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Improving the nutritional profile of jelly candies

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ABSTRACT

A Central Composite Rotatable Design (CCRD) was used to evaluate the influence of adding orange juice and a fiber: polyol mix (1:1) on the moisture content, water activity, and texture of starch jellies. Based on the results of CCRD, a sample was selected for a stability study over 180 days at 25 °C (Diet Fruit - DF), together with two sugar-added control samples (Regular Fruit – RF; Regular - R). The nutritional facts and front-of-pack labeling were made according to the Brazilian and European Regulations. The coefficient of determination (R^2) and the $F_{calculated}$ resulted in first-order models for hardness and stickiness responses. The addition of orange juice above 11.5 % reduced hardness and stickiness of the candies. Concentrations above 38.3 % of fiber: polyol mix reduced the hardness, with less influence on stickiness. Major changes in the jellies occurred between 0 and 90 days, primarily with a reduction in moisture and an increase in hardness, adhesiveness, and stickiness. The DF sample, which contained a higher amount of juice, presented a higher content of total phenolic and antioxidant capacity, was characterized as a source of fiber, did not require the "high added sugar" front-of-pack label, and received a Nutri-Score B, indicating an improvement in the nutritional profile.

1. Introduction

Jelly candies are confectionery products enjoyed worldwide (Guiné et al., 2020). They represent a class within the sector based on the use of hydrocolloids, which form a network (gel) capable of maintaining a 'syrup or mixture' of sugars with a relatively high moisture content. The most common hydrocolloids used in the production of these candies are gelatine, starch, and pectin, each imparting distinct organoleptic properties and textures to the product. Variations of these attributes are due to differences in the structures and chemical bonds of the hydrocolloids and depend on the nature of the sugars present in the formulation, as these impact gelation properties. (Hartel, Von Elbe, Hofberger, 2018).

The global gummy and jelly market grew from USD 2.47 billion in 2022 to USD 2.59 billion in 2023, at a compound annual growth rate (CAGR) of 2.7 %. North America remains the largest region and Asia is expected to show the fastest growth in the coming years (Reportlinker, 2023).

While gummies continue to experience increasing demand, consumers are becoming more aware of their food choices, seeking healthier and more "natural" products (Carreiro, 2020; Lima et al., 2020).

However, Non-Communicable Diseases (NCDs) are among the main causes of death worldwide, and some of the major risk factors for the development of these diseases are diabetes and eating behaviors (Egnell et al., 2018). Thus, the World Health Organization (WHO) has recommended that food manufacturers reduce levels of saturated and trans fatty acids, sodium, and sugar in their products to improve nutritional composition and prevent the occurrence of NCDs in society. Additionally, public health policies can be adopted to guide and motivate consumers to make 'truly' healthier choices (Feunekes et al., 2008; WHO, 2018).

A strategy adopted to promote healthier dietary patterns in various countries worldwide is the front-of-pack (FOP) nutritional labeling or

Abbreviations: NCDs, Noncommunicable diseases; FOP, Front-of-pack; CCRD, Central Composite Rotatable Design; DF, Diet Fruit Jelly Candy; R, Regular Jelly Candy; RF, Regular Fruit Jelly Candy; A_w, Water Activity.

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warning labels (Deliza et al., 2020). The FOP aims to contribute clearly and directly with information about the nutritional aspects of food and encourage product reformulation (Champagne et al., 2020; Neal et al., 2017).

In Brazil, Resolution RDC n° 429 (Brazil, 2020a) and Normative Instruction IN n° 75 (Brazil, 2020b) both dated October 8, 2020, which establish new technical requirements for the declaration of nutritional labeling of packaged foods and address the guidelines for the implementation of FOP labels, recently came into effect. The proposed Brazilian model (Fig. 1) is a type of indicator for excessive nutrient content.

In Europe, the Nutri-Score system has been adopted as the front-of-package (FOP) labeling model by several countries such as France, Italy, The Netherlands, Belgium, Switzerland, Luxembourg, and Germany (FoodNavigator, 2020). Nutri-Score is a grading indicator of the relative healthiness of foods, based on the classification of products using a scoring system generated by calculations that consider the nutritional profile of the items. Depending on the overall score obtained, the food is labeled in one of five reference categories, ranging from green to red and coded with the letters A to E for better label readability (Fig. 2). Under the Nutri-Score system, whole wheat bread or natural yogurt, for example, are classified in Green/A; jam or breakfast cereal in Yellow/C; and chocolate biscuits or chocolate and hazelnut spreads in Red/E (Hafner & Pravst, 2024; Julia & Hercberg, 2017).

Confectionery is among the products most likely to receive FOP labels or a low Nutri-score (D or E) due to the poor nutritional quality of their conventional formulations. A regular starch jelly candy, for example, typically consists of 45 to 50 % glucose syrup and 25 to 35 % sucrose (Hartel, Von Elbe, Hofberger, 2018).

At the same time, the global market for vegan products has also been growing significantly. According to BCC Research, the global vegan food market in 2021 was \$35.6 billion and is estimated to grow from \$40.1 billion in 2022 to \$91.9 billion in 2027, with a compound annual growth rate (CAGR) of 18.1 % (BCC Research, 2022).

Around the world, people are increasingly opting for a vegan diet and seeking out candy or confectionery made with vegan ingredients (Reportlinker, 2022). This particular group of consumers, which prefers products that use stabilizers and hydrocolloids of plant origin in their formulations due to the prevalence of vegan diets or sociocultural and religious attitudes, is stimulating the industry to find new market solutions (Konar et al., 2022).

Additionally, confectionery consumers are concerned with health, sustainability, and price, with an interest in low-calorie, sugar-free products enhanced with fruits and prebiotic ingredients (Konar et al., 2022).

Given the scenario presented, the objective of this study was to evaluate the technological viability of producing sugar-free jelly candies using starch, fiber, polyol, and concentrated fruit juice, with an improved nutritional profile.

2. Materials and methods

2.1. Materials and suppliers

Modified corn starch Candymil® 5061 (Ingredion Brasil Ing. Ind. Ltda.), maltitol (powder) HKMC30 (Zhejiang Huakang Pharmaceutical Co. Ltd.), maltitol (liquid) POLYGLOBE 1351 (Ingredion Brasil Ing. Ind. Ltda.), resistant wheat dextrin Nutriose® FB 06 (Roquete), frozen concentrated orange juice (Agroterenas Industrial Citrus Ltda), sucrose (Açucareira Boa Vista Ltda.), glucose syrup 40DE (Ingredion Brasil Ing. Ind. Ltda.), citric acid (Cargill), orange natural flavor (Cramer), pan oil gum gloss B7401 (Stéarinerie Dubois), standard corn starch FARAMIL (Ingredion Brasil Ing. Ind. Ltd.) and vegetable concentrated shade Mandarin (Exberry-GNT).

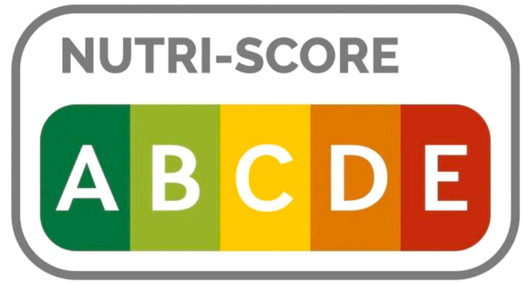

Fig. 2. European frontal warning model (FoodNavigator, 2020).

2.2. Experimental design

The Central Composite Rotatable Design (CCRD), a Response Surface Method, is a robust and cost-effective statistical experimental design widely used for process analysis and modeling, specifically to study the effects of different variables on a response. Initially developed by Box and Wilson (1951) and later improved by Box and Hunter (1957), the CCRD is a two-level full or fractional factorial design (2^k factorial) that includes added center points and axial points (Ahmed, 2020; Aslan, 2008; Bhattacharya, 2021).

For the starch jelly candy formulation definition, a Central Composite Rotatable Design (CCRD) was used, consisting of 11 experimental trials (2^2 factorial with 3 repetitions of the central point, and combinations of the axial points with the alpha value, as shown in Fig. 3).

To improve the nutritional profile of the candies, preliminary trials were conducted to define the levels of the independent variables, exploring different sugar substitutes and fruit juice contents until the desired starch jellies were obtained. It was crucial that the candy mass viscosity did not negatively affect the dosing process, and that structured jellies were successfully produced.

The influence of two independent variables, concentrate fruit juice (x_1) and fiber: polyol mix (fixed in a 1:1 ratio) (x_2) was assessed through the evaluation of candies physicochemical characteristics, adopted as response variables: water activity (aw) (Y_1) moisture content (Y_2), hardness (Y_3), stickiness (Y_4), and adhesiveness (Y_5). The ranges used to perform the CCRD are stated at Table 1.

The Statistica® 12 (StatSoft Inc., Tulsa, USA) program was used for data analysis with a 95 % confidence interval. The following polynomial Eq. (1) was fitted to the data.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} {x_1}^2 + \beta_{22} {x_2}^2 + \beta_{12} x_1 x_2 \quad (1)$$

Where Y is the predicted response β_0 is the model constant, β_1 and β_2

(a) (b) (c)

Fig. 1. Brazilian frontal warning model: (a) High in Added Sugar; (b) High in Saturated Fat; (c) High in Sodium (Brazil, 2020a, 2020b).

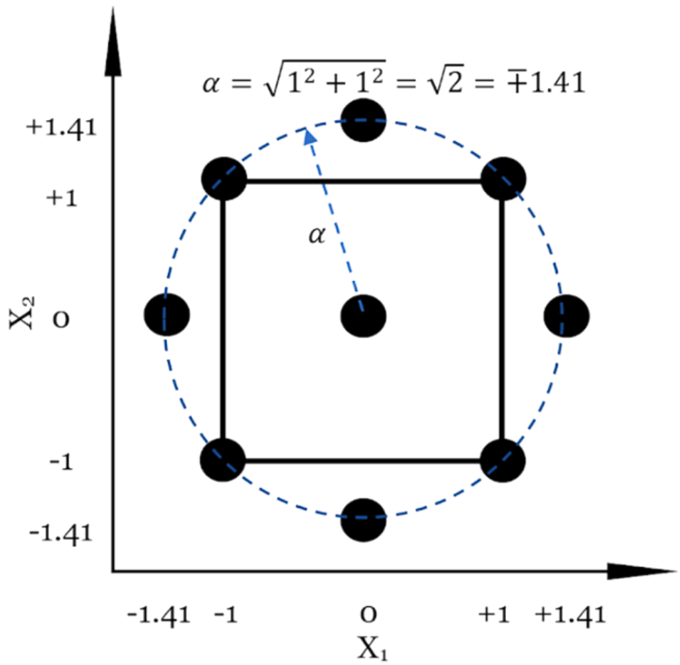

Fig. 3. Central Composite Rotatable Design, CCRD from the Base 2^2 Factorial Design with Alpha Value 1.41 for Rotatability (Ahmed S., 2020).

Table 1
Levels of independent variables.

Independent variables	Values codified				
	−1.41	−1	0	1	+1.41
Concentrated orange juice (%) (x_1)	3.0	5.5	11.5	17.5	20.0
Fiber: Polyol (1:1) (%) (x_2)	28.0	29.7	34.0	38.3	40.0

the linear effects terms, β_{11} and β_{22} are the squared effects, β_{12} is the interaction effects and x_1 and x_2 correspond to independent variables.

Since textural properties are primary factor in consumer preference for soft confectionery products and because moisture content and water activity are crucial for quality control, food safety and product stability (shelf life), these characteristics were defined as response variables. (Gunes et al., 2022; Ranalli et al., 2020).

Moisture content was evaluated using volumetric Karl Fischer titration (Titrando 901, Methrom, Switzerland) with methanol: formamide solution (2:1, v/v) as solvent. Water activity was measured using an electronic water activity meter (Chilled-Mirror Dewpoint System) at 25.0 ± 0.5 °C (Acqua Lab series 4 model TEV, Decagon Devices Inc., USA). All measurements were conducted in triplicate.

The instrumental texture was evaluated using candies with a height of about 1 cm and truncated cone shape. The hardness, stickiness, and adhesiveness parameters were determined using a TA.XT2i Texture Analyzer (Stable Micro System), with a P/2 probe (cylindrical, $\varnothing = 2$ mm). The readings were carried out at test speeds of 2.0 mm/s, and a penetration depth of 5.0 mm. The analysis was conducted with 10 replicates (Guiné et al., 2020).

2.3. Starch jelly candy preparation

The jelly candies were formulated using water, frozen concentrated orange juice, starch, a prebiotic fiber (Nutriose®), a polyol (maltitol), and citric acid. Based on this composition, the candies were manufactured following a conventional production process, as illustrated in Fig. 4. The specific formulation is detailed in Table 2, presented in the subsequent section.

First, the dry ingredients were mixed and dissolved in water at ambient temperature. The heating process began with cooking the sugar or sugar substitute syrup, followed by the addition of the starch suspension after 3 min. The concentrated orange juice was added after 13 to 17 min, and the process concluded after 21 to 25 min of cooking, when the desired °Brix (72.5 ± 1.0) was achieved (Fig. 5a). The soluble solids content and its range were specified in the preliminary tests, ensuring that the final mixture was liquid enough to be dosed (Fig. 5b), yet concentrated enough to form the candy after the stoving time.

2.4. Characterization of starch jelly candies during storage

From the analysis of the CCRD results, a diet starch jelly was chosen for the stability study, performed during six months. The samples were packaged in polypropylene bags and stored at 25 °C (Fig. 5c). For

Table 2
Jelly Candies formulations used in the study.

Ingredient (%)	R Jelly	RF Jelly	DF Jelly (CCRD)
Sucrose	22.8	21.6	–
Glucose Syrup 40DE	19.8	18.1	–
Fiber: Poliol	–	–	40.0 (20:20)
Water	51.0	51.3	40.5
Starch	6.0	6.0	8.0
Conc. Orange Juice (66 °Brix)	–	3.0	11.5
Natural Colorant	0.1	–	–
Natural Flavor	0.3	–	–
Organic Acids	0.5	0.5	0.5
Oil coating	1–2	1–2	1–2

Note: The samples were labeled as follows: R, regular jelly; RF, regular fruit jelly; and DF, diet fruit jelly.

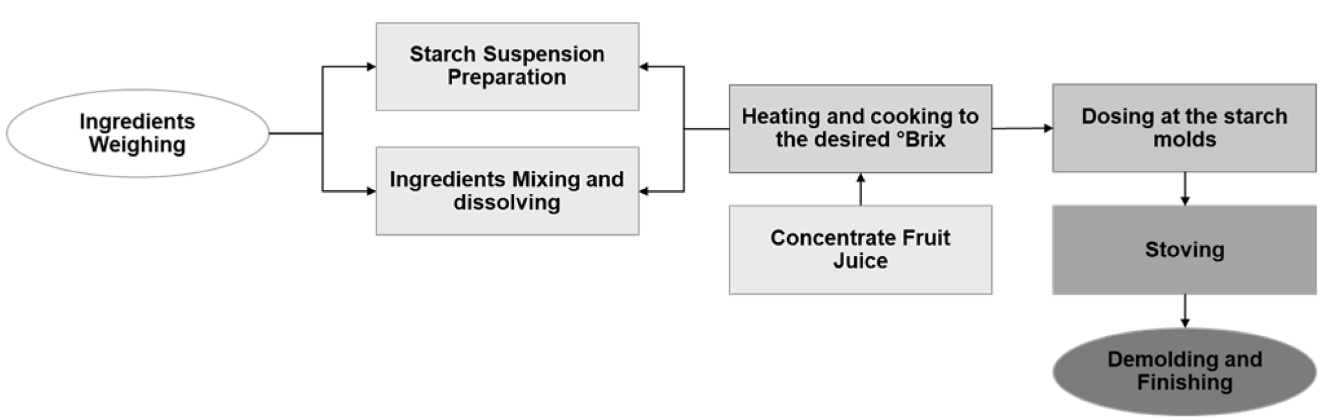

Fig. 4. Conventional Production Process (adapted from Hartel, Von Elbe, Hofberger, 2018 and Edwards, 2000).

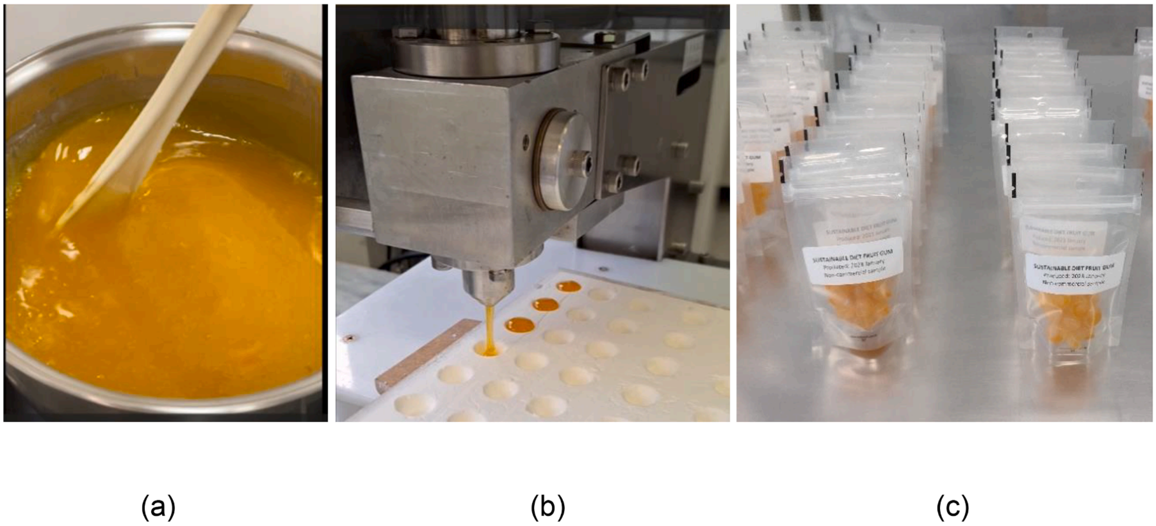

Fig. 5. Jelly production process: (a) Heating and Cooking; (b) Dosing; (c) Packaging.

comparison purposes, two other samples were also evaluated. The samples studied are described below and detailed in Table 2:

- Diet fruit jelly candy (DF): chosen based on the results obtained in the CCRD;
- Regular fruit jelly candy (RF): with added sugars and 3 % concentrated orange juice, replacing color and flavor additives.
- Regular jelly candy (R): with added sugars, natural orange flavor, and vegetable concentrate for coloring purposes.

In addition to the characterization described in Section 2.2, the samples were also evaluated for color and bioactive compounds. The samples were analyzed at 0, 90, and 180 days:

- Instrumental color, using a MiniScan XE colorimeter, model 65/10 (Hunter Laboratory, USA), Commission Internationale de I'Eclairage system (CIE LAB). The analysis was conducted with 5 replicates.
- Total phenolic content and antioxidant activity were evaluated according to Légua et al. (2021) and Rufino et al. (2007) on a Cirrus 80 spectrophotometer (Femto, São Paulo, SP, Brasil). To determine phenolic content, 3 extractions and 2 dilutions were carried out for each sample, totaling 6 replicates. For antioxidant activity, 2 extractions and 3 dilutions were carried out, totaling 6 replicates as well.

To better understand the contribution of the concentrated orange juice for the bioactive compounds, the juice was also analyzed in six replicates for total phenolic content and antioxidant activity according to the same methods described above at time zero.

The analysis of variance (ANOVA) was performed to evaluate the significance of main effects and interaction between them at 95 % confidence interval. All sample measurements were carried out in minimum triplicate and results are presented as mean ± standard deviation. Graphs were generated using excel and error bars in figures represent standard deviation. The one-way analysis of Variance (ANOVA) and the post-hoc Tukey HDS test were performed at a 95 % confidence level using Statistica® 12 software to establish the statistical differences among means.

2.5. Microbial risk assessment

The diet fruit (DF) candy, selected from the CCRD, was microbiologically evaluated for *Salmonella* (based on AOAC 2003.09, 2012), Enterobacteriaceae, molds and yeasts, and osmophilic yeasts, according to the American Public Health Association (APHA) compendium (American Public Health Association, 2015), at time zero (after production) and at 90 days of storage for molds, yeasts, and osmophilic yeasts.

2.6. Nutritional facts and front-of-pack labeling

The nutritional facts and front-of-pack labeling were developed to provide a comprehensive overview of various international labeling systems and to illustrate the impact of the nutritional improvements achieved with the CCRD formula. These were calculated in accordance with Brazil's RDC Nº 429 (Brazil, 2020a), IN Nº 75 (Brazil, 2020b), and European regulations (EU No. 1169/2011 – European Commission, 2011; French Ministry of Health & Prevention, 2021). For both sets of calculations, theoretical nutritional data and specifications provided by each ingredient supplier were used.

3. Results and discussion

3.1. Starch jelly candy formulation definition

Changes in consumer trends and preferences in the confectionery market have led to a significant demand for products that contain more natural ingredients, lower calorie content, health-promoting active components, as well as vegan and sustainable options (Konar et al., 2022; Reportlinker, 2022).

In this context, the use of dietary fibers such as Nutriose®, a resistant dextrin derived from wheat (comprising β and α−1,2-, α−1,3-, and α−1,6-glycosidic bonds), with a prebiotic fiber content ranging from 82 % to 88 %, offers a technological alternative to further enhance these products. Formulations containing 10 % to 25 % of this fiber have been shown not to cause discomfort after ingestion (Himat et al., 2021; Włodarczyk & Śliżewska, 2021).

Additionally, polyols can be used to replace sucrose in confectionery products. Maltitol, one such polyol, offers greater gastrointestinal tolerance, is non-cariogenic, and has a low glycemic index, making it suitable for consumption by individuals with diabetes. This ingredient does not participate in the Maillard reaction, is relatively stable at high temperatures, and has a negative heat of dissolution similar to sucrose, meaning it has virtually no cooling effect. It is recommended that an individual portion contains no more than 0.3 g of maltitol per kg of body weight to avoid a laxative effect, or up to 0.8 g per kg of daily total consumption (Hartel, Von Elbe, Hofberger, 2018; O'Donnell & Kearsley, 2012).

Furthermore, adding fruits to jelly candy formulations can reduce the need for food additives (Cano-Lamadrid et al., 2020). Citrus fruits, such as concentrated orange juice, are rich in phenolic acids and flavonoids, which are considered two of the main groups of natural antioxidants. The variability in the composition of these acids and flavonoids between fruits is mainly due to the genotype of each one. These secondary metabolites participate in various functions in the plant, but particularly in the fruit, they are associated with the color, flavor, nutritional characteristics, and antioxidant activity. The antioxidant activity of different foods has been extensively investigated because of their neutralizing oxidation processes that prevent chronic diseases related to oxidative stress in the human body. A range of antioxidant compounds, including ascorbic acid, flavonoids and phenolic acids have been identified as natural sources in food products (Légua et al., 2021).

Starch is an important plant-based ingredient that has been used for many years as a gelling agent or stabilizer in the confectionery industry. Many types of starch have been, and continue to be, modified to meet specific industry requirements. Structurally, starches are polysaccharides composed of numerous glucose units and are also referred to as complex carbohydrates (Hartel, Von Elbe, Hofberger, 2018). As a cost-effective ingredient, starch is a popular choice for large-scale production. It is also widely available and can be sourced from various plants, making it a versatile option for manufacturers (Cai et al., 2020; Guo et al., 2023; Ingredion, n.d.).

The jelly candies were prepared using the ingredients previously described, following the conventional production process outlined in Fig. 4. This process was applied uniformly across all experimental runs to ensure reproducibility. The experimental design and corresponding results are summarized in Table 3, illustrating the effects of varying formulation parameters on the measured responses. Additionally, the mathematical models derived from the data are presented in Table 4, highlighting the relationships between the independent variables and the key response variables. These models provide a quantitative basis for understanding the influence of formulation and processing factors on the final product characteristics.

According to Ergun, Lietha and Hartel (2010), the water activity (a_w) of jelly candies ranges from 0.50 to 0.75 and the moisture content from 8 to 22 %. Pereira, Benassi and Beleia (2022) studied corn starch and cassava starch gummies with moisture ranging from 15.9 % to 17.0 % and a_w between 0.63 and 0.67. The moisture and a_w values observed in the CCRD trials (Table 3) are within the ranges described above.

The hardness, stickiness, and adhesiveness of the candies studied varied between 1.23 to 7.91 N; −1.40 to −5.16 N and −0.38 to −1.62 N.s, respectively (Table 3). Guiné et al. (2020) report hardness (firmness of the candy crust) values ranging from 0.86 to 0.94 N, stickiness between −0.37 to −0.48 N, and adhesiveness between −1.75 and −2.15 N.s for candies formulated with a mix of pectin and agar, i.e., softer and less sticky candies than the starch jellies studied.

The R^2 and the $F_{calculated}$ values indicate that first-order models (equations Y_3 and Y_4) could be obtained for the evaluated responses of hardness and stickiness. The responses for a_w, moisture, and adhesiveness did not result in predictive models, as no effects were significant. In other words, water activity, moisture and candy texture adhesiveness did not show a statistically significant correlation with the content of orange juice and/or fiber:polyol mixture in the formula. The mathematical models obtained are presented in Table 4.

Table 4
Analysis of Variance (ANOVA) (coefficient of determination - R^2, $F_{calculated}$, $F_{tabulated}$ values) for the responses of hardness and stickiness as a function of the % of orange juice and % of the fiber: polyol mix.

Response	R^2 (%)	$F_{calculated}$	$F_{tabulated}$	Math Equation
Hardness (N)	97.95	190.81	4.46	Y_3=4.25–1.76 x_1–1.60 x_2
Stickiness (N)	94.53	69.07	4.46	Y_4=−3.23+1.19 x_1+0.68 x_2

x_1, x_2: independent variables codified for orange juice (%) and polyol: fiber mix 1:1 (%).

The addition of the polyol: fiber mix led to a reduction in the hardness of the candies, especially above 38.3 %, as did the addition of orange juice, particularly at concentrations above 11.5 % (Fig. 6). The impact on reducing stickiness was greater for orange juice concentrations above 11.5 %, while the fiber: polyol mix had little influence on this variable.

Prakash and Priya (2016) studied pectin candies with a 40 % sugar reduction, added with fibers (fructooligosaccharides-FOS) and 10 % blueberry pulp, and observed that there was no difference in the sensory texture of these candies compared to a standard sample. Rivero et al. (2021) studied sugar-free gelatine gummies containing maltitol syrup and isomalt, 10.9 % orange juice or 5.2 % reconstituted raspberry powder, and observed that the addition of fruit significantly reduced the hardness of the candies, as observed in the present study.

To assist in the selection of the trial that would proceed to the stability study, a comparison was made between the results of the CCRD and the control candies (RF and R) (Table 5).

The candies from trials 4, 6, and 8 of the CCRD (Table 3) showed values of hardness, stickiness, and adhesiveness closer to the R and RF samples. The water activity and moisture levels of these three trials were typical for this product category. The orange juice concentrations in samples 4, 6, and 8 were 17.5 %, 20.0 %, and 11.5 %, respectively. According to observations made by the project team, a high content of orange juice resulted in candies with a dark and brownish color (Fig. 7), as well as a bitter taste.

Considering the results, the formulation chosen for the stability study was trial 8, henceforth referred to as “diet fruit” (DF). In addition to this sample, the RF and R samples also had their stabilities evaluated.

3.2. Stability study

In an assessment made for the same sample at different storage times (Fig. 8, lowercase letters, $p < 0.05$), a reduction in moisture was observed, mainly between 0 and 90 days. The moisture levels of the RF

Table 3
Water activity (a_w), moisture, hardness, stickiness, and adhesiveness of candies obtained from different percentages of orange juice concentrate and fiber: polyol (1:1).

Trials	Orange Juice (%) x_1	Fiber: Polyol (1:1) (%) x_2	a_w Y_1	Moisture (%) Y_2	Hardness (N) Y_3	Stickiness (N) Y_4	Adhesiveness (N.s) Y_5
1	−1 (5.5)	−1 (29.7)	0.6435	12.81	7.91	−4.92	−1.49
2	1 (17.5)	−1 (29.7)	0.6143	12.40	4.04	−3.03	−1.20
3	−1 (5.5)	1 (38.3)	0.6247	10.60	4.41	−4.09	−1.60
4	1 (17.5)	1 (38.3)	0.6452	13.87	1.23	−1.40	−0.62
5	−1.41 (3.0)	0 (34.0)	0.6417	11.86	7.00	−5.16	−1.62
6	1.41 (20.0)	0 (34.0)	0.6535	16.46	2.03	−1.68	−0.64
7	0 (11.5)	−1.41 (28.0)	0.6412	14.02	6.46	−3.89	−1.26
8	0 (11.5)	+1.41 (40.0)	0.6548	12.16	1.88	−1.77	−0.38
9	0 (11.5)	0 (34.0)	0.6557	12.43	4.36	−3.10	−0.94
10	0 (11.5)	0 (34.0)	0.6185	16.22	3.73	−3.56	−1.61
11	0 (11.5)	0 (34.0)	0.6257	14.68	3.70	−2.96	−1.20

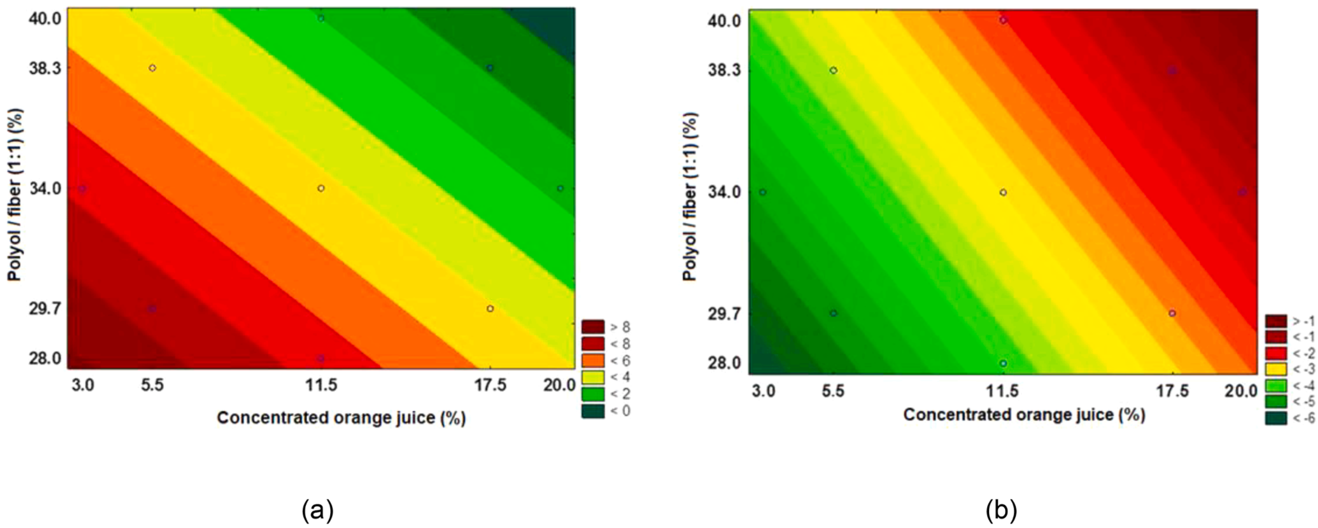

Fig. 6. Contour curves for the results of hardness (a) and stickiness (b) of the diet jellies samples, as a function of the concentration of concentrated orange juice (%) and fiber: polyol mix (1:1) (%).

Table 5
Water activity (a_w), moisture, and texture of the jelly candies added with sucrose, with and without the incorporation of concentrated orange juice (± standard deviation, triplicate).

Sample	a_w	Moisture (%)	Hardness (N)	Stickiness (N)	Adhesiveness (N.s)
RF	0.6006 ± 0.0024	10.97 ± 0.44	2.28 ± 0.09	−1.72 ± 0.28	−0.66 ± 0.13
R	0.6200 ± 0.0026	11.06 ± 0.06	1.38 ± 0.06	−0.85 ± 0.10	−0.23 ± 0.07

Note: The samples were labeled as follows: R, regular jelly; and RF, regular fruit jelly.

and DF samples were statistically similar between 90 and 180 days. This reduction in moisture levels over the first 90 days resulted in an increase in the product hardness during the same period. Although the water activity of the R sample remained stable over the 180-day period, the RF sample demonstrated a significant reduction in a_w only at the end of the study. In contrast, the DF sample exhibited continuous decrease in a_w.

For the same storage time and comparison between different samples (Fig. 8, uppercase letters, $p < 0.05$), it was observed that at time 0, the moisture was higher for the RF and DF samples, reflecting the variation in soluble solids content observed at the end of cooking, which was between 71.5 to 73.4 °Brix. After 180 days, the moisture levels of all three samples were found to be similar.

Regarding the texture parameters (Fig. 9, lowercase letters, $p < 0.05$), notable changes were observed in all samples between 0 and 90 days, with a significant increase in hardness, stickiness, and adhesiveness. RF was the hardest sample, while DF was the stickiest and most adhesive. During the shelf life of jelly candies, in addition to quality loss related to water migration (i.e., moisture loss or gain), other textural changes may occur due to the rearrangement of starch molecules (starch retrogradation) (Hartel, Von Elbe, Hofberger, 2018). Furthermore, starch-based foods can exhibit water mobility, involving the redistribution of water within the matrix during storage (Ruan et al., 1996). Between 90 and 180 days, texture parameters significantly decreased in all samples, which may be attributed to structural changes resulting from water mobility and its interaction with product components. Even with stable overall moisture content, the plasticizing effect of water could lead to a softer texture.

Throughout the stability study, the DF sample, the focus of this study, showed lower hardness and higher stickiness, adhesiveness, and water activity (a_w) compared to the other samples (Fig. 9, uppercase letters, $p < 0.05$). To ensure the stability of the candy characteristics during storage, the use of water vapor barrier packaging is recommended.

As the DF sample has higher content of concentrated orange juice (11.5 %), it showed a higher content of total phenolic compounds and a greater antioxidant activity. The DF samples differed significantly from the other candies in both analyses (Fig. 10, uppercase letters, $p < 0.05$). The results for phenolic content were stable over the 90 days of the study, only showing a significant drop ($p < 0.05$) at 180 days of storage;

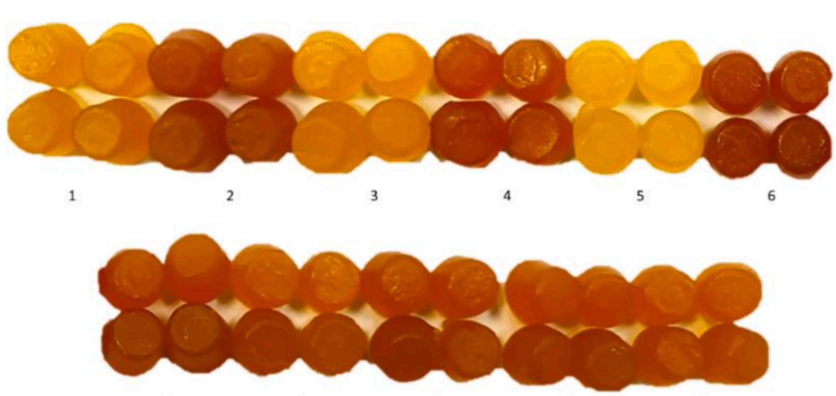

Fig. 7. Jellies produced by the experimental design, from trial 1 to 11.

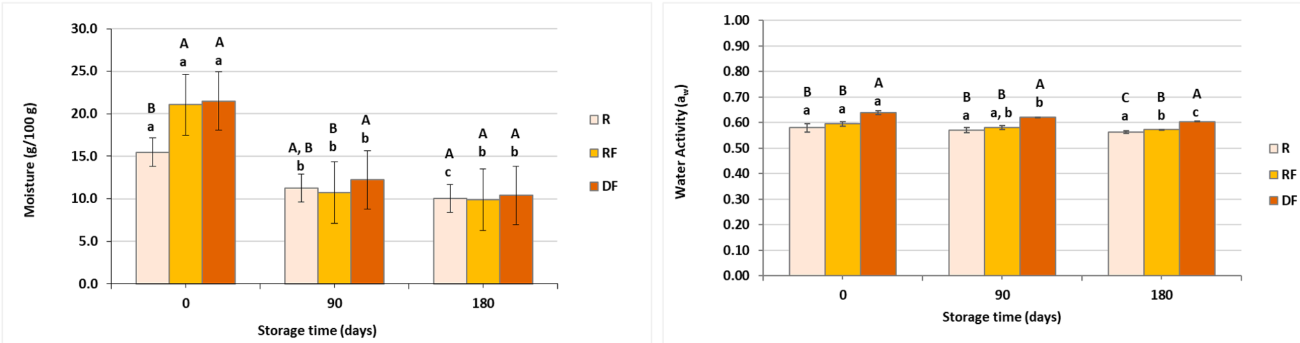

Fig. 8. Moisture content and water activity for the different samples (R, regular jelly; RF, regular fruit jelly; and DF, diet fruit jelly) at 0, 90 and 180 days of storage at 25 °C. Different lowercase letters for the same sample at different storage times indicate a significant difference between the results obtained for the sample ($p < 0.05$). Different capital letters for different samples at the same storage time indicate a significant difference between the values obtained for the specified storage time ($p < 0.05$).

while the antioxidant activity showed a significant drop ($p < 0.05$) at 90 days and remained stable afterward.

Regarding the RF sample, despite the lower results in phenolic content compared to DF candies, they were significantly different and higher ($p < 0.05$) from the R samples and remained constant throughout the 90-day storage period. At 180 days of storage, the phenolic content dropped and showed no significant difference ($p < 0.05$) from the R candies at Zero and 90 days of storage. As for antioxidant activity, the low results found for the RF samples did not differ significantly from the R samples ($p < 0.05$), thus indicating that the impact of this antioxidant activity found would not be representative.

Although the R samples did not have any orange juice in their formulation, they presented very low total phenolic content values, probably due to intrinsic errors in the colorimetric method used. The Folin-Ciocalteu (FC) method is well-established and uses the FC reagent to oxidize phenolic compounds. The method is widely used for the quantification of total polyphenols in fruit juices and beverages (Everette et al., 2010). It is based on redox reactions between reducing compounds in the sample, including, but not limited to, polyphenols. Compounds other than phenolics, such as reducing sugars (e.g., glucose, fructose, maltose) and ascorbic acid, are also able to reduce the FC reagent. Thus, the presence of sugar and vegetable concentrate for coloring purposes in this sample formulation resulted in the reported values of total phenolic content (Lawag et al., 2023; Ma et al., 2019; Muñoz-Bernal et al., 2017). As for the antioxidant activity, considering the size of the deviation found, it can be considered null.

The frozen concentrated orange juice used in the formulation of the DF and RF jellies had a total soluble solid content of 66 °Brix. According to the juice supplier, the standard soluble solid content of average orange juice is 11.5 °Brix. Based on this, the final formulas of the DF and RF candies presented in Table 2 contain 66 % and 17.2 % of orange juice, respectively. Therefore, the total orange juice content in the fruit jelly formulas is high, which is why both products also exhibited an interesting total phenolic content and antioxidant activity, even after cooking and stoving process. To better understand the contribution of the frozen concentrated orange juice to the bioactive compounds, we also analyzed it individually. The results are presented in Table 6.

In the study by Légua et al. (2021), the phenolic content of eleven orange varieties ranged from 117.26 to 241.91 mg of gallic acid per 100 g. And the study by Modica et al. (2024) reported that the antioxidant activity of five orange varieties from three different regions ranged from 1001.2 to 4255.1 μM Trolox per g, after converting the reported units from mM Trolox to μM Trolox per g. The orange juice used to produce the jellies exhibited total phenolic content and antioxidant activity within the ranges reported in both studies.

The color of the candies was also monitored throughout the 180 days of storage at 25 °C, as shown in Fig. 11. An increased orange juice content in the formulation was associated with a more pronounced darkening of the samples, most likely due to non-enzymatic browning. The degradation of ascorbic acid and the Maillard reaction have been identified as the main non-enzymatic pathways contributing to the browning of orange juice and orange juice–containing products (Kacem, 1987; Paravisini & Peterson, 2019; Santos et al., 2020). Therefore, to minimize changes in candy characteristics during storage, the use of packaging with barriers against oxygen, water vapor, and light is recommended.

3.3. Microbial assessment

Microbiological analysis confirmed the absence of *Salmonella* and microbial counts below 10 CFU/g for Enterobacteriaceae, molds, yeasts, and osmophilic yeasts, demonstrating the microbiological stability of the DF jelly throughout the evaluated storage period. No significant variations were detected after 90 days of storage. The product maintained its microbiological integrity and remained safe for consumption, even following the substitution of sucrose with a fiber: polyol mix.

3.4. Nutritional facts and front labeling

The nutritional facts and front of pack warning / positive labels for three samples are presented according to the Brazilian and European legislations (Fig. 12) (Brazil, 2020a, 2020b; European Commission, 2011; French Ministry of Health & Prevention, 2021).

These findings indicate that the diet fruit (DF) samples possess a significantly improved nutritional profile compared to the regular sugar-containing formulations (R and RF). The substantial increase in dietary fiber content (27 g/100 g vs. 0.3–0.4 g/100 g) is particularly noteworthy, as it enhances the functional value of the product, potentially contributing to improved gastrointestinal health and glycemic control (Dreher, 2018; Gbakayoro et al., 2024).

Additionally, the reduction in total carbohydrates (61 g/100 g in DF vs. 84–87 g/100 g in R and RF) reflects a decrease of approximately 27–30 %, which is beneficial for consumers seeking lower-carbohydrate alternatives. The DF samples also exhibited markedly lower total sugar content (12 g/100 g), representing reductions of 76.5 % and 77.8 % compared to R and RF, respectively - an important factor in the context of reducing added sugars in the diet.

Furthermore, the energy content of the DF samples was reduced by approximately 29–31 % relative to the control formulations, which may support weight management and overall caloric intake moderation. Collectively, these nutritional improvements suggest that the DF formulation is a viable alternative to conventional sugar-based confections, with potential health benefits aligned with current dietary recommendations (Lamothe et al., 2017; Tan, Drewnowski, Lê, 2023).

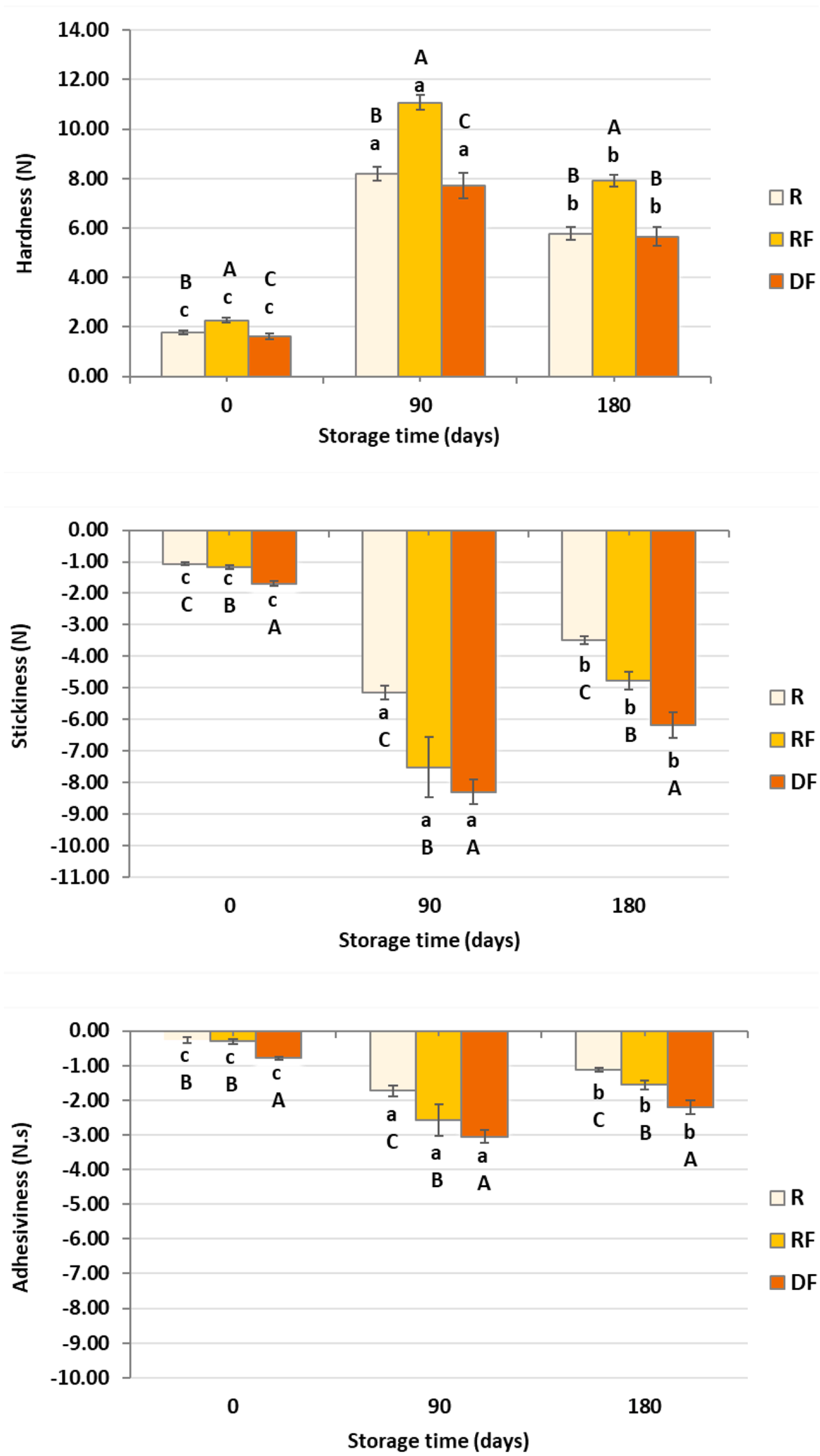

Fig. 9. Texture parameters for the different samples (R, regular jelly; RF, regular fruit jelly; and DF, diet fruit jelly) at 0, 90 and 180 days of storage at 25 °C. Different lowercase letters for the same sample at different storage times indicate a significant difference between the results obtained for the sample ($p < 0.05$). Different capital letters for different samples at the same storage time indicate a significant difference between the values obtained for the specified storage time ($p < 0.05$).

In Brazil, the DF sample did not meet the criteria for the “high added sugar” warning and therefore did not require inclusion in the front-of-package (FOP) label. Similarly, in Europe, this sample was classified with a Nutri-Score of B (green), indicating a more favorable nutritional profile. In contrast, the RF and R samples contained elevated levels of added sugar. Consequently, both would require the “high added sugar” FOP warning label in Brazil and were assigned a Nutri-Score of E (red) in Europe, reflecting a less favorable nutritional quality.

Not only did the DF jelly exhibit a better nutritional profile, but the proposed formulation also had a positive impact on front-of-package (FOP) labeling. FOP labeling plays a significant role in influencing consumer behavior and promoting healthier food choices. These labels provide consumers with easily accessible information about a product’s nutritional content at a glance, thereby influencing purchasing decisions

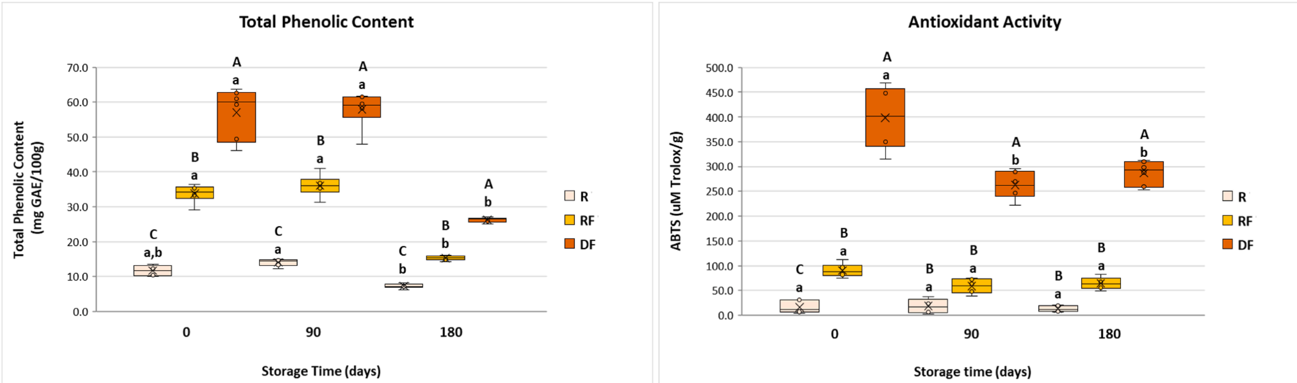

Fig. 10. Total phenolic content and antioxidant activity for the different samples (R, regular jelly; RF, regular fruit jelly; and DF, diet fruit jelly) at 0, 90 and 180 days of storage at 25 °C. Different lowercase letters for the same sample at different storage times indicate a significant difference between the results obtained for the sample ($p < 0.05$). Different capital letters for different samples at the same storage time indicate a significant difference between the values obtained for the specified storage time ($p < 0.05$).

Table 6
Total phenolic content (mg GAE /100 g) and antioxidant activity (µM Trolox /g) of the orange juice (± standard deviation, 6 replicates).

Sample	Total Phenolic Content (mg GAE / 100 g)	Antioxidant Activity (µM Trolox /g)
Orange juice	183.7 ± 7.8	1615.9 ± 79.9

and dietary habits. As such, positive FOP labels can have a beneficial effect on consumer choices (An et al., 2021; Stiletto et al., 2024).

4. Conclusion

The orange juice, mainly at levels above 11.5 %, reduced the hardness and stickiness of the samples and concentrations above 38.3 % of the fiber: polyol mix (1:1) also reduced the hardness of the candies, with less impact on stickiness. The sample containing 20 % maltitol, 20 % Nutriose®, 11.5 % concentrated orange juice and 8 % corn starch (trial 8) was selected for the stability study. The stability study indicated that the DF differed from the other samples, being less hard, stickier, and more adhesive. As the DF sample had higher content of concentrated orange juice (11.5 %), it showed a higher content of total phenolic compounds and of antioxidant capacity ($p < 0.05$). The DF candy was characterized as a source of fiber, did not require the "high added sugar" FOP label and received a Nutri-Score B.

Ethical statement

No studies in human or animals were conducted in this research.

CRediT authorship contribution statement

Melissa Filipini da Silveira: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Prof. Dr. Priscilla Efraim:** Writing – review & editing, Investigation, Formal analysis, Conceptualization. **Maria Júlia Viscondi Silva:** Investigation, Formal analysis, Data curation. **Júlia das Neves de Aro:** Investigation, Formal analysis, Data curation. **Ana Lúcia Fadini:** Writing – review & editing, Investigation, Formal analysis, Data curation, Conceptualization. **Guilherme de Castilho Queiroz:** Writing – review & editing, Project administration, Methodology, Formal analysis, Conceptualization. **Flávio Martins Montenegro:** Writing – review & editing, Methodology, Conceptualization. **Marise Bonifácio Queiroz:** Writing – review & editing, Resources, Investigation, Funding acquisition, Formal analysis, Conceptualization.

STORAGE TIME	Zero days			90 days			180 days		
DF	Mean	S.D.	Ref. Color**	Mean	S.D.	Ref. Color*	Mean	S.D.	Ref. Color**
L*	73.76 aB	0.65		58.64 bB	1.58		51.28 cC	1.35	
a*	30.87 aA	0.49		26.80 bA	1.10		27.86 bA	1.12	
b*	70.89 aA	1.99		53.24 bB	3.03		40.81 cB	3.42	
RF	Mean	S. D.	Ref. Color**	Mean	S. D.	Ref. Color**	Mean	S. D.	Ref. Color**
L*	92.22 aA	1.74		87.36 bA	2.45		78.18 cB	2.79	
a*	17.14 bB	0.48		14.45 cC	0.64		18.78 aB	0.57	
b*	74.66 aA	2.16		61.00 bA	2.96		57.07 bA	2.64	
R	Mean	S. D.	Ref. Color**	Mean	S. D.	Ref. Color**	Mean	S. D.	Ref. Color**
L*	89.36 aA	1.82		88.79 aA	2.06		88.19 aA	1.18	
a*	29.58 aA	0.71		17.92 bB	0.64		18.26 bB	0.72	
b*	46.94 aB	1.28		35.74 bC	1.21		39.70 bB	1.04	

Fig. 11. Instrumental color (CIE LAB*) for the different samples (R, regular jelly; RF, regular fruit jelly; and DF, diet fruit jelly), at 0, 90 and 180 days of storage at 25 °C (mean ± standard deviation, 5 replicates, **reference color made with Nix color sensor). Different lowercase letters for the same sample at different storage times indicate a significant difference between the results obtained for the sample ($p < 0.05$). Different capital letters for different samples at the same storage time indicate a significant difference between the values obtained for the specified storage time ($p < 0.05$).

Nutricional Facts - R sample

Serving size per package: 1
Serving size: 20 g (14,3 units)

	100g	20g	%DV*
Energy (kcal)	339	68	3
Carbohydrate (g)	84	17	6
Total Sugar (g)	51	10	
Added Sugar (g)	51	10	21
Proteins (g)	0.1	0.0	0
Total Fat (g)	0.2	0.0	0
Saturated Fat (g)	0.2	0.0	0
Trans Fat (g)	0	0	0
Dietary Fiber (g)	0.3	0.1	0
Sodium (mg)	39	7.7	0
Vitamin C (mg)	0	0.0	0

* Percentage of daily value provided per serving size

ALTO EM AÇÚCAR ADICIONADO **

** High in added sugar

Nutricional Facts - RF Sample.

Serving size per package: 1
Serving size: 20 g (14,3 units)

	100g	20g	%DV*
Energy (kcal)	350	70	4
Carbohydrate (g)	87	17	6
Total Sugar (g)	54	11	
Added Sugar (g)	50	10	20
Proteins (g)	0.4	0.1	0
Total Fat (g)	0.3	0.1	0
Saturated Fat (g)	0.2	0.0	0
Trans Fat (g)	0	0	0
Dietary Fiber (g)	0.4	0.1	0
Sodium (mg)	39	7.7	0
Vitamin C (mg)	2	0.4	0

* Percentage of daily value provided per serving size

ALTO EM AÇÚCAR ADICIONADO **

** High in added sugar

Nutricional Facts - DF sample

Serving size per package: 1
Serving size: 20 g (14,3 units)

	100g	20g	%DV*
Energy (kcal)	242	48	2
Carbohydrate (g)	61	12	4
Total Sugar (g)	12	2.4	
Added Sugar (g)	0.2	0.0	0
Proteins (g)	0.9	0.2	0
Total Fat (g)	0.3	0.1	0
Saturated Fat (g)	0.2	0.0	0
Trans Fat (g)	0	0	0
Dietary Fiber (g)	27	5.3	21
Sodium (mg)	21	4.3	0
Vitamin C (mg)	7	1.4	1

* Percentage of daily value provided per serving size

Source of Fibers
IN n°75, 2020 (10% of DV = 2,5g per size)

(a)

Nutricional Facts - R sample

	100g
Energy (kcal)	1419 kJ/ 339 kcal
Fat (g)	0.2 g
of which saturated fatty acids (g)	0.2 g
Carbohydrate (g)	84 g
of which sugar (g)	51 g
of which polyols (g)	-
Fiber (g)	-
Proteins (g)	0.1 g
Salt (mg)	0.10 g

NUTRI-SCORE A B C D E

Nutricional Facts - RF Sample.

	100g
Energy (kcal)	1465 kJ/ 350 kcal
Fat (g)	0.3 g
of which saturated fatty acids (g)	0.2 g
Carbohydrate (g)	87 g
of which sugar (g)	54 g
of which polyols (g)	-
Fiber (g)	-
Proteins (g)	0.4 g
Salt (mg)	0.10 g

NUTRI-SCORE A B C D E

Nutricional Facts - DF sample

	100g
Energy (kcal)	1013 kJ/ 242 kcal
Fat (g)	0.3 g
of which saturated fatty acids (g)	0.2 g
Carbohydrate (g)	61 g
of which sugar (g)	12 g
of which polyols (g)	32 g
Fiber (g)	27 g
Proteins (g)	0.9 g
Salt (mg)	0.05 g

NUTRI-SCORE A B C D E

Source of Fibers
(EU No 1169/2011)

(b)

Fig. 12. Nutritional facts and front-of-pack labels in accordance with Brazilian (a) and European (b) legislation. The samples were labeled as follows: R, regular jelly; RF, regular fruit jelly; and DF, diet fruit jelly.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Marise B. Queiroz reports financial support was provided by State of Sao Paulo Research Foundation. Melissa Filipini da Silveira reports financial support was provided by Coordination of Higher Education Personnel Improvement. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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