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PHYTOCHEMICAL COMPOSITION AND SENSORY ACCEPTABILITY OF MACARONS SUPPLEMENTED WITH CARROT POMACE

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Abstract

The root vegetable known as carrots (*Daucus carota L.*) is renowned for its exceptional nutritional value, due to its chemical composition which consists in bioactive substances such as antioxidants, carotenoids, vitamins, and dietary fibers. Despite its high nutritional content, carrot pomace, a by-product of carrot juice processing, is often underutilized.

This research aimed to improve the nutritional content of macarons by incorporating carrot pomace powder into their formulations at varying concentrations (10% and 20% by weight). Furthermore, it is designed to evaluate the impacts on phytochemicals and physicochemical composition, as well as on texture, color, sensory characteristics, and consumer acceptance. The inclusion of carrot pomace powder led to a notable enhancement of dietary fibers and bioactive compounds levels (total carotenoids: 18.30-35.20 mg/g DW). Antioxidant activity (31.60-52.50 %) was also improved proportionally with the quantity of added carrot pomace. The results of the sensory evaluation indicated that macarons with a maximum of 10% carrot pomace exhibited desirable flavor and texture characteristics while having a negligible effect on consumer acceptance. Nevertheless, the 20% inclusion level led to a noticeable change in texture and was less preferred. The study revealed that the addition of carrot pomace powder into desserts is not only a feasible approach but also facilitates the incorporation of food by-products, hence enhancing sustainability in the area of food processing.

Keywords*:* carrot pomace, nutritional enrichment, carotenoids, antioxidant activities, macarons

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Introduction

The recovery of biological residues has been of great interest for the production of antioxidant and color compounds with added value for use by various industries, such as nutraceuticals and food (Martins and Ferreira, 2017), being a sustainable approach that allows meeting the current needs of the industry and the demands of society.

Carrots (*Daucus carota L.*) are extensively consumed vegetables on a global scale, highly valued for their multifunctionality in culinary contexts as well as their significant contributions to human health (Al-Amin *et al.*, 2015). Carrots are known as a multi-nutrient food source and are rich in natural bioactive compounds such as β-carotene, phenolics, carotenoids, polyacetylenes and ascorbic acid, vitamins such as thiamine, riboflavin, B complex vitamins (Ahmad *et al.*, 2019), dietary fibers and minerals. As a result, carrots can be used as a functional ingredient in any product to increase biological and nutritional values (Ergun, 2018). Carrots include β-carotene, which is a very effective antioxidant that the body transforms into vitamin A. Vitamin A is crucial for vision, growth, and immune system functioning. Moreover, carrots include essential nutrients such as dietary fiber, vitamin C, potassium, and other antioxidants, which in tandem enhance cardiovascular well-being and aid in the prevention of cancer (Samtiya *et al.*, 2021).

The global production of carrots has experienced a substantial increase during the past three decades. Following the completion of the harvest, carrots that fail to meet the quality criteria or size and shape specifications set by the consumer market are disposed of. As a result, packaging companies produce a significant quantity of waste, accounting for around 30% of the whole harvest, which is subsequently utilized as animal feed (Clementz *et al.*, 2018).

In addition to the financial loss, carrot waste causes environmental issues since only 15-20% of it is eaten by animals; the remaining portion rots and releases noxious odors, attracts more insects, and produces decomposition products. Processing a substantial amount of carrot discards is necessary to ensure the sustainability of the production of such a big primary commodity. The production of valuable by-products from the waste would enable this conventional crop to be positioned differently.

Large-scale commercial carrot processors can generate a maximum of 175,000 tons of carrot waste per year. There are two distinct types of carrot waste, namely pomace and mash. Pomace refers to the residual substance resulting from the extraction of carrot juice, while mash denotes the residual substance obtained from the process of peeling and chopping ready-to-eat carrot goods, such as peeled baby carrots, matchsticks, shredded carrots, and carrot chips. The distinctiveness of carrot waste lies in its frequent availability as an edible and nutrient-rich material, in contrast to the predominantly leafy and stalky nature of cauliflower or broccoli waste (Amin *et al.*, 2021).

Carrot pomace has a notable abundance of phytonutrients, particularly β-carotene, renowned for its antioxidant characteristics and its contribution to the enhancement of visual acuity and immune system functionality (Samtiya *et al.*, 2021). Carotenoids are considered Substances Generally Recognized as Safe (GRAS) by several regulatory agencies, among which the Food and Drug Administration and the European Food Safety Authority could be mentioned. However, an acceptable daily intake for β-carotene of <15 mg/kg bw/day has been proposed (Meléndez-Martínez, 2019). Carotenoids are powerful antioxidants present in carrots that help neutralize the effect of free radicals. Vitamin A is an essential carotenoid required for a multitude of metabolic purposes in the human body (immunity, growth development and vision) (Clementz *et al.*, 2018).

According to Hernández-Alcántara *et al.* (2016), carrot pomace contains 52% total dietary fiber, 42% insoluble dietary fiber, and 9% soluble dietary fiber. Carrot pomace possesses dietary fibers that have the potential to alleviate the glycemic response triggered by high-sugar diets and promote gastrointestinal well-being. The presence of antioxidants and vitamins in carrot pomace has advantageous effects in mitigating oxidative stress and diminishing the susceptibility to chronic ailments, including heart disease and specific forms of cancer (Clementz *et al.*, 2018).

The literature contains many reports regarding the possibility to include carrot pomace in various food products such as cookies, wheat bread, pasta, dressings, high-fiber biscuits, and cakes (Filipini, 2001; Schweiggert, 2004; Kumari and Grewal, 2007; Gull *et al.*, 2015; Turksoy and Ozkaya, 2011; Psimouli and Oreopoulou, 2017), emphasizing on its functionality. Being rich in fiber, carrot pomace powder can be incorporated into food products as inexpensive, non-caloric thickeners for partial replacement of flour, fat or sugar, as water and oil retention enhancers and to improve emulsion or oxidative stability (Elleuch *et al.*, 2011).

Bakery products are enjoyed by people of all age groups and include a wide variety of products such as cakes, breads, biscuits, etc. As the demand and acceptability of bakery products is rises, they can be used as matrices for fortification and improvement of nutritional quality. Bakery products such as cakes are high in starch, fat and energy but low in fiber (Singh, 2016).

Utilization of carrot pomace, which abounds in fibers, carotenoids and minerals, in bakery increases the intake of dietary fiber, lowers the caloric density of the products and prolongs freshness due to its water-holding capacity, thus reducing economic losses. For example, supplementing wheat flour with carrot pomace powder will improve the nutritional quality of products with outstanding sensory attributes (Sudha *et al.*, 2007; Kohajdová *et al.*, 2011).

The macaron, an emblematic representative of French patisserie, is highly esteemed globally due to its complex, meringue-like consistency and diverse assortment of hues and tastes. Macaron is a small, round cookie with a crunchy and moist texture. This dessert, first produced in Italy, is a luxury dessert that is loved worldwide today because it is associated with French desserts and it is also considered an expensive and refined dessert (Kim and Sim, 2017; Lee *et al.*, 2015).

Macaron is a meringue-based cake made with egg white, powdered sugar, granulated sugar, almond flour, and often food coloring. These are sometimes baked on edible rice paper placed on a baking tray. As it is baked, the macaron presents a smooth top with rounded edges. It is slightly moist and melts easily into mouth. Macarons can be found in a wide variety of flavors, ranging from traditional sweets like raspberry or chocolate to savory (like foie gras) (Poem, 2013; Palczak *et al.*, 2020). Nevertheless, similar to the most traditional confections, macarons generally exhibit a deficiency in vital nutrients, including dietary fibers, and possess a substantial sugar content that offers little nutritional advantages. The food industry is progressively using creative ingredient substitutes to meet the rising consumer demand for healthier dessert options that maintain taste and texture. These substitutions aim to increase the health benefits of conventional recipes.

The aim of the study is to develop natural, functional, inexpensive ingredients by capitalizing on vegetable by-products, rich in biologically active compounds, which allow the development of healthy alternatives to chemically synthesized additives, in order to improve the sensory characteristics of obtained food products.

Carrot pomace, a residual material generated from the manufacturing of carrot juice, was added to conventional macaron recipes at varying proportions (10% and 20% by weight). The physicochemical content, phytochemical composition, β-carotene levels, and antioxidant capacity of the experimental macarons were examined. A sensory study was conducted to assess the acceptability of the products. Additionally, color and texture were examined through instrumental techniques.

Materials and methods

Obtaining of carrot pomace powder (CPP)

Carrots (*Daucus carota L.*) were procured from a local market in Galați, Romania, and maintained under refrigerated until processing. In order to obtain the pomace, the carrots were washed, shredded and compressed. The carrot pomace resulted by separating the juice with a Bosch MES3500 device manufactured by Philips Consumer Lifestyle B.V. in Drachten, The Netherlands.

The juice-depleted carrot pomace was then frozen for the freeze-drying experiment. Drying was carried out using a CHRIST Alpha 1-4 LD plus lyophilizer, Germany, at -44°C, under a pressure of 10 Pa, for 50 h. Finally, the dried pomace with a relative humidity of 7% was ground in an electric grinder (Heinner HCG-150SS; Bucharest, Romania). Afterwards, the obtained fine powder was collected, packed in PVC polymer adhesive film and stored at 20°C until characterization and utilization.

Materials and reagents

Carrots were bought from a local market in Galați, Romania. Macarons were manufactured from the following ingredients: almond flour, egg white, powdered sugar, granulated sugar, and salt, which were all purchased from a supermarket in Galați.

The following laboratory chemicals were acquired from Sigma Aldrich Steinheim (Darmstadt, Germany): Folin-Ciocalteu reagent, hexane, acetone, HPLC purity methanol, [2,20 azinobis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt]

(ABTS), ethanol, 6-hydroxy 2,5,7,8 tetramethylchromane-2-carboxylic acid (Trolox), Gallic acid, sodium hydroxide, aluminium chloride, and sodium carbonate.

Ultrasound-Assisted Extraction

The carrot pomace powder extraction of phytochemicals was performed utilizing the ultrasound-assisted extraction technique, adhering to the approach established by Umair *et al.* (2021) with minor modifications. The extraction solution for carrot pomace consisted of a mixture of hexane and acetone in a 3:1 (v/v) ratio, along with 70% ethanol for the total polyphenols and total flavonoids. The ultrasound-assisted extraction procedure employed a triple-stage batch extraction conditions at 25 °C for 25 minutes, a frequency of 40 kHz and a plant-to-solvent ratio of 1:10 (*w/v*). This extraction regime was used in order to protect the temperature sensitive bioactive molecules. Afterwards, the extracts were centrifugated for 10 minutes at 6500 rpm and 4 °C. The resulting supernatant was then examined to determine the phytochemicals from CPP.

Determination of total carotenoid, β-carotene, and lycopene contents

The total carotenoids content, β-carotene and lycopene contents was determined according to the description of Rațu *et al.* (2024).

Consequently, a volume of 0.2 mL of the extract was dissolved in the mixture of extraction solvent (hexane:acetone, 3:1) and thereafter introduced into the UV quartz cuvette. The Libra S22 UV-VIS spectrophotometer (Biochrom, Cambridge, UK) was used to measure the absorbance at λ = 450 nm for total carotenoids, λ= 470 nm for β-carotene, and λ = 503 nm for lycopene. The values were expressed as the dry weight (DW) in milligrams per gram (mg/g). Equation 1 was employed to ascertain the concentrations:

$$\text{Contents of carotenoids (mg/g)} = \frac{A\ x\ Mw\ x\ Df\ x\ Vd}{\text{m x L x Ma}} \qquad (1)$$

where, A represents the absorbance of the sample, Mw represents the molecular weight (536.873 g mol^{-1}), Df represents the sample dilution rate, Vd represents the solution volume, m represents the mass/weight of the concentrated extract, and L represents the length of the optical path of the cuvette (1 cm), Ma represents the molar absorptivity, which is 2500 L mol^{-1} cm^{-1} for total carotenoids, 2590 L mol^{-1} cm^{-1} for β-carotene, and 3450 L mol^{-1} cm^{-1} for lycopene.

Determination of total flavonoid content

The quantification of total flavonoid content was conducted using the methodology outlined by Rațu *et al.* (2024), with certain adjustments made. Essentially, 0.15 mL of $AlCl_3$ 10% was combined with 0.25 mL of extract, and then 0.5 mL of 1 M NaOH solution was added. The mixes were homogenized and thereafter placed in a dark environment for 5 minutes. The absorbance readings were then recorded at a wavelength of 510 nm. The findings are quantified to milligrams of catechin equivalents per gram of dry weight (mg CE/g DW).

Determination of total polyphenol content

The measurement of the total phenolic content was conducted using the Folin–Ciocâlteu reagent and Na_2CO_3 20% (w/v), as outlined in the comprehensive study conducted by Rațu *et al.* (2024). The phytochemical characterization was assessed using colorimetric methods (Biochrom; Libra 22 UV/Visible Spectrophotometer; Holliston, MA, USA) in triplicate experiments. The absorbance was quantified at a wavelength of 765 nm in relation to a reference sample. The total polyphenolic content was determined by calculating the Gallic acid equivalent per gram of dry weight (mg GAE/g DW) using the Gallic acid standard (50–250 mg/L).

Determination of antioxidant activity

Gheonea *et al.* (2020) presented a colorimetric technique that was subsequently adapted for the assessment of ABTS Radical Cation Scavenging Activity.

Concisely, 7 mM ABTS solution and 2.45 mM potassium persulfate were combined in the absence of light at a temperature of 21°C for 16 hours to produce the ABTS stock solution. 1 mL solution of ABTS+ was diluted with 40 mL of ethanol to achieve an absorbance value of 0.700±0.02 at a wavelength of 734 nm. Additionally, a mixing of 0.02 mL of carrot pomace extract with 1.98 mL of ABTS solution was performed. Subsequently, the combination was allowed to stand at ambient temperature and without light for 2 hours. Libra 22 UV/Visible spectrophotometer was used to measure the decrease in absorbance of the combination at a wavelength of 734 nm. The findings were reported in terms of inhibition percentage and Trolox Equivalent per gram of dry weight (μM TE /g DW). The standard used was Trolox (0.125 mg/mL). The inhibition % was determined using equation (2):

$$\text{ABTS scavenging activity (\%)} = \frac{\text{Abs Control} - \text{Abs Sample}}{\text{Abs Control}} \cdot 100 \qquad (2)$$

The absorbance value of the ABTS solution alone is referred to as Abs Control, while the absorbance value of the ABTS solution combined with the carrot pomace extract is referred to as Abs Sample.

Preparation of CPP-enriched macaron samples

The CPP-enriched macarons contain the following ingredients, % (g/g): almond flour (26%), egg white (17%), powdered sugar (43%), sugar (14%), salt (0.3%) and CPP (M10 – 10% and M20 –20%). The process of obtaining macaron samples is simple and involves mixing the ingredients with the carrot pomace powder.

First the ingredients in the recipe were weighed and sifted. Then, the whites were separated from the yolks and the whites were mixed with the sugar and salt.

The sugar was incorporated gradually until a consistent foam was obtained, starting from the first speed of the mixer to the last. Powdered sugar together with almond flour and carrot powder (10%, 20%) were gradually incorporated into the obtained composition. The composition thus obtained was poured with the help of a cone into a tray prepared with baking paper, having a thickness of around 1.5 cm. The baking pan was moved slightly right-left so that the obtained composition settled and at the same time dried gradually for 2 hours. After preheating the oven and reaching 150 ºC, the product was baked for 15 minutes and another 7 minutes at 130 ºC. After cooling the products to 25-35°C, they were packed into bags (cellophane, polyethylene).

For comparison, a control sample (C) was also made, which followed the same technology, but in which no carrot powder was added.

Characterization of phytochemicals, physicochemical, and antioxidant activity of CPP-enriched macarons

Moisture, crude protein, crude fiber, fat and ash content in the samples were determined according to AOAC (2012). The ash content was assessed using gravimetric methods after dry mineralization in an oven set at a temperature of 550 ºC for 6 hours. The international standard method (ISO 928–1998) was employed for this purpose. The determination of protein content was conducted using the Kjeldahl method, as outlined in the standard AFNOR NF V03-050 (1970). The factor considered for conversion was 6.25. The determination of lipid content was conducted using the Soxhlet technique. The crude fibers (acid and alkali treatment) of the macarons were determined according to the method described by Dendegh *et al.* (2019). The carbohydrate quantities of macarons were determined through the application of the formula proposed by Egan *et al.* (1981). The carbohydrate content (%) is calculated by subtracting the percentage of protein, fats, ash, and water from 100%.

The methodologies previously described were employed to evaluate the total carotenoids, phenolics content, flavonoids content and antioxidant activity of macarons enriched with CPP.

Color evaluation of CPP-enriched macarons

The Minolta Chroma meter CR 410 (Konica Minolta, Inc. Osaka, Japan) was used to determine color values, following the International Commission on Illumination L*, a*, b* scale.

The Chroma or color intensity (Chroma $=\sqrt{(a^*)^2+(b^*)^2}$) as well as the Hue Angle (Hue angle = arctan(b*/a*) for quadrant I (+a*, +b*), and ΔE ($\sqrt{(L^*-L_0)^2+(a^*-a_0)^2+(b^*-b_0)^2}$)) the total color difference were determined (Dag *et al*., 2017).

Textural parameters of CPP-enriched macarons

For the instrumental texture assessment, the Texture Profile Analysis (TPA) method was employed: the samples underwent a twofold penetration test utilizing a Brookfield CT3 Texture Analyzer (Brookfield Ametek, Middleboro, MA, USA) equipped with a 4 mm diameter metallic cylinder. The experimental conditions were established as follows: a penetration speed of 1 mm/s, a target distance of 15 mm, a trigger load of 0.067 N, and a load cell of 9.8 N. The deformation-stress response was analyzed using TexturePro CT V1.5 software (Brookfield Engineering Labs. Inc.).

Textural parameters, including firmness (N), adhesiveness, (mJ), cohesiveness (-), and springiness (mm), were determined according to Bourne (2002). Three replicates were performed for each sample.

Sensory evaluation of CPP-enriched macarons

The sensory analysis of the macarons was conducted using Bissar and Ozcan (2022) technique with same adjustments.

The samples underwent sensory examination using the hedonic test method (9-point hedonic scale). The evaluated parameters were External Appearance, Sectional Appearance, Color, Consistency, Taste, Odor, Aroma, Aftertaste, Firmness, and General acceptance. Twenty untrained panelists were selected for sensory analysis, including students, and staff members from the Faculty of Food Science and Engineering (Dunarea de Jos University of Galati). The sensory evaluation test was carried out in agreement with the decision no. 28/19.10.2022 of the Dunarea de Jos University Ethics Commission. The panelists were provided with details regarding the main goal of the study, along with the necessary procedures for handling personal data. In the sensory analysis laboratory, the tests were conducted. Porcelain dishes were utilized to present samples to the panelists. The use of water between samples didn't affect the sensory qualities of the other sample.

Statistical analysis

The determinations were made in duplicate, or triplicate and the results are presented as mean ± standard deviation (SD). The statistical analysis was conducted using Minitab Software for Windows, specifically Version 19.1. The ANOVA approach was employed to analyze the disparities between the extracts derived from CPP and the Tukey test was then performed at a significance level of 5% ($p < 0.05$).

Results and discussion

CPP characterization

The ultrasound-assisted method was used to extract the biological active compounds from CPP and the total carotenoids was 180.11 ±5.87 mg/100g DW. Regarding the β-carotene and lycopene contents, the average values were 150.12 ±1.22 mg/100g DW and 30.37±0.19 mg/100g DW, respectively.

The total polyphenolic content was 176.10 ±1.92 mg GAE/100 g DW, with a total flavonoids content of 62.78 ±0.88 mg CE/100 g DW. The extract showed a ABTS radical scavenging capacity of 1056.96±19.54 µM TE/g DW, with 71.68 ±1.19% inhibition of ABTS radical.

Umair *et al.* (2021) quantified the level of β-carotene (14.89 ± 0.40 µg/g), lutein (5.77 ± 0.19 µg/g), and lycopene (2.65 ± 0.12 µg/g) in carrot pomace, when 59% ethanol solution was used and the extraction was assisted by ultrasounds, for 16 minutes, at temperature of 29 °C.

The data in Table 1 indicates that CPP is a promising source of ash, fiber, carbohydrates, and β-carotenes. Consistent with the findings reported in the literature by Gazalli *et al*. (2013), CPP's protein and fiber contents registered values of 6.16% and 24.66% respectively.

The CPP color parameters were measured to be 69.08 for the L* value, 9.17 for the a* value, and 29.12 for the b* value. The values for Chroma, and hue angle were determined to be 30.53, and 1.26, respectively, based on color parameters. Results from the powder's color indices indicated that it was located in the first quadrant (+a*, +b*).

Table 1. Phytochemical, physico-chemical, and color characteristics of carrot pomace powder (CPP).

Parameters	CPP powder
Total Carotenoids (mg/100g DW)	180.11 ±5.87
β-caroten (mg/100g DW)	150.12 ±1.22
Lycopen (mg/100g DW)	30.37±0.19
Total flavonoids (mg CE/100g DW)	62.78 ±0.88
Total polyphenols (mg GAE/100g DW)	176.10 ±1.92
ABTS (µM TE/g DW)	1056.96±19.54
Inhibition (ABTS) %	71.68 ±1.19
Ash, %	10.67±0.04
Moisture, %	9.93±0.03
Crude protein, %	9.85±0.05
Crude Fat, %	0.21±0.02
Carbohydrates, %	69.33±0.11
Total dietary fiber, %	44.00±0.03
L*	69.08±0.55
a*	9.17±0.27
b*	29.12±0.17
Hue angle	1.26±0.02
Chroma	30.53±0.15

The composition of carrot pomace varies depending on the variety, agronomic conditions of the growing area, methods of extraction (such as solvent type, temperature, and light intensity), and applied measurement techniques.

Physicochemical characterization of CPP-enriched macarons

The enriched macarons were analyzed from a physicochemical point of view; the results being presented in Table 2. The addition of 10% and 20% of CPP increased the total protein, insoluble fibers, ash content, and energy values of the enriched macarons compared with the control.

The moisture and ash content of CPP-enriched products increased with CPP supplementation, being 5.70 and 1.70 for the M20 sample, respectively. According to the results presented in Table 2, macarons that have had carrot powder added registered a lipid level that is comparable to that of the control group. Regarding the protein and fiber content, a more significant rise was noted as the amount of carrot powder added increased. In regard to the carbohydrate content, there was a modest reduction noticed in correlation with the proportion of powder added. Additionally, macaron samples containing 20% CPP exhibited enhanced nutritional value in comparison to the control sample.

Table 2. Physicochemical characteristics of macarons with added carrot pomace powder (CPP) (C – control sample, M10 and M20 - samples with 10 and 20% (*w/w*) added CPP).

Physical-Chemical Characteristics	C	M10	M20
Proteins, g/100 g	11.20±0.20[c]	12.60±0.23[b]	13.90±0.25[a]
Lipids, g/100 g	18.40±0.13[a]	18.50±0.26[a]	18.60±0.29[a]
Carbohydrates, g/100 g	63.90±0.30[a]	61.90±0.35[b]	60.10±0.38[c]
Insoluble fibers, g/100 g	6.60±0.08[c]	8.10±0.10[b]	9.70±0.17[a]
Moisture, g/100 g	5.50±0.04[a]	5.60±0.07[a]	5.70±0.10[a]
Ash, g/100 g	0.90±0.03[c]	1.40 ±0.05[b]	1.70±0.09[a]
Energetic value: Kcal/100 g	479.2±0.10[b]	480.70±0.11[a]	482.80±0.12[a]
kJ/100 g	2003.06±0.10[b]	2009.33±0.10[a]	2018.10±0.10[a]

Means on the same row that do not share a letter are significantly different ($p < 0.05$).

In a study conducted by Prashant and Shere (2017), it was shown that the moisture, crude fiber, and ash content of wheat blend CPP cookies increased while the proteins and carbohydrates levels decreased with the percent of added CPP. The cookies exhibited no significant change in their fat content.

Characterization of phytochemicals of CPP-enriched macarons

To emphasize the enhanced quality of macarons, varying proportions of CPP (10% for M1 and 20% for M2) were included. Subsequently, the phytochemical composition and antioxidant activity were assessed. The findings are displayed in Table 3. The findings demonstrated that including CPP powder into the macaron samples significantly increased the concentrations of total carotenoids, total flavonoids, and total phenolic compounds.

A statistically significant increase ($p<0.05$) was seen due to this addition, which was directly proportional to the quantity of CPP used. As the powder amount rose from 10% to 20%, the quantities of phytochemicals and antioxidant activity increased substantially. While the richness of CPP with such elements is generally recognized, our findings in Table 1 indicated that CPP contains β-carotenes at a concentration of 150.12 (mg/100g). Enhancing the CPP concentration led to a significant improvement of antioxidant activity (43.80–52.50%) in the supplemented macarons. The products containing 20% CPP had the greatest levels of bioactive and antioxidant activities among those examined. The observed trend may be ascribed to the high concentration of the CPP, resulting in improved extraction of antioxidant-active chemicals.

Table 3. Phytochemical characteristics and antioxidant activity of carrot pomace powder (CPP)-enriched macarons (C – control sample, M10 and M20 - samples with 10 and 20% (*w/w*) added CPP).

Phytochemical contents	Macarons sample		
	C	M10	M20
Total carotenoids (mg/100 g DW)	-	18.30±0.71^{b}	35.20±0.96^{a}
Total flavonoids (mg CE/100 g DW)	29.30±1.03^{c}	34.10±1.09^{b}	38.40±1.04^{a}
Total polyphenols (mg GAE/100 g DW)	52.60±1.29^{c}	55.20±1.26^{b}	57.80±1.17^{a}
Antioxidant activity % Inhibition ABTS	31.60±1.07^{c}	43.80±1.15^{b}	52.50±1.19^{a}

Variations in letters for the same parameter (per line) indicate statistically significant variations in means ($p < 0.05$).

Ahmad *et al.* (2016) reported enhanced phytochemicals levels and antioxidant activity of cookies with 10, 15 and 20 % added CPP. Bansal *et al.* (2022) reported that β-carotene in cookies enhanced with carrot powder varied from 13.27 to 583.01 µg/100 g for both the control and the cookies enriched with carrot powder. Variations in the quantity of β-Carotene may be attributed to the use of distinct ingredients and varying quantities of carrot powder throughout the food preparation process. The results presented in Table 3 indicate the improved quality of macarons observed when CPP is added, as evidenced by the increased concentrations of carotenoids and polyphenols.

Color evaluation of CPP-enriched macarons

The quality of macarons, as perceived by consumers, is associated with certain characteristics such as color, non-crumbly texture, and crispy consistency. The current investigation found that the attractive hue of the CPP had a substantial impact on the visual and chromatic properties of the developed macarons, as indicated in Table 4. The analyzed color characteristics were lightness (L*), red-green component (a*), blue-yellow component (b*), Chroma, Hue angle and color variation (ΔE) and are presented in Table 4.

It could be noticed that lightness and yellowness are highest for the control sample, while the value of redness is lower for the control sample when it is compared to the samples with added CPP. When CPP concentration is increased, the L* and b* values are reduced the a* value is raised in the developed macarons. The color of the cookies darkened in exact proportion to the amount of CPP. This impact agrees with results of Ahmad *et al.* (2016) in cookie with carrot pomace. The Chroma, which represents the intensity and level of color saturation, registered the highest value for the control sample and the lowest in the CPP samples. The value of hue angle variated proportionality with the received color and included hue angles below 10º (Mahdavee Khazaei *et al.*, 2014). ΔE is the attribute of total color change ranging from 58.24 to 79.53 and decreased with CPP addition.

Table 4. Colorimetric parameters of the enriched macarons: C – control sample, M10 and M20 - samples with 10 and 20% (*w/w*) added CPP).

Sample	C	M10	M20
L*	76.71±0.37^{a}	55.61±0.30^{b}	50.70±0.28^{c}
a*	7.94±0.04^{c}	12.01±0.08^{b}	13.47±0.10^{a}
b*	19.43±0.22^{a}	26.32±0.18^{b}	25.31±0.12^{c}
Chroma	20.99±0.21^{a}	28.93±0.08^{b}	28.67±0.11^{c}
Hue angle	1.18±0.02^{a}	1.14±0.01^{b}	1.08±0.01^{c}
ΔE	-	22.48±0.21^{b}	27.18±0.18^{c}

Different letters in a raw for the same analyzed parameter show significant differences between means ($p < 0.05$).

Textural properties of CPP-enriched macarons

The textural attributes are crucial features of food products that contribute to the assessment of their quality and acceptance. For the textural analysis of CPP-enriched macarons, the textural parameters determined were firmness, adhesiveness, cohesiveness, and springiness and are presented in Table 5.

Table 5. Textural parameters of the enriched macarons: (C – control sample, M10 and M20 - samples with 10 and 20% (*w/w*) added CPP).

Textural parameters	C	M10	M20
Firmness, N	5.66±0.09^{c}	7.41±0.02^{b}	9.06±0.05^{a}
Adhesiveness, mJ	0.15±0.01^{c}	0.62±0.01^{b}	0.87±0.03^{a}
Cohesiveness,-	0.11±0.02^{c}	0.25±0.01^{b}	0.35±0.01^{a}
Springiness, mm	0.52±0.01^{b}	1.02±0.03^{ab}	1.42±0.02^{a}

The presence of a, b and c superscript of each textural parameter indicates significant differences between the samples with $p < 0.05$, based on the Tukey test.

Significant differences ($p< 0.05$) were observed for the samples with CPP addition in terms of firmness, adhesiveness, cohesiveness, and springiness. Addition of CPP significantly increased the firmness of macarons. This could be owned to the structure of the samples, which is more aerated in the control, leading to a lower resistance to deformation. Similar trend was reported by Prashant and Shere (2017). The hardness of the cookies increased in direct correlation with the quantity of CPP included into the flour mixes. Adhesiveness showed values ranging between 0.15±0.01 and 0.87±0.03 mJ for control sample and for M20 sample.

Cohesiveness refers to the ability of a sample to resist a second deformation, therefore indicating the strength of the internal bonds among the individual components of the samples (Bourne, 2002). In the control sample, the cohesiveness initially measured 0.11 but then rose to 0.25 and 0.35 as the quantity of carrot powder increased. Therefore, it is possible to see a direct correlation between cohesiveness and both firmness and the concentration of additional powder. This correlation may suggest a reduced ability to develop adequately during mastication. The springiness of material samples is indicated by their capacity to recover from the deformation achieved during the initial penetration cycle (Bourne, 2002). Hence, the springiness of the samples exhibits a positive correlation with the concentration of the additional substance, which is linked to the materials' solid behavior. Furthermore, the inclusion of CPP has shown advantageous benefits on textural characteristics.

Sensory evaluation of CPP-enriched macarons

The developed macarons were subjected to sensory analysis using a 9-point hedonic scale. The results are shown in Figure 1. The analysis evaluated sensorial attributes such as: Appearance, Appearance in section, Firmness, Color, Consistency, Taste, Odor, Aroma, Aftertaste, and General acceptability.

Sensory analysis of the macaron samples showed that the addition of carrot powder did not affect the acceptability of the products as perceived by the panelists. Positive assessment was received from panelists. The taste, aftertaste, and aroma of the macarons CPP-enriched were all determined to be acceptable.

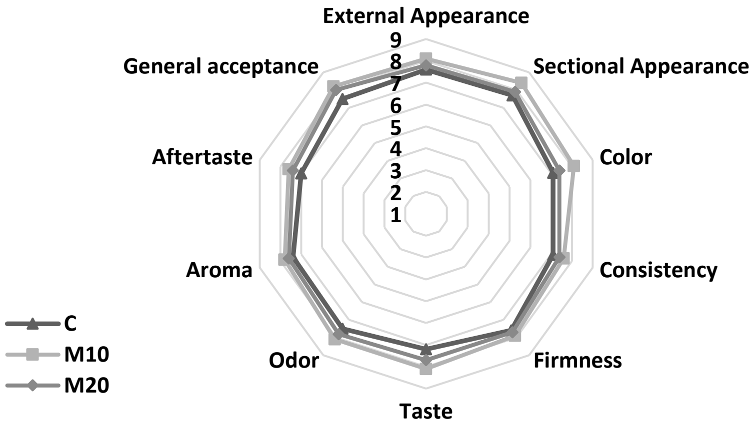

Figure 1. Comparative diagram of the sensory attributes specific to macarons: C – control sample, M10 and M20 - samples with 10 and 20% (*w/w*) added CPP)

The use of CPP led to creating an attractive yellow to brown color in the product (Figure 2). Macaron samples with 20% powder (M20) achieved the highest color score, emphasizing its more vibrant and appealing brown hue.

Vénica *et al*. (2020) found that the inclusion of 1% CP was considered acceptable for enhancing flavor and color. The study by Prashant and Shere (2017) confirmed that the addition of carrot powder had positive effects on the sensory acceptability of cookies. Cookies with 10% CPP were found to be most acceptable due to attractive appearance and better taste and flavor.

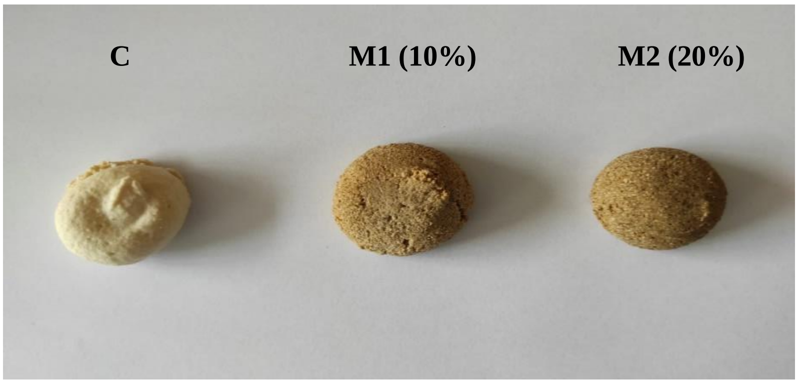

Figure 2. Images of the macarons without carrot pomace powder (CPP), control (C); macarons with 10% CPP (M10); macarons with 20% CPP (M20).

The addition of CPP up to 10% in macaron received a “like very much (8)” liking score on appearance, taste, odor, aroma, texture, aftertaste, and overall acceptability in comparison with control sample by the panelists (Figure 1). The samples that received the highest scores in all 10 characteristics were M10 macaron with 10% CPP.

The appearance of the macaron samples was characterized by pieces with regular shapes, round semi-glossy surfaces, smooth, and not burnt. In the section, they were well baked with uniform layers, without gaps. The taste was pleasant, sweet, and specific to the product without foreign smells or tastes. Normal smell, specific to the assortment of macarons. The consistency of the macarons was specific to the product, noting the crunchy, tender, non-crumbling consistency.

Color and texture of macarons were considerably influenced by the added carrot pulp powder. Thus, the color become darker with the increasing of powder amount while the texture become harder. Similar results were reported by Kumari and Grewal (2007), who found that the addition of 30% carrot pulp in whole flour biscuits determined texture hardening and color darkening in biscuits.

Figure 3 illustrates the products and qualities within a singular plane, offering a comprehensive perspective of the interrelations between products and attributes.

By analyzing Figure 3, we can observe that the characteristics located in the upper-right quadrant are represented by aroma, taste, aftertaste, and general acceptance, which have positive contributions on axis F1. The arrangement of these sensory attributes indicates that product M10, which is nearest to these traits and situated on the positive side of the Biplot, is seen favourably by customers regarding aroma and taste. Also, external appearance, sectional appearance, color, odor, firmness, and consistency have positive contributions on axis F1. The two axes explained 73.82% of the total variance. Since all sensory attributes were exclusively linked to the same axis, F1, the control was neutral. The biplot analysis facilitates the accurate positioning of the three macaron samples according to their sensory attributes. It also facilitates the distinction between sensory properties through positive correlations, as well as among sensory attributes and macaron samples.

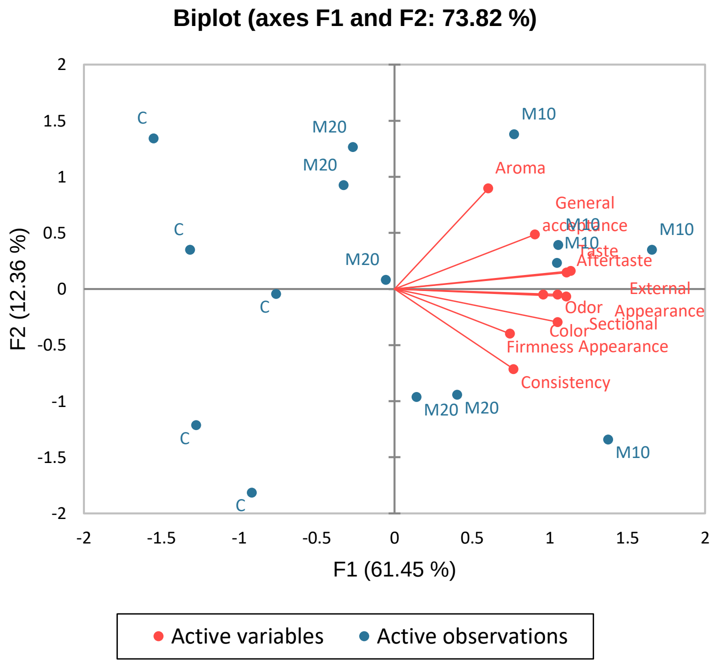

Figure 3. Illustration of the correlation of sensory attributes by Principal Component Analysis (PCA).

Analyzing the results of the sensory evaluation of the value-added macarons samples, it is noted that the M10 variant was the most appreciated by the panelists, having a balanced, pleasant taste, smell and aroma, with a compact, fine consistency. Thus, carrot powder is a natural colorant and suitable ingredient for the preparation of macaron samples with improved functional and antioxidant properties, the obtained products being well accepted by the panelists.

The innovative aspect is represented by the use of different proportions of carrot powder 10% and 20%, when obtaining new assortments of macarons cookies. The value-added products thus obtained are differentiated by superior sensory and nutritional characteristics. The nutritional and functional properties of these products are due to the addition of carrot powder rich in phytochemical compounds (fiber, β-carotene).

Conclusions

The present study demonstrated a substantial concentration of protein, fiber, and β-carotenes in carrot pomace powder and highlighted the importance of macarons as an appropriate food matrix for the incorporation of a natural ingredient (carrot pomace powder-CPP). This led to enhanced physico-chemical and sensorial properties of the products. The inclusion of CPP in the formulation of macarons led to the development of cookies with enhanced antioxidant properties and sensory attributes.

From the nutritional point of view, the macarons obtained from carrot powder have higher ash content, protein and crude fiber content than the control samples, but a lower amount of carbohydrates. The findings suggest that including carrot pomace in macarons can substantially augment their nutritional fiber content and improve their antioxidant qualities while maintaining their visual attractiveness and flavor.

This indicates that juiced carrot pulp generated from the juice industry could be successfully used in the preparation of macarons with high antioxidants and dietary fiber content.

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