Nutritional and bioactive composition of different carrot pomace varieties

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Abstract

Introduction. Carrot pomace is a by-product with functional value that is usually discarded. This work aimed to evaluate the properties of carrot pomace from four varieties: Baltimore, Belgrado, Niagara and Sirkana.

Materials and methods. The proximate composition was determined according to international standards; fiber was determined by acid and alkaline digestion; total polyphenols, β-carotene and antioxidant activity were measured spectrophotometrically; color was analyzed by reflectance and molecular properties were evaluated by FT-IR spectrometry.

Results and discussion. Carrot pomace nutritional value differed significantly ($p < 0.05$) in function of variety. The highest protein, lipids, ash and fiber content and the lowest carbohydrates amount was observed in Sirkana carrot pomace. Sirkana variety also presented the greatest total polyphenols and β-carotene content, while the highest antioxidant activity was observed for Baltimore carrot pomace. Sikrana pomace was also distinguished by its highest hue angle and yellow index, while Baltimore exhibited the greatest white index. FT-IR spectra confirmed the presence of polyphenols, fibers and β-carotene as main bioactive compounds. The lowest transmittance for almost all the main peaks identified were for Niagara, followed by Sirkana, Baltimore and Belgrado. Niagara carrot pomace powder presented different vibrations at 2929, 2853 and 2375 cm^{-1} compared to the other samples. The relationships between variables indicated that Baltimore carrot pomace can be differentiated from the other varieties by its dry matter content, white index, carbohydrates content and antioxidant activity, while Sirkana can be distinguished through its total polyphenols, ash and fiber content. Strong positive correlations ($p < 0.05$, $r > 0.95$) were observed among some of the chemical components (proteins and fibers, ash and β-carotene) and between lipids content and color parameters (yellow index and hue angle).

Conclusion. These results suggest that carrot pomace characteristics depend on variety. This by-product can be successfully used as a functional ingredient to enhance staple food nutritional value.

Introduction

The carrot (*Daucus carota* L.) is a widely cultivated root vegetable that can be effectively processed into such products as juices, nectars, and soft drinks. The most important carrot cultivator in the European Union is Polonia, followed by France and Germany. Romania ranks 6th in the European Union with a carrot cultivation area of 7570 ha in 2021 and a total production of 203.3 thousand tons (National Institute of Statistics: Bucharest, Romania, 2022).

Carrot pomace (CP), the main by-product of carrot juice processing, with a yield of 30–50% concerning the total raw material (Rezvani and Goli, 2024), is usually disposed of in the environment or treated as a substance of low economic value, being often used as animal feed or fertilizer (Virtanen et al., 2017). This by-product of carrot juicing is a valuable source of carotenoids, polyphenols, dietary fiber, vitamins, minerals, and other nutrients that can be used to enhance the quality of food products by improving their nutritional content (Bajraktari et al., 2024; Garg et al., 2024; Halim et al., 2024) or functional properties (Richards et al., 2024).

The high fiber content (20.09–33.34%), carbohydrates (46.55–58.95%), proteins (6.87–9.14%), and ash (5.29–5.89%) found in carrot pomace derived from different carrot varieties (Luca et al., 2022; Rezvani and Goli, 2024) revealed a sustainable opportunity to improve the nutritional and functional properties of food products by its addition, and in the same time, the reduction of food waste with positive impact on the environment. Regarding the fiber content, it was reported that carrot pomace contains approximately 55% total dietary fiber on a dry weight basis (Sharma et al., 2012). Moreover, both insoluble and soluble fibers, with the ideal levels of pectic polysaccharides, hemicellulose, and cellulose are found in carrot pomace (Richards et al., 2024; Yadav et al., 2017). These components play an essential role in food manufacturing, affecting the water-holding capacity, gel-forming ability, and fat-binding capacity of dietary fiber. The consumption of fiber helps reduce blood pressure and the risks of chronic diseases, including heart disease and diabetes, and improves cholesterol levels, along with the feeling of satiety (Anderson et al., 2009).

As a rich source of bioactive compounds, particularly carotenoids, such as β-carotene (Elik et al., 2020; Richards et al., 2024), carrot pomace can be used as a functional ingredient or as natural food coloring and flavor enhancer (Arscott and Tanumihardjo, 2010; Oncică et al., 2024). The total carotene content in pomace may be up to 2 g/kg dry matter depending on processing conditions (Singh et al., 2006). In a study on the composition of bound polyphenols from carrot dietary fibers and its antioxidant capacity, forty-two bound polyphenols compounds were identified, promoting their potential to develop functional food (Dong et al., 2021). The bioactive substances like polyphenols presents in carrot pomace are related to the antioxidant activities and prebiotics properties of carrot dietary fiber (Liu et al., 2019) and could potentially play a role in gastrointestinal and colonic health (Mall and Patel, 2024).

Carrot pomace can therefore be used as a functional ingredient for the development of pasta production with enhanced nutritional, functional, and sensorial properties, affecting also the color of pasta which has a very strong influence on the final choice of consumers.

The aim of this paper was to evaluate the nutritional profile in terms of dry matter, protein, fat, ash, lipids and carbohydrates, bioactive compounds such as β-carotene and total polyphenols content, molecular characteristics and color properties of four carrot pomace varieties.

Materials and methods

Materials

Carrots from four varieties (Baltimore – Ba, Belgrado – Be, Niagara – Ni and Sirkana – Si) were purchased in 2024 from a local producer from Romania and the juice was extracted by using a domestic blender. The resulting pomace was dried at 60 °C until less than 6% moisture content was achieved, then it was ground and sieved to obtain carrot pomace powder with particle size < 200 µm.

Nutritional profile determination

The nutritional profile in terms of dry matter, protein, fat, ash of carrot pomace powders was analyzed using international methods (ICC): moisture (101/1), fat (104/1), protein (105/2), and ash (105/1). The total crude fiber content was evaluated by acid and alkaline digestion using an automatic analyzer (Fibertec 2010, Tecator, Hillerod, Sweden). The carbohydrate content was calculated by difference.

Total polyphenols content determination

The extract preparation was carried out according to the method described by Ziobro et al. (2022). A total of 6 g of sample powder was dissolved in 30 mL of 80% ethanol, and the mixture was stirred for 120 min using a shaker. After centrifugation for 15 min at 4500 rpm, the supernatant was collected and subsequently used for the analysis of phenolic compounds (Ziobro et al., 2022).

In a test tube, 0.2 mL of the sample extract was mixed with 2 mL of Folin-Ciocalteu reagent and 1.8 mL of 7.5% Na_2CO_3. The mixture was kept in the dark at 20°C for 30 min before measuring the absorbance at 750 nm. A Shimadzu 3600 UV-VIS-NIR spectrophotometer (Tokyo, Japan) was used, and the calibration curve was prepared using gallic acid (R^2 = 0.99). The results were expressed as mg GAE/100 g of sample weight.

β-carotene content evaluation

For the extraction of β-carotene, 0.1 g of the sample was weighed and quantitatively transferred into a 10 mL volumetric flask, and the volume was adjusted with $CHCl_3$. The mixture was sonicated for 15 min at 20°C and then centrifuged at 1500 × g for 10 min. The extraction was repeated twice, and the combined supernatant was filtered through a sterile 0.45 µm syringe filter and diluted 3:10 mL. The absorbance of the extracts was measured at 450 nm using a UV-Vis spectrophotometer (Jasco V630). A calibration curve was prepared with β-carotene standard (R^2 = 0.99), and the results were expressed as mg β-carotene/100 g of product.

Optical properties analysis

The optical properties were measured by reflectance, using the CIE Lab system, with a Konica Minolta CR-400 device (Konica Minolta, Tokyo, Japan). The hue angle (H), yellow index (YI) and white index (WI) were calculated based on a* – red-green intensity, b* – yellow-blue intensity and L* – luminosity parameters by using Equations 1–3.

$$H = arctg\frac{b^*}{a^*}. \quad (1)$$

$$YI = 142.86\left(\frac{b^*}{L^*}\right). \quad (2)$$

$$WI = 100 - \sqrt{\left(100 - L^*\right)^2 + a^2 + b^2} \quad (3)$$

Molecular properties determination

The FT-IR spectra used for the molecular characterization of carrot pomace powders were collected in the range of 650 – 4000 cm^{-1}, using a Thermo Scientific Nicolet iS20 instrument (Waltham, MA, USA), at a resolution of 4 cm^{-1} and 32 scans. The spectra were processed with the Omnic software.

Statistical analysis of data

All the experimental results were expressed as mean ± SD (n = 3). The software used was XL STAT 23 version and the means were compared by ANOVA with the Tukey test ($p \leq 0.05$). To highlight the relationships between variables, a Principal Component Analysis (PCA) was performed.

Results and discussion

Nutritional profile

The content of protein, ash, lipids, dry matter, fiber and carbohydrates in carrot pomaces is displayed in Figure 1. Belgrado and Baltimore varieties exhibited the highest dry matter content, while Niagara and Sirkana showed significantly lower values. The highest content of protein was observed for Sirkana carrot pomace, followed by Niagara, Belgrado and Baltimore with the lowest content. Niagara carrot pomace showed the smallest lipids content, while Sirkana was the richest in lipids (Figure 1). The ash content also showed significant differences ($p < 0.05$) among carrot pomace varieties, with the highest value registered for the Sirkana variety and the lowest for Niagara. Significant differences were obtained for fiber content ($p < 0.05$) and it varied in the following order: Sirkana > Niagara > Belgrado > Baltimore. The greatest value for carbohydrates was exhibited by Baltimore carrot pomace, while the lowest content was observed for the Sirkana variety. The values obtained for protein, fiber, ash and lipid content are in line with those reported previously in the literature: 4–5% protein, 8–9% reducing sugar, 5–6% minerals and 20–48% total dietary fiber ≈ 1.3 % ash and ≈ 70% carbohydrates (Surbhi et al., 2018). Another study reported values of 6.54% for moisture, 6.50% for protein, 2.12% lipids, and 5.12% ash for carrot pomace used to enhance cookies nutritional value (Bellur Nagarajaiah and Prakash, 2015). Haq et al. (2016) stated that the content of fibers and minerals depends on carrot size since a bigger root size led to an increased formation of fibers and accumulation of minerals. Genetic factors have a great importance for a species' adaptation to different environmental conditions. Carrot chemical composition depends on both biotic and abiotic factors during the entire production stage and the genotypes dictate the quantity of bioactive compounds, with key gene being implied in differentiation especially regarding sugars and vitamins (Paudel and Subedi, 2023).

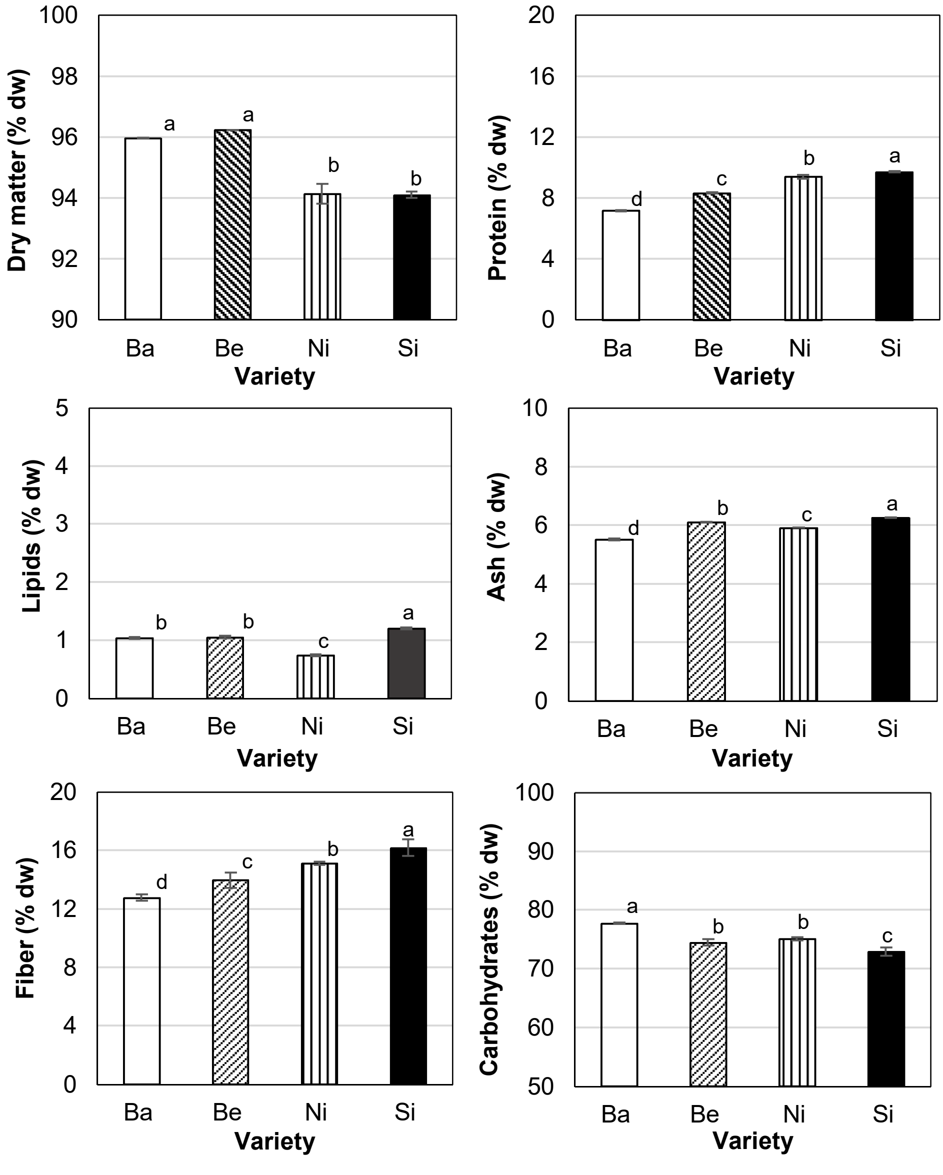

Figure 1. Proximate composition of carrot pomace varieties:
Ba – Baltimore, Be – Belgrado, Ni – Niagara, Si – Sirkana

The total polyphenol content of carrot pomace powders is presented in Table 1. Significant differences were observed between the carrot varieties ($p<0.05$), with the highest polyphenol content found in the carrot pomace from the Sirkana variety. The results are similar to those reported by Hernández-Ortega et al. (2013) for carrot pomace (14.12-18.41 mg GAE/g, depending on the drying method applied). The polyphenol content depends on both the variety and the methods used for juice extraction and processing of the resulting pomace (Purkiewicz et al., 2020).

Among the carrot varieties, pomace from the Sirkana and Belgrado varieties had the highest β-carotene content (Table 1). The results were consistent with those reported in the literature by Begum et al. (2023) for carrot pomace (11.83 mg/100 g). The β-carotene content varies depending on the carrot variety, as demonstrated by Alasalvar et al. (2001). Significant differences ($p < 0.05$) were found between samples regarding antioxidant activity. The highest value was observed in the carrot pomace from the Baltimore variety. Antioxidant activity was attributed to the presence of bioactive compounds, such as proanthocyanidins, flavonoids, and anthocyanins, and is influenced by the carrot variety (Ma et al., 2013).

Table 1

Bioactive compound content and antioxidant activity of carrot pomace from different varieties

Sample	TPC (mg GAE/g)	β-carotene (mg/100 g)	AA (%)
Ba	21.45 ± 0.05 [b]	5.14 ± 0.01 [c]	19.66 ± 0.28 [a]
Be	19.55 ± 0.05 [d]	7.34 ± 0.00 [a]	11.10 ± 0.29 [d]
Ni	20.70 ± 0.00 [c]	6.74 ± 0.00 [b]	12.56 ± 0.36 [c]
Si	24.05 ± 0.05 [a]	7.34 ± 0.01 [a]	16.22 ± 0.21 [b]

Different letters in the same column indicate statistic difference between means at $p \leq 0.05$, Ba – Baltimore, Be – Belgrado, Ni – Niagara, Si – Sirkana, AA – antioxidant activity, TPC – total polyphenols content

The optical properties of carrot pomaces differed significantly ($p < 0.05$) among the studied varieties (Table 2). Whiteness index refers to the extent to which a surface resembles the characteristics of a perfect reflecting diffuser—an ideal surface that reflects light with equal intensity in all directions, without absorbing or transmitting any light. Yellow index indicates the degree to which the nuance of a surface shifts from a desired white (or colorless) state towards yellow.

Table 2

Optical properties of carrot pomace from different varieties

Sample	H	YI	WI
Ba	62.99 ± 0.24 [b]	280.28 ± 2.90 [b]	65.93 ± 0.20 [a]
Be	62.32 ± 0.30 [c]	272.32 ± 3.42 [c]	63.85 ± 0.09 [b]
Ni	56.36 ± 0.11 [d]	214.69 ± 0.86 [d]	58.66 ± 0.05 [d]
Si	64.69 ± 0.14 [a]	302.05 ± 1.90 [a]	62.56 ± 0.03 [c]

Different letters in the same column indicate statistic difference between means at $p \leq 0.05$, Ba – Baltimore, Be – Belgrado, Ni – Niagara, Si – Sirkana, WI – white index, H – hue angle, YI – yellow index, AA – antioxidant activity, TPC – total polyphenols content.

Niagara variety exhibited the lowest H, YI and WI values, while Sirkana showed the greatest H and YI (Table 2). WI varied among carrot pomace varieties in the following order: Niagara < Sirkana < Belgrado < Baltimore. The hue angle values located between 0 (red) and 90° (yellow) suggest the orange color of the samples. Sirkana exhibited a more yellow nuance (greater H value), while Niagara variety was more reddish (smaller H value). It was demonstrated that the content of pigments in carrots is affected by factors like genotype, growth temperatures, and storage conditions (Ahmad et al., 2019), which may explain the color variations in the four carrot pomaces studied. It was demonstrated that carotene content is correlated with yellow color (Rakcejeva et al., 2012). This fact is supported by our results since Sirkana carrot pomace is the richest in β-carotene and presents the highest Yi value.

FT-IR spectra of carrot pomace powders for the four varieties investigated are presented in Figure 2. The lowest transmittance values for almost all the peaks were obtained for the Niagara sample, followed by Sirkana, Baltimore and Belgrado. Sirkana showed the highest peak at 2929 cm^{-1} which may be explained by its highest β-carotene content (Table 2). The peak at 1556 cm^{-1} given by the C=C groups linked with CH_3, the peak at 1421 cm^{-1} and 1368 cm^{-1} assigned to the asymmetrical and symmetrical CH_3 bending (Joda et al., 2022) suggested the presence of β-carotene in the samples studied. Niagara and Sirkana carrot pomaces exhibited the highest peak at 1610 cm^{-1} which can suggest the content of pectin because in this region the peaks are given by C=C stretching vibrations (Jayesree et al., 2021). The presence of polyphenols can be indicated by the peaks at 3320 cm^{-1} generated by the –OH stretching vibrations (Sucheta et al., 2019). All the samples studied exhibited peaks at 1421, 1368, and 1107 cm^{-1} which may be given by the presence of cellulose (Szymanska-Chargot and Zdunek, 2013). Sikrana and Niagara carrot pomaces exhibited the highest protein content (Table 1), a fact confirmed by the highest peaks at 1556 cm-1 given by the N–H, C–N (Amide II) vibrations (Thummajitsakul et al., 2020).

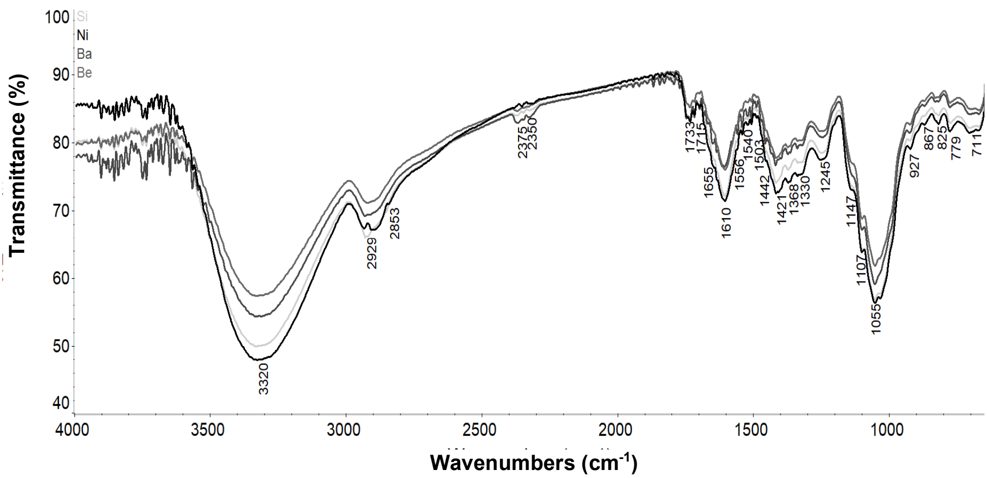

Figure 2. FT-IR molecular characteristics of carrot pomace from different varieties

The correlations between variables are listed in Table 3. Fiber content was strongly positively correlated with proteins ($p < 0.05$, $r = 0.98$). Lipids content was positively correlated with H and YI ($p < 0.05$, $r = 0.99$). Strong positive correlation ($p < 0.05$, $r = 0.97$) was obtained between ash and β-carotene. The antioxidant activity (AA) was strongly positively correlated with YI (p < 0.05, r = 0.99). Ash and carbohydrates were negatively correlated (p < 0.05, r = -0.99). Similar to our results, Riaz et al. (2022) reported significant positive correlation (p < 0.05) between carrot protein content and fiber. Lipids may influence the stability of carotenoids during processing and storage, potentially affecting the color intensity of carrot products (Mutsokoti et al., 2017). This could explain the correlation between lipids content and color parameters.

Table 3

Correlations between variables

Variables	DM	Proteins	Lipids	Ash	Fiber	CH	TPC	β-carotene	AA	H	YI	WI
Dry matter	1											
Proteins	-0.86	1										
Lipids	0.21	-0.07	1									
Ash	-0.42	0.80	0.34	1								
Fiber	-0.86	0.98*	0.10	0.82	1							
Carbohyd.	0.55	-0.87	-0.32	-0.99*	-0.89	1						
TPC	-0.61	0.43	0.56	0.29	0.59	-0.39	1					
β-carotene	-0.37	0.78	0.16	0.97*	0.76	-0.95	0.07	1				
AA	0.06	-0.46	0.39	-0.59	-0.32	0.52	0.56	-0.76	1			
H	0.32	-0.23	0.99*	0.19	-0.05	-0.16	0.51	0.00	0.48	1		
YI	0.26	-0.18	0.99*	0.22	0.01	-0.20	0.56	0.03	0.49	0.99*	1	
WI	0.77	-0.78	0.68	-0.37	-0.66	0.44	0.03	-0.48	0.58	0.78	0.75	1

Values marked with * are significant at $p < 0.05$,
DM – Dry matter; CH - Carbo hydrates; WI – white index, YI – yellow index, H – hue angle, AA – antioxidant activity, TPC – total polyphenols content

The relationships between variables are highlighted by the PCA (Figure 3).

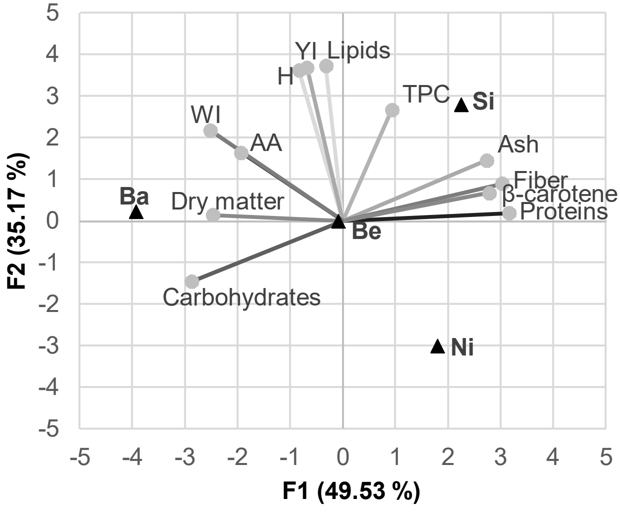

Figure 3. Principal Component Analysis bi-plot:
Ba – Baltimore, Be – Belgrado, Ni – Niagara, Si – Sirkana, WI – white index, H – hue angle, YI – yellow index, AA – antioxidant activity, TPC – total polyphenols content

A percent of 49.53% of data variability was explained by the first component (PC1) and 35.17% by the second one (PC2). Proteins, β-carotene, fiber, ash, dry matter, carbohydrates AA and WI were associated with PC1, while H, Yi, lipids and TPC were associated with PC2.

Baltimore variety is differentiated by the other samples by the content of dry matter, WI, AA and carbohydrates, white TPC, ash, fiber, β-carotene and proteins contribute to the differentiation of Sirkana variety from the other carrot pomaces. Baltimore sample was positioned in the left upper quadrant, Sirkana was positioned in the right upper one, while Niagara was positioned in the right lower quadrant. The position of the Belgrado sample in the middle of the graphic highlights its small contribution to data variability.

Conclusions

Carrot pomaces from different varieties were investigated. The results highlighted that the nutritional composition, color and the bioactive compound content of carrot pomace depend on the variety. The richest in protein, fiber, lipids, β-carotene and total polyphenols was the carrot pomace from Sirkana variety. These data confirm the opportunity to create new functional foods with enhanced antioxidant potential and fiber content by using carrot pomace. Further research will be directed towards the evaluation of carrot pomace impact on wheat flour dough and pasta quality.

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