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ORIGINAL RESEARCH PAPER

DEVELOPMENT OF VALUE-ADDED MUFFINS USING CARROT POMACE POWDER AS A NATURAL PIGMENT

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Abstract

Carrots (*Daucus carota L.*) are very nutritious root vegetables that include a variety of bioactive substances such as antioxidants, carotenoids, vitamins, and dietary fibers. Carrot pomace (CP) is rich in β-carotene and is a useful by-product that may be used to improve food products like cakes, biscuits, and bread at reasonable costs. This study aimed to investigate the use of CP powder as a natural pigment for producing muffins. The effect of adding CP powder at various percentages (0-5%) to muffin recipes was evaluated for its influence on nutritional content, texture, color, taste, and phytochemical properties. The study showed that CP powder addition resulted in muffins with enhanced fiber content, antioxidant properties, and sensory acceptability. Moreover, the carrot powder ensured a natural color to muffins, improved their apperance, and had remarkable antioxidant activity. The findings of this research contribute not only to the development of healthier and more visually appealing bakery products, but also to their sustainability by significantly reducing food waste. The study addresses the health and environmental risks associated with artificial colorants by providing promising insights into the possible use of carrot pomace powder as a natural pigment in various food applications, paving the way for a more sustainable future in food production.

Keywords: carrot by-products, nutritional enrichment, carotenoids, antioxidant activity, muffins

Introduction

Natural bioactive compounds have drawn much attention lately due to their possible biological benefits and practical advantages. Hence, researchers and companies are

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very interested in studying various residues, wastes, or by-products derived from the food processing industry, which are abundant, cost-effective, renewable, and sustainable reservoirs of bioactive substances. The food industry consistently explored novel approaches to improve products' nutritional value, while addressing relevant environmental issues. In this context, the use of the food by-products as functional ingredients offers a potentially effective strategy to accomplish both goals. (Nguyen and Scarlett 2016).

The biennial root vegetable carrot (*Daucus carota L.*) is a member of the *Apiaceae* or *Umbelliferae* families. Orange carrots are the most preferred cultivar due to their high α- and β-carotene content, contributing to provitamin A activity. Carrots are classified as a vitamin-rich food and are a notable source of natural bioactive compounds such as phenolics, polyacetylenes, fibers, and carotenoids, as well as ascorbic acid and tocopherols (Surbhi *et al.*, 2018). Carrots are regarded as a functional food with considerable health-promoting qualities, including antioxidant, antimutagenic, anti-diabetic, anti-hypertensive, and anticarcinogenic activities, since they contain an appreciable amount of a range of different compounds (Ikram *et al.*, 2024).

The Food and Agriculture Organization (FAO) estimates that 43 million tons of carrots and turnips are produced for human consumption annually on 1.15 million hectares worldwide. Between 2007 and 2017, the global output increase of turnips and carrots was 28.75%. Asia is the world's largest producer of turnips and carrots, turning out 27.572 million tons, or 64.37% of the world's total production. Europe comes in second with 21.49%, followed by North and South America (8.47%) and Africa (4.80%) (FAO, 2017).

Up to 50% of the the carrots used as raw materials in various industrial processing areas is wasted. These wastes are primarily used as fertilizer and animal feed, or they are dumped into landfills, which has a negative impact on the environment. Nonetheless, significant quantities of useful residual molecules in this waste have been connected to several health and nutritional advantages (Nicolle *et al.*, 2003).

The amount of waste carrot pomace produced globally is about 175,000 tons per year. The term "carrot pomace" describes a residual product left behind after processing carrots, usually after extracting the carrot juice or using another processing technique. After being processed in the industry, carrot pomace makes up 30% to 50% of the raw material and is remarkably rich in useful compounds (Bao & Chang, 1994). It comprises carrot pulp, skins, and other leftovers (Liu *et al.*, 2023). The specific components could vary based on the type of carrot and on the processing methods used. Carrot pomace is a by-product that is high in nutrients and bioactive compounds, suc as dietary fiber, vitamins, minerals, and antioxidants (lutein and β-carotene) (Singh *et al.*, 2021). Carotenoids and dietary fiber extraction were the main goals of earlier attempts to make carrot waste more valuable (Surjadinata *et al.*, 2017). In fact, carrot wastes' most valuable substances are considered carotenoids, while fiber and phenolics are other important components (Schieber *et al.*, 2001; Singh *et al.*, 2006). Provitamin A carotenes are the most common carotenoids, consisiting of 1.9% of lutein and 75% and 23% of β- and α-carotene, respectively.

The carrot root segment has a heterogeneous distribution of β-carotene, with the phloem, or outer root, having the highest level, and the xylem having a significantly lower amount (Baranska *et al.*, 2006).

Innovative methods for recycling, reusing, and recovering these wastes are being developed in response to the increasing need for natural bioactive chemicals and renewable nutrient sources for the food and feed, pharmaceutical, and cosmetic industries (Teixeira *et al.,* 2014).

Carrot pomace can be added to baked goods, smoothies, soups, and infant food as an ingredient or natural food coloring and flavor enhancer (Arscott *et al.*, 2010).

Demand has grown for healthier baked goods, such as muffins and biscuits, which often contain high sugar and fat contents. Muffins are a popular sweet, spongy morning or evening snack, usually made using eggs, milk, sugar, oil, and wheat flour. Muffins are popular, worldwide bakery items, offering a convenient and versatile matrix for incorporating a large variety of functional ingredients. However, nowadays, those who are interested in gluten-free foods and those who are intolerant to gluten are interested in fruits and vegetables, most low-fat dairy products, gluten-free flours, beans, seeds, legumes and nuts in their natural, unprocessed forms (Nachay, 2010).

The objective of the present study was to create enriched muffins using carrot pomace (CP) powder (0-5%) with the goal of introducing natural coloring, antioxidants, and other bioactive compounds. The study also investigated the impact of CP powder supplementation on the muffins' phytochemical content, sensory characteristics, color, and texture. This study assesses the practicality of including carrot pomace as a functional ingredient in bakery products, aiming to improve nutrition and reduce waste in the food sector.

Materials and methods

Carrot pomace powder preparation

Carrots were bought from Galați local market. After washing, the carrots were cut into cubes (of 5 mm±0.2 length) using a kitchen knife. Carrot pomace was recovered following juice extraction using a domestic MJ-M176P juice extractor (Panasonic Manufacturing Berhad, Malaysia). Carrot pomace freeze-drying was done using an Alpha 1-4 LD plus equipment (Christ, Germany). The temperature of -40 ± 1◦C and the pressure of 0.10 ± 5 mBar were automatically established. The raw material was freeze-dried for 48 h at a temperature of -42°C up to a relative humidity of 8±0.5%. Following freeze-drying, the pomace was finely powdered (~ 1 mm) using a blade grinder and stored in a glass container with an airtight lid at room temperature in the dark.

Materials and reagents

Hexane, acetone, acetonitrile, ethylacetate, Folin-Ciocalteu reagent, [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, aluminum chloride, sodium nitrite and sodium carbonate were obtained from Sigma Aldrich Steinheim (Darmstadt, Germany).

Extraction

The phytochemicals were extracted from the powdered carrot pomace using the ultra-sound-assisted extraction method, as described by Umair *et al.* (2021) with minor modifications. To summarize, a volume of 10 mL of a 3:1 v/v n-hexane/acetone solvent mixture or 70% ethanol (exclusively for extracting total polyphenols and flavonoids) was mixed with 1.0 g of CP powder. The sample was then ultrasonically treated for 30 minutes at 40°C and 40 kHz (Smart MRC LLC, Holon, Israel). The resulting crude extract was recovered and centrifuged for 10 minutes at 10°C and 6000 rpm. Following separation, the supernatant was examined to determine the concentrations of lycopene, β-carotene, total carotenoids, total flavonoids, and total polyphenols from CP powder.

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

The contents of lycopene, β-carotene, and total carotenoids were measured by spectrophotometric technique described by Nistor *et al.* (2022), which was slightly modified. To summarize, a volume of 0.2 milliliters of extract was dissolved in the extraction solvent mixture and then added to the UV quartz cuvette. The absorbance was measured at $\lambda = 450$ nm for total carotenoids, $\lambda = 470$ nm for β-carotene, and $\lambda = 503$ nm for lycopene, using a Libra S22 UV-VIS spectrophotometer (Biochrom, Cambridge, UK). The results were expressed as mg/g dry weight (DW). The Equation 1 was used to quantify the lycopene, β-carotene, and total carotenoids:

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

where A=Absorbance of the sample; Mw =molecular weight (536.873 g mol^{-1}); Df=sample dilution rate; Vd=solution volume; m=Mass/weight of concentrated extract; L=length of the optical path of the cuvette (1 cm); Ma=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

A revised method developed by Dewanto *et al.* (2002) was used to calculate the total flavonoid concentration. In summary, a mixture was created by mixing 250 µL of CP extract with 2500 µL of ultrapure water and 75 µL of 5% $NaNO_2$ solution. The solution was subsequently allowed to react for five minutes. Then, 150 µL of a 10% solution of aluminum chloride, 500 µL of a 1 M solution of sodium hydroxide, and 3000 µL of ultrapure water were added. The absorbance of the mixture was measured at a wavelength of 510 nm. The results were expressed as mg catechin equivalents (CE)/g DW.

Determination of total polyphenol content

The Folin-Ciocâlteu method was used to assess the total polyphenolic contents (Bolea & Vizireanu, 2017). Briefly, 7.9 mL of deionized water, 100 µL of the CP extract (1 mg/mL), and 0.5 mL of the Folin-Ciocalteu reagent (0.25 mol/L) were first mixed. After 10 minutes, a 1.5 mL 20% Na_2CO_3 volume was introduced to the mixture. Subsequently, the whole mixture was left to react in a dark environment for one hour, after which the absorbance was measured at a wavelength of 765 nm. The total polyphenolic content was calculated as the gallic acid equivalent per gram of dry weight (mg GAE/g DW).

Determination of antioxidant activity

The colorimetric technique of Gheonea *et al.* (2020) was slightly modified for the ABTS Radical Cation Scavenging Activity determination. Briefly, aliquots of 1 mL ABTS+ solution were diluted with 40 mL ethanol to obtain an absorbance of 0.700±0.02 at 734 nm. Further, 0.02 mL of CP extract was mixed with 1.98 mL ABTS solution. After that, the mixture was left at room temperature in the dark for 2 hours. The decrease in the absorbance of the mixture was spectrophotometrically read at $\lambda = 734$ nm. The results were expressed as percentage of inhibition, and as µM Trolox Equivalent per gram of dry weight (µM TE /g DW). Trolox was used as standard (0.125 mg/mL). The percentage of inhibition was determined based on the equation (2):

$$\text{ABTS scavenging activity (\%)} = \frac{A_c - A_s}{A_c} \text{ x } 100 \qquad (2)$$

Ac is the absorbance value of the ABTS solution only, As is the absorbance value of the ABTS solution mixed with CP extract.

HPLC investigation of the carotenoids from the CP extract

The individual carotenoids were characterized using chromatographic analysis, following the methodology outlined by Gavril *et al.* (2024). The chromatographic profile of the extract was obtained using a Thermo Finnigan Surveyor HPLC system equipped with a DAD UV–visible detector (Finnigan Surveyor LC, Thermo Scientific, Waltham, MA, USA). The equipment was operated by the Xcalibur software version 2.0.7. The carotenoid components included in the carrot extract were examined using a Lichrosorb RP-18 (5 µm) Hibar RT 125–4 column, with the analysis performed at a wavelength of 450 nm. The main carotenoids were identified and measured using calibration curves of the available standards, specifically lutein, α-carotene, and β-carotene.

Preparation of the value-added muffin samples

Value-added muffins contain the following ingredients: rice flour (93 g), coconut butter (37 g), green sugar (36 g), 2 eggs (70 g), water (43 g), baking powder (5 g), salt (3 g) and carrot powder (2.5% (7.17 g) – sample coded M1, and 5 % (14.35 g) – sample coded M2.

The muffin dough was prepared using the following steps: first, the whole eggs were mixed for 6 minutes. The coconut butter was mixed separately with salt and green sugar for 5 minutes, then homogenized with eggs, rice flour, and baking powder. Finally, the carrot powder previously hydrated with water (relative to the total amount of raw materials) was added. The composition thus obtained was mixed for 10 minutes at 300 rpm to get complete incorporation of the mix, until becoming uniform in terms of color and texture, thus obtaining the muffin dough. The obtained dough was then left to cool in the refrigerator for 12 hours. Baking was done at 185

°C for 15 minutes in a convection oven with forced air circulation. The muffins were packed in vacuum bags at 800 mbar and stored at 25 °C for 21 days to conduct physicochemical and phytochemical analyses. A control sample (C) without carrot powder was also made for comparison, by following the same procedure.

Physicochemical and phytochemical characterization of the value-added muffins

The physicochemical characteristics of CP powder and muffin samples, such as their moisture, protein, fat, ash, total sugar, and calorie content, were assessed using the AOAC protocols outlined by Horwitz and Latimer (2010).

The total carotenoid, phenolic content, and antioxidant activity of value-added muffins enhanced with CP powder were assessed using previously described techniques.

Color evaluation of value-added muffin samples

A MINOLTA Chroma Meter CR-410 (Konica Minolta, Osaka, Japan) was used to analyze the colors of the control and CP-enriched muffin samples. L* (whiteness/darkness), a* (redness/greenness), and b* (yellowness/blueness) were the color values measure on the samples. 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 ($\sqrt{(L^{*})^2 + (a^{*})^2 + (b^{*})^2}$)) the total color differences were determined (Dag *et al.*, 2022).

Textural parameters of value-added muffin samples

The texture characteristics of enhanced muffins were assessed using the Texture Profile Analysis (TPA) technique, which was applied using a Brookfiel texture analyzer, model CT3-1000 (Brookfield Ametek, Middleboro, MA, USA). The core of the muffins was used for t esting after the tops and bottoms were removed. The core was cut into cylindrical pieces, having a diameter of 15 mm and a height of 21 mm. A cylindrical device with a diameter of 21.5 mm was used for compression. Two compression cycles were applied, without holding, over a distance of 3 mm at a speed of 0.5 mm/s. The textural parameters analyzed were firmness, adhesion, cohesiveness, elasticity, and chewability.

Each sample was subjected to three determinations. The samples were maintained at room temperature for two hours before testing.

Sensory evaluation of value-added muffin samples

With a few minor adjustments, the muffins were analyzed in agreement with Lu *et al.* (2010). Twenty untrained panelists were selected for the 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 information about the study's overall goal and the protocols for managing personal data. Informed consent forms were provided that clearly outlined the voluntary nature of participation, the right to withdraw at any time, and their confidentiality.

They evaluated randomly presented value-added muffins identified with random three-digit numbers for external appearance, sectional appearance, porosity, color, consistency, taste, smell, aroma, aftertaste, firmness, and general acceptability using a 9-point hedonic scale. The samples were provided at room temperature of 25 °C. To minimize residual effects, panelists were instructed to rinse their mouths with water between samples, while evaluating the samples in a testing area.

Statistical analysis of data

Every experiment was carried out at least three times. The values are displayed as mean ± standard error and are reported on a dry basis. One-way analysis of variance (ANOVA) was used to identify statistically significant differences between the results, and the Tukey test was then performed at a significance level of 5% ($p < 0.05$). Minitab version 19 (Romsym Data, Bucharest, Romania) was used as the statistical software program for the analysis.

Results and discussion

CP powder phytochemical characterization

The bioactives were extracted from CP powder using the ultrasound-assisted method and the results are provided in Table 1. The total carotenoids were 185.03 ±6.45 mg/100g DW. Regarding the β-carotene content, the average value was 152.52 ±1.07 mg/100g DW, while for lycopene, a 31.24±0.23 mg/100g DW value was obtained.

The total polyphenolic was 1.75 ±0.02 mg GAE /g DW, with a total flavonoid content of 0.62 ±0.08 mg CE/g DW. The extract showed an ABTS radical scavenging capacity of 1052.81±20.46 µM TE/g DW, with 71.73 ±1.28 % inhibition of ABTS radical.

Hernandez-Ortega *et al. (*2013) revealed a lower content of total carotenoids of 65.74–92.64 mg/100g and β-carotene of 6.83–15.81mg/100g when subjecting the carrot pomace to conventional extraction with 80% acetone. Also, the total carotenoid content when applying the microwave-assisted extraction to the waste obtained at carrot juice processing was 4.13 mg/g carrot waste powder (Elik *et al.*, 2020).

Borowska *et al.* (2017) examined the fresh, dried, and lyophilized carrot pomace. They reported the maximum amount of phenolics in the lyophilized carrot pomace (1188.04 mg GAE/100g DW), followed by convective dried (1013.02 mg GAE/100g DW) and fresh pomace (987.88 mg GAE/100 g DW). They used a mixture of 80% methanol (*v/v*) and 20% water (*v/v*) for extracting the bioactive compounds, and reported for the lyophilized carrot pomace a β-carotene content of 43.50 ± 2.13 mg/100 g, and DPPH scavenging activity of 13.74 ± 1.56 µmol DPPH /mg.

Carrot cultivars, growth season, soil, maturity, and genetic variables are the key determinants of the total carotenoid content (Gajewski *et al.*, 2010). Variations in the amount of β-carotene among cultivars with distinct genetic compositions ranged from 7 to 11 times (Seljasen *et al.*, 2013).

Table 1. Phytochemical and physicochemical characteristics of CP extract

Parameters	CP extract
Total Carotenoids (mg/100g DW)	185.03 ±6.45
β-caroten (mg/100g DW)	152.52 ±1.07
Lycopene (mg/100g DW)	31.24±0.23
Total flavonoids (mg CE/g DW)	0.62 ±0.08
Total polyphenols (mg GAE/g DW)	1.75 ±0.02
ABTS (µM TE/g DW)	1052.81±20.46
Inhibition (ABTS) %	71.73 ±1.28
Ash,%	10.68±0.03
Crude fat, %	0.2±0.03
Crude protein, %	9.86±0.03
Total carbohydrates (%), including	69.32±0.03
Total dietary fibre, (%)	44.1±0.03
Moisture (%)	9.94±0.03
L*	69.05±0.61
a*	9.11±0.12
b*	29.09±0.13
Hue angle	1.27±0.01
Chroma	30.45±0.14

The L*, a*, and b* color parameters were 69.05±0.61, 9.11±0.12, and 29.09±0.13, respectively. The parameter b* represents the intensity of the blue-to-yellow color, where a positive value indicates a tendency towards yellow hues in the CP powder. The observed Chroma correlated with the parameter b*, indicating that the yellow hue exhibited the highest degree of expressiveness in determining the color of the CP powder. Based on the findings about the values of a* and b*, it was seen that all data points were positioned inside the first quadrant (+a*, +b*), indicating a tendency towards yellow and red shades, which is a distinctive feature of carotenoids. Comparable to the findings of the current investigation, Alam *et al.* 2013 found values of 65.0 for L*, 8.6 for a*, and 20.6 for b* parameters for carrot pomace that was convectively dried (65°C). Also, Luca *et al.* (2022) obtained for the Sirkana carrot pomace powders dried in a convector using hot air (60°C) for 24 hours the following values: 69.44 ± 0.01 for L*, 9.25 ± 0.06 or a*,19.56 ± 0.04 for b* parameters.

Table 1 also presents the CP powder's approximate composition. Carrot pomace is an important source of carbohydrates, protein, and total dietary fibers, rendering it a highly valued nutritional resource. Carrot pomace powder was also characterized by Bamal and Dhull (2024) and reported to contain 68.8 % total dietary fiber, 8.75 % moisture, 4.25 % protein, 0.2 % fat, and 1.2 % ash. Bao and Chang (1994) reported that carrot pomace consists of around 4-5% protein, 8-9% reducing sugar, 5-6% minerals, and 37-48% total dietary fiber (based on dry weight). Consequently, carrot products are recognized as a valuable source of dietary fiber. The dietary fiber components of carrot pomace consist of pectin (3.88%), hemicellulose (12.3%), cellulose (51.6%), and lignin (32.1%) (Surbhi *et al.*, 2018).

However, the phytochemical content of the extract can be influenced by the cultivar, different extraction parameters (such as the type of solvent, temperature, and pH), agronomic conditions, and the measurement methods employed. Current study indicates that CP powder exhibits high levels of antioxidant-active phytochemicals, making it a valuable addition in food products for the purpose of minimizing agro-industrial wastes.

HPLC Analysis of the Carotenoids from the CP Extract

A chromatographic investigation was performed to describe the CP extract and assess the existence of carrots' biologically active compounds, specifically carotenoids. The chromatographic profile of the carrot pomace extract is presented in Figure 1. The following compounds were identified: lutein (1), α-carotene (2), and β-carotene (3).

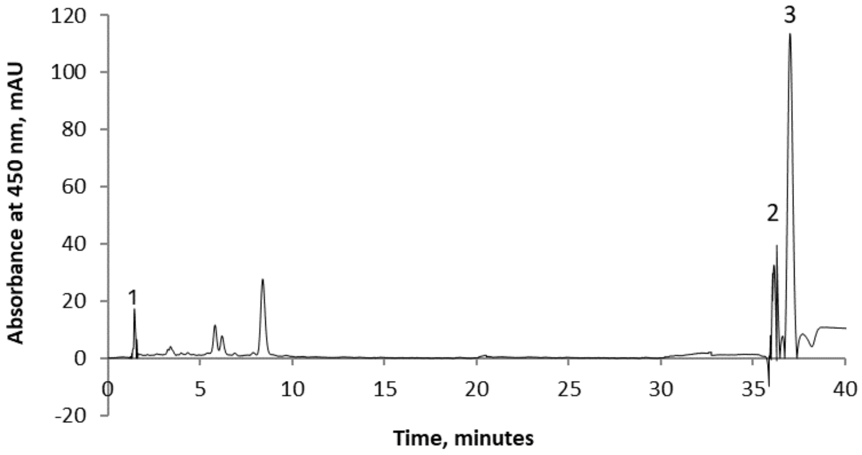

Figure 1. The chromatographic profile of the carrot pomace powder at 450 nm lutein (1), α-carotene (2), β-carotene (3)

According to Sharma *et al.* (2012), the most prevalent carotenoids found in carrot processing waste are β-carotene. Lau *et al.* (2018) performed a chromatographic investigation on an extract derived from carrot peels, and the carotenoids identified as the major compounds were β-carotene, lycopene, and lutein. In another study on fresh orange carrots (*Daucus carota* var. sativa) nanoemulsion extracts, Jalali-Jivan *et al.* (2021) identified four carotenoids (lutein, lycopene, α-carotene, and β-carotene) by RP-HPLC analysis. Kaur *et al.* (2022) used microwave-assisted extraction with green solvents (ethanol, ethyl acetate, acetone) and identified β carotene as the main component in the culled carrot waste. The main variations between these compounds could result from fluctuations in the cultivar and seasonal conditions, which might impact the level of biologically active compounds.

Physicochemical characterization of supplemented muffin samples

The value-added muffins were analyzed from the physicochemical point of view, and the results are presented in Table 2.

Table 2. Physicochemical characteristics of the muffin samples (C - muffins without added CP powder, M1 and M2 - muffins with 2.5 and 5% (*w/w*) CP powder)

Physico-chemical characteristics	**C**	**M1**	**M2**
Protein, g/100 g	4.30±0.20^{c}	5.40±0.60^{b}	6.30±0.40^{a}
Lipids, g/100 g	42.20±5.30^{a}	42.30±3.50^{ab}	42.40±6.10^{a}
Total carbohydrates, g/100 g	22.60±1.30^{a}	21.00±0.01^{b}	19.20±0.21^{c}
of which Insoluble fibers, g/100 g	1.60±0.01^{c}	2.30±0.01^{b}	3.10±0.02^{a}
Moisture, g/100 g	30.90±2.30^{c}	31.30±1.20^{b}	32.10±2.90^{a}
Energetic value, kcal/100g	484.20 ±0.01^{a}	481.70 ± 0.02^{a}	477.40±0.01^{b}
kJ/100 g	2023.96±0.01^{a}	2013.51±0.02^{a}	1995.53±0.01^{b}

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

The results presented in Table 2 indicate that muffins supplemented with carrot powder are characterized by a lipid content similar to that of the control muffins. From the point of view of the protein content, a slight increase is observed concerning the percentage of carrot powder added. A slight decrease in the carbohydrate content was observed with the increase of the CP addition, which is consistent with Phebean *et al.* (2017) on the biscuits enriched with carrot powder and cowpea flour. Muffin samples with 5% carrot powder also showed improved nutritional value compared to the control sample. This addition includes significant contributions to the content of insoluble fibers. Thus, the positive effects of carrot powder on the nutritional quality of gluten-free muffins are mainly related to the high fiber and protein content. However, the energy value of the powder-added product is close to that of the conventional product. Adding carrot powder increases the nutritional value of the muffins and adds value to the juiced carrot pulp. Thus, dried carrot pulp is a rich source of fiber (10-20%), antioxidants, minerals, carotenoids, and ascorbic acid that benefit human health.

Salehi *et al.* (2016) also observed the same trend in the sponge cake-type product with carrot powder. Carrot powder is incorporated into the sponge cake recipe in varying amounts, ranging from 0% to 30%, to increase its fiber content. The precise quantity of carrot powder used is determined by the sponge cake’s specifications and desired qualities. Thus, a cake using carrot powder will have higher moisture levels, ash, complex carbohydrates, and β-carotene. Carrot powder also improved the cakes’ absorption of water and fiber content (Salehi *et al.*, 2016). The addition of carrot pomace improved the nutritional characteristics of the cake by raising the levels of carotenoids, phenolic acids, and antioxidant activity, while also altering its physicochemical features (Kamiloglu *et al.*, 2017).

Characterization of bioactive potential of supplemented muffins

The phytochemical composition and antioxidant capacity of the muffin samples supplemnetd with different levels of CP powder were analyzed to emphasize their enhanced nutritional properties and biological value (Table 3).

Table 3. Phytochemical characteristics and antioxidant activity of muffin samples (C-muffins without CP powder, M1 and M2 - muffins with 2.5 and 5% (w/w) CP powder)

Phytochemical contents	**Muffins sample**		
	C	**M1 (2.5%)**	**M2 (5%)**
Total carotenoids (mg/100g DW)	-	113.07±1.31^{b}	133.41 ±1.42^{a}
Total flavonoids (mg CE/g DW)	32.01±1.89^{c}	36.82±1.38^{b}	40.16±1.72^{a}
Total polyphenols (mg GAE/g DW)	84.53±1.96^{c}	96.98±1.50^{b}	101.03±1.87^{a}
Antioxidant activity µM TE/ g DW (ABTS)	979.03±6.49^{c}	1060.49 ±8.60^{b}	1201.28 ±9.40^{a}

Different letters for the same parameter (per line) show significant differences between means ($p < 0.05$).

Table 3 indicates that the muffin samples supplemented with increasing amounts of CP powder, exhibited increasing levels of carotenoids and polyphenols, which were further corroborated by the antioxidant activity values.

The *in vitro* antioxidant activity of the value-added muffins was positively impacted by the bioactive components originating from the powdered CP. They had higher levels of antioxidant activity than the muffins used as a control.

Our results comply with experimental observations of Bas-Bellver *et al.* (2024), and Hernandez-Ortega *et al.* (2013). Hernandez-Ortega *et al.* (2013) increased the amount of phytochemicals in cookies by including hot-dried or microwave-dried carrot pomace powders. Cookies were manufactured using carrot pomace powders instead of 30% wheat flour as in a classic cookie recipe. This substitute showed a high level of phenolic chemicals and carotenoids. The cookies prepared using microwave-dried carrot pomace powder exhibited the highest levels of gallic, ferulic, epicatechin, and β-carotene acids.

To improve the fiber content of the cookies made with wheat flour, Kumar and Kumar (2011) added carrot pomace to the formulation. Various quantities of dehydrated carrot waste (ranging from 0% to 9%) were incorporated into a mixture of refined wheat flour, fat, sugar, and water. As the amount of carrot pomace in the cookies grew, so did the moisture content, hardness, and Hunter's L* (light vs. dark) and a* (red vs. green color) values; however, the b* (yellow vs. blue color) value showed no trend of change.

The results presented in Table 3 confirm the added value of the muffins with the addition of carrot powder, by enhancing the overall concentration of carotenoids and polyphenols, which allows obtaining food products with exceptional antioxidant activity. It is evident that muffins containing a higher concentration of carrot powder (5%) exhibit the most significant levels of phytochemical components, which can be attributed to the addition of carrot powder.

The significant quantity of compounds with high biological qualities found in carrot waste makes it a valuable and sustainable source of natural bioactive substances. Owing to their potential applications in disease prevention, treatment, and health promotion, the scientific community is becoming more interested in the antioxidant activity and content of bioactive chemicals found in carrot waste.

Color evaluation of supplemented muffin samples

Table 4 displays the results of the measurement of the color characteristics (L*, a*, b*, Chroma, Hue angle, ΔE) after the processing of the value-added muffin samples.

According to the a* and b* results, all data were placed in the first quadrant (+a*, +b*), suggesting a tendency to reddish and yellowish, characteristic of carotenoids. Thus, the value-added muffin samples had a reduction in lightness (L*), and lower values indicate a darker color. The color of the muffins changes to orange due to he inclusion of CP powder, which contains beneficial substances such as β-carotene and orange pigments.

Table 4. Colorimetric parameters of the muffin samples: C—muffins without CP powder, M1 and M2—muffins with 2.5 and 5% (w/w) CP powder added

Sample	**L***	**a***	**b***	**Chroma**	**Hue angle**	**ΔE**
C	67.99±0.01^{a}	1.34±0.04^{b}	36.43±0.02^{a}	36.45±0.02^{a}	1.53±0.02^{a}	77.15±0.02^{a}
M1	59.95±0.01^{ab}	4.83±0.09^{ab}	30.97±0.02^{b}	31.37±0.02^{b}	1.42±0.02^{a}	67.66±0.02^{b}
M2	58.37±0.05^{b}	4.98±0.06^{a}	27.38±0.02^{c}	27.80±0.02^{c}	1.40±0.02^{a}	64.65±0.02^{c}

Different letters on the column for the same analyzed parameter show significant differences between means ($p < 0.05$).

According to the results presented in Table 4, the value-added muffins (M1 and M2) are characterized by shades of yellow (+b*), and the color intensity is directly proportional to the percentage of carrot powder added. This aspect demonstrates that carrot powder has a high coloring power, and can be used to improve the color of muffins while increasing the consumer appeal of this product and its nutritional value. Our investigation noticed that the fortified muffins exhibited a darker coloration due to the presence of β-carotene, a pigment responsible for coloration. The degree of darkening was determined by the quantity of CP powder added and the interactions between polyphenols and other components (Xu & Diosady, 2000).

The results are similar to reports from other researchers such as Salehi et al. (2016). Carrot powder was added to sponge cake dough in different proportions, from 0% to 30%, to produce a high-fiber cake. The preferred choice was the sample with 10%

carrot powder, which exhibited a more vibrant and distinct crumb color with shades of red and yellow. The observed alteration in the color of the crumb in the sample containing 10% carrot powder can be ascribed to the pigments present in carrots. Carotenoids, which are pigments naturally occurring in carrots, are accountable for the orange hue of the vegetable. Combined with carrot powder, these carotenoids can give baked goods a reddish-yellow crumb (Salehi *et al.*, 2016).

Textural properties of supplemented muffin samples

The textural parameters measured on the value-added muffins were firmness, adhesion, cohesiveness, elasticity, and chewability, as presented in Table 5.

Table 5. Textural parameters of the supplemented muffins: C- muffins without adding CP powder, M1, and M2 - muffins with adding 2.5 and 5% (w/w) CP powder.

Textural parameters	C	M1	M2
Firmness, N	6.10±0.17^c	8.52±0.24^b	9.47±0.38^a
Adhesion, mJ	0.07±0.01^c	0.15±0.01^b	0.30±0.09^a
Cohesiveness	0.77±0.02^a	0.54±0.03^b	0.45±0.01^c
Elasticity, mm	2.59±0.01^a	2.23±0.05^{ab}	1.81±0.07^b
Chewability, mJ	10.43±0.39^a	9.74±0.25^b	8.95±0.84^c

Lowercase letters per row highlighted differences between the analyzed samples. Mean values that share a letter are not significantly different (p>0.05).

Firmness (N) was expressed as the maximum force recorded during the first penetration cycle (Bourne, 2002). The firmness of the muffins showed higher values in the case of the samples supplemented with carrot powder (8.52±0.24 N for the M1 sample, 9.47±0.38 N for the M2 sample), compared with the control sample. The stabilizing effect of the fibers from the carrot powder can explain these results. A similar behavior can be observed for adhesion. The addition of fibers resulted in a higher water absorption capacity of the dough, leading to an increase in adhesion from 0.07±0.01 mJ for the control sample to 0.15±0.01 mJ, and 0.30 ±0.09 mJ for the value-added muffin samples.

Regarding cohesiveness, it is seen that the values decrease when powder is added, likely because the solid particles in the powder disrupt the dough matrix, resulting in a more friable texture. This effect can also be ascertained in accordance with the recorded values of elasticity and chewability: the discontinuities in the matrix lead to the irreversible deformation of the samples during compression, because of their breaking. The elasticity was reduced by 16% for the sample with a 2.5% powder addition and by 43% for the sample with a 5% powder addition, compared to the control sample. At the same time, the energy required for chewing decreases by 7% and 17%, respectively.

Similar values of textural parameters were reported for sponge cake by Salehi *et al.* (2016) and Yüceer (2020). Carrot powder was added to sponge cake batter in different proportions, from 0% to 30%, to create a high-fiber cake. The cake's hardness, chewiness, and gumminess decreased when using 10% dry carrot powder

(Salehi *et al.*, 2016). Changes in texture characteristics were detected when 20% of the carrot powder was added to the control cake. The values for inflexibility, chewiness, cohesiveness, resilience, and springiness were 1.88, 0.35, 1.37, 0.81, and 0.54 times, respectively, as reported by Jafari *et al.* (2017).

Sensory evaluation of supplemented muffin samples

From a sensory point of view, the muffins were analyzed using the following attributes: external appearance (Figure 2), sectional appearance, porosity, color, consistency, taste, smell, aroma, aftertaste, firmness, and general acceptability, using the scoring scale from 1 to 9.

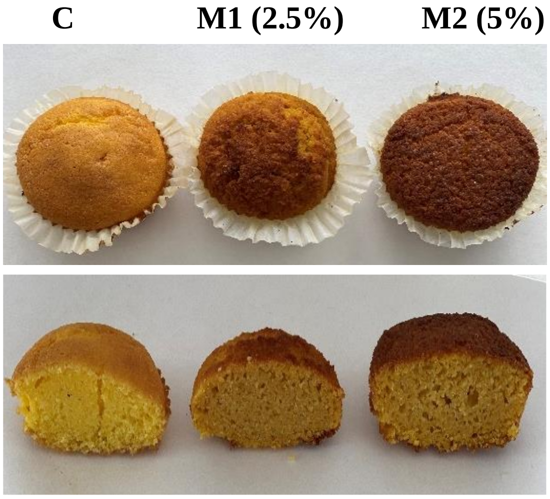

Figure 2. Images of the muffins without CP, control (C); muffins with 2.5% CP (M1); muffins with 5% CP (M2).

Analyzing the results of the sensory evaluation of value-added muffins (Figure 3), it is noted that the variants of muffins with carrot powder were evaluated as having a balanced, pleasant taste, smell, and color corresponding to carrots, with a soft consistency. The addition of carrot powder contributed to the formation of a more airy core structure. Also, the panelists did not perceive the intense flavor of the carrot pulp, regardless of the analyzed sample. All the samples proposed for analysis were positively appreciated by the panelists. However, following the sensory analysis, the muffins with 5% carrot powder were the most appreciated, at the opposite pole being the muffins without adding carrot powder. Thus, carrot powder is suitable for preparing rice flour muffins with improved functional and nutraceutical properties.

Regarding porosity, an important characteristic of muffins, its highest values were observed for M2 muffins with 5% carrot powder addition. These results indicate that the value-added gluten-free muffins made with rice flour could be a healthy alternative for people suffering from gluten intolerance. Based on the sensory analysis, it can be stated that adding carrot powder up to 5% provides results with a higher degree of acceptability regarding the taste, appearance, porosity, and color of the analyzed products compared to the control muffins. Durrani *et al.* (2011) revealed that adding carrots to candies with a honey base resulted in positive sensory scores.

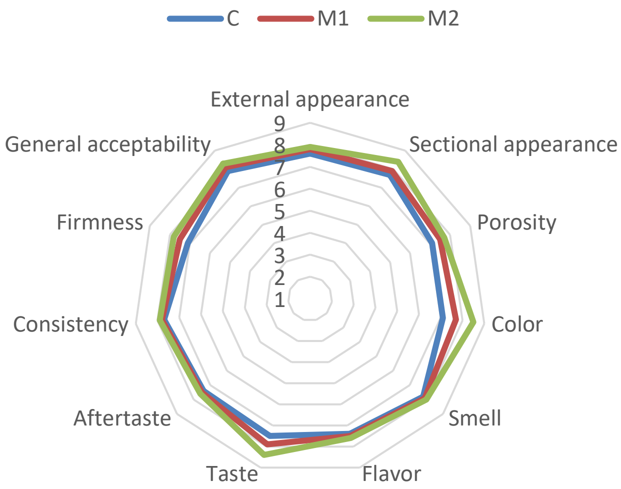

Figure 3. Comparative diagram of the sensory attributes specific to muffins: C- muffins without the addition of CP powder; M1 and M2 – muffins with 2.5 and 5% powder of CP

Cookies with an enhanced carotenoid concentration and a pleasant orange color were acceptable. Other researchers have also confirmed that adding carrot pomace powder to cookies improved their antioxidant and sensory qualities (Aglawe *et al.*, 2018; Sharma *et al.*, 2017; Ahmad *et al.*, 2016).

Conclusions

The results demonstrated that the CP represents a significant reservoir of bioactive chemicals with notable antioxidant potential for being a good source of dietary fiber and β-carotenoids, among other nutrients. The study showed that using CP powder enhances the bioactive content and antioxidant capability of muffins, enhancing its nutritional profile. The sensory study indicated that the panelists found the enhanced hue of the muffin samples to be favorable. Additionally, the sensory investigation revealed that increasing the CP powder to 5% increased muffin acceptance among consumers. Thus, it can be concluded that including CP powder at a concentration of up to 5% will effectively yield fiber-enriched muffins with desirable sensory attributes. The textural analysis indicated that the addition of CP caused the increase of firmness, and adhesion, while the cohesiveness, chewability and elasticity were lower compared with the control sample, which can be attributed to a weaker binding between the components.

In conclusion, the by-products obtained from the industrial processing of carrots have good potential to be used as alternatives to artificial colors and as a reservoir of antioxidants. CP can be efficiently employed to manufacture value-added muffins rich in fiber, resulting in enhanced nutritional profiles and satisfactory sensory attributes.

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