CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

OPEN ACCESS

CC BY SA

Research article

BOOSTING BIOACTIVES AND SENSORY QUALITY IN SWEET SNACKS: A FORMULATION STRATEGY FROM WHEAT FLOUR TO BLUEBERRY-ENRICHED PRODUCTS

Nadia Lingiardi[1,2,3]✉, Lucrecia López Marenghini[2], Emilce Llopart[1,2], Germán Baez[1,4], Roxana Verdini[1,2,3], Gilda Revelant[3], Marina Soazo[1,2,3], Gisela Piccirilli[2,3]

[1]National Scientific and Technical Research Council (CONICET), Rosario, Argentina
[2]Instituto de Química de Rosario (IQUIR), Rosario, Argentina
[3]Department of Food and Environmental Sciences, Bromatology and Nutrition Area, Faculty of Biochemical and Pharmaceutical Sciences, National University of Rosario (UNR), Rosario, Argentina
[4]Food Technology Area, Research, Development and Food Evaluation Laboratory (LIDEA), Faculty of Biochemical and Pharmaceutical Sciences, National University of Rosario (UNR), Rosario, Argentina
✉Nadia Lingiardi, ORCID 0000-0003-1968-8637, nadia.lingiardi@unr.edu.ar

https://doi.org/10.34302/crpjfst/LTDO9779

Article history:
Received:
May 18th 2026
Accepted:
July 17th 2026
Published:
November 23th 2026

Keywords
Blueberry powder
Polyphenols
Anthocyanins
Value-added snacks

Abstract
This study aimed to evaluate the physicochemical characteristics and antioxidant capacity of sweet cookies, a widely consumed snack product, enriched with different concentrations of freeze-dried blueberry powder (2%, 6%, and 10% w/w), used as a partial substitute for wheat flour. The effects of blueberry incorporation on the physicochemical and technological properties of cookies, as well as their antioxidant capacity, total phenolic and anthocyanin content, and sensory characteristics, were analyzed. Antioxidant capacity was largely retained after baking, with cookies preserving 70%-90% of the activity measured in freeze-dried blueberries. The 10% formulation exhibited the highest antioxidant capacity, highlighting the potential of blueberry enrichment to enhance the functional value of cookies. The addition of blueberries imparted an appealing purple-blue coloration characteristic of the fruit, which could improve product identification and sensory perception. A fruit-like flavor was detected in all fortified formulations, while cookies with higher blueberry levels were perceived as significantly sweeter. Within the scope of this sensory evaluation, the overall acceptability of the formulations was good. This enhanced sweetness suggests the possibility of reducing added sugar in future formulations, offering an additional nutritional advantage. Given the widespread consumption and consumer acceptance of cookies, incorporating freeze-dried blueberries is a promising strategy for developing value-added bakery products.

1. Introduction

Consumers are increasingly demanding snacks that provide not just indulgence but also

health benefits, driving a shift in the bakery industry toward functional foods. Cookies, as a staple and highly consumed snack, represent an ideal platform for nutritional enhancement. By incorporating bioactive-rich fruit-derived powders into cookie formulations, it is possible to improve their antioxidant profile, giving traditional baked goods a functional twist (Krajewska & Dziki, 2025).

Blueberries (species of *Vaccinium*) are considered a rich source of bioactive and nutritive compounds beyond basic macronutrients. They provide relevant amounts of minerals such as potassium, magnesium, calcium, iron, zinc, copper, and manganese, depending on variety and origin, contributing to dietary mineral intake (Cabrera et al., 2021). In addition, blueberries are abundant in polyphenolic compounds, including flavonoids, phenolic acids, and particularly anthocyanins, which together contribute significantly to their total antioxidant capacity. Recent compositional analyses have documented a diverse polyphenolic profile, including quercetin, catechin, and epicatechin among flavonoids, consistently present across different blueberry-based products (Buiarelli et al., 2025).

The concentration of anthocyanins and total phenolics in blueberry-derived ingredients supports their potential role not only as dietary antioxidants but also as functional ingredients when incorporated into processed foods (Estupiñan-Amaya et al., 2020). Moreover, freeze-drying has been shown to effectively preserve these phenolic compounds in blueberry powders, maintaining high antioxidant activity (Antal, 2024).

However, incorporating fruit powders into bakery products such as cookies presents technological challenges. The addition of berry powders can alter dough behavior, moisture, pH, and the baking process may lead to partial degradation of phenolics (Salihu et al., 2023). Therefore, assessing both the retention of antioxidant compounds after baking and the physicochemical properties of the final product is critical.

In addition to technological effects, the incorporation of fruit powders can substantially influence the sensory attributes of baked products. Berry-derived ingredients often intensify coloration, imparting red-purple or blue hues that can enhance product distinctiveness and consumer appeal (Nour et al., 2025; Wang et al., 2025). However, they may also introduce perceptible changes in flavor, sweetness, astringency, or acidity, depending on the concentration used and the specific phenolic profile of the fruit powder (Tolve & Simonato, 2024).

Recent research highlights viable strategies for enriching cookies with phenolic-rich ingredients. Santuccione et al., (2025) studied the incorporation of blueberry leaf powder, a by-product of pruning, into wheat-soy-based cookies, resulting in a significant increase in total phenolic content and antioxidant capacity, with good retention of bioactive compounds after baking. Moreover, formulations with moderate levels of blueberry extract substitution maintained acceptable sensory characteristics, demonstrating the feasibility of such functional products (Salihu et al., 2023).

Therefore, this study investigates the incorporation of freeze-dried blueberry powder at 2%, 6%, and 10% flour substitution levels in cookie formulations. The resulting impact on key physicochemical and technological attributes is assessed, along with the retention of antioxidant capacity, total phenolic content, and anthocyanins after baking. Moreover, sensory acceptability is evaluated to establish the consumer viability of the enriched sweet snacks. This work contributes to the formulation of value-added bakery products and explores the potential of blueberry powder as a functional ingredient that enhances both nutritional and sensory qualities.

2.2. Materials and Methods

2.1. Materials

Wheat flour type 0000 (Molino Juan Semino S.A., Argentina), trans-fat-free margarine (Compañía Argentina de Levaduras S.A.I.C., Argentina), baking powder (Kraft Foods, Argentina), refined sugar (David

Rosental e Hijos S.A.I.C., Argentina), powdered egg (Industria del Huevo, Argentina), potable water, and fresh mature blueberries (cv. purchased from a local market). Folin–Ciocalteu reagent, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), gallic acid, and 2,2′-azino-bis 3-ethylbenzthiazoline-6-sulphonic (ABTS) acid were purchased from Sigma-Aldrich®. All other reagents were of analytical grade.

2.2. Methods

2.2.1. Preparation of freeze-dried blueberry powder

Blueberries were washed, dried, and processed using a domestic mixer (LM5076, ATMA, Argentina) to obtain a homogeneous paste. The paste was evenly spread (≈1 cm thick) onto stainless steel trays and frozen at –40 °C (SIAM, China) for 24 hours. The frozen paste was then placed in the drying chamber of a benchtop freeze-dryer (L101, LIOTOP, USA) and dried for approximately 12 hours, until completely dehydrated. The freeze-dried product was removed from the trays and used for cookie preparation. The total weight loss during freeze-drying was 82%, corresponding to the water content of the fruit.

2.2.2. Cookie formulation

Control cookies (CC) were prepared according to a recipe previously optimized by the research group, using the ingredients and proportions listed in Table 1. For the other formulations, wheat flour was partially replaced with blueberry powder to obtain samples containing 2%, 6%, and 10% blueberry (hereafter referred to as BB-2, BB-6, and BB-10, respectively). Trans-fat-free margarine and refined sugar were creamed using a domestic mixer (HR 1480, Philips, Argentina). Powdered egg was then added, and the mixture was continued until a homogeneous dough was obtained. Wheat flour and baking powder were previously mixed, sifted, and incorporated. Blueberry powder, pre-hydrated with potable water at room temperature, and the remaining water were then added. All ingredients were mixed until a uniform dough without lumps was achieved. For CC, only water was added. Doughs were sheeted using a dough sheeter (Sol Real, Argentina), and cookies (5 cm diameter) were cut with metallic molds. Baking was performed in a convection oven (Zonda, Argentina) at 180 °C for 8 minutes. The cookies were then cooled to room temperature before analysis.

Table 1. Ingredients of control cookie (CC) and cookies with 2%, 6%, and 10% blueberry (BB-2, BB-6, and BB-10) replacement.

Ingredients (%)	CC	BB-2	BB-6	BB-10
Wheat flour	44	42	38	34
Blueberry powder	0	2	6	10
Margarine	21	21	21	21
Sugar	21	21	21	21
Egg powder	3	3	3	3
Water	10	10	10	10
Baking powder	1	1	1	1
Total	100	100	100	100

2.2.3. Analysis of physicochemical and technological attributes of cookies

The physical and technological attributes of the cookies (weight, diameter, thickness, spread ratio, texture, and color) were determined according to Santuccione et al., (2025). Moisture was determined according to the AOAC (1990) method. Dimensional parameters were measured using a precision caliper, and the spread ratio was calculated as the diameter-to-thickness ratio. Texture was assessed by a three-point bending test conducted on a motorized universal testing

machine (Multitest 2.5-d, Mecmesin, UK) at a crosshead speed of 180 mm/min, with hardness defined as the peak fracture force. Color attributes (*L, a*, b**) were quantified by digital image analysis under controlled illumination on both the cookie surface and the fractured internal section (cross-sectioned cookies). The total color difference (ΔE*) was additionally computed to evaluate the perceptibility of chromatic variations among samples, following the equation (Bodart & Pen, 2008).

$$\Delta E^* = \sqrt{[(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]} \quad (1)$$

where L_0^*, a_0^*, and b_0^* are the values for the CC formulation, while L^*, a^*, and b^* correspond to the values for BB-2, BB-6, and BB-10.

All measurements were performed in quintuplicate (n = 5).

2.2.4. Chemical extracts obtention

For antioxidant activity, total phenolics, and anthocyanin assays, extracts were prepared from blueberry powder and cookie samples (CC, BB-2, BB-6, and BB-10). Extractions were performed following the method described by Zapata, (2014). Briefly, 0.5 g of each sample was mixed with 20 mL of methanol:HCl (pH 2, 50:50) and stirred for 1 hour, followed by centrifugation (15 minutes, 3500 rpm). A second extraction of the residue was carried out using 20 mL of acetone:water (70:30). The supernatants from both extractions were combined for subsequent analyses. Extracts were obtained in duplicate.

2.2.5. Antioxidant activity (ABTS)

Antioxidant activity was determined using a modified procedure based on Llopart et al., (2023). A 7 mM ABTS solution and a 2.45 mM potassium persulfate solution were mixed in equal volumes to generate the ABTS•$^+$ radical, which was allowed to develop for 16 hours at room temperature in the dark. The radical solution was subsequently diluted with a 50:50 ethanol–water mixture to an absorbance of 0.70 ± 0.02 at 734 nm. For the assay, 100 µL of each extract was mixed with 900 µL of ABTS•$^+$, and absorbance at 734 nm was measured after 30 minutes of reaction at room temperature in the dark. A Trolox calibration curve (0.01–0.1 mg/mL) was used, and antioxidant activity was expressed as mg Trolox equivalents (TE) per 100 g of sample. All measurements were performed in triplicate.

2.2.6. Total phenolic content

Total phenolic content was quantified using a modified Folin–Ciocalteu colorimetric assay (Llopart et al., 2023). For the reaction, 40 µL of each extract was mixed with 2 mL of a 1:10 dilution of Folin–Ciocalteu reagent and 1 mL of 7.5% (w/v) anhydrous sodium carbonate (Na_2CO_3). The mixture was vortexed and incubated at 40 °C for 10 minutes. Absorbance was then recorded at 765 nm using distilled water as the blank. A calibration curve prepared with gallic acid was used, and results were expressed as mg gallic acid equivalents (GAE) per 100 g of sample. All determinations were performed in triplicate.

2.2.7. Total anthocyanin content

Total anthocyanin content was determined using the differential pH method (AOAC, 2005.02). Each extract (1 mL) was diluted with 4 mL of pH 1.0 and pH 4.5 buffers, respectively, and allowed to equilibrate for 20 min. Turbidity was corrected by subtracting absorbance at 700 nm from that at 520 nm. Total anthocyanin content was calculated using the formula:

$$C\ (\text{mg/L}) = (A / (\varepsilon \cdot L)) \times MW \times 10\text{^}3 \times \text{DF} \quad (2)$$

where A is the absorbance measured in the spectrophotometer; ε, the molar absorptivity, a physical constant for molecular species in a given solvent at a specific wavelength; C, the molar concentration (mg/L); L, the optical path length of the spectrophotometer cuvette (1 cm), MW, the molecular weight of the pigment; and DF, the dilution factor.

For the calculation of total anthocyanin content, the molecular weight and molar absorptivity of cyanidin-3-glucoside were used, namely 449.2 and 26,900, respectively. The absorbance value (A) was obtained by subtracting the corrected absorbance at pH 4.5

from the corrected absorbance at pH 1.0, as follows:

$$A = (A_{520nm}\ \text{pH}\ 1.0 - A_{700nm}\ \text{pH}\ 1.0) - (A_{520nm}\ \text{pH}\ 4.5 - A_{700nm}\ \text{pH}\ 4.5) \quad (3)$$

All determinations were carried out in triplicate, and results were expressed as mg cyanidin-3-glucoside equivalents (CE) per 100 g of sample.

2.2.8. Sensory analysis

A Quantitative Descriptive Analysis (QDA) was conducted to evaluate the sensory attributes of the cookies. Eight semi-trained panelists, experienced in baked goods and recruited from the Faculty of Biochemical and Pharmaceutical Sciences at the National University of Rosario (Argentina), participated in the study. All participants provided written informed consent before the evaluations. Unstructured 10-cm line scales were defined for the relevant sensory attributes, including color, aroma, sweet taste, blueberry taste, hardness, chewiness, graininess, and overall quality. Extreme anchor points (1 and 9) were established using experimental samples. Before evaluations, the panelists were familiarized with the sensory attributes and their definitions, and the corresponding reference samples were presented to clarify the meaning and intensity of each descriptor (Supplementary Table S1). Scales indicated relative intensity without numerical bias, with directionality from low to high (e.g., weak to strong, light to dark) (Santuccione et al., 2025; Stone et al., 2020). Evaluations were performed in duplicate in individual booths, in accordance with (ISO 11132:2021; ISO 8589:2007).

2.2.9. Chemical composition

The proximal composition of the cookies was assessed by determining moisture (AOAC 925.10), ash (AOAC 923.03), protein (AOAC 920.87, NF*6.25), fat (AOAC 920.85), soluble, insoluble, and total dietary fiber (AOAC 991.43). Carbohydrates were calculated by difference (AOAC, 1990). Each analysis was conducted in triplicate. Energy density (kcal/g) was estimated from proximate composition using the Atwater factors.

2.3. Data analysis

Statistical analyses were carried out using SigmaStat 3.5 (SYSTAT Software, Inc.). Data are presented as the mean ± standard deviation of the replicates. Experimental results were evaluated by analysis of variance (ANOVA), and significant differences were identified using Tukey's post hoc test at a 0.05 significance level.

3. Results and discussions

3.1. Physicochemical and technological characterization of the formulated cookies

3.1.1. Weight and dimensional parameters

The dimensional and weight parameters of the formulated cookies are presented in Table 2. When evaluating weight, no significant differences were found among the cookies, indicating that substituting flour with blueberry powder did not produce an increase or decrease in mass. Likewise, although the CC exhibited a slightly lower average diameter than those with blueberry powder (e.g., BB-6), the difference was not significant. The additional sugars provided by blueberry powder may reduce dough viscosity and relaxation time, allowing for a greater lateral spread during baking, a mechanism consistent with observations in fiber- or fruit–powder–fortified cookies (Santuccione et al., 2025). Indeed, the pre-baking batch count of BB-10 (50 units vs. 46 for other formulations) suggests a dough with lower adhesiveness and cohesiveness, likely driven by its high blueberry powder content. Sugar enrichment can increase dough collapse, retard the action of chemical leavening agents, and modulate vertical expansion during baking (Kausar et al., 2024). As for thickness, the CC were significantly thicker than those containing blueberry powder, indicating that thickness decreases as more fruit powder is added. This reduction in thickness could stem from the higher sugar and moisture retention contributed by blueberry powder, both of which interfere with gluten development. Enhanced moisture content lowers the dough's structural strength

and increases its extensibility: water hydrates the protein network, weakens protein–protein interactions, and disrupts gluten strand formation, thereby limiting the gluten network's ability to trap gas during baking (Chikpah et al., 2023; Santuccione et al., 2025).

Regarding the spread factor, an increase was observed with the addition of blueberry powder relative to CC **(Table 2)**. Higher spread ratio values are generally desirable, as they are associated with better cookie quality (Panghal et al., 2018).

Table 2. Physicochemical and technological parameters of control cookie (CC) and cookies with 2%, 6%, and 10% blueberry powder (BB-2, BB-6, and BB-10) replacement

Sample	Weight (g)	Diameter (cm)	Thickness (cm)	Spread ratio	Hardness (N)	Moisture (%)	ΔE*
CC	11.1±0.9^{a}	4.99±0.01^{b}	0.95±0.01^{a}	5.27±0.06^{b}	17±3^{a}	8.60±0.01^{b}	-
BB-2	11.0±0.7^{a}	5.17±0.03^{a}	0.85±0.01^{b}	6.11±0.10^{a}	12±1^{b}	8.50±0.01^{b}	21.5 ± 0.5^{a}
BB-6	10.1±0.9^{a}	5.06±0.04^{b}	0.82±0.02^{b}	6.17±0.09^{a}	12±2^{b}	8.65±0.07^{b}	30.0 ± 1.0^{b}
BB-10	10.7±0.5^{a}	5.18±0.04^{a}	0.82±0.01^{b}	6.32±0.02^{a}	10±1^{b}	9.55±0.07^{a}	42.1 ±0.6^{c}

Color variation (ΔE) relative to CC. Data are presented as mean ± standard deviation from five replicates (n = 5). Different letters in the same column indicate significant differences ($p<0.05$) between samples.

3.1.2. Texture

Texture is a key physical attribute influencing the commercial stability and consumer acceptability of baked products. Assessing textural properties of carbohydrate-rich foods such as cookies is particularly challenging due to their heterogeneous composition and irregular structure. These products generally do not deform plastically under compressive stress but are brittle and prone to fracture (Marzec et al., 2025). The results of the three-point binding test showed that CC were significantly harder than those enriched with blueberry powder, demonstrating that blueberry powder incorporation may reduce cookie hardness (Table 2). This behavior is consistent with recent studies showing that fiber-rich ingredients, such as inulin or plant-based powders, can soften baked products by disrupting the matrix and weakening internal structure (Hajas et al., 2022). Similarly, substitution with date seed powder has been shown to darken and crisp cookies while reducing their hardness, presumably due to altered microstructure and moisture interactions (Najjar et al., 2022).

Thickness also plays a crucial role in resistance to external forces: thicker samples generally withstand higher breaking forces. According to this principle, studies of texture in cookies have shown that increased thickness correlates with higher hardness and consistency (Varghese et al., 2020). In our work, the CC samples, which exhibited greater thickness, were also characterized as harder. Furthermore, variation in hardness among the formulations may be related to differences in moisture content. Higher moisture generally reduces cookie firmness, as water acts as a plasticizer and facilitates fracture under stress (Liu & Chen, 2023). As shown in Table 2, all cookies containing blueberry powder had higher moisture content than the control (CC). Overall, these cookies were also softer than the control, although differences among the blueberry powder formulations were not statistically significant. This softening effect is likely due to the water-holding capacity of the blueberry-derived ingredient, as its high

carbohydrate and sugar content enhances hydration through hydrogen bonding (Huang et al., 2025). Consistently, recent studies have shown that increasing the proportion of fruit- or by-product–derived powders in baked goods increases moisture retention and contributes to reduced hardness (Santos et al., 2022).

3.1.3. Color

Color is an essential attribute for product acceptability. When a food is baked, the color changes that occur are associated with a complex phenomenon commonly known as non-enzymatic browning, principally the Maillard reaction (Qi et al., 2025). The color parameters of the whole cookies are shown in Fig. 1A. Lightness (L^*) decreased as the proportion of blueberry powder used as a replacement increased, resulting in the BB-10 cookies being darker than the other formulations (Fig. 1C). A comparable trend has been observed by Nour et al., (2025) who found that L^* values of cookies significantly decreased as the level of bilberry and blackcurrant pomace powders increased, resulting in darker cookie surfaces. The a^* value increased significantly in the BB-10 formulation, indicating a more pronounced reddish hue compared with the remaining samples. Comparable behavior has been reported in literature, where redness values rose markedly as blueberry plant extract increased from 0% to 9% in biscuit formulations, and likewise intensified with the incorporation of cranberry powder from 0% to 3% and from 3% to 9% (Salihu et al., 2023). Conversely, the b^* value decreased in all cookies containing blueberry powder, with the reduction being most marked in the BB-10 formulation. This behavior demonstrates that the blueberry-enriched cookies exhibited increasingly bluish tones, whereas the CC showed a more yellowish coloration. These trends are consistent with the presence of anthocyanins in blueberries, which are the dominant pigments responsible for the characteristic red-blue hues of berry fruits (Šarić et al., 2016). Furthermore, the higher the blueberry powder content, the greater the sugar contribution to the dough. The increased sugar content may have enhanced non-enzymatic browning reactions, including both Maillard reactions and caramelization, during baking. These reactions likely contributed to the darker, redder tones observed in the blueberry-enriched cookies, as sugars serve as key reactants in the formation of brown pigments and flavor compounds (Qi et al., 2025). A similar pattern was observed in fractured internal sections (cross-sectioned cookies) (Fig. 1B). The characteristic color of the cookies was associated both with the pigments contributed by blueberry powder and with the typical browning generated during baking, driven by sugar-mediated Maillard and caramelization reactions.

Regarding the ΔE* parameter, which indicates the overall color difference of the different formulations relative to CC, significant differences were observed among the samples. All ΔE* values exceeded 6, indicating that the color difference between the CC and those containing blueberry powder is readily perceptible to the human eye. Moreover, this difference increased proportionally with the percentage of blueberry powder added to the formulation (Table 2).

3.2. Antioxidant activity, total phenolic content, and anthocyanin content

Table 3 shows the antioxidant activity, total polyphenol content, and anthocyanin content measured in the blueberry powder and in the different cookie formulations. The incorporation of freeze-dried blueberry powder into cookies produced a clear, dose-dependent increase in measured antioxidant capacity and total phenolic content in the baked products. These increases align with prior literature reporting enhanced antioxidant capacity and phenolic content when berry-derived powders or pomaces are incorporated into bakery snacks. Roppolo et al., (2024) formulated cookies fortified with blackberry powder and reported notable increases in ABTS antioxidant capacity and total phenolic content relative to the control samples. Similarly, Tagliani et al., (2019) observed progressive enhancements in both polyphenols and antioxidant activity as blueberry pomace levels increased from 3% to

9%, although final values were strongly influenced by baking conditions. Nour et al., (2025) further demonstrated that phenolic enrichment is highly dependent on the intrinsic composition of the berry source. They showed that bilberry pomace powder exhibited high phenolic content (≈3.6 g GAE/100 g), and replacing 10% of wheat flour increased cookie total phenolic content seven-fold, reaching 214.73 mg GAE/100 g, whereas the same level of substitution with blackcurrant pomace led to only a three-fold increase. The total phenolic values obtained in our study fall within the range reported for similar replacement levels and show a comparable proportional increase with rising berry powder incorporation. These trends reinforce that the magnitude of phenolic enhancement depends both on the substitution level and on the phenolic richness of the specific berry matrix used.

Regarding measured cookie values expressed as a percentage of the contribution from the powder, anthocyanin retention is relatively low, whereas antioxidant activity and total phenolic retention are notably higher. This pattern, partial loss of heat-sensitive anthocyanins but maintenance or increase of antioxidant capacity and polyphenols, is consistent with what many authors report when using fruit pomaces or powders in baked goods, indicating that degradation products, liberated bound phenolics, and Maillard-type reaction products contribute to overall antioxidant capacity (Krajewska & Dziki, 2023; Kruczek et al., 2023).

Therefore, our data support that adding freeze-dried blueberry powder effectively increases the functional load of cookies. However, the relatively low recovery of anthocyanins suggests that if the aim is to preserve these colored and potentially health-relevant compounds, processing conditions may need optimization.

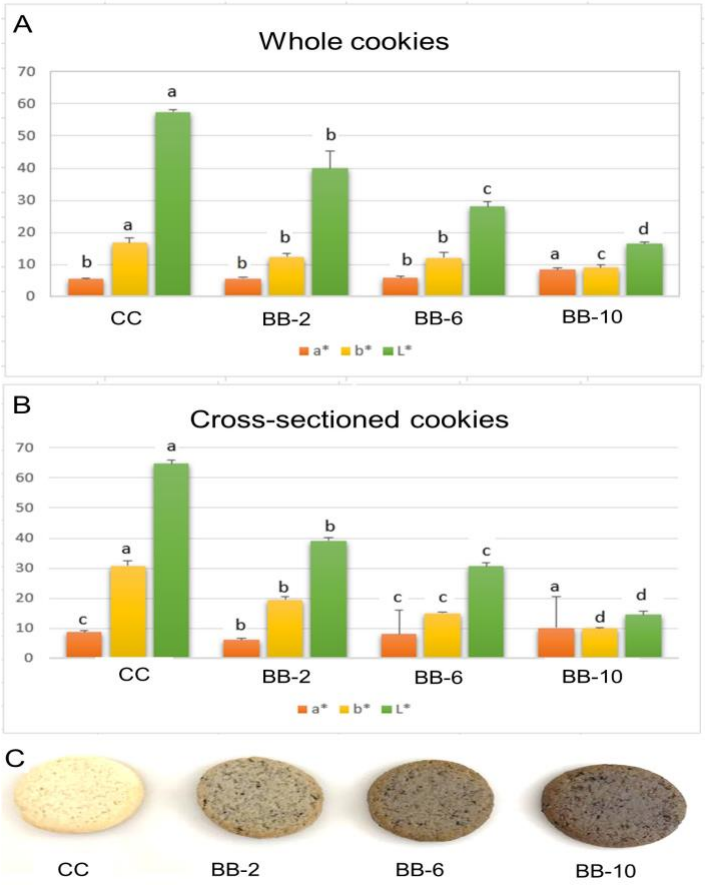

Figure 1. Color parameters (L^*, a^*, b^*) of whole cookies **(A)** and cross-sectioned cookies **(B)** with 2%, 6%, and 10% blueberry powder (BB-2, BB-6, BB-10). Visual appearance of the cookies **(C)**. Different letters indicate significant differences between formulations.

Table 3. Antioxidant activity (AA), total polyphenol content (TPC), and anthocyanin content (AC) in blueberry powder and cookies

Samples	AA (mg TE/100g)	AA retention in cookies (%)	TPC (GAE mg/100g)	TPC retention in cookies (%)	AC (CE mg/100g)	AC retention in cookies (%)
BB	4019±152		2013±37		735±7	
BB-2	64±5^{c}	89	31±7^{c}	81	6.0±0.5^{c}	43
BB-6	162±9^{b}	70	101±5^{b}	90	18±1^{b}	44
BB-10	304±46^{a}	68	213±2^{a}	96	37±2^{a}	45

BB: blueberry powder, cookies with 2% (BB-2), 6% (BB-6), and 10% (BB-10) blueberry powder. Different letters in the same column indicate significant differences ($p<0.05$) between cookie samples.

3.3. Sensory analysis

According to the QDA sensory analysis (**Fig. 2**), no differences were perceived in the aroma ($p=0.987$) of the different formulations. Color became progressively darker as the blueberry powder content increased ($p=0.001$), consistent with the ΔE^* values, which indicated that the color change was perceptible to the human eye. The BB-6 and BB-10 cookies were perceived as sweeter ($p=0.001$), and the BB-10 also exhibited a more pronounced blueberry-like taste ($p=0.001$). As regards hardness, the BB-10 cookies were perceived as significantly harder ($p=0.001$).

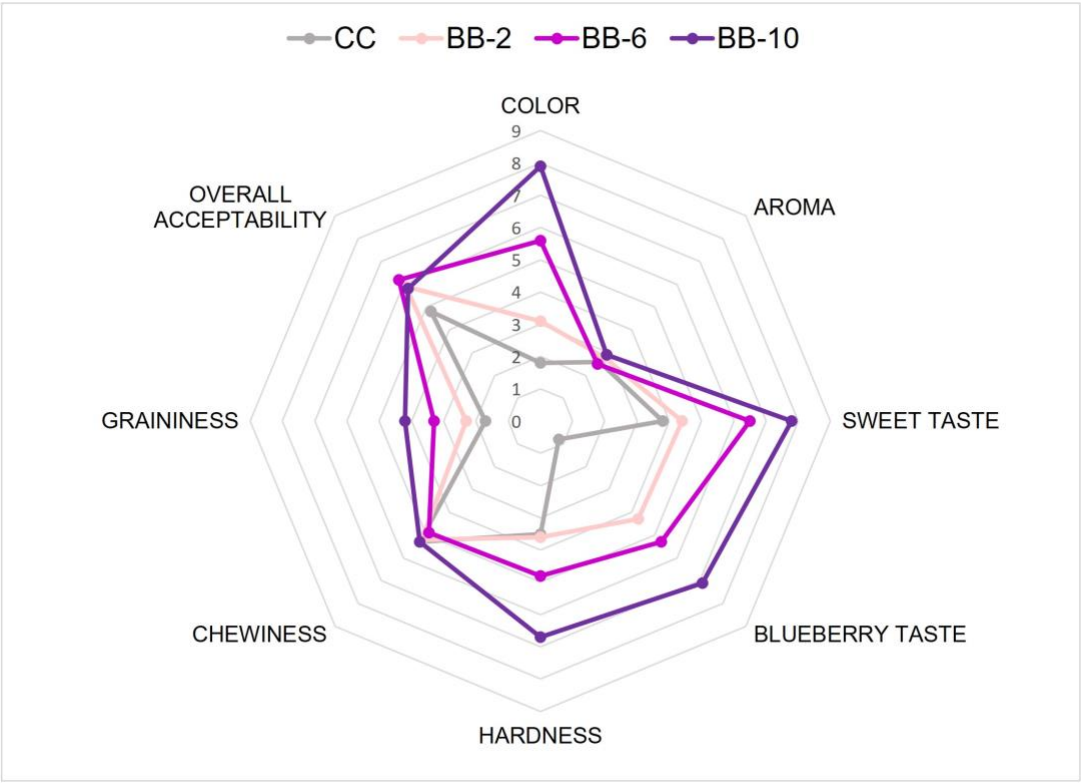

Figure 2. Descriptive sensory analysis (QDA) of control cookies (CC) and cookies formulated with 2% (BB-2), 6% (BB-6), and 10% (BB-10) blueberry powder

In some products, sensory hardness increases with moisture content, and this apparent contradiction may be attributed to the way sensory hardness is perceived: a moister product does not crumble easily and may require greater force to bite "through" it (Hough, 2000). Maybe, for this reason, the higher moisture of the BB-10 cookies was perceived as harder in the sensory analysis. Graininess tended to increase with higher blueberry powder content, although only the highest level showed a significant increase ($p=0.004$); intermediate formulations (2% and 6%) did not differ significantly from the control. This slight increase in this attribute could be related to the presence of the blueberry powder itself. For chewiness, no differences were detected ($p=0.891$), and overall acceptability was also similar among all formulations ($p=0.479$). These findings align with reports indicating that moderate levels of fruit pomace incorporation do not negatively impact sensory perception. Nour et al., (2025) similarly observed that cookies containing 10% bilberry or blackcurrant pomace achieved the highest general acceptability scores, suggesting that higher substitution levels can still be well received when textural attributes remain balanced.

3.4. Chemical composition

Given that overall acceptability did not differ significantly among formulations, the BB-10 cookies were selected for proximal composition analysis. This formulation exhibited the most pronounced blueberry flavor due to its higher inclusion level and demonstrated the greatest antioxidant activity, indicating a potentially enhanced health-promoting capacity. Table 4 shows the chemical composition of the BB-10 cookies.

Table 4. Chemical composition of the cookies with 10% blueberry powder (BB-10)

Component	g/100 g
Moisture (g/100g)	9.55±0.07
Fat (g/100g)	17.7±0.6
Carbohydrates (g/100g)	63.4±0.2
Total dietary fiber (g/100g)	2.0±0.2
Soluble fiber (g/100g)	1.4±0.2
Insoluble fiber (g/100g)	0.6±0.1
Proteins (g/100g)	6.4±0.1
Ash (g/100g)	0.99±0.1

Data are presented as mean ± standard deviation from three samples (n = 3).

These cookies provide 446 kcal per 100 g, consistent with high energy density typically reported for sweet baked products (Šarić et al., 2016). The high carbohydrate content, together with the fat content, largely explains the energetic value of the formulation. Given that most of the fat derives from non–trans-fat margarine included in the recipe, future formulation adjustments could explore reducing or partially replacing this ingredient to improve the nutritional profile. The protein content reached 6.4 g/100 g, mainly contributed by wheat flour and powdered egg. In comparison, Nour et al., (2025) reported similar values for cookies enriched with 2.5, 5, and 10 % bilberry and blackcurrant pomaces as wheat flour replacements, despite their formulations not including egg; in this case, the

protein contribution likely came from the pomace, which may be richer in protein than freeze-dried whole fruit. The ash content was higher than typical levels observed in cookies made with wheat flour, reflecting the mineral contribution of the blueberry powder, particularly rich in potassium, magnesium, calcium, and manganese (Lachowicz-Wiśniewska et al., 2024; Totad et al., 2020). Regarding dietary fiber, the total content in the cookies is consistent with the contribution expected from the 10% blueberry powder incorporated into the formulation, with soluble fiber being predominant. Consuming two standard 30 g portions per day would provide approximately 1.2 g of fiber, covering nearly 5% of the recommended daily intake for adults (25 g) (Institute of Medicine, 2005). Although this represents a modest contribution to daily fiber intake, the blueberry powder also provides additional functional benefits through its soluble fiber and associated phytochemical compounds (Lachowicz-Wiśniewska et al., 2024). It further contributes polyphenols, anthocyanins, and antioxidant capacity, as previously reported.

4. Conclusions

The present study successfully produced sweet cookies incorporating blueberry powder at 2%, 6%, and 10% levels. The addition of blueberry powder significantly increased the spread ratio, a parameter associated with product quality, across all formulations. Cookies enriched with blueberry powder retained between 70% and 90% of the antioxidant activity of the original powder, with the 10% formulation exhibiting the highest activity.

The inclusion of blueberry powder imparted a fruit-associated coloration, facilitating product identification, and a perceptible fruit flavor was reported in all enriched cookies. Cookies with higher blueberry powder content were perceived as significantly sweeter, suggesting the potential to reduce added sugar in the recipe while maintaining palatability, representing an additional nutritional benefit. Furthermore, within the scope of this sensory evaluation, the overall acceptability of the formulations was good.

Given the widespread consumption and acceptance of cookies, their enrichment with blueberry powder offers a promising strategy to deliver a value-added, functional food product to consumers. Overall, these findings highlight the feasibility of producing antioxidant-rich, sensorially appealing cookies, positioning them as a potential functional snack with health-promoting properties.

Funding: This research was funded by the National Scientific and Technical Research Council (CONICET) under grant number CONICET P-UE 22920170100068CO, and the National University of Rosario under grant number UNR-BIO539.

5. References

Antal, T. (2024). The effect of refrigeration and room temperature storage conditions on the physico-chemical characteristics of hybrid and freeze-dried blueberries. *Journal of Agriculture and Food Research*, *16*(2023) 101083. https://doi.org/10.1016/j.jafr.2024.101083

AOAC. (1990). *Official Methods of Analysis of AOAC International* (Issue v. 1). AOAC International, 15th edition. https://law.resource.org/pub/us/cfr/ibr/002/aoac.methods.1.1990.pdf.

Bodart, M., & Pen, R. De. (2008). Photometry and colorimetry characterisation of materials in daylighting evaluation tools. *Building and Enviroment*, *43*(2008), 2046–2058. https://doi.org/10.1016/j.buildenv.2007.12.006

Buiarelli, F., Presutti, M., Astolfi, M. L., Riccardi, C., Pomata, D., Fricano, A., Simonetti, G., & Di Filippo, P. (2025). Exploring the Composition of Blueberry-Based Functional Products: Polyphenolic and Elemental Characterization and Quantification. *Foods*, *14*(7), 1–20. https://doi.org/10.3390/foods14071210

Cabrera, C., Carlier, E., & Marina Zapata, L. (2021). Mineral composition of blueberries (Vaccinium corymbosum) cultivated in the northeast region of Argentina. *Revista Iberoamericana de Tecnología Postcosecha*, *22*(1), 71–85. https://www.redalyc.org/articulo.oa?id=81367929007

Chikpah, S. K., Korese, J. K., & Osman, S. (2023). Characterization of physicochemical, antioxidants and sensory properties of cookies enriched with shea (Vitellaria paradoxa) fruit pulp as a functional ingredient. *Food Production, Processing and Nutrition*, *5*(1), 1–16. https://doi.org/10.1186/s43014-023-00152-1

Estupiñan-Amaya, M., Fuenmayor, C. A., & López-Córdoba, A. (2020). New freeze-dried Andean blueberry juice powders for potential application as functional food ingredients: Effect of maltodextrin on bioactive and morphological features. *Molecules, 25*(23), Article 5635. https://doi.org/10.3390/molecules25235635

Hajas, L., Benedek, C., Csajbókné Csobod, É., & Juhász, R. (2022). Development of Protein- and Fiber-Enriched, Sugar-Free Lentil Cookies: Impact of Whey Protein, Inulin, and Xylitol on Physical, Textural, and Sensory Characteristics. *Foods*, *11-3819*. https://doi.org/10.3390/foods11233819

Hough, G. (2000). *Textura sensorial de galletitascrocantes en función de sucomposición, humedad ytemperatura de transición vítrea*. 1–177. [Universidad de Buenos Aires]. http://digital.bl.fcen.uba.ar/Download/Tesis/Tesis_3258_Hough.pdf

Huang, T., Zhang, Y., Qiao, L., Luo, D., Ba, L., Xu, S., Meng, L., Cao, S., Wang, T., & Kou, X. (2025). Active ingredients of blueberry pomace: A comprehensive review of isolation, identification, health benefits and food applications. *Food Chemistry: X*, *27*(2025) 102459. https://doi.org/10.1016/j.fochx.2025.102459

Institute of Medicine. (2005). Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients). In *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. National Academies Press. https://doi.org/10.17226/10490

ISO 11132: Sensory Analysis—Methodology— Guidelines for the Measurement of the Performance of a Quantitative Sensory Panel. (2021). International Organization for Standardization (ISO).

ISO 8589: Sensory analysis — General guidance for the design of test rooms. (2007). International Organization for Standardization (ISO).

Kausar, T., Saeed, E., Hussain, A., Firdous, N., Bibi, B., Kabir, K., Ul An, Q., Ali, M. Q., Najam, A., Ahmed, A., Yaqub, S., & Elkhedir, A. E. (2024). Development and quality evaluation of cookies enriched with various levels of grapefruit pomace powder. *Discover Food*, *4*(1):4-65. https://doi.org/10.1007/s44187-024-00148-x

Krajewska, A., & Dziki, D. (2023). Enrichment of Cookies with Fruits and Their By-Products: Chemical Composition, Antioxidant Properties, and Sensory Changes. *Molecules*, 28, 4005.

Krajewska, A., & Dziki, D. (2025). Utilization of pear pomace as a functional additive in biscuit production: Physicochemical and sensory evaluation. *International Agrophysics*, *39*(1), 53–60. https://doi.org/10.31545/intagr/195660

Kruczek, M., Gumul, D., Korus, A., Buksa, K., & Ziobro, R. (2023). Phenolic Compounds and Antioxidant Status of Cookies Supplemented with Apple Pomace. *Antioxidants*, *12*(2), 1–17. https://doi.org/10.3390/antiox12020324

Lachowicz-Wiśniewska, S., Pratap-Singh, A., Ochmian, I., Kapusta, I., Kotowska, A., & Pluta, S. (2024). Biodiversity in nutrients

and biological activities of 14 highbush blueberry (Vaccinium corymbosum L.) cultivars. *Scientific Reports*, *14*(1), 1–18. https://doi.org/10.1038/s41598-024-71114-x

Liu, S. X., & Chen, D. (2023). Novel Gluten-Free Amaranth and Oat Flour Cookies Fortified with Soybean Hulls. *Food and Nutrition Sciences*, *14*(08), 699–719. https://doi.org/10.4236/fns.2023.148046

Llopart, E. E., Verdini, R. A., Delorenzi, N. J., & Busti, P. A. (2023). Characterization of polyphenols compounds extracted from stressed apple peel and their interaction with β-lactoglobulin. *Heliyon*, *9*(9), 4–11. https://doi.org/10.1016/j.heliyon.2023.e20010

Marzec, A., Stępień, A., Goclik, A., Kowalska, H., Kowalska, J., & Salamon, A. (2025). Analysis of the Correlation of Microstructure, Instrumental Texture, and Consumer Acceptance of Shortbread Biscuits with Selected Sweeteners and Fibre. *Applied Sciences (Switzerland)*, *15*(3), 1–15. https://doi.org/10.3390/app15031137

Najjar, Z., Alkaabi, M., Alketbi, K., Stathopoulos, C., & Ranasinghe, M. (2022). Physical Chemical and Textural Characteristics and Sensory Evaluation of Cookies Formulated with Date Seed Powder. *Foods*, *11*(3), 1–13. https://doi.org/10.3390/foods11030305

Nour, V., Blejan, A. M., & Codină, G. G. (2025). Use of Bilberry and Blackcurrant Pomace Powders as Functional Ingredients in Cookies. *Applied Sciences (Switzerland)*, *15*(10), 1–26. https://doi.org/10.3390/app15105247

Panghal, A., Chhikara, N., & Khatkar, B. S. (2018). Effect of processing parameters and principal ingredients on quality of sugar snap cookies: a response surface approach. *Journal of Food Science and Technology*, *55*(8), 3127–3134. https://doi.org/10.1007/s13197-018-3240-9

Qi, Y., Wang, W., Yang, T., Ding, W., & Xu, B. (2025). Maillard Reaction in Flour Product Processing: Mechanism, Impact on Quality, and Mitigation Strategies of Harmful Products. *Foods*, *14*(15), 2721. https://doi.org/10.3390/foods14152721

Roppolo, P., Buzzanca, C., D'Amico, A., Culmone, A., Tinebra, I., Passafiume, R., Bonacci, S., Farina, V., & Di Stefano, V. (2024). Improvement of Antioxidant Activity and Sensory Properties of Functional Cookies by Fortification with Ultrasound-Assisted Hot-Air-Drying Blackberry Powders. *Foods*, *13*(15). https://doi.org/10.3390/foods13152402

Salihu, S., Gashi, N., & Hasani, E. (2023). Effect of Plant Extracts Addition on the Physico-Chemical and Sensory Properties of Biscuits. *Applied Sciences (Switzerland)*, *13*(17). https://doi.org/10.3390/app13179674

Santos, D., Lopes da Silva, J. A., & Pintado, M. (2022). Fruit and vegetable by-products' flours as ingredients: A review on production process, health benefits and technological functionalities. *Lwt*, *154*(2021) 112707. https://doi.org/10.1016/j.lwt.2021.112707

Santuccione, F. A., Soazo, M., Llopart, E., & Rossi, M. (2025). Innovative and Healthy Cookies Enriched with Blueberry Leaf Powder. *Molecules 30,* 3671. https://doi.org/10.3390/molecules30183671

Šarić, B., Mišan, A., Mandić, A., Nedeljković, N., Pojić, M., Pestorić, M., & Đilas, S. (2016). Valorisation of raspberry and blueberry pomace through the formulation of value-added gluten-free cookies. *Journal of Food Science and Technology*, *53*(2), 1140–1150. https://doi.org/10.1007/s13197-015-2128-1

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2020). *Sensory Evaluation Practices* (5th ed.). Academic Press.

Tagliani, C., Perez, C., Curutchet, A., Arcia, P., & Cozzano, S. (2019). Blueberry pomace, valorization of an industry by-product source of fibre with antioxidant capacity. *Food Science and Technology (Brazil)*, *39*(3), 644–651. https://doi.org/10.1590/fst.00318

Tolve, R., & Simonato, B. (2024). Impact of

Functional Ingredients on the Technological, Sensory, and Health Properties of Bakery Products. *Foods*, *13*(20). https://doi.org/10.3390/foods13203330

Totad, M. G., Sharma, R. R., Sethi, S., Joshi, A., Verma, M. K., Sharma, V. K., Singh, S., Dhiman, M. R., & Jaiswal, S. (2020). Genotypic variability in nutritional and functional attributes of blueberry varieties grown in northern-western Himalayas. *Journal of Food Science and Technology*, *57*(6), 2251–2258. https://doi.org/10.1007/s13197-020-04261-4

Varghese, C., Wolodko, J., Chen, L., Doschak, M., Srivastav, P. P., & Roopesh, M. S. (2020). Influence of selected product and process parameters on microstructure, rheological, and textural properties of 3D printed cookies. *Foods*, *9*, 907. https://doi.org/10.3390/foods9070907

Wang, Y., Liu, L., & Wei, Y. (2025). The Influence of Consumption Purpose on Consumer Preferences for Fruit Attributes: The Moderating Effect of Color Perception. *Foods*, *14*(11), 1–23. https://doi.org/10.3390/foods14111902

Zapata, L. M. (2014). *Obtención De Extracto De Antocianinas A Partir De Arándanos Para Ser Utilizado Como Antioxidante Y Colorante En La Industria Alimentaria.* [Universidad Politécnica de Valencia.]. https://doi.org/doi:10.4995/Thesis/10251/39105.

Supplementary material

Table S1. Descriptors and references used in the sensory evaluation of cookies

Descriptor	References	
Color color intensity	1 = light Reference: alfajor cookie layers FANTOCHE®	9 = dark Reference: cookie "Chocolinas" ARCOR®
Aroma intensity of blueberry aroma	1 = imperceptible Reference: water	9 = intense Reference: blueberry powder
Sweet taste sweet taste	1 = imperceptible Reference: water	9 = high Reference: saturated sugar solution
Blueberry taste intensity of blueberry taste	1 = imperceptible Reference: water	9 = intense Reference: blueberry powder
Hardness force applied at first bite, evaluated by the front teeth	1 = low Reference: alfajor cookie layers FANTOCHE®	9 = high Reference: cookie "Muesli" MURKE®
Chewiness number of times that is necessary masticate to allow the deglutition	1 = low Reference: alfajor cookie layers FANTOCHE®	9 = high Reference: cookie "Muesli" MURKE®
Graininess granules perception by pressing masticated food between the tongue and the palate	1 = low Reference: alfajor cookie layers FANTOCHE®	9 = high Reference: cookie "Muesli" MURKE®
Overall acceptability harmony level of all mentioned parameters	1 = low	9 = high