carbohydrate content in the various crisps ranged from 76.12% to 87.66% (Table 2). EP8% was found to contain the highest amount of total carbohydrates, while EP10% had the lowest. A significant increase was observed when using soy proteins and whey proteins at increasing concentrations ($p < 0.05$). Additionally, soursop pulp used to produce crisps had levels greater than that of EP10% and WP8%.

The ash content of the soursop-based crisps ranged from 0.94% to 6.60% (Table 2). EP8% had the highest level, while EP10% had the lowest. Apart from EP10% and WP8%, all samples had a lower ash content compared to the control ($p < 0.05$). An increase in ash content was observed when using soy proteins and egg proteins at increasing concentrations (8% and 10%). Conversely, as the concentration of whey proteins increased, the ash content decreased. Additionally, the ash content of crisps made only with soursop pulp was greater than that of SP8%, SP10%, EP8%, and WP10%.

The calorie content of the soursop-based crisps ranged from 340.15 kcal to 385.87 kcal, with EP10% being the most caloric and EP8% the least energy-dense (Table 2). All the crisps were statistically more energy-dense than crisps made with only soursop pulp. As concentrations of foaming agents increased, energy content decreased when using soy proteins and egg proteins. The reverse was observed when using whey proteins.

**Table 2: Proximate composition of soursop-based crisps made with soy proteins, egg proteins and whey proteins as foaming agents.**

| Content (g/100g) | SP8% | SP10% | EP8% | EP10% | WP8% | WP10% | Control |
|---|---|---|---|---|---|---|---|
| Moisture | 8.60 ± 0.02$^{d}$ | 7.57 ± 0.07$^{c}$ | 5.33 ± 0.01$^{a}$ | 9.92 ± 0.02$^{e}$ | 9.71 ± 0.07$^{e}$ | 6.88 ± 0.04$^{b}$ | 6.43 ± 2.15$^{ab}$ |
| Fat | 4.15 ± 0.03$^{d}$ | 2.06 ± 0.06$^{b}$ | 2.62 ± 0.28$^{c}$ | 2.76 ± 0.02$^{c}$ | 2.94 ± 0.06$^{c}$ | 1.87 ± 0.01$^{b}$ | 0.17 ± 0.06$^{a}$ |
| Protein | 3.11 ± 0.20$^{ab}$ | 3.29 ± 0.09$^{abc}$ | 3.45 ± 0.08$^{bc}$ | 4.60 ± 0.34$^{d}$ | 3.88 ± 0.14$^{c}$ | 2.75 ± 0.42$^{a}$ | 2.60 ± 0.04$^{a}$ |
| Crude fiber | 1.27 ± 0.02$^{b}$ | 0.47 ± 0.02$^{a}$ | 0.53 ± 0.04$^{a}$ | 1.90 ± 0.05$^{d}$ | 1.99 ± 0.04$^{d}$ | 0.57 ± 0.12$^{a}$ | 6.95 ± 0.24$^{e}$ |
| Carbohydrate | 82.31 ± 0.20$^{c}$ | 83.74 ± 0.16$^{d}$ | 87.66 ± 0.35$^{f}$ | 76.12 ± 0.34$^{a}$ | 77.65 ± 0.24$^{b}$ | 85.92 ± 0.29$^{e}$ | 85.56 ± 2.19$^{cd}$ |
| Ash | 1.83 ± 0.01$^{b}$ | 3.34 ± 0.03$^{d}$ | 0.94 ± 0.20$^{a}$ | 6.60 ± 0.01$^{g}$ | 5.82 ± 0.24$^{f}$ | 2.58 ± 0.09$^{c}$ | 5.24 ± 0.06$^{e}$ |
| Calory (Kcal) | 373.92 ± 0.23$^{f}$ | 364.82 ± 0.72$^{d}$ | 385.87 ± 1.70$^{g}$ | 340.15 ± 0.11$^{b}$ | 344.59 ± 0.58$^{c}$ | 369.24 ± 0.82$^{e}$ | 326.38 ± 9.06$^{a}$ |

The values carrying the same superscript in the same row are not statistically significant ($p \geq 0.05$)
SP8%: Soursop-based crisps made with soy protein 8%, SP10%: Soursop-based crisps made with soy proteins 10%, EP8%: Soursop-based crisps made with egg proteins 8%, EP10%: Soursop-based crisps made with egg proteins 10%, WP8%: Soursop-based crisps made with whey proteins 8%, WP10%: Soursop-based crisps made with whey proteins 10%, control: soursop-based crisps without foaming agents.

## Phytochemicals of Soursop-Based Crisps

The phytate content of the seven soursop-based crisps ranged from 2.74 to 5.80 mg/ml (Table 3). There was no significant difference ($p \geq 0.05$) among the test samples. However, the control sample had a higher amount of phytates compared to the test samples ($p < 0.05$).

The oxalate content of the soursop-based crisps ranged from 0.49 to 2.73 mg/ml (Table 3). There was no significant difference among the samples ($p \geq 0.05$). However, the control sample had a higher amount of oxalates compared to the test samples ($p < 0.05$).

The tannin content of the soursop-based crisps ranged from 0.01 to 0.05 mg/ml (Table 3). The samples SP10%, WP8% and WP10% had similar levels of tannins as compared to the control ($p \geq 0.05$). The highest tannin content was found in SP10%, while the lowest content was observed in EP8% and SP8%.

The study revealed that the total polyphenol content in soursop-based crisps ranged from 5.48 to 8.67 mgGAE/g (Table 3). The total phenolic content in the soursop-based crisps was statistically similar to that found in the control sample ($p \geq 0.05$).

This study demonstrated that the total flavonoid content in soursop-based crisps ranged from 2.20 mgQE/ml to 10.71 mgQE/ml (Table 3). The samples WP8% and WP10% had the highest flavonoid content compared to the control sample ($p < 0.05$).

**Table 3: Phytochemicals content of soursop-based crisps made with soy proteins, egg proteins, and whey proteins as foaming agents.**

| Content | SP8% | SP10% | EP8% | EP10% | WP8% | WP10% | Control |
|---|---|---|---|---|---|---|---|
| Phytates (mg/ml) | 4.05 ± 0.84$^{a}$ | 2.74 ± 0.23$^{a}$ | 5.80 ± 1.64$^{a}$ | 3.62 ± 1.02$^{a}$ | 4.30 ± 0.07$^{a}$ | 5.80 ± 0.27$^{a}$ | 13.23 ± 0.03$^{b}$ |
| Oxalates (mg/ml) | 0.06 ± 0.03$^{a}$ | 0.41 ± 0.27$^{a}$ | 0.62 ± 0.79$^{a}$ | 0.49 ± 0.38$^{a}$ | 1.15 ± 1.47$^{a}$ | 2.73 ± 1.11$^{a}$ | 1.20 ± 1.43$^{a}$ |
| Tannins (mg/ml) | 0.01 ± 0.00$^{a}$ | 0.05 ± 0.00$^{e}$ | 0.01 ± 0.00$^{ab}$ | 0.02 ± 0.00$^{bc}$ | 0.03 ± 0.00$^{cd}$ | 0.03 ± 0.00$^{de}$ | 0.04 ± 0.00$^{de}$ |
| Total Polyphenol content (mgGAE/g) | 8.31 ± 1.83$^{b}$ | 7.78 ± 0.63$^{b}$ | 6.53 ± 1.29$^{ab}$ | 8.67 ± 1.40$^{b}$ | 5.48 ± 0.60$^{ab}$ | 6.53 ± 1.29$^{ab}$ | 7.78 ± 0.63$^{b}$ |
| Total flavonoid content (mgQE/g) | 2.20 ± 0.03$^{a}$ | 4.25 ± 1.65$^{a}$ | 2.83 ± 0.08$^{a}$ | 4.20 ± 0.02$^{a}$ | 10.16 ± 0.07$^{b}$ | 10.71 ± 1.18$^{b}$ | 1.22 ± 0.01$^{a}$ |

*The values carrying the same superscript in the same row are not statistically significant ($p \geq 0.05$) SP8%: Soursop-based crisps made with soy protein 8%, SP10%: Soursop-based crisps made with soy proteins 10%, EP8%: Soursop-based crisps made with egg proteins 8%, EP10%: Soursop-based crisps made with egg proteins 10%, WP8%: Soursop-based crisps made with whey proteins 8%, WP10%: Soursop-based crisps made with whey proteins 10%, control: soursop-based crisps without foaming agents.*

## Functional Properties of Soursop-Based Crisps

In this study, the swelling capacity of the seven samples ranged from 2.27 to 3.03 (Table 4). EP8% and EP10% had the lowest swelling index, while SP8%, SP10%, WP8% and WP10% had the highest swelling index ($p>0.05$). The swelling index was greater in the samples SP8%, EP8%, EP10%, and WP8% when compared to the control ($p < 0.05$).

Water absorption capacity refers to a food product's ability to incorporate water. In the context of soursop-based crisps, the water absorption capacity ranged from 35.33% to 63.67% (Table 4). The samples SP8%, SP10%, WP8% and WP10% had greater water absorption capacity than the control ($p < 0.05$). The samples with the highest water absorption capacity were SP8%, SP10%, WP8%, and WP10%, while EP8% and EP10% had the lowest water absorption capacity.

The oil absorption capacity is the product's ability to absorb lipids. In the case of soursop-based crisps, the oil absorption capacity ranged from 2.70% to 25.33% (Table 4). The control sample exhibited a greater oil absorption capacity than the WP8% and SP8% samples ($p < 0.05$). The lowest oil absorption capacity was observed in WP8%, while the highest was found in EP10%. In the present study, the bulk density of the soursop-based crisps ranged from 64.28 g/ml to 95.40 g/ml (Table 4). All samples had higher bulk density as compared to the control ($p < 0.05$). EP10% and WP8% had the lowest bulk density, while SP8% and SP10% had the highest bulk density.

The pH of the seven soursop-based crisps ranged from 5.03 to 6.95 (Table 4). There were no significant differences ($p \geq 0.05$) among the samples except for the control sample (soursop pulp) which exhibited the highest pH as compared to all soursop-based crisps ($p < 0.05$).

**Table 4: Functional properties of soursop-based crisps made with soy proteins, egg proteins, and whey proteins as foaming agents.**

| Property | SP8% | SP10% | EP8% | EP10% | WP8% | WP10% | Control |
|---|---|---|---|---|---|---|---|
| Swelling index (%) | 2.57 ± 0.15$^{b}$ | 2.27 ± 0.06$^{a}$ | 2.57 ± 0.06$^{b}$ | 3.03 ± 0.06$^{c}$ | 2.53 ± 0.06$^{b}$ | 2.43 ± 0.11$^{ab}$ | 2.26 ± 0.06$^{a}$ |
| Water absorption (%) | 61.33 ± 1.53$^{c}$ | 63.67 ± 1.53$^{c}$ | 35.33 ± 0.58$^{a}$ | 39.00 ± 2.64$^{a}$ | 62.00 ± 3.46$^{c}$ | 63.00 ± 1.00$^{c}$ | 45.00 ± 1.00$^{b}$ |
| Oil absorption (%) | 6.00 ± 1.00$^{b}$ | 14.98 ± 0.03$^{d}$ | 10.65 ± 0.57$^{c}$ | 25.33 ± 0.58$^{e}$ | 2.70 ± 0.20$^{a}$ | 10.00 ± 0.00$^{c}$ | 10.66 ± 0.57$^{c}$ |
| Bulk density (g/ml) | 95.40 ± 0.39$^{d}$ | 95.06 ± 0.25$^{d}$ | 82.20 ± 1.19$^{c}$ | 80.26 ± 0.45$^{b}$ | 80.33 ± 0.58$^{b}$ | 83.25 ± 0.79$^{c}$ | 64.28 ± 0.20$^{a}$ |
| pH | 5.36 ± 0.25$^{a}$ | 5.42 ± 0.21$^{a}$ | 5.03 ± 0.17$^{a}$ | 5.20 ± 0.18$^{a}$ | 5.19 ± 0.18$^{a}$ | 5.32 ± 0.19$^{a}$ | 6.95 ± 0.38$^{b}$ |

*The values carrying the same superscript in the same row are not statistically significant ($p \geq 0.05$) SP8%: Soursop-based crisps made with soy protein 8%, SP10%: Soursop-based crisps made with soy proteins 10%, EP8%: Soursop-based crisps made with egg proteins 8%, EP10%: Soursop-based crisps made with egg proteins 10%, WP8%: Soursop-based crisps made with whey proteins 8%, WP10%: Soursop-based crisps made with whey proteins 10%, control: soursop-based crisps without foaming agents.*

## Antioxidant Activity of Soursop-Based Crisps

The inhibitory concentration 50 of the ferric reducing antioxidant power or FRAP activity of samples varied from 2.40 $10^{-2}$ mg/ml to 7.89 $10^{-2}$ mg/ml (Table 5). The sample EP8% displayed the lowest ferric-reducing power. EP10%, SP10%, WP8%, and WP10% had statistically the same ferric reducing power as tert-butyl hydroquinone (TBHQ) indicating that these soursop-based crisps have high antioxidant activity. The control had similar ferric-reducing power as TBHQ.

This study showed that soursop-based crisps had DPPH-scavenging activities with inhibitory concentrations 50 varied between 5.58 $10^{-2}$ mg/ml and 29.66 $10^{-2}$ mg/ml (Table 5). SP8% had the lowest DPPH-scavenging activities while EP10%, SP10%, WP8%, and WP10% had the highest DPPH-scavenging activities comparable to Butylated hydroxytoluene (BHT). BHT and the control had similar DPPH-scavenging activities.

**Table 5: Inhibitory concentrations 50 (IC50) of soursop-based biscuits from FRAP and DPPH tests.**

| Sample | IC50 | |
|---|---|---|
| | FRAP ($10^{-2}$ mg/ml) | DPPH ($10^{-2}$ mg/ml) |
| SP8% | 2.76 ± 0.01$^{b}$ | 29.66 ± 1.72$^{c}$ |
| SP10% | 2.44 ± 0.00$^{a}$ | 5.81 ± 0.04$^{a}$ |
| EP8% | 7.89 ± 0.16$^{c}$ | 15.47 ± 2.08$^{b}$ |
| EP10% | 2.43 ± 0.00$^{a}$ | 5.58 ± 0.37$^{a}$ |
| WP8% | 2.56 ± 0.00$^{ab}$ | 9.02 ± 0.37$^{ab}$ |
| WP10% | 2.51 ± 0.01$^{a}$ | 11.16 ± 2.72$^{ab}$ |
| Control | 2.40 ± 0.02$^{a}$ | 9.31 ± 0.17$^{ab}$ |
| TBHQ | 2.39 ± 0.02$^{a}$ | - |
| BHT | - | 7.31 ± 0.39$^{a}$ |

*The values carrying the same superscript in the same column are not statistically significant ($p \geq 0.05$)*
*TBHQ: Tert-butylhydroquinone; IC50: Inhibitory concentration 50; BHT: Butylated hydroxytoluene; SP8%: Soursop-based crisps made with soy protein 8%, SP10%: Soursop-based crisps made with soy proteins 10%, EP8%: Soursop-based crisps made with egg proteins 8%, EP10%: Soursop-based crisps made with egg proteins 10%, WP8%: Soursop-based crisps made with whey proteins 8%, WP10%: Soursop-based crisps made with whey proteins 10%, control: soursop-based crisps without foaming agents.*

## Sensory Analysis

The sensory evaluation of soursop-based crisps included an assessment of appearance, aroma, taste, and sweetness. The taste scores ranged from 1.9 to 7.4, with the highest score of 7.4 found in the SP8% and SP10% samples, which were considered moderately pleasant, and the lowest score of 1.9 found in the control sample, considered very unpleasant. In terms of appearance, scores ranged from 2.0 to 8.2, with SP10% receiving the highest score of 8.2 and the control sample receiving the lowest score of 2.0. Aroma scores fluctuated between 1.4 to 8.1, with EP8% receiving the highest score of 8.1 and the control sample receiving the lowest score of 1.4. Additionally, EP8%, EP10%, SP8%, WP8%, and WP10% recorded the highest sweetness scores between 7.6 and 8.4, all considered very pleasant.

The overall acceptability of soursop-based crisps varied between 24% and 100% (Figure 1). Among the 50 panelists, 100% of the panelists liked the SP10% sample, while only 24% of the panelists liked the control sample. Figure 2, which displayed discriminant sensory analysis based on appearance, taste, aroma, and sweetness, demonstrated that all test samples had the same sensory profile and were significantly different from the control sample.

**Table 6: Appearance, aroma, taste, and sweetness of six different soursop-based crisps**

| Sample | Appearance | Aroma | Taste | Sweetness |
|---|---|---|---|---|
| SP8% | 6.7 ± 1.0$^{bc}$ | 6.6 ± 0.9$^{bc}$ | 7.0 ± 1.6$^{cd}$ | 7.9 ± 1.3$^{bc}$ |
| SP10% | 8.2 ± 0.9$^{d}$ | 6.9 ± 1.1$^{bc}$ | 7.4 ± 0.9$^{d}$ | 7.6 ± 1.4$^{b}$ |
| EP8% | 7.1 ± 1.4$^{c}$ | 8.1 ± 0.9$^{d}$ | 6.5 ± 1.6$^{bc}$ | 8.0 ± 0.9$^{bc}$ |
| EP10% | 7.8 ± 0.7$^{d}$ | 7.1 ± 0.9$^{c}$ | 6.0 ± 0.9$^{b}$ | 8.0 ± 0.8$^{bc}$ |
| WP8% | 6.2 ± 1.1$^{b}$ | 7.0 ± 1.0$^{c}$ | 6.0 ± 1.0$^{b}$ | 8.4 ± 0.7$^{c}$ |
| WP10% | 7.1 ± 1.2$^{c}$ | 6.3 ± 1.3$^{b}$ | 6.3 ± 1.3$^{bc}$ | 8.2 ± 0.7$^{c}$ |
| Control | 2.0 ± 0.9$^{a}$ | 1.4 ± 0.5$^{a}$ | 1.9 ± 1.1$^{a}$ | 1.2 ± 0.4$^{a}$ |

The values carrying the same superscript in the same column are not statistically significant ($p \geq 0.05$) SP8%: Soursop-based crisps made with soy protein 8%, SP10%: Soursop-based crisps made with soy proteins 10%, EP8%: Soursop-based crisps made with egg proteins 8%, EP10%: Soursop-based crisps made with egg proteins 10%, WP8%: Soursop-based crisps made with whey proteins 8%, WP10%: Soursop-based crisps made with whey proteins 10%, control: soursop-based crisps without foaming agents.

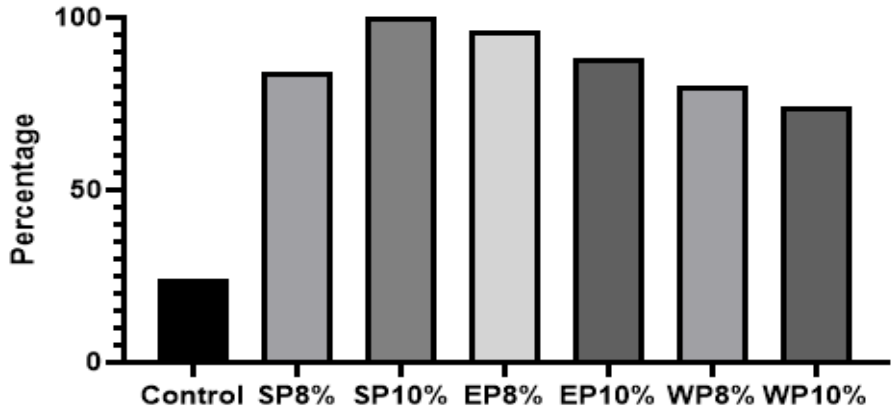


**Figure 1: Evaluation of soursop-based crisps using a sensory preference scale**

Legend: SP8%: Soursop-based crisps made with soy protein 8%, SP10%: Soursop-based crisps made with soy proteins 10%, EP8%: Soursop-based crisps made with egg proteins 8%, EP10%: Soursop-based crisps made with egg proteins 10%, WP8%: Soursop-based crisps made with whey proteins 8%, WP10%: Soursop-based crisps made with whey proteins 10%, control: soursop-based crisps without foaming agents.

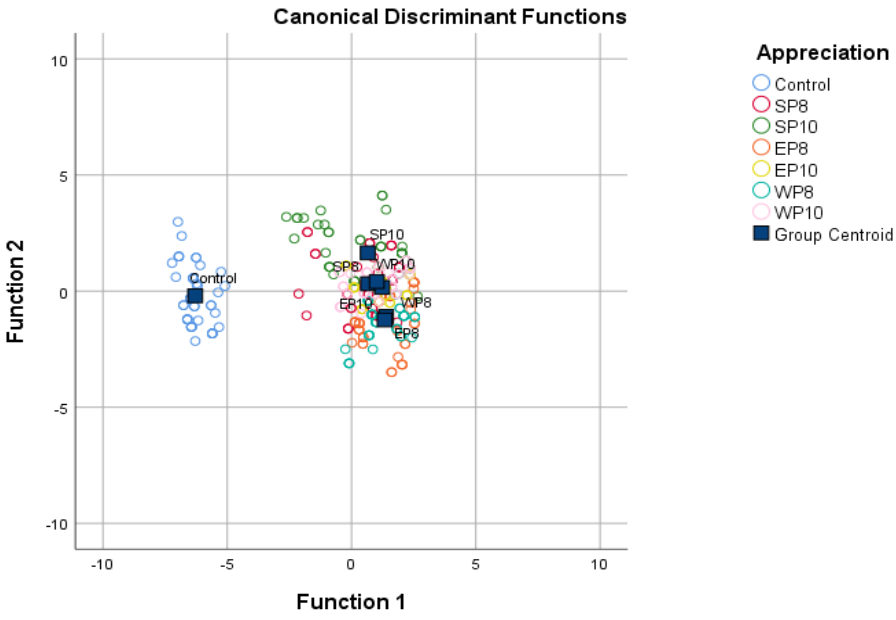


**Figure 2: Sensory discriminant analysis of soursop-based crisps**

Legend: SP8%: Soursop-based crisps made with soy protein 8%, SP10%: Soursop-based crisps made with soy proteins 10%, EP8%: Soursop-based crisps made with egg proteins 8%, EP10%: Soursop-based crisps made with egg proteins 10%, WP8%: Soursop-based crisps made with whey proteins 8%, WP10%: Soursop-based crisps made with whey proteins 10%, control: soursop-based crisps without foaming agents.

## DISCUSSION

The findings on moisture content of the different crisps indicated that an increase in foaming agent concentration led to a decrease in moisture content, except for SC made with egg proteins, where the opposite was observed. In foam mat drying, the rise in the water removal rate is attributed to the increase in air temperature and the reduction in the thickness of the foam layer [35]. It is advantageous to have crisps with low water content, as dried food products are better at maintaining quality when their water content is below 10% [36]. Microorganisms cannot develop when the water content is below 8% in dehydrated foods [37]. Therefore, soursop-based crisps made with the three foaming agents should exhibit good stability properties.

Regarding fat content, a significant decrease was observed as the concentration of foaming agents increased, except when using egg proteins as a foaming agent. The concentration of fat-soluble compounds in the final product can significantly affect its quality. Fat-soluble compounds, such as fat-soluble vitamins, play a crucial role in defining the sensory properties of foods and can affect flavor release during eating and subsequent perception [38]. Fat is generally a highly valued element of the diet to provide energy, and palatability to dry foods [39].

No significant difference was observed among crisp samples with respect to protein content. This suggested the concentrations of foaming agents were marginal to cause a significant increase in protein content. Protein quality is also a critical factor when assessing the nutrient adequacy of the food supply and dietary intake at the individual and population levels [40].

All the crisps exhibited a low dietary fiber content. Researchers found that during foam mat drying, nutrients such as total sugar, ascorbic acids, and β-carotene tend to decrease due to increased drying time and temperature [13]. Drying time and temperature might have contributed to the removal of fibers from the various crisps. Dietary fiber intake is associated with overall metabolic health, insulin sensitivity, and various pathologies including cardiovascular disease and colonic health [41].

A decrease in carbohydrate content was noted during foam mat drying of soursop. This decrease in content could still be associated with the drying time and temperature used, as highlighted by Javed et al. [13].

A decrease in ash content due to foam mat drying was witnessed in this study. This decrease was still correlated with the drying time and temperature used, as outlined by Javed et al. [13]. It is important to note that minerals act as inorganic co-factors in metabolic processes, which means that in the absence of these inorganic co-factors, there could be impaired metabolism [42].

The phytate levels in the seven soursop-based crisps varied between 2.74 and 5.80 mg/ml. These values were greater than the value reported by Degnon et al. [43] for soursop pulp, which is 2.72 mg/ml. Phytic acid, also known as phytate, can bind to one or more of the phosphate groups of the minerals, and the stoichiometry of the complexes can influence the solubility of

phytate. The presence of other metal ions, such as calcium, can increase the proportion of the phytic acid-metal aggregate, affecting the solubility of the complexes [44].

The oxalate levels in the soursop-based crisps varied between 0.49 and 2.73 mg/ml. These values were lower than the oxalate content reported by Degnon et al. [43] for soursop pulp, which is 6.45-6.53 g/100 ml, indicating a lower oxalate concentration in the soursop-based crisps. The oxalate concentration in the crisps is in line with the findings of Ezeike et al. [45], who demonstrated that increasing the temperature and cooking time can decrease the concentration of oxalate in food. This suggests that the oxalate concentration in the soursop-based crisps may have been reduced due to the temperature applied during processing. Oxalate can bind to calcium present in food, rendering it unavailable for normal physiological and biochemical roles, such as the maintenance of strong bones, and teeth, and as a cofactor in enzymatic reactions, nerve impulse transmission, and blood clotting [46].

The tannin levels in the crisp samples were observed to be low. Ezeike et al. [45] demonstrated that increasing the temperature and cooking time of food decreases the concentration of tannins, indicating that the tannin concentration in the soursop-based crisps may have been reduced due to the applied temperature. Tannins in fruits impart an astringent taste that can affect palatability, reduce food intake, and consequently, body growth. They also bind to both exogenous and endogenous proteins, including digestive enzymes, thereby affecting protein utilization [47].

The research found that the overall polyphenol content in crisps made from soursop varied between 5.48 and 8.67 mgGAE/g. These concentrations were found to be lower than that observed in soursop fruits varying between 19.84 and 50.15 mgCE/g [48]. Additionally, Tiencheu et al. [49] reported the total phenolic content of soursop juice to range from 0.26-0.89 mgGAE/g. This suggests that food processing can affect the total phenolic compound content differently. Phenolic compounds can regenerate endogenous α-tocopherol in the phospholipid bilayer of the membrane to its active antioxidant form. The low levels of total phenolic compounds and flavonoids in soursop-based crisps may be attributed to the thermal degradation of these bioactive compounds [50].

The research showed that the total flavonoid content in crisps made from soursop ranged from 2.20 to 10.71 mgQE/ml. The slightly acidic pH observed (5.03-6.95) in this study could increase the release of bound flavonoids as suggested by Settharaksa et al. [51]. These contents were lower than that reported by Orak et al. [48] which showed that soursop fruits had total flavonoid content between 2.16 and 34.41 mgCE/g.

Functional property is an important parameter for the suitability of diet behavior of nutrients in food during processing, storage, preparation, application, and end-use. This is because they not only impact the overall food quality but also their acceptability to consumers [52]. The decreasing trend of the swelling index with the increase of foam agent concentration using egg proteins is consistent with the findings of Julianti et al. [53]. This may be attributed to the following factors: lipids act as amylose swelling inhibitors limiting starch swelling and/or

starch and protein interactions, such as the attraction of opposite charges to form inclusion complexes during gelatinization, which restrict swelling [54].

Water absorption capacity refers to a food product's ability to incorporate water. The water absorption capacity of soursop-based crisps in this study ranged from 35.33% to 63.67%. The results of obtained from water absorption capacity aligns with the research of Akubor and Onimawo [55]. High water absorption capacity can be attributed to the presence of numerous hydrophilic components in foods, such as carbohydrates (particularly polysaccharides), proteins (especially those containing polar amino acid residues), which have a high affinity for water molecules [56].

In this study, some of the crisp samples presented high level of oil absorption capacity. The ability of proteins to interact with water and oil in foods, and the foaming agents used for formulation were proteins by nature, which may contribute to the oil absorption capacity. The physical entrapment of oil within proteins and non-covalent bonds, such as hydrophobic, electrostatic, and hydrogen bonding, are forces involved in lipid-protein interactions [57].

The bulk density of all samples was higher than that of the control. Bulk density is important for dietary bulk and packaging requirements [58]. Nutritionally, a loose bulk density not only promotes easy digestibility of food but also enhances nutrient and calorie density per feed.

The pH values of the seven crisps made from soursop varied between 5.03 and 6.95. The final product, crisps, had a pH greater than that of soursop fruits, which is 3.7 [10].

The FRAP activity of the samples, expressed as inhibitory concentration 50, ranged from 2.40 10-2 mg/ml to 7.89 10-2 mg/ml. Soursop fruits are also known to exhibit ferric-reducing antioxidant power [48]. The ability of a food to reduce ferric ions to ferrous ions is indicative of its potential to act as an antioxidant and to protect against oxidative damage in the body [59].
The DPPH-scavenging activities of soursop-based crisps in this study had inhibitory concentrations 50 that ranged from 0.06 mg/ml to 0.30 mg/ml. These antiradical activities were found to be greater than those found in soursop fruits with inhibitory concentrations 50 fluctuating between 0.28 and 0.41 mg/ml [48]. DPPH scavenging assays are used to measure the antioxidant capacity of food samples, as antioxidants help neutralize free radicals and prevent oxidative stress, which can lead to various diseases [60].

## CONCLUSION

The study investigated the effects of foam mat drying on soursop-based crisps. The results indicated that the crisps generally had higher fat and calorie content but lower levels of oxalate, phytate, fiber, and ash compared to the control. However, they showed similar total phenolic and protein content to the control. Specific crisps displayed varying functional properties, with some exhibiting higher swelling index, water absorption capacity, and ferric-reducing power, while others showed lower oil absorption capacity. Additionally, all samples had greater bulk density compared to the control. Importantly, the sensory attributes of all test samples were found to be superior to those of the control. Furthermore, the comparison of different foaming agents in the production of soursop-based crisps revealed notable variations in their nutritional

composition and functional properties. Moreover, the comparison of crisps made with the same foaming agent revealed distinct nutritional and functional differences based on the protein concentration used. Thus, the research highlights the diverse characteristics and potential health benefits of soursop-based crisps produced using foam mat drying, as well as the impact of different foaming agents and protein concentrations on the nutritional and functional attributes of the crisps. Likewise, these insights could be instrumental in guiding the development of new products and promoting consumer health.

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