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BEETROOT POMACE POWDER AS A BIOACTIVE POWDER INGREDIENT IN MAYONNAISE FORMULATION

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Abstract

Beetroot pomace powder (BPP), a by-product of beetroot processing, is a rich source of bioactive compounds, including phenolics and betalains These compounds provide antioxidant, anti-diabetic, anti-inflammatory, and antiproliferative activities. The integration of beetroot pomace powder (BPP) as a bioactive component in mayonnaise formulation signifies an innovative method for improving mayonnaise's nutritional and functional attributes. This research examines the impact of BPP incorporation (with varying BPP concentrations) on the physicochemical characteristics, phytochemical, color, sensory qualities, and texture of BPP-enriched mayonnaise. The findings indicated that BPP markedly improved the antioxidant activity (7.66-9.75 µmol TE/g dw) and betalain contents (2.18-3.93 mg/g) of mayonnaise while maintaining sensory acceptability, with an optimal 3% BPP inclusion level. Moreover, BPP enhanced mayonnaise's aesthetic properties. The results indicate that beetroot pomace is a feasible natural coloring ingredient, consistent with consumer demand for healthier and more sustainable food products. Subsequent investigations may examine the wider applicability of BPP in food systems and its long-term storage effects.

Key words: *agro-industrial by-products, antioxidants, betalains, phytochemicals, value-added food products.*

INTRODUCTION

The rising consumer desire for functional foods that integrate nutritional advantages with improved health benefits has propelled the investigation of novel food ingredients. Agro-industrial by-products, including beetroot pomace, have become attractive resources due to their abundant bioactive components (Bharat Helkar, & Sahoo, 2016; Simioniuc et al., 2021). Approximately 15-30% of the raw material generated by the juice company, comprising red beetroot peel and pulp, is regarded as waste and is subsequently discarded as animal feed. Beetroot pomace, the fibrous residue remaining post-juice extraction, is a nutrient-dense by-product that has attracted interest for its possible uses in food systems. Often discarded or utilized as animal feed, beetroot pomace encompasses a variety of beneficial substances, including betalains, polyphenols, dietary fiber, and vital minerals such as potassium, magnesium, and calcium. These substances not only improve the nutritional quality of food products but also augment many functional and technological attributes (Sahni & Shere, 2017).

Beetroot pomace is distinguished by its elevated betalain concentration, consisting of betacyanins (red-violet pigments) and betaxanthins (yellow pigments). These chemicals are powerful antioxidants with documented anti-inflammatory, anticancer, and cardiovascular protective properties. The phenolic components in beetroot pomace augment its antioxidant ability, rendering it a valuable element for health-oriented food compositions. Additionally, the dietary fiber content promotes gastrointestinal health and aids in the regulation of blood glucose and cholesterol levels, rendering beetroot pomace a functional food component with extensive health advantages (Vulić et al., 2014).

Betalains, potent antioxidants, are present in beetroot by-products, accounting for their vibrant red and yellow hues. Delgado-Vargas et al. (2000) indicated that betacyanins comprise around 75-95% of the pigments present in beetroot, whereas betaxanthins constitute the remaining 5-25%.
Betalains have been demonstrated to have antiviral, antioxidant, antibacterial, antifungal, antidiabetic, anticancer properties, anti-lipidemic effects, cardiovascular effects, and anti-inflammatory effects (Sadowska-Bartosz & Bartosz, 2021).
Commercially available red beet-based colorants exist as either juice concentrates (derived by vacuum concentration of red beet juice to 60-65% total solids) or powders, with a pigment level ranging from 0.3% to 1%. In 2009, betalains from red beetroot comprised 10% of the worldwide food coloring market (Manchali et al., 2012).
The application of red beetroot by-product powders in various food products has garnered attention due to its capacity to improve nutritional value and provide functional benefits. Kumar et al. (2018) explored the development of ginger (*Zingiber officinale*) candy enriched with beetroot pomace extract to enhance its phytochemical profile and functional properties. The study determined that the maximum phytochemical activity was achieved under optimized conditions, specifically with a blanching time of 7.81 minutes and the addition of 9.24% beetroot pomace extract. Lazar et al. (2022) obtained a value-added mayonnaise with different concentrations of beetroot peels. The findings provide a new formulation and technological understanding of the impact of beetroot peel-powder enrichment on the physical, sensory, and textural attributes of mayonnaise.
Mayonnaise, a popular sauce, serves as a suitable medium for incorporating bioactive compounds due to its emulsion structure and market approval. Nevertheless, the conventional composition of mayonnaise frequently lacks substantial health-enhancing qualities. The oxidation of mayonnaise can be inhibited with the incorporation of natural antioxidants derived from plant extracts (Khalid et al., 2021). Fortifying mayonnaise with beetroot pomace powder (BPP) has the potential to improve its nutritional profile while maintaining its organoleptic characteristics, including texture, flavour, and colour. Moreover, integrating BPP adheres to the tenets of sustainability and circular bioeconomy by minimizing food waste and enhancing the valuation of by-products.
This study examines the viability of BPP as a bioactive component in mayonnaise formulation. The study examines the powder's impact on the physicochemical qualities, bioactives, antioxidant activity, colour, texture, and sensory attributes of the red BPP-supplemented product. The results may facilitate wider utilization of beetroot pomace in various food systems, offering creative solutions for health-conscious customers and the food sector.

MATERIALS AND METHODS

Beetroot (*Beta vulgaris* var. 'Rubiniu') was procured from a local farmer in Iasi. All ingredients utilized for the mayonnaise were procured from a local market, comprising sunflower oil, lemon juice, egg powder, vinegar, and salt.
All the following chemicals were obtained from Sigma-Aldrich (Steinheim, Germany): ethanol (70%), citric acid, methanol, 2,2-diphenyl1-picrylhydrazyl (DPPH), Folin-Ciocalteu reagent, gallic acid, sodium nitrite solution, sodium acetate solution, sodium hydroxide, aluminium chloride, potassium chloride, sodium carbonate.

Beetroot Pomace Powder Preparation

The red beetroot of the 'Rubiniu' variety was purchased from a local producer in Iasi County, Romania. The beetroots were washed, after which the skins were removed. Next, the raw materials were pre-shredded, and then subjected to compression. The beetroot juice was extracted with a Bosch MES3500 (Philips Consumer Lifestyle B.V., Drachten, The Netherlands) equipment, resulting in the red beetroot pomace. The beetroot pomace underwent freeze-drying for 50 hours at –45°C under a pressure of 0.10 mBar till achieving a moisture content of 9.00%, utilizing a freeze-dryer (Biobase bk-fd10t equipment, Jinan, China). Finally, the dried pomace was then ground with a grinder and stored in a hermetically sealed container in the dark at room temperature.

Ultrasound-Assisted Extraction

For the phytochemical characterization of red beetroot pomace extract, the extraction of biologically active compounds from beetroot pomace was carried out by homogenizing 1 g of powder obtained previously with 9 mL of ethanol (70%) and 1 mL of citric acid (1%). The obtained mixture was maintained on the ultrasonic bath (Elmasonic S 180 H, Elma, Germany) for 40 min, at a temperature of 30±2°C and 40 kHz. Then the beetroot extract was centrifuged for 10 min at 5500 rpm, 8°C, and the supernatant was collected and characterized for phytochemical content.

Determination of total betalain content

The betaxanthins and betacyanins in the extracts were measured using UV-Vis spectrophotometer (Analytik Jena-Specord 210 Plus, Germany) at 538 nm and 480 nm. (Kushwaha et al., 2018). The results were expressed as milligrams per gram of dry weight (dw). The overall betalain concentration (in mg per 100 g of sample) was ascertained by totaling the value's contents for betacyanin and betaxanthin.

Determination of total flavonoid content

The technique outlined by Dewanto et al. (2002) was employed to evaluate the total flavonoid content. A 250 µL sample is combined with 1.25 mL of purified water and 0.075 mL of 5% sodium nitrite. The mixture is allowed to react for 5 minutes, after which 0.15 mL of 10% aluminium chloride is introduced and permitted to react for an additional 6 minutes. Add 0.5 mL of 1 M sodium hydroxide and 0.775 mL of distilled water. The absorbance of the resultant mixture is promptly measured at a wavelength of 510 nm. The findings were expressed as milligrams of catechin equivalents (CE/g of dw). Quantification of results was performed based on the catechin calibration curve.

Determination of total polyphenol content

The total polyphenol content was evaluated using the Folin-Ciocalteau technique, and the concentrations were expressed in milligrams of gallic acid equivalents (GAE/g of dw) (Horincar et al., 2019). In this procedure, 0.20 mL of the sample was combined with 15.8 mL of distilled water and 1 mL of Folin-Ciocalteu reagent in a test tube. The mixture was allowed to stand for 6 minutes, after which 3 mL of 20% sodium carbonate was added. It was then left to react for one hour at room temperature in the dark. The absorbance was recorded at 765 nm.

Determination of antioxidant activity

The antioxidant activity was measured using the DPPH free radical-scavenging technique and expressed as µM Trolox Equivalents (TE/g of dw) (Horincar et al., 2019). To analyse the sample, 100 µL of it was added to a test tube containing 3.9 mL of DPPH solution. For the control, 100 µL of methanol was mixed with 3.9 mL of DPPH. After incubating the mixture in the dark for 90 minutes, the absorbance was measured at a wavelength of 515 nm using a UV-visible spectrophotometer (Analytik Jena Specord 210 Plus, Jena, Germany). Additionally, a standard curve was created using different concentrations of Trolox. The inhibition % was determined using the following equation:

$$\text{DPPH scavenging activity (\%)} = \frac{\text{Abs Control} - \text{Abs Sample}}{\text{Abs Control}} \times 100$$

Preparation of red BPP-supplemented mayonnaise samples

The recipe for mayonnaise samples contains the following ingredients: sunflower oil (80%), egg powder (8%), vinegar (2%), water (6%), lemon juice (3%), salt (0.2%), and red beetroot pomace powder (M1-1% and M2-2%).

A coarse emulsion was formed in water by dissolving egg powder, lemon juice, salt, and vinegar. Mayonnaise was obtained by incrementally incorporating the oil into the watery liquid and rapidly mixing the ingredients for 13 minutes. Then red beetroot pomace was added at different proportions (1% - M1 and 2% - M2). It was homogenized so that the composition was uniform in terms of color and texture. After preparation, the mayonnaise was kept at a temperature of 4°C to carry out the physicochemical and phytochemical analyses. For ease of comparison, a control sample (C) was also prepared using the same processing but without the inclusion of beetroot pomace.

Physicochemical, phytochemicals, and antioxidant activity evaluation of red BPP-supplemented mayonnaise

The samples were analyzed for moisture, ash, total protein, lipids, and carbohydrates using the standard procedures of AOAC and Gavril (Rațu) et al. (2024).

The methodologies previously described were employed to evaluate the total betalain, total flavonoid content, polyphenolic content, and antioxidant activity of red BPP-supplemented mayonnaise samples.

Colour evaluation

The colour characteristics of the red BPP-supplemented mayonnaise were measured using a CR300 Chroma Meter (Konica Minolta, Sensing Americas, Inc., Ramsey, NJ, USA) equipped with a D65 illuminant. The CIELAB colour parameters (L*, a* and b*) were recorded in triplicate. Hue Angle (Hue angle = arctan(b*/a*) for quadrant I (+a*, +b*), the Chroma or colour intensity (Chroma=$\sqrt{(a^{*})^{2}+(b^{*})^{2}}$), and the total colour difference, (ΔE= $\sqrt{(L^{*}-L_{0})^{2}+(a^{*}-a_{0})^{2}+(b^{*}-b_{0})^{2}}$), were also determined (Dag et al., 2017).

Textural parameters

Texture analysis was conducted using a Brookfield Ametek CT3 Texture Analyser, employing the Texture Profile Analysis (TPA) technique. A double dispersion technique was employed on a 38.1 mm diameter acrylic cylinder sample to attain a depth of 20 mm. The test velocity was established at one millisecond per second, the trigger load at 0.067 N, and the load cell at 9.8 N. The textural characteristics of hardness, cohesiveness, adhesiveness, and chewiness were computed utilizing the TexturePro CT V1.5 program. Each sample was replicated three times.

Sensory evaluation

A 9-point hedonic scale, ranging from 1 (dislike very much) to 9 (like very much), was utilized in the questionnaire to evaluate the experimental mayonnaise samples. The assessment focused on several attributes: appearance, color, spreadability, consistency, and taste; aroma, odor, aftertaste, and general acceptability (Raikos et al., 2016). Twenty untrained panelists were selected for sensory analysis, including students, and staff members from the Faculty of Agriculture, Iasi University of Life Sciences, Romania. Samples were served at room temperature, with water and crackers provided to cleanse the palate between tastings.

Statistical analysis

The results are presented as the mean ± standard deviation. Statistical differences among the results were assessed using analysis of variance (ANOVA). Tukey's test was employed to identify significant pairwise comparisons, utilizing Minitab 18 software. A p-value of less than 0.05 was considered indicative of statistical significance in all tests. The XLSTAT software (Paris, France, 2019, version 2024.3) was utilized for Principal Component Analysis (PCA).

RESULTS AND DISCUSSIONS

Phytochemical and color characterization of red beetroot pomace extract

Table 1 shows the phytochemical profile of the ethanolic extract obtained by the ultrasound-assisted extraction method from red beetroot pomace. It can be seen from Table 1 that the red beetroot pomace extract showed a high content of biologically active compounds, especially polyphenols (225.90±1.41 mg GAE/100 g dw).

Table 1. Phytochemical and color characteristics of beetroot pomace extract

Parameters	Beetroot pomace extract
Total betalain content (mg/100 g dw)	211.43 ±1.29
Total flavonoid content (mg CE/ 100 g dw)	112.65 ±1.17
Total polyphenol content (mg GAE/100 g dw)	225.90 ±1.41
Antioxidant activity (μMol TE/g dw)	42.11 ±0.32
DPPH inhibition (%)	79.84 ±0.49
L*	35.64±0.39
a*	30.88±0.43
b*	4.82±0.10
Hue angle	0.15±0.03
Chroma	31.25±0.25

Also, a total betalain content of 211.43±1.29 mg/100 g was noted. High concentrations of bioactive compounds led to high antioxidant activity with a DPPH free radical inhibition capacity of approximately 80%. According to Vulić et al. (2012), the betalain content in various beetroot genotypes ranged between 0.75 and 3.75 mg/g dry weight of beetroot pomace extract. Kujala et al. (2001) highlighted that the extraction process and the choice of solvent significantly influence the efficiency of phenolic extraction from beetroot by-products. They reported a polyphenol content of 24.1 mg GAE/g in a methanolic extract. Alshehry (2019) reported a beetroot pulp extract with a higher total polyphenolic content of 255±10.48 mg GAE/100 g and antioxidant activity of 137±8.29 mg TE/100 g.

The L* parameter was recorded as 36.89±0.18, with higher values indicating a lighter color. The a* parameter measured 31.71±0.39, where positive values signify a shift toward red hues. The vibrant purple color of beetroot is primarily due to the presence of betalains. The positive b* value (4.82±0.10) indicates a shift toward yellow. Additionally, the color properties were analysed, revealing Chroma and Hue angle values of 31.25±0.25 and 0.15±0.03, respectively. Therefore, the beetroot powder was situated within quadrant I (+a*, +b*).

The observed discrepancies in results may be ascribed to changes in geographical origins or genotypes examined, extraction methods, and analytical procedures. Research has shown that BP powder is a valuable source of phytochemicals with antioxidant effects. These powders can be included in foods as a natural component to efficiently diminish the presence of agro-industrial residues.

Characterization of phytochemicals of red BPP-supplemented mayonnaise samples

The phytochemicals results are highlighted in Table 2. The incorporation of red BPP (1 and 2%) into the mayonnaise formulation resulted in a substantial elevation ($p<0.05$) in the concentrations of the bioactive molecules. Consequently, total betalains varied from 218.22±0.72 to 393.11±0.94 mg/100g, the flavonoid content ranged from 46.22±0.22 to 96.54 ±0.73 mg CE/100 g, while phenolic content ranged from 81.31±0.32 to 146.27±1.03 mg GAE/100 g in red BPP-supplemented mayonnaise samples.

Table 2. The phytochemical characteristics and antioxidant activity of the mayonnaise with red BPP (C- mayonnaise without the addition of red BPP, M1 and M2 - mayonnaise with the addition of 1% and 2% (*w/w*) red BPP)

Parameters	**Mayonnaise samples**		
	C	M1 (1%)	M2 (2%)
Total betalain content, mg/100 g dw	-	218.22±0.72b	393.11 ±0.94a
Total flavonoid content, mg CE/100 g dw	46.22±0.22c	78.31 ±0.62b	96.54 ±0.73a
Total polyphenol content, mg GAE/100 g dw	81.31±0.32c	102.09 ±1.02b	146.27 ±1.03a
Antioxidant activity, µMol TE/100 g dw	412.03 ±0.44c	766.13 ±0.96b	975.03 ±1.17a
DPPH Inhibition, %	14.80 ±0.08c	29.99 ±0.22b	38.76 ±0.23a

Different lowercase letters in a row highlight significant differences ($p<0.05$) between mayonnaise samples.

Furthermore, M1 and M2 samples exhibited significantly elevated quantities of bioactive chemicals ($p<0.05$) relative to the control sample. The mayonnaise samples enriched with red BPP exhibited more antioxidant activity than the control due to elevated quantities of bioactive components from the red BPP.

Raikos et al. (2016) demonstrated that mayonnaise samples fortified with processed (microwaved) beetroot extract exhibit elevated levels of bioactive components (betanin 337.9 mg/L; polyphenols 399.6 mg GAE/mL) and notable antioxidant activity (6.9 mol/L) in comparison to the control sample.

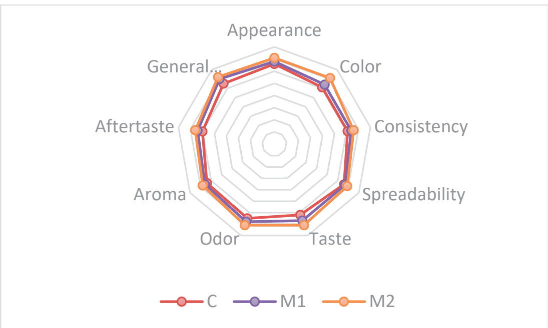

Figure 1. Comparative representation of the sensory attributes specific to mayonnaise samples: C- control mayonnaise sample; M1 and M2 - mayonnaise samples with 1 and 2% of red BPP

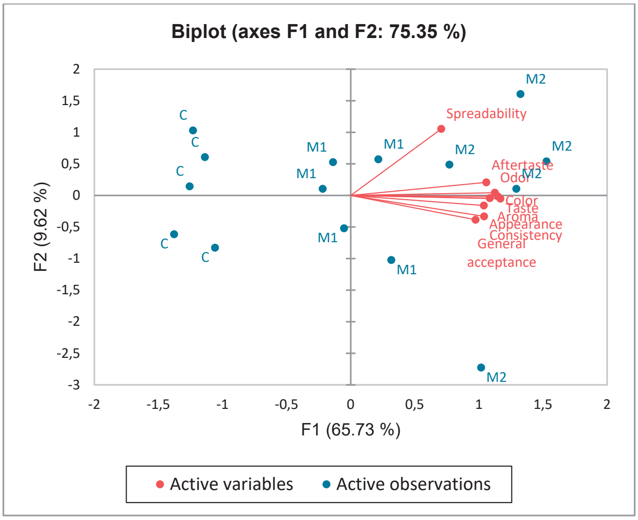

Figure 2. Biplot of Principal Component Analysis (PCA) depicting the positions of the three mayonnaise samples (C, M1, and M2) for the assessment of sensory qualities

Table 3. The physicochemical characteristics of the mayonnaise samples (C-control mayonnaise, M1 and M2 - mayonnaise with the addition of 1 and 2 % (w/w) red BPP)

Physicochemical characteristics	Mayonnaise samples		
	C	M1 (1%)	M2 (2%)
Moisture (g/100 g)	18.06 ± 0.06a	17.99± 0.11b	17.95± 0.21b
Lipids (g/100 g)	72.01 ± 0.21a	71.51 ± 0.19b	71.29 ± 0.13b
Proteins (g/100 g)	5.39± 0.16a	5.22± 0.03b	5.09± 0.02c
Carbohydrates (g/100 g)	2.61± 0.03c	3.17± 0.04b	3.28± 0.05a
Ash (g/100 g)	1.93± 0.03c	2.11± 0.06b	2.39± 0.08a
Energetic value %: kcal/100 g: kJ/100 g :	680.09± 5.12a 2842.78± 5.12a	677.15± 5.09b 2830.49± 5.09b	675.09± 5.48b 2821.88± 5.48b

Different lowercase letters in a row highlight significant differences ($p<0.05$) between mayonnaise samples.

Table 4. Colorimetric parameters of the red BPP-supplemented mayonnaise samples

Parameters	Mayonnaise samples		
	C	M1 (1%)	M2(2%)
L*	78.60±0.55a	35.97±0.37b	32.15±0.35c
a*	2.27±0.20c	26.25±0.18b	30.68±0.30a
b*	38.07±0.39a	4.14±0.10c	4.52±0.06b
Chroma	38.14±0.38a	26.64±0.31c	30.96±0.29b
Hue angle	1.51±0.03a	0.17±0.02b	0.13±0.02b
ΔE	-	59.31±0.40b	64.16±0.39a

Different lowercase letters in a row highlight significant differences ($p<0.05$) between mayonnaise samples

Table 5. Textural parameters of the BPP-supplemented mayonnaise samples

Textural parameters	Mayonnaise samples		
	C	M1 (1%)	M2 (2%)
Firmness, N	0.66±0.02c	1.02±0.03b	1.67±0.05a
Adhesiveness, mJ	1.72±0.06b	5.13±0.17a	5.65±0.21a
Cohesiveness,-	0.80±0.02a	0.77±0.02a	0.75±0.01a
Chewiness, mJ	5.51±0.11c	9.86±0.16b	12.23±0.22a

Different lowercase letters in a row highlight significant differences ($p<0.05$) between mayonnaise samples

Table 2 indicates that red BPP enhances mayonnaise quality, as demonstrated by the substantial levels of betalains and polyphenols. Antioxidants enhance the mayonnaise's health benefits by scavenging free radicals.

Physicochemical characterization of red BPP-supplemented mayonnaise samples

The red BPP-supplemented mayonnaise samples were analyzed from a physicochemical point of view, and the results are presented in Table 3. The proximate analysis of mayonnaise with BP showed significant differences ($p<0.05$) between samples. Moisture content decreased with the addition of BP, while ash content increased as mayonnaise enrichment progressed. Additionally, the incorporation of beetroot powders led to an increase in carbohydrate content. The results were consistent with the findings of Lazar et al. (2022) in mayonnaise with beetroot peel.
Moreover, lipids and proteins decrease with the addition of red beetroot pomace. The energetic value differs from control with a decreasing trend.

Color evaluation of red BPP-supplemented mayonnaise samples

The incorporation of red BPP into the mayonnaise produced major color changes. The inclusion of BP significantly influenced the color of the mayonnaises, as indicated by the analysis of the color parameters.

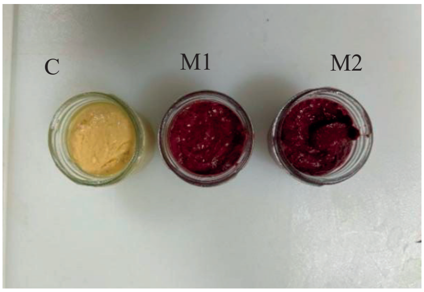

Figure 3. Images of the control mayonnaise sample (C); mayonnaise sample with 1% red BPP (M1); mayonnaise sample with 2% red BPP (M2)

The experimental mayonnaise sample exhibited the lowest lightness (L*) and yelowness (b*) values, alongside the highest redness (a*) values.
The value b* indicates a hue nearer to yellow. The red hue (a*) of beetroot is attributed to the presence of significant quantities of betalains. According to Table 4, a significant lightness decrease is observed with the BPP concentration increase and a tendency to red. The ΔE values demonstrated substantial variances across all mayonnaise samples. The overall color difference ΔE value in the mayonnaise samples increase rapidly with extract concentration, with ΔE reaching a higher value of 64.16±0.39 for mayonnaise made with 2% red BPP. A similar increase was observed by Lazar et al. (2022) in the mayonnaise samples enriched with beetroot peels.
Red beetroot pomace powder possesses significant coloring potency and can enhance the hue of the sauce, hence improving its consumer appeal.

Textural parameters of BPP-supplemented mayonnaise samples

Firmness (expressed in N) (Table 5) is defined as the maximum resistance force opposed by the sample during the first penetration cycle (Bourne, 2002). The firmness of mayonnaise is a crucial element as it affects both sensory attributes (mouthfeel) and usability (Chang et al., 2017). All samples demonstrated low firmness and cohesiveness values, alongside elevated adhesiveness and chewiness values, consistent with those documented in the literature (Di Mattia et al., 2015; Rojas et al., 2017). The results indicate that the incorporation of red BPP in mayonnaise samples resulted in greater firmness values compared to the control sample. This phenomenon results from the stabilizing molecules present in the incorporated plant material, such as pectin (Bai et al., 2017). Moreover, the incorporation of red BPP into the mayonnaise formulation enhanced adherence and chewiness, resulting in a refined and tender texture. Adhesion is defined as the energy required to remove the sample from the test device (Bourne, 2002). The lowest adhesion value, 1.72 mJ, was recorded for the control sample. The addition of red BPP in the composition of the mayonnaise samples contributed to improving the adhesion, giving the product a fine and creamy texture.
Cohesiveness is defined as the strength of the internal bonds between the constituent elements

of the mayonnaise (Bourne, 2002), which gives it its consistency. The higher the value, the more "sticky" or "cohesive" the mayonnaise. Thus the most cohesive mayonnaise was the control.
Instrumental texture analysis revealed that the addition of re BPP improves the textural characteristics of the mayonnaise in proportion to the concentration of added powder.

Sensory evaluation of red BPP-supplemented mayonnaise samples

The sensory assessment of the produced mayonnaise samples was performed on a nine-point hedonic scale. Figure 1 displays the average ratings obtained from the sensory assessment. Sensory analyses revealed that the mayonnaise formulated with the addition of 2% BPP (M2) received higher scores for most of the analyzed attributes (appearance, odor, consistency, taste, aroma, aftertaste, spreadability, and general acceptability) compared to the other mayonnaise formulations.
Color is a key indicator of a product's quality that draws the attention of customers. The color of mayonnaise was significantly influenced by the concentration of red BPP ($p < 0.05$), with the M2 sample containing 2% red BPP receiving the highest color score. Enriching mayonnaise with BPP imparted an appealing red-purple hue, attributed to the increased presence of beetroot pigments (Figure 3). The amounts of red BPP incorporated into the mayonnaise influenced its odour, flavour, aftertaste, and spreadability.
Furthermore, it is noteworthy that the incorporation of higher concentrations of BPP into the mayonnaise led to a moderately elevated consistency rating.
Analyzing the results of the sensory evaluation of the value-added mayonnaise, it is noted that the mayonnaise variants with the addition of red beetroot powder were evaluated as having a balanced, pleasant taste, smell, and color corresponding to red beetroot, with a fine and creamy consistency. The findings are consistent with those of Raikos et al. (2016), who discovered that the incorporation of microwaved beetroot enhanced the color, texture, and overall acceptability of the mayonnaise.
In summary, the supplemented mayonnaise samples were well accepted by consumers. Figure 2 presents a PCA biplot that visually depicts the locations of the three mayonnaise samples (plain compared to those enhanced with BPP) according to the sensory qualities outlined in Figure 1. The initial principal component (PC1) represented 65.73% of the variance and comprised the two mayonnaise samples with BPP. The second component constituted 9.62% of the total and was comprised of control mayonnaise. Consequently, the two axes represented 75.35% of the total variation. The characteristics of aftertaste, odor, and spreadability exhibited a high correlation on the first axis, F1. Likewise, the characteristics of appearance, aroma, color, taste, consistency, and general acceptance were also identified as having a positive correlation within the same quadrant on the first axis, F1. Since all sensory attributes were exclusively linked to the same axis, F1, the control proved neutral. The biplot analysis enables the accurate positioning of the three mayonnaise samples according to their sensory attributes. It facilitates the distinction of sensory properties via positive correlations, as well as between sensory attributes and mayonnaise samples.

CONCLUSIONS

Beetroot pomace, a by-product of beetroot processing, has been effectively established as a significant source of bioactive chemicals, providing a unique approach to creating novel, value-added food products. The use of red BPP markedly enhanced the betalain, polyphenol concentrations and antioxidant efficacy in mayonnaise, hence augmenting its nutritional profile relative to the control sample.
The incorporation of red BPP enhanced the mayonnaise's aesthetic by augmenting redness and diminishing yellowness, attributable to the natural colors derived from red beetroot. Furthermore, it improved textural attributes, including firmness, adherence, and chewiness, yielding a softer and more appealing product consistency.
Sensory analysis verified that the incorporation of red BPP enhanced the color of mayonnaise without negatively impacting other sensory characteristics, such as aroma, aftertaste, spreadability, and overall approval among consumers. The use of beetroot by-products as a natural substitute for synthetic colors, flavorings, and antioxidants shows promise in

minimizing waste within the food industry. This corresponds with the tenets of a circular economy, promoting environmental sustainability and waste reduction. Red BPP functions as a natural and versatile component in the food sector, offering natural bioactive compounds and improving the visual and functional attributes of products. This method encourages the sustainable utilization of agro-industrial by-products and fosters creative food product fabrication.

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REFERENCES

Alshehry, G. A., University, T. & Arabia, S. (2019). Utilization of beetroot as a natural antioxidant, pigment and antimicrobial in cupcake during the storage period. *International Journal of Engineering Research & Technology,* V8(10). DOI: 10.17577/ijertv8is100053

AOAC. (1990). Official Methods of Analysis. 15 th edn. Association of Official Analytical

Bai, L., Huan, S., Li, Z. & Mcclements, D.J. (2017). Comparison of emulsifying properties of food-grade polysaccharides in oil-in-water emulsions: Gum arabic, Beet Pectin, and Corn Fiber Gum. *Food Hydrocolloids*, 66, 144–153.

Bharat Helkar, P. & Sahoo, A. (2016). Review: Food industry by-products used as a functional food ingredients. *International Journal of Waste Resources*, 6(3). doi:10.4172/2252-5211.1000248

Bourne, M.C. (2002). *Food texture and viscosity: Concept and measurement*. Academic Press, New York.

Chang, C., Li, J., Li, X., Wang, C., Zhou, B., Su, Y & Yang, Y. (2017). Effect of protein microparticle and pectin on properties of light mayonnaise. *LWT Food Science Technology,* 82, 8–14.

Dag D., Kilercioglu. M. & Oztop. M.H. (2017). Physical and chemical characteristics of encapsulated goldenberry (*Physalis peruviana* L.) juice powder. *LWT - Food Science Technology*. 83, 86–94.

Delgado-Vargas, F., Jiménez, A.R. & Paredes-López, O. (2000). Natural pigments: carotenoids, anthocyanins, and betalains–characteristics, biosynthesis, processing, and stability. *Critical Reviews in Food Science and Nutrition,* 40(3), 173–289. DOI: 10.1080/10408690091189257

Dewanto, V., Wu, X., Adom, K.K. & Liu, R.H. (2002). Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. *Journal of Agricultural and Food Chemistry,* 50(10), 3010–3014. DOI: 10.1021/jf0115589.

Di Mattia, C., Balestra, F., Sacchetti, G., Neri, L., Mastrocola, D. & Pittia, P. (2015). Physical and structural properties of extra-virgin olive oil based mayonnaise. *LWT Food Science Technology*, 62, 764–770.

Gavril (Rațu) R.N., Carlescu P.M., Veleșcu I.D., Arsenoaia V.N., Stoica F., Stanciuc N., Aprodu I., Constantin O.E. & , Rapeanu G. (2024). The development of value-added yogurt based on pumpkin peel powder as a bioactive powder. *Journal of Agriculture and Food Research*. Volume 16, 101098.

Horincar, G., Enachi, E., Stanciuc, N. & Rapeanu. G. (2019). Extraction and characterization of bioactive compounds from eggplant peel using ultrasound - assisted extraction. *The Annals of the University Dunarea de Jos of Galati Fascicle VI - Food Technology*. 43, 40–53.

Khalid, M.U., Shabbir, M.A., Mustafa, S., Hina, S., Quddoos, M.Y., Mahmood, S., Maryam, Y., Faisal, F. & Rafique, A. (2021.) Effect of Apple peel as an antioxidant on the quality characteristics and oxidative stability of mayonnaise, *Applied Food Research,* 1, 100023.

Kujala, T., Loponen, J. & Pihlaja, K. (2001). Betalains and phenolics in red beetroot (*Beta vulgaris*) peel extracts: Extraction and characterisation. *Zeitschrift für Naturforschung C,* 56(5–6), 343–348. DOI: 10.1515/znc-2001-5-604

Kumar, V., Kushwaha, R., Goyal, A., Tanwar, B., & Kaur, J. (2018). Process optimization for the preparation of antioxidant rich ginger candy using beetroot pomace extract. *Food Chemistry*, 245, 168–177. doi:10.1016/j.foodchem.2017.10.089.

Kushwaha, R., Kumar, V., Vyas, G. & Kaur, J. (2018). Optimization of different variable for eco-friendly extraction of betalains and phytochemicals from beetroot pomace. *Waste biomass valorization*. 9(9), 1485–1494. DOI: 10.1007/s12649-017-9953-6.

Lazar, S., Constantin, O.E., Horincar, G., Andronoiu, D.G., Stanciuc, N., Muresan, C. & Râpeanu, G. (2022). Beetroot by-product as a functional ingredient for obtaining value-added mayonnaise. *Processes,* 10, 227. https://doi.org/10.3390/pr10020227

Manchali, S., Murthy, K.N.C., Nagaraju, S. & Neelwarne, B. (2013). *Stability of betalain pigments of red beet*. In Red Beet Biotechnology; Neelwarne, B., Ed.; Boston, USA Springer ; pp. 55–74.

Raikos, V., McDonagh, A., Ranawana, V. & Duthie, G.G. (2016). Processed beetroot (*Beta vulgaris* L.) as a natural antioxidant in mayonnaise: Effects on physical stability, texture and sensory attributes. *Food Science and Human Wellness*, 5, 191–198.

Rojas, V.M., Marconi, L., Guimarães-Inácio, A., Leimann, F.V., Tanamati, A., Gozzo, A.M., Fuchs, R.H.B., Barreiro, M.F., Barros, L. & Ferreira, I.C.F.R. (2019). Formulation of mayonnaises containing pufas by the addition of microencapsulated chia seeds, pumpkin seeds and baru oils. *Food Chemistry*, 274, 220–227.

Sadowska-Bartosz, I. & Bartosz, G. (2021). Biological properties and applications of betalains. *Molecules*, 26, 2520. https://doi.org/10.3390/molecules26092520

Sahni P. & Shere D.M. (2017). Comparative evaluation of physico-chemical and functional properties of apple, carrot and beetroot pomace powders, International *Journal of Food and Fermentation Technology*, 7, 2 317-323.

Simioniuc, D.P., Simioniuc, V., Topa, D., van den Berg, M., Prins, U., Bebeli, P.J. & Gabur, I. (2021). Assessment of Andean lupin (*Lupinus mutabilis*) genotypes for improved frost tolerance. *Agriculture,* 11, 155. https://doi.org/10.3390/agriculture11020155

Vulić, J. J., Ćebović, T. N., Čanadanović-Brunet, J. M., Ćetković, G. S., Čanadanović, V. M., Djilas, S. M., & Tumbas Šaponjac, V. T. (2014). *In vivo* and *in vitro* antioxidant effects of beetroot pomace extracts. *Journal of Functional Foods,* 6, 168–175. doi:10.1016/j.jff.2013.10.003

Vulic´, J.J., Canadanovic´-Brunet, J., C´etkovic´, G., Tumbas, V., Djilas, S.M., Cetojevic´-Simin, D. & Canadanovic´, V. (2012). Antioxidant and cell growth activities of beet root pomace extracts. *Journal of Functional Foods*, 4, 670–678.

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