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Beetroot By-Product as a Functional Ingredient for Obtaining Value-Added Mayonnaise

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Abstract: Beetroot peel is a by-product obtained during the processing of beetroots and is an essential source of bioactive substances beneficial to health. This study used antioxidant-rich beetroot peels powder (BPP) in different concentrations (1.5, 3, 5, and 7%) to obtain value-added mayonnaise. The impact of BPP on the phytochemical composition, sensory characteristics, viscosity, color, and textural properties of the mayonnaises were also investigated. The BPP was characterized by a high betalain content (1.18 ± 0.03 mg/g DW) and rich polyphenolic content (225.36 ± 1.97 mg GAE/g DW) and showed high antioxidant activity. The purple-red colored powders added to the mayonnaise allowed a significant increase in total phenolic content and the antioxidant activity of purple-red colored powders added to the mayonnaise. The total color difference ΔE value in the mayonnaise samples increased with extract concentration. The instrumental texture analysis findings revealed that BPP addition to the mayonnaise increased the firmness, adhesiveness, and cohesiveness and improved the samples' chewiness. The viscosity of mayonnaise was also significantly improved. The inclusion of BPP improved the color, according to sensory evaluation and overall acceptability of the mayonnaise formulation. The results give a novel formulation and technological insights into the influence of BPP-powder enrichment on the physical, sensory, and textural qualities of mayonnaise. BPP could be employed as a natural ingredient in several value-added emulsions, including sauces, mayonnaise, dressings, and creams.

Keywords: beetroot peel; mayonnaise; polyphenols; betalains; antioxidant activity

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1. Introduction

Currently, agro-food by-product re-valorization is important for reducing generated wastes and could be achieved by implementing a circular economic model to protect the environment. Moreover, these by-products can be used as an alternative source of natural additives to improve the quality of food products [1].

Mayonnaise is one of the most popular and well-liked condiments used in a variety of foods to improve flavor and taste. The ingredients used for mayonnaise formulation include egg, either as a whole or egg yolk, vinegar, water, mustard, spices, and vegetable oil, such as soybean, rapeseed, sunflower, or corn oil [2]. Mayonnaise preparation uses different emulsifying proportions of vegetable oil (65–80%) with other ingredients, such as eggs and mustard [3]. Although it is highly appreciated for its flavor and taste, mayonnaise is susceptible to lipid oxidation due to the high polyunsaturated fatty acid content (PUFA) from vegetable oil [4]. The lipid oxidation process is initiated at the interface between oil and aqueous phases and continues after the oil phase, during product storage. Lipid oxidation affects the organoleptic and nutritional properties and even the storage stability of mayonnaise [5,6]. Factors such as fatty acid profile, pro-oxidants, and storage conditions make multiphase food systems, such as mayonnaise, susceptible to oxidation [5,7]. It is well established that lipid oxidation degrades product quality through rancid odors production, and unpleasant flavors, and potentially compromises food safety through the production of toxic chemicals [8]. Synthetic ingredients are commonly used to prevent lipid degradation in mayonnaise composition, which is included in the recipe to accomplish a variety of functions to ensure product quality. Synthetic antioxidants, such as butylated hydroxyanisole (BHA), ethylenediaminetetraacetic acid (EDTA) and butylated hydroxytoluene (BHT), are added to mayonnaise composition to control the oxidative degradation and avoid fast degradation [7,9]. However, there is increased concern about food products that include synthetic ingredients, that may seriously affect consumers' health. Although synthetic antioxidants are inexpensive and effective, they are not widely accepted by consumers. Therefore, the food industry is currently focused on substituting natural antioxidants with those obtained from natural resources [10].

Plant materials represent rich sources of phenolic compounds which demonstrate a broad range of biological functions, including antioxidative protection, antimicrobial, antimutagenic, and anti-inflammatory properties [11]. Therefore, the food industry has been focused on using natural sources of bioactive compounds with multiple functionalities to obtain healthy products. Numerous studies have demonstrated that antioxidants derived naturally from phenolic-rich plant components, such as extracts from berries [12], olives [13], olive leaves [14], grape seed [15], buckwheat hull [10], purple corn [6], or sesame sprouts powder [16], can increase the stability and delay the oxidation process of emulsions.

Beetroot (*Beta vulgaris* L.) belongs to the *Amaranthaceae* family. It is one of the most potent vegetables concerning antioxidant activity, mainly because it is rich in betalains and phenolic compounds [17]. Betalains are water-soluble pigments that have been authorized by the European Union as E-162 for use in food as colorants [18]. Moreover, beetroot is an important source of beneficial compounds to health, including: folate, which offers protection against congenital disabilities; iron, which helps prevent and treat anemia; and dietary fibers, with a crucial role in improving colon health [19]. Although the resulting pomace from the beetroot processing is abundant in dietary fibers, antioxidants, and minerals, it is not fully valorized and might be targeted as a significant source of naturally occurring antioxidants that can help enhance food quality. Therefore, incorporating beetroot by-products into food products such as mayonnaise may be affordable. Beetroot has been used as a natural ingredient in different food products for obtaining value-added products. Hence in the reviewed literature beetroot added products were identified that improved both nutritional and sensorial properties, such as yogurt with beetroot juice [20], yogurt beetroot powder [21], ice cream with beetroot puree [22], and with beetroot juice [23], and cakes enriched with beetroot powder [24]. In this way, beetroot by-products can be used as low-cost food components, hence reducing food waste. Therefore, plant wastes could represent a nutraceutical source used in functional food production [25].

A previous study has shown that either raw or processed beetroot may be successfully incorporated in the mayonnaise composition to replace synthetic antioxidants and extend shelf-life [4]. The present research focused on utilizing freeze-dried beetroot peels as a source of natural antioxidants and other lipophilic bioactive compounds into the mayonnaise composition to obtain a value-added product. Furthermore, the impact of beetroot peels powder (BPP) supplementation on the phytochemical composition, sensory characteristics, viscosity, color, and textural properties of the mayonnaise were also investigated.

2. Materials and Methods

2.1. Materials

Beetroot was collected from a Galați local farmer. All ingredients used for the mayonnaise were obtained at a local market, including refined sunflower oil, vinegar, egg powder, lemon salt, and salt. Folin–Ciocalteau reagent, sodium carbonate, 2,2-diphenyl-

1-picrylhydrazyl (DPPH), 6-hydroxi-2,5,7,8-tetrametilcroman-2-carboxilic acid (Trolox), ethanol (70%), and citric acid were supplied from Sigma-Aldrich (Steinheim, Germany).

2.2. Beetroot Peels Powder (BPP) Preparation

The beetroots were washed and dried. Then, the peel was removed using a knife, and the collected peels were lyophilized using Alpha 1–4 LD plus equipment (Christ, Germany), at −42 °C, under a pressure of 0.10 mBar, for 48 h. Following that, the freeze-dried peels were ground to a fine powder using a grinder MC 12 (Producer Stephan, Germany) and stored in the dark at room temperature.

2.3. Extraction of Polyphenols and Betalains from Beetroot Peels Powder and Antioxidant Activity Evaluation

An amount of 1 g of BPP was added to 9 mL of a 50% (*v*/*v*) ethanol solution and 1 mL citric acid (1%) and then manually mixed for 1 min. Samples were sonicated in a water bath (Smart Sonic cleaner MRC) for 50 min, at 40 °C. After that, the extract was centrifuged at 5000 rpm for 15 min, at 20 °C, followed by collection of the supernatant. The residue was extracted again with a solvent (10- and 20-mL ethanol 50%), and the extracts were mixed and kept at 4 °C.

2.3.1. Betalains

The concentration of betalains in the BPP extract was determined using the spectrophotometric method described by Stintzing et al. [26]. The absorbances of the betalains were read at 538 nm for betacyanins and 480 nm for betaxanthins. The betalain concentration (BC) was determined as follows:

$$\text{BC(mg/g)} = [(\text{A} \times \text{DF} \times \text{MW} \times \text{Vd})/(\text{e} \times \text{L} \times \text{Wd})] \quad (1)$$

where A is the sample absorbance, DF—the dilution factor, l—cuvette pathlength (1 cm), W d/g is the amount of BPP, and Vd is the volume of BPP solution. The molecular weights (MW) and molar extinction coefficients of betacyanins and betaxanthins were used to quantify them (e) (MW = 550 g/mol; e = 60.000 L/mol cm in H_2O) and (MW = 308 g/mol; e = 48,000 L/mol cm in H_2O) were applied.

2.3.2. Total Polyphenolic Content

The total soluble phenolics contained in BPP extract were quantified using the Folin–Ciocalteu assay in accordance with the procedure specified by Turturica et al. [27]. Briefly, to tubes containing 15.8 mL distilled water, 1.0 mL Folin–Ciocalteau solution, and 0.2 mL BPP extract was added. After 10 min, 3 mL of Na_2CO_3 20% was added to the mixture. The mixture obtained was stored for 60 min at room temperature in the dark, prior to determining the absorbance at 765 nm against a control (pure ethanol). Milligrams of gallic acid equivalents per gram of dry weight (mg GAE/g DW) were used to express the results.

2.3.3. Antioxidant Activity

The DPPH technique was used to determine the antioxidant activity, and the findings were represented as Trolox equivalents in millimoles per gram of dry weight (mM TE/g DW) [28]. Briefly, the absorbance of the blank, 3.9 mL DPPH solution 0.1 M in ethanol, was measured at 515 nm. Then, to the reaction mixture of 3.9 mL DPPH solution 0.1 M, a volume of 0.1 mL of BPP extract was added, and afterward, the mixture was kept for 1 h and 30 min at room temperature in the dark before the absorbance at λ = 515 nm was recorded.

2.4. Mayonnaise Preparation

A mayonnaise recipe was created by combining the following ingredients in the following weight ratios (*w*/*w*): sunflower oil (80%), egg powder (8%), water (7%), vinegar

(2%), lemon salt (3%), salt (0.3%) and different proportions (1.5%, 3%, 5%, and 7%) of BPP hydrated with water (1:1).

To begin, a coarse emulsion was created in water by dissolving egg powder, lemon salt, salt, and vinegar. Mayonnaise was prepared by gradually adding the oil to the aqueous mixture and quickly blending the components with a Morphy Richards hand blender1.5 (Argos, Milton Keynes, UK) for 10–15 min. The BPP was further added to the mayonnaise at four different concentrations of 1.5%, 3%, 5%, and 7%, while continuing mixing until the purple samples were uniform and coded S1, S2, S3, and S4, respectively. The control mayonnaise was produced in the same manner as the experimental mayonnaise but without the addition of BPP. The mayonnaise samples obtained were kept at 4 °C until measurements were taken.

2.5. Characterization of Phytochemicals, Physicochemical, and Antioxidant Activity of Mayonnaise Supplemented with BPP

The physicochemical parameters of mayonnaise samples (e.g., moisture content, protein content, fat content, ash content, total sugar content, and energy value) were estimated using AOAC methods [29]. The betalains, phenolic content, and antioxidant activity of mayonnaise enhanced with BPP, were assessed using the techniques described above in Sections 2.3.1–2.3.3.

2.6. Color Measurements

Color attributes of the supplemented mayonnaise containing varying amounts of BPP were quantified using the CR300 Chroma Meter (Konica Minolta, Sensing Americas, Inc., Ramsey, NJ, USA) provided with a D65 Illuminant. The CIELAB color parameters (L*, a*, and b*) were obtained in triplicate following equipment calibration against the white plate. The total color change (ΔE) was also calculated for each sample according to Polat et al. [30] using the formula below:

$$\Delta E = \sqrt{\left[(L^*_m - L^*_{bm})^2 + \left(a^*_m - a^*_{bm}\right)^2 + (b^*_m - b^*_{bm})^2\right]} \quad (2)$$

where the abbreviation of color parameters represents m—sample without BPP, and bm—sample with BPP.

2.7. Textural Profile Analysis

The texture profile analysis (TPA) approach was used to examine the textural features of the mayonnaise samples, using a CT3-1000 Texture Analyzer (Brookfield Ametek, Chandler, AZ, USA). Double dispersion into a 38.1 mm diameter acrylic cylinder sample was used to achieve a depth of 20 mm. The test speed was set to one millisecond per second, the trigger load to 0.067 N, and the load cell to 9.8 N. The textural parameters firmness, cohesiveness, springiness, adhesiveness, and chewiness were calculated using the TexturePro CT V1.5 software. Each sample was subjected to three determinations. The samples were maintained at room temperature for two hours before testing.

2.8. Viscosity

The viscosity of the mayonnaise samples was assessed using a rotational viscometer (Brookfield Viscometers Ltd., Harlow, UK), equipped with an LV2 Spindler, with a diameter of 18.72 mm and a height of 115 mm. The mayonnaise samples were added into cylindrical plastic containers, with 37 mm diameter and 200 mm height. All measurements were performed at room temperature. The dynamic viscosity was read directly for different values of the rotational speed of the spindler. A thixotropic loop measurement was performed first, increasing the shear rate from 0.06 to 21.2 s^{-1} followed by decreasing it back to 0.06 s^{-1} and reading the values of dynamic viscosity. The power-law model was used to express the dependence between shear rate and shear stress.

2.9. Oxidative Stability

All samples were kept in glass containers and stored in the dark at a refrigerated temperature of 4 °C for 28 days. To evaluate the samples' oxidative stability, titratable acidity, peroxide value, phytochemical and color parameters were monitored. Titratable acidity was assessed using the official method by AOAC [29]. The results were reported as mg KOH per gram of sample (mg KOH/g). Peroxide value was quantified using the method described by AOAC [29]. Extraction of oils from the mayonnaise samples before the peroxide value determination was carried out in accordance with the procedure specified by Park et al. [10]. In brief, the samples were freeze-dried at −20 °C for 24 h and then kept at room temperature for 2 h in the dark for breaking the emulsion. Then, the samples were centrifuged at 1000 rpm for 10 min, and the oily phase was used for peroxide value analysis. Peroxide value was reported as milliequivalents per kg of the sample (meq/kg).

2.10. Sensory Analysis

The sensory attributes of mayonnaise samples were evaluated by 20 untrained consumers ranging from 25 to 60 years old (80% women and 20% men). A training session was provided to the panelists before sensory analysis. A 9-point hedonic assessment with scores from 1 (very dislike) to 9 (very like) was used in the questionnaire to evaluate the mayonnaise samples. Spreadability, consistency, texture, and color uniformity were assessed for appearance and structure; aroma, odor, and taste were reviewed for flavor and perception; aftertaste and acceptability for overall acceptance were also rated [7,14]. The samples were served at room temperature, and water and crackers were served to rinse and eat between tasting samples. The data were adjusted to the average score assigned to each attribute by each panelist.

2.11. Statistical Data

All analyses were conducted in triplicate, and the data are presented as mean and standard deviation. Significant differences among results were identified using analysis of variance (ANOVA). Tukey's test was applied using Minitab 18 software to determine which pairwise comparisons were significant. For all tests, p-values of $p < 0.05$ were considered statistically significant.

3. Results and Discussion

Adding in mayonnaise-type food compounds with antioxidant activity can prevent the onset of oxidation or slow down the reaction. Usually, their role is not only to improve the quality of food, but also to keep it unaltered and increase its shelf life, thus contributing to the shelf life of food [31]. Starting from this property of antioxidant compounds, this research intended to obtain a value-added product (mayonnaise) by using freeze-dried beetroot peels as a source of natural antioxidants by investigating their proximal composition, phytochemical composition, color, viscosity, textural properties, and sensory characteristics. In addition, the stability of the BPP enriched mayonnaise was monitored by determining the oxidative stability, phytochemical and color parameters.

3.1. Phytochemicals Extraction and Characterization of BPP

The phytochemical content and antioxidant activity of the BPP extract were determined. The betalain and polyphenolic contents were 1.18 ± 0.03 mg/g DW and 225.36 ± 1.97 mg GAE/g DW. The extract showed a DPPH radical scavenging capacity of 33.42 mM Trolox/g DW. The obtained results are in agreement with the data reported in other studies. Vulić et al. [25] reported that betalain content from different beetroot genotypes ranged from 0.75 to 3.75 mg/g DW of beetroot pomace extract. Raikos et al. [7] and Jasna et al. [32] have reported that the total phenolic content of aqueous beetroot peel extract is 399.6 µg GAE/mL extract and 218.3 mg GAE/g DW, respectively. Maqbool et al. [33] reported that the radical scavenging activity ranged from 70.12 ± 0.90% to 91.62 ± 0.90% for beetroot peel extract. However, the phytochemical composition of beetroot peels extracts can vary with genetic and agronomic factors, different extraction conditions (e.g., type of solvent, temperature, pH, light intensity), and the measurement methods applied.

3.2. Product Characterization

3.2.1. Proximal Composition

The value-added mayonnaise samples were obtained by enrichment with different amounts of BPP (1.5, 3, 5, and 7%), and their physical-chemical composition was evaluated (Figure 1, Table 1).

Figure 1. Images of the mayonnaise without BPP, control (S0); mayonnaise with 1.5% BPP (S1); mayonnaise with 3% BPP (S2); mayonnaise with 5% BPP (S3); mayonnaise with 7% BPP (S4).

Table 1. The physical-chemical characteristics (g/100 g) of the beetroot-extract-enriched mayonnaise.

Physical-Chemical Characteristics	S0	S1	S2	S3	S4
Proteins	5.4 ± 0.01 [a]	5.2 ± 0.01 [b]	5.1 ± 0.03 [c]	5.02 ± 0.01 [d]	4.91 ± 0.01 [e]
Lipids	72.05 ± 0.01 [a]	71.6 ± 0.14 [ab]	71.3 ± 0.14 [b]	71.7 ± 0.14 [ab]	71.5 ± 0.14 [b]
Carbohydrates	2.65 ± 0.01 [e]	3.11 ± 0.03 [d]	3.26 ± 0.01 [c]	3.52 ± 0.01 [b]	3.7 ± 0.01 [a]
Humidity	18.04 ± 0.01 [a]	17.97 ± 0.01 [b]	17.92 ± 0.01 [b]	17.15 ± 0.01 [c]	17.01 ± 0.01 [d]
Ashes	1.91 ± 0.01 [e]	2.12 ± 0.01 [d]	2.42 ± 0.01 [c]	2.61 ± 0.01 [b]	2.88 ± 0.01 [a]

S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP. Means on the same row that do not share a letter are significantly different.

The nutritional composition of the mayonnaise (without BPP) was 72.05 ± 0.01 g/100 g for lipids, 2.65 ± 0.01 g/100 g for carbohydrates, and 5.4 ± 0.01 g/100 g for protein content, which agrees with those reported by Rojas et al. [34]. The proximate composition of the mayonnaise with BPP revealed a significant difference ($p < 0.05$) between samples. The results revealed that the moisture was lower as the BPP was added, and the ash content was higher as the enrichment of mayonnaise was realized. Moreover, the carbohydrate content was increased by adding the beetroot powders.

3.2.2. Phytochemical Composition and Antioxidant Activity

The phytochemical composition and antioxidant activity of the mayonnaise obtained are presented in Table 2. As predicted, the bioactive chemical content rose as increasing amount of BPP was added to the mayonnaises.

The betalains were not detected in the sample without BPP, and phenolic content had a low level (24.6 ± 0.06 mg GAE/100 g). The addition of BPP (1.5, 3, 5, and 7%) to the mayonnaise composition determined a significant increase ($p < 0.05$) in the levels of the bioactive compound. Thus, betalains ranged from 1.32 ± 0.01 to 5.61 ± 0.16 mg/100 g, and phenolic content went from 197.10 ± 1.91 to 325.9 ± 5.61 mg GAE/100 g for BPP supplemented mayonnaises. Moreover, all the samples (S1, S2, S3, and S4) had considerably higher levels of bioactive compounds ($p < 0.05$) in comparison to the control sample. In addition, the mayonnaise samples supplemented with BPP presented an antioxidant activity higher than the control because of the increased levels of bioactive compounds from the BPP.

Table 2. Phytochemical characteristics (mg/100 g) and antioxidant activity (mM Trolox/100 g) of mayonnaise enriched with beetroot peel powder (BPP).

Phytochemical Characteristics		**Mayonnaise Samples**				
		S0	**S1**	**S2**	**S3**	**S4**
Betalains	0 days	-	1.32 ± 0.01 ^{aD}	2.48 ±0.06 ^{aC}	4.19 ± 0.09 ^{aB}	5.61 ± 0.16 ^{aA}
	14 days	-	1.10 ± 0.04 ^{abD}	2.20 ± 0.02 ^{bE}	3.69 ± 0.24 ^{aB}	4.86 ± 0.09 ^{bA}
	28 days	-	0.82 ± 0.13 ^{bD}	1.81 ± 0.02 ^{cC}	2.84 ± 0.11 ^{bB}	4.12 ± 0.06 ^{cA}
Polyphenols	0 days	24.60 ± 0.06 ^{aE}	197.10 ± 1.91 ^{aD}	271.4 ± 11.06 ^{aC}	307.4 ± 4.06 ^{aB}	325.9 ± 5.61 ^{aA}
	14 days	20.85 ± 0.64 ^{bE}	188.10 ± 3.96 ^{aD}	251.65 ± 1.34 ^{bC}	278.95 ± 3.75 ^{bB}	310.50 ± 1.27 ^{bA}
	28 days	18.15 ± 1.06 ^{bE}	152.15 ± 2.19 ^{bD}	227.50 ± 1.98 ^{cC}	253.85 ± 7.71 ^{cB}	285.05 ± 0.78 ^{cA}
Antioxidant activity	0 days	1.81 ± 0.01 ^{aE}	29.5 ±0.11 ^{aD}	37.07 ±0.90 ^{aC}	45.60 ± 0.61 ^{aB}	52.09 ±2.91 ^{aA}
	14 days	1.77 ± 0.03 ^{aD}	27.20 ± 0.42 ^{aC}	34.65 ± 1.77 ^{abB}	39.25 ± 1.20 ^{bB}	48.75 ± 1.63 ^{abA}
	28 days	1.60 ± 0.10 ^{aE}	21.15 ± 0.6 ^{bD}	30.35 ± 0.78 ^{bC}	34.80 ± 1.27 ^{cB}	46.05 ± 0.21 ^{bA}

S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP. Means on the same row (capital letters) and the same column (small letters) for each index analyzed that do not share a letter are significantly different.

Raikos et al. [7] showed that mayonnaise samples enriched with processed (microwaved) beetroot extract have higher contents of bioactive compounds (betanin 337.9 mg/L; polyphenols 399.6 mg GAE/mL) and significant antioxidant activity (FRAP) (6.9 mol/ L) compared to mayonnaise without beetroot extract (control), demonstrating added value. The bioactive compound oxidative stability of the mayonnaise sample revealed degradation of polyphenols ($p > 0.05$) at the end of the storage period for all the samples. Similar results were identified for antioxidant activity, with a slight decrease for S4.

3.2.3. Color Parameters of BPP-Enriched Mayonnaise

The mayonnaise samples were analyzed for CIELAB colorimetric parameters using a portable colorimeter with a C illuminator standardized using a white reference tile before each measurement. The results were expressed as L*, a*, and b*. Color parameter values, including L* (brightness), a* (tendency to red for an a* "+" or green for an a* "−"), b* (tendency to yellow for b* "+" or blue for b* "−") and total color change ΔE were analyzed (Table 3). The value b* suggests a color closer to yellow. BPP addition to the mayonnaise resulted in important color changes. The red color of the beetroot was ascribed to the presence of essential amounts of betalains that occur in two forms, i.e., betacyanin (red-violet pigment) and betaxanthin (yellow-orange pigment) [35]. The CIELAB color system was used to record the chromatic data: mayonnaise without BPP (control) producing a greenish shade (a* of −1.19), and the presence of a yellow hue (b* of 32.92), suggesting the absence of betacyanin in the sample.

The estimated ΔE values indicated significant differences in all mayonnaise samples. The total color difference ΔE value in the mayonnaise samples increased with extract concentration, and ΔE was higher (63.49 ± 0.01) for mayonnaise produced with 7% BPP. A similar increase was observed by Santipanichwong and Suphantharika [36] in the mayonnaise samples enriched with both β-glucan and carotenoids.

The samples' lightness dropped considerably ($p < 0.05$) with the amount of BPP added to the mayonnaise. As a result of increasing the amount of BPP added to the mayonnaise samples, which provide important amounts of beetroot pigments, the a* values changed from the green to the red domains (a* of 23.14 for S4). In contrast, the yellow color decreased, and b* reached −2.01. Similar results were obtained by Nour et al. [9] for mayonnaise samples enriched with sea buckthorn pomace carotenoids. Color changes of mayonnaise samples during 28 days of storage at 4 °C were also presented. The increase in lightness and yellowness during storage in all the samples was noted, while redness decreased.

At the end of storage, mayonnaise containing 3% BPP had the highest L* values (S2), and the lowest a* values were found in sample S1, apart from the control sample.

Table 3. The CIELAB color parameters of mayonnaise samples enhanced to varying degrees with BPP.

CIELAB Color Parameters		Mayonnaise Samples				
		S0	S1	S2	S3	S4
L*	0 days	67.14 ± 0.00^{aA}	26.63 ± 0.03^{bB}	24.44 ± 0.03^{cC}	21.72 ± 1.73^{cD}	20.06 ± 0.30^{cE}
	14 days	68.76 ± 0.91^{abA}	28.24 ± 0.18^{bB}	26.27 ± 0.49^{bB}	23.66 ± 0.36^{bC}	22.75 ± 0.11^{bC}
	28 days	70.88 ± 1.09^{bA}	31.90 ± 1.10^{aB}	29.03 ± 0.15^{aBC}	26.68 ± 0.05^{aCD}	24.71 ± 0.54^{aD}
a*	0 days	-1.19 ± 0.02^{bE}	13.82 ± 0.22^{aD}	16.20 ± 0.08^{aC}	18.20 ± 0.02^{aB}	23.14 ± 0.02^{aD}
	14 days	1.10 ± 0.01^{aE}	12.69 ± 0.40^{bD}	15.34 ± 0.23^{bC}	17.16 ± 0.19^{abB}	20.86 ± 0.30^{bA}
	28 days	1.44 ± 0.33^{aE}	12.02 ± 0.13^{bD}	14.94 ± 0.17^{bC}	16.24 ± 0.30^{bB}	20.19 ± 0.17^{bA}
b*	0 days	32.92 ± 0.16^{bA}	5.11 ± 0.09^{cB}	3.06 ± 0.07^{bC}	-1.2 ± 0.01^{bD}	-2.01 ± 0.03^{bE}
	14 days	33.82 ± 0.13^{bA}	6.72 ± 0.28^{bB}	5.84 ± 0.10^{aC}	1.42 ± 0.06^{aD}	-1.83 ± 0.11^{bE}
	28 days	36.24 ± 0.40^{aA}	7.92 ± 0.06^{aB}	6.45 ± 0.30^{aC}	1.53 ± 0.02^{aD}	0.97 ± 0.08^{aD}
ΔE	0 days	-	51.38 ± 0.05^{aD}	54.95 ± 0.02^{aC}	60.04 ± 0.16^{aB}	63.49 ± 0.01^{aA}
	14 days	-	50.12 ± 0.46^{bD}	52.37 ± 0.38^{bC}	57.37 ± 0.30^{bB}	61.04 ± 0.12^{bA}
	28 days	-	49.33 ± 0.15^{cD}	52.42 ± 0.24^{bC}	57.43 ± 0.13^{bB}	60.38 ± 0.51^{cA}

S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP. L*—lightness; a*—green-to-red; b*—blue-to-yellow. Means on the same row (capital letters) and the same column (small letters) for each index analyzed that do not share a letter are significantly different.

3.2.4. Textural Properties of Mayonnaise Enriched with BPP

The textural properties of mayonnaise enriched with BPP were assessed using the texture profile analysis (TPA) method. The textural parameters analyzed were: firmness (expressed in N and defined as the maximum resistance of the sample during the first penetration cycle), adhesiveness (expressed in mJ and defined as the energy required to remove the sample from the test instrument), cohesiveness (dimensionless size), defined as the strength of the internal bonds that give the consistency of the product) and chewability (expressed in mJ and defined as the energy required for chewing food until the phase preceding swallowing). The results were processed using TexturePro CT V1.5 software and are presented in Table 4.

Table 4. Texture profile analysis of mayonnaise samples enriched with different levels of BPP.

Textural Parameters	S0	S1	S2	S3	S4
Firmness, N	0.74 ± 0.02^{b}	1.16 ± 0.01^{a}	1.83 ± 0.13^{a}	1.74 ± 0.10^{a}	1.54 ± 0.02^{a}
Adhesiveness, mJ	1.82 ± 0.27^{c}	5.32 ± 0.38^{ab}	5.68 ± 0.45^{a}	4.63 ± 0.14^{ab}	3.93 ± 0.00^{b}
Cohesiveness	0.81 ± 0.01^{a}	0.77 ± 0.03^{ab}	0.79 ± 0.01^{ab}	0.71 ± 0.02^{ab}	0.61 ± 0.07^{b}
Chewiness, mJ	5.56 ± 0.18^{b}	10.99 ± 0.65^{ab}	13.41 ± 1.67^{a}	11.61 ± 1.56^{ab}	8.24 ± 1.67^{ab}

S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP. Means on the same row that do not share a letter are significantly different.

The firmness of mayonnaise is an important parameter because it influences both sensory characteristics (mouthfeel) and applicability [37]. All samples exhibited low firmness and cohesiveness values and high adhesiveness and chewiness values, comparable to those reported in the literature [34,38]. The results show that the addition of BPP in mayonnaise samples determined higher firmness values than the control sample. This aspect is due to the stabilizing compounds in the added plant material, such as pectin [39]. Furthermore, the addition of BPP in the composition of mayonnaise improved adhesion and chewiness, giving the product a delicate and soft texture. Similar results were obtained by

Raikos et al. [7] regarding the adhesiveness of mayonnaise samples enriched with beetroot, in which the adhesiveness was improved with the addition of beetroot.

3.2.5. Effect of BPP Addition on Mayonnaise Viscosity

The variation of the dynamic viscosity depending on the shear rate indicates thixotropic rheological behavior for all the analyzed mayonnaise samples. This type of behavior is characterized by decreased dynamic viscosity as the shear rate increases (Figure 2). However, the results show that by adding BPP in mayonnaise samples, the viscosity of mayonnaise is significantly improved, helping to achieve a creamy consistency. The results follow the study conducted by Raikos et al. [7], in which all samples with processed beetroot presented a higher viscosity than the control sample. This behavior might be due to the pectin content in BPP, which acts like a thickening agent. On the other hand, as shown in Table 5, the consistency index K (Pa·s^n) registered increasing values with increasing concentration of BPP until 3% (9.97 Pa·s^n for 1.5% BPP and 14.35 Pa·s^n for 3% BPP). Higher concentrations of BPP addition (5% and 7%) determined a reduction in consistency index. This might be due to the increased amount of solid particles, which cause structure disruption.

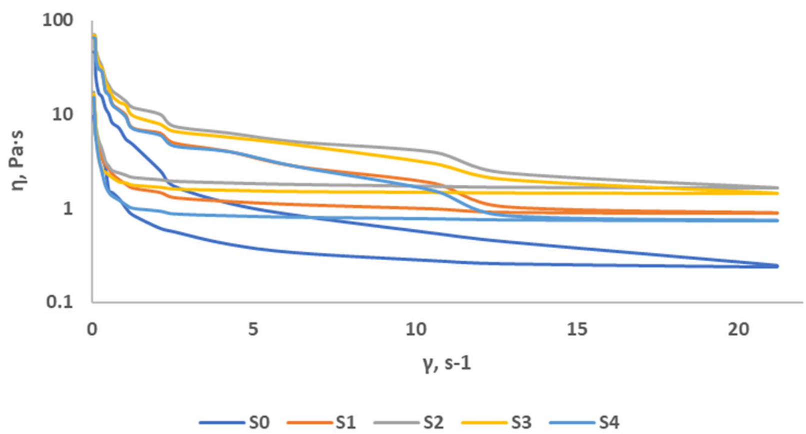

Figure 2. Hysteresis loop for the mayonnaise samples: S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP.

Table 5. Power-law model fitting parameters for mayonnaise samples.

Parameter	S0	S1	S2	S3	S4
K (Pa·s^n)	4.91	9.97	14.35	12.81	9.46
n	0.07	0.24	0.36	0.33	0.21
R^2	0.93	0.85	0.91	0.91	0.73

S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP.

3.3. Oxidative Stability

The oxidative stability of the BPP-enriched mayonnaise was analyzed in Table 6. The acid value obtained was observed to increase during storage. This increase could be mainly attributed to hydrolytic and oxidative enzymes from eggs [40,41] and acid-tolerant microorganisms in the aqueous mayonnaise phase [40]. Except for sample S4, there was no significant difference ($p < 0.05$) between the sample at the 28th day of storage. The lower value of the acid index was for samples S3 and S4, samples with an increasing BPP concentration of 5% BPP and 7% BPP that inhibited the progress in acid value. This may be due to beetroot extracts' phytoconstituents that possess antibacterial properties [42].

Table 6. The oxidative stability of the mayonnaise.

Storge Indices		S0	S1	S2	S3	S4
Acid values, mg KOH/g	0 days	0.96 ± 0.01 ^{cA}	0.85 ± 0.01 ^{cB}	0.85 ± 0.01 ^{cB}	0.85 ± 0.01 ^{cB}	0.85 ± 0.01 ^{bB}
	14 days	1.21 ± 0.01 ^{aA}	0.96 ± 0.01 ^{bB}	0.91 ± 0.01 ^{bC}	0.89 ± 0.01 ^{bCD}	0.86 ± 0.01 ^{bD}
	28 days	1.44 ± 0.02 ^{bA}	1.12 ± 0.01 ^{aB}	1.06 ± 0.01 ^{aC}	0.99 ± 0.01 ^{aD}	0.94 ± 0.01 ^{aD}
Peroxide value, meq/kg	0 days	1.81 ± 0.01 ^{cA}	1.76 ± 0.01 ^{cB}	1.76 ± 0.01 ^{cB}	1.76 ± 0.01 ^{bB}	1.76 ± 0.01 ^{bB}
	14 days	3.03 ± 0.08 ^{bA}	2.06 ± 0.01 ^{bB}	1.91 ± 0.01 ^{bBC}	1.85 ± 0.05 ^{bC}	1.80 ± 0.03 ^{bC}
	28 days	6.94 ± 0.02 ^{aA}	4.17 ± 0.08 ^{aB}	3.83 ± 0.05 ^{aC}	2.62 ± 0.04 ^{aD}	2.01 ± 0.04 ^{aD}

S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP. Means on the same row (capital letters) and the same column (small letters) for each index analyzed that do not share a letter are significantly different.

The peroxide values showed a significant difference ($p < 0.05$) for all the mayonnaise samples stored at refrigerated temperature for 14 and 28 days, except for samples S3 and S4. The gradual increase in the peroxide values during storage indicated the rancidity of mayonnaise samples. Peroxide values less than 10 indicated that both enriched and simple mayonnaise samples are considered safe in refrigerated conditions [41].

3.4. Sensorial Evaluation of Mayonnaise Enriched with BPP

The sensory characteristics of mayonnaise samples supplemented with varying concentrations of BPP are listed in Table 7. Among the sensory features, color is the first sign of a product's quality that captures the attention of customers. The color of mayonnaise was impacted considerably by the concentration of BPP ($p < 0.05$). Thus, the S4 sample with 7 % BPP received the highest color score, followed by S3 with 5% BPP. The enrichment of mayonnaise with BPP created an attractive red-purple color due to increasing beetroot pigments.

Table 7. The consumer acceptability scores of mayonnaise enriched with BPP.

Sensorial Attributes	Control	S1	S2	S3	S4
Color	7.2 ± 1.39 ^{c}	8.25 ± 0.71 ^{b}	8.65 ± 0.48 ^{ab}	8.80 ± 0.41 ^{ab}	8.95 ± 0.22 ^{a}
Aroma	6.45 ± 0.99 ^{b}	7.05 ± 0.94 ^{ab}	7.45 ± 0.99 ^{a}	7.80 ± 0.69 ^{a}	7.75 ± 0.96 ^{a}
Taste	6.8 ± 0.89 ^{c}	7.3 ± 0.86 ^{bc}	7.8 ± 0.61 ^{ab}	8.45 ± 0.51 ^{a}	7.85 ± 0.98 ^{ab}
Consistency	7.7 ± 0.73 ^{a}	7.85 ± 0.67 ^{a}	8.05 ± 0.99 ^{a}	8.05 ± 0.99 ^{a}	7.45 ± 0.94 ^{a}
Texture	8.5 ± 0.68 ^{a}	8.65 ± 0.58 ^{a}	8.65 ± 0.58 ^{a}	8.80 ± 0.41 ^{a}	8.95 ± 0.22 ^{a}
Odor	7.15 ± 1.38 ^{a}	7.30 ± 1.08 ^{a}	7.2 ± 1.10 ^{a}	7.25 ± 1.11 ^{a}	7.25 ± 1.11 ^{a}
Aftertaste	7.4 ± 0.82 ^{a}	7.35 ± 1.03 ^{a}	7.65 ± 1.18 ^{a}	7.75 ± 1.25 ^{a}	7.40 ± 1.35 ^{a}
Spreadability	8.65 ± 0.48 ^{a}	8.65 ± 0.48 ^{a}	8.50 ± 0.51 ^{a}	8.50 ± 0.51 ^{a}	8.35 ± 0.58 ^{a}
Acceptability	8.4 ± 0.68 ^{a}	8.5 ± 0.60 ^{ab}	8.80 ± 0.41 ^{ab}	8.80 ± 0.41 ^{ab}	8.85 ± 0.36 ^{a}

S0—mayonnaise without BPP, control; S1—mayonnaise with 1.5% BPP; S2—mayonnaise with 3% BPP; S3—mayonnaise with 5% BPP; S4—mayonnaise with 7% BPP. Means on the same row that do not share a letter are significantly different.

The quantities of BPP added to the mayonnaise did not affect odor, aftertaste, and spreadability. However, the taste and texture of the product were affected by the high level of BPP (7%). Additionally, it is worth noting that the addition of larger concentrations of BPP to the mayonnaise resulted in a slightly increased consistency score. There were no significant variations in overall acceptability across the three samples. Nevertheless, the panelists appreciated the S4 sample with 7% BPP due to the color. The results agree with Raikos et al. [7], who evaluated the sensory properties of mayonnaise enriched with beetroot processed by microwave and found that the addition of microwaved beetroot improved the color, textural properties, and overall acceptability of the mayonnaise.

4. Conclusions

The current paper proposes a unique strategy for valorizing beetroot by-products as a source of bioactive chemicals to develop novel value-added products. BPP extract characterization revealed a high concentration of phenolic compounds and exhibited significant antioxidant activity. BPP functionality was further evaluated by adding it to a mayonnaise composition. The mayonnaise samples' antioxidant activity increased with BPP content and, due to the enhanced polyphenol content, demonstrated a greater nutritional quality than the control sample. Due to the presence of considerable levels of beetroot pigments, BPP addition resulted in a rise in the redness value and a reduction in the yellowness of the mayonnaise sample. Moreover, the addition of BPP in mayonnaise samples determined higher firmness and an improvement of adhesion and chewiness, giving the product a soft texture. The viscosity of mayonnaise was also significantly improved. Sensory evaluation of value-added mayonnaise indicated that the addition of BPP enhanced the product's color attributes and caused no noticeable impact on the odor, aftertaste, spreadability, and overall acceptance score of the samples. Moreover, using by-products obtained from the industrial processing of beetroots, by considering them a source of biologically active compounds, may become a viable alternative to synthetic dyes, flavorings, and antioxidants. This can have multiple uses in the food industry and can contribute to the reduction of wastes and support the implementation of a circular economic model for the protection of the environment.

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