Original scientific paper
Journal of Central European Agriculture, 2024, 25(1), p.223-233
DOI: /10.5513/JCEA01/25.1.4164

Nutritional quality of organically grown carrot (*Daucus carota* L.) and effect of processing

Nutritivna vrednost organski gajene mrkve (*Daucus carota* L.) i efekat termičke obrade

Nenad PAVLOVIĆ[1] (✉), Miloš MARJANOVIĆ[1], Jelena MLADENOVIĆ[1], Vladeta STEVOVIĆ[1], Mirjana PETROVIĆ[2], Ivana ŽIVKOVIĆ[3], Jasmina ZDRAVKOVIĆ[2]

[1] University of Kragujevac, Faculty of Agronomy in Čačak, Cara Dušana 34, 32000 Čačak, Serbia

[2] Institute for Forage Crops, Globoder, 37000 Kruševac, Serbia

[3] Institute for Vegetable Crops, Karadjordjeva 71, 11420 Smederevska Palanka, Serbia

✉ Corresponding author: nenadpavlovic@kg.ac.rs

Received: November 3, 2023; accepted: January 14, 2024

ABSTRACT

Organically produced food is gaining increased attention from consumers due to the belief that, besides being environmentally friendly, it also contains higher quantities of phytochemical components that play a protective role in human health. In this study, carrots grown organically by six different certified producers were analyzed. The antioxidant nutritional quality of fresh organic carrots, thermally processed juice at 70 °C and 90 °C, and dried slices (55 °C) was investigated. Variations in the concentration of vitamin C, β-carotenoids, total phenolic compounds (TPC), and total antioxidant activity (TAA) were observed depending on the producer and the method of thermal processing. The minimal losses of phytochemical components were observed during juice pasteurization at 70 °C, while the drying process resulted in the highest losses. Additionally, a significant positive correlation was identified among vitamin C, β-carotenoids, and TPC with TAA content.

Keywords: vitamin C, β-carotenoids, TAA, carrot

APSTRAKT

Organski proizvedena hrana izaziva sve više pažnje kod potrošača, jer se smatra da pored toga što proizvodnja ne ugrožava životnu sredinu sadrži veću količinu fitohemijskih komponenti koje imaju zaštitnu ulogu po ljudsko zdravlju. U ovom eksperimentu analizirana je mrkva uzgajana u organskom sistemu kod 6 različitih, sertifikovanih proizvođača. Ispitivan je nutritivni kvalitet kod sveže organski gajene mrkve, soka termički obrađenog na 70 °C na 90 °C i sušenih slajseva (55 °C). Utvđeno je da postoje razlike u sadržaju vitamina C, β-karotena, ukupnih fenola i ukupne antioksidativne aktivnosti u zavisnosti od proizvođača i izabranog načina termičke obrade. Najmanji gubici fitohemijskih komponenti tokom termičke obrade utvrđeni su pri pasterizaciji soka na 70 oC, dok najveći sušenjem. Zatim, izračunato je postojanje signifikantne pozitivne korelisanosti između vitamina C, β-karotena i fenola (TPC) sa ukupnom antioksidativnom aktivnošću (TAA).

Ključne reči: vitamin C, β-karotenoidi, TPC, TAA

INTRODUCTION

The carrot (*Daucus carota* L.) belongs to the Umbelliferae family and is among the most important vegetable species cultivated worldwide. Carrot roots are used both in human nutrition and as animal feed. They are commonly cooked and combined with other vegetables, used in the preparation of bouillon, soups, salads, pies, etc. (Upadhyay et al., 2008). Considered a healthy food, carrots are rich in vitamins, carotenes, minerals, and fibers (Ozcan and Chalchat, 2007; Upadhyay et al., 2008). Carrots are a significant source of β-carotene, a precursor of vitamin A (O'Neill et al., 2001; Berger et al., 2008). Carotenes, especially in the form of β-carotene, contribute to human health, serving as an alternative measure in preventing certain types of cancer (Block and Langseth, 1994; Astorg, 1997). The level of carotene in carrots depends on the variety, with the common orange type having the highest levels of α and β-carotene, while carrots of other colors exhibit different carotene compositions (Hammershoj et al., 2010). Additionally, carrots contain strong antioxidants such as phenols and vitamin C, which protect cells from the harmful effects of oxygen (Paulauskiene et al., 2006; Podsedek, 2007).

Carrot root is consumed in human diets in various forms, including fresh, as juice, canned carrots, dried carrot slices (chips), candy, kheer, halwa, powder, etc. (Raees-ul and Prasad, 2015). Different food processing methods can have varying effects on the biochemical content of the final product (Guldiken et al., 2016). Vegetable juices are known for being rich in vitamins, minerals, fibers, and having low caloric content. Recently, there has been an increased consumption of vegetable and fruit juices (Kaur et al., 2009). Carrot juice, in particular, is considered a natural and healthy source of α- and β-carotene, representing a generally nutritious product (Chen and Tang, 1998). Some studies indicate that organic carrot juice may contain higher levels of vitamin C, caffeic acid, and lutein compared to conventionally grown carrots. Carrot juice is recognized as a natural antioxidant, maintaining the high antioxidative activity of polyphenols even after processing (Hallmann et al., 2011; Tingting et al., 2013). Drying is one of the oldest methods of food preservation (Roberts et al., 2008). Dried carrots are used in instant soups, oil-free food preparation, and as a healthy snack (Lin et al., 1998). Moreover, dried carrot slices can be preserved for more than six months with minimal quality changes (Sra et al., 2011).

Vegetable cultivation can be implemented in various systems (Zdravković et al., 2010). The conventional system is the most prevalent method of vegetable cultivation worldwide, relying heavily on pesticides to achieve high yields and prevent plant diseases (Aktar et al., 2009). The potential toxic effects on human health are associated with pesticide overuse in conventional production systems. If technical recommendations are not adequately followed, the conventional system can be detrimental to human health and contribute to environmental pollution (Fernanda et al., 2016). An alternative to conventionally grown carrots is the organic system, even though it is often considered more expensive. Some studies indicate that crops grown in organic production systems have higher levels of protective substances, such as polyphenols, flavonoids, phenols, and antioxidants in general (Castro et al., 2014; Fernanda et al., 2016).

The object of this research was to determine the effect of different ways of thermal processing of carrot root on antioxidant nutritional quality. Furthermore, fresh juice and dried organic carrots produced at 6 different farms in Serbia were compared.

The objective of this research was to assess the impact of various thermal processing methods on the antioxidant nutritional quality of carrot roots. Additionally, a comparison was made between fresh juice and dried organic carrots obtained from six different farms in Serbia. The results obtained aim to offer valuable insights into the production of carrot products with elevated phytochemical content, including vitamin C, β-carotenoids, total phenolic compounds (TPC), and total antioxidant activity (TAA). This information can guide the selection of suitable thermal processing methods, benefiting consumers and the processing industry.

MATERIAL AND METHOD

Plant material

All the samples analyzed in this study were sourced from six distinct organic producers, each holding an organic certificate. These organic carrot samples are of the Nantes type. Geographically, the organic farms are situated in various locations in Serbia: Suvobor (SB), Taras (TS), Glozanj (GL), Padina (PD), Kikinda (KI), and Kisač (KS).

In this experiment, the analysis included fresh carrot roots, juice, and dried carrot slices. The carrot roots were thoroughly washed and then blended using a home blender (centrifugal juicer). The juice obtained was pasteurized in a water bath at two different temperatures (70 °C and 90 °C) for 15 minutes. To activate enzymes that impact quality, the organic carrot slices were blanched at 100 °C for 2 minutes. Subsequently, the prepared samples were dried in a home dehydrator at temperatures ranging from 50 °C to 55 °C.

Determination of vitamin C

The pale carrot juice was obtained by pressing 100 cm^3 of carrot juice and mixing with an equal quantity of (100 cm^3) solution of a mixture of HPO_3 and glacial acid CH_3COOH. Then, the mixture was filtered through creased filter paper. The first 5-10 cm^3 of the filtrated mixture was thrown away and the aliquot part was taken from the rest for further investigation. If necessary, the investigated sample was diluted with cooled boiled distilled water, so the aliquot part contained about 2 mg of ascorbic acid. The process of determining ascorbic acid in the sample: - 10 cm^3 of the filtrated sample (containing 5 cm^3 of juice and 5 cm^3 HPO_3 and glacial acid CH_3COOH) was applied to three Erlenmeyer dishes using a pipette. Each sample was titrated with Tillman's reagent (TR) solution until pale pink, for about 5 seconds. At the same time, the solution of TR was titrated and blind tested until pale pink (Cvijović and Aćamović-Đoković, 2005).

The content of ascorbic acid (mg/cm^3) = (V - V1) x T x 100/g,

where:

V – cm^3 of TR solution used for titration in trial testing

V1 - cm^3 of TR solution used in blind testing

T– titer solution TR (mg $C_6H_8O_6$/1 cm^3 TR solution)

g – juice volume in cm^3 in the aliquot part of the sample.

Total phenols content

Total phenols in the carrot ethanol extract of 20 g carrot juice, 100 cm^3 in ethanol were estimated according to the Folin–Ciocalteu method (Singleton et al., 1999). The extract was diluted to the concentration of 1 mg/mL, and aliquots of 0.5 mL were mixed with 2.5 mL of Folin–Ciocalteu reagent (previously diluted 10-fold with distilled water) and 2 mL of $NaHCO_3$ (7.5%). Aliquots were left for 15 minutes at 45 °C, and then the absorbance was measured at 765 nm with a spectrophotometer against a blank sample. Gallic acid (GA) was used to calculate the standard curve. The assays were carried out in triplicate; the results were the mean values ± standard deviations and expressed as mg of gallic acid equivalents per gram of dry extract (mg of GA/g).

Total antioxidant activity

Determination of total antioxidant activity by the DPPH method has been done spectrophotometrically model uv-vis MA9523-SPEKOL211 (Xu et al., 2010). 8 mg of DPPH (2,2-diphenyl-1-picrylhydrazyl) were dissolved in methanol (100 mL) to give a concentration of 80 g/mL. Serial dilutions were made from the stock solution (1 mg/mL) of extract. Solutions (2 mL each) were then mixed with DPPH (2 mL) and allowed to stand for 30 minutes to any reaction occurred, and the absorption was measured at 517 nm. Ascorbic acid was used as the reference standard and dissolved in methanol to make a stock solution with the same concentration of 1 mg/mL. The control sample was prepared to contain the same volume but without the test compound or reference antioxidants. A 95% per cent methanol was used as a blank. Three measurements were made.

Analysis data

Differences in growers have been determined according to the ANOVA model, and the significant difference was expressed by the LSD test. Differences among levels of phytochemistry components in fresh fruits and products, ratio fresh: dried, fresh juice, and dried: juice have been shown according to significant differences according to Tukey's test. The correlative ratio among the traits according to researched samples has been determined by applying the Pearson matrix at the significance level $P < 0.005$. The connection of samples and traits was done by multi-variation technique of PCA-Principal Component analysis using Statistical software: XLSTAT Version 2012.4.02 Copyright Addinsoft 1995-2012. The analysis was performed according to the average values of the researched parameters.

RESULTS AND DISCUSSION

Ascorbic acid (Vitamin C)

Carrot represents a significant source of vitamin C in the plant world. The biosynthesis of ascorbic acid in carrots occurs in nine steps following the D-Man/L-Gal pathway model (Wang et al., 2015). The vitamin C content in the analyzed samples of organic carrots from different farms varied.

Table 1 indicates that it ranged from 7.15 mg/100 g to 9.27 mg/100 g. Analysis of results from other studies shows that the total vitamin C content in carrots varied from 5.9 mg/100 g to 32.60 mg/100 g (Upadhyay et al., 2008; Profir and Vizireanu, 2013; Raees-ul and Prasad, 2015). There is a statistically significant difference (LSD test, $P < 0.001$) in the total vitamin C level among the analyzed samples of organic carrots from different farms. The total content of vitamin C in carrots varies depending on the variety, growing conditions, maturity, and storage (Leong and Oey, 2012a; Seljåsen et al., 2013; Char, 2018). The deficiency of boron increases the ascorbic acid content by 47-70% (Singh et al., 2012). Martín-Diana et al. (2007) and Rico et al. (2007) emphasize that plants cultivated in lighter sandy soils tend to accumulate less vitamin C than those grown in clayey soils Different temperature treatments can significantly reduce the content of ascorbic acid, as determined by Yadav et al. (2015). Calskantur et al. (2011) emphasize that the rate of reduction is higher with longer treatments at high temperatures. In addition to thermolability, Nagy (1980) points out that the loss of ascorbic acid in processed products can be due to aerobic and anaerobic non-enzymatic reactions.

Thermal processing of carrots results in significant losses of vitamin C. The lowest losses of vitamin C occurred during the thermal processing of juice at 70 °C, while the greatest losses were observed during the drying process (Table 1). Tukey's test confirmed a statistically significant difference ($P < 0.001$) in the vitamin C levels among fresh carrots, juice at 70 °C, juice at 90 °C, and dried carrot slices (55 °C). Directly impacting the denaturation of vitamin C in carrots, as well as in other plant species, researchers such as Leong and Oey (2012b), Adefegha and Oboh (2011), Pavlovic et al. (2017), and Char (2018) have found that lower processing temperatures result in less denaturation of vitamin C in the product. In addition to temperature, the duration of the process can also influence the loss of vitamin C (Paciull et al., 2016).

β-carotenoids content

The total content of carotenoids is responsible for the orange color of carrots, and the intensity of the color is considered an indicator of higher nutritional value (Gonçalves et al., 2010). In carrot roots, β-carotene (75%), α-carotene (23%), and lutein (1.9%) are the most prevalent, along with β-cryptoxanthin, lycopene, and zeaxanthin (Søltoft et al., 2011; Stan et al., 2008). The level of β-carotenoids in fresh organic carrots ranged from 7.45 mg/100 g FW to 10.05 mg/100 g FW (Table 2). The obtained results were consistent with those reported by Kidmose et al. (2004) and Profir and Vizireanu (2013). On the other hand, an extremely high level of β-carotenoids (55.25 mg/100 g) was observed. The difference (LSD test, $P < 0.001$) in β-carotenoids content among the analyzed samples of organic carrots grown at different farms was statistically significant. Additionally, a statistically significant variation in β-carotenoids was observed in different carrot crops (Kidmose et al., 2004; Gajewski et al., 2010). The carotenoid content in carrot roots depends on genetic factors (inheritance) and environmental influences in which the carrot crop grows (Kidmose et al., 2004; Gajewski et al., 2010). The environment's influence during the growth and packaging of carrots alters the carotenoid levels (Gajewski and Dabrowska, 2007). If carrot roots are exposed to sunlight after harvesting, there is a reduction in carotenoid content (Fuentes et al., 2012). Seljåsen et al. (2013), comparing carrots grown in different climatic conditions, locations, and years, found that the β-carotenoid content can vary by 40%. Therefore, comparing results from multiple geographical locations is complex.

Some studies indicate that during the processing of fresh carrots into juice and drying of slices, there is a reduction in the concentration of β-carotenoids, as well as other colored substances (anthocyanins). In fact, thermal treatments lead to the isomerization of carotenoids, resulting in the degradation of their physiological function and the modification of the color of the product (Marx et al., 2003). Research by Assous et al., 2014, demonstrates their high stability during processing at temperatures from 40-70 °C, while degradation starts above 80 °C. Gonçalves et al. (2010), in their studies, found significant sensitivity to heat in the β-carotenoids content in carrots.

This research affirms that the minimal losses of β-carotenoids happen at lower processing temperatures. The least loss was observed during juice pasteurization at 70°C, while the most substantial loss occurred during carrot drying. Tukey's test demonstrated a statistically significant difference ($P < 0.001$) in β-carotenoid content among fresh, juice pasteurized at 70 °C, juice pasteurized at 90 °C, and dried carrot slices (Table 2).

Kidmose et al. (2004), González-Blair et al. (2010), Yadav et al. (2015), and Agiriga et al. (2015) found a significant impact of the processing temperature on the reduction of β-carotenoids content in carrots in their studies. In addition to the temperature's effect on the stability of β-carotenoids, the duration of thermal processing also plays a significant role. The longer the processing time, the greater the losses, even at lower temperatures (Gonçalves et al., 2010; Assous et al., 2014; Kapusta-Duch et al., 2017). Therefore, Zhang-Xue et al. (2007) suggest the use of combined carrot drying techniques because the degradation of β-carotenoids is significantly lower in vacuum drying and low superheated steam drying compared to conventional air drying (Suvarnakuta et al., 2005).

Table 1. Vitamin C (mg/100 cm^3) in carrot in fresh dried and juice sample

Carrot growers	Vitamin C mg/100 cm^3				Tukey's test	Significant $P < 0.05; 0.01$
	Fresh	Juice 70 °C	Juice 90 °C	Dried		
SB	8.35	5.25	3.25	0.35	2.50	Yes
TS	9.27	6.05	4.25	0.55	3.98	Yes
GL	7.45	5.75	4.15	0.38	7.73	Yes
PD	7.75	5.15	4.55	0.42	1.48	Yes
KI	9.05	6.75	4.97	0.65	5.23	Yes
KS	7.15	5.05	3.95	0.29	3.75	Yes
$LSD_{0.05}$	0.203	0.533	0.483	0.169		
$LSD_{0.01}$	0.289	0.759	0.688	0.240		

Table 2. Total β-carotene (mg/100 g FW) in carrot in fresh, dried and juice sample

Carrot growers	Total Phenols (mg/100g FW)				Tukey's test	Significant *P* < 0.05; 0.01
	Fresh	Juice 70 °C	Juice 90 °C	Dried		
SB	7.45	5.76	3.45	1.15	1.99	Yes
TS	8.65	6.25	4.75	2.05	4.82	Yes
GL	8.05	5.98	3.15	1.19	6.93	Yes
PD	9.45	7.15	4.22	2.25	2.83	Yes
KI	10.05	8.24	4.35	2.55	4.93	Yes
KS	9.45	7.75	4.25	2.34	2.11	Yes
$LSD_{0.05}$	0.113	0.185	0.103	0.398		
$LSD_{0.01}$	0.160	0.263	0.147	0.566		

However, some studies indicate that the concentration of β-carotenoids in carrots increases with an increase in processing temperature (Upadhyay et al., 2008; Knockaert et al., 2012).

Total Phenolic Compounds (TPC)

The total content of phenolic components in carrots affects their organoleptic properties such as taste, smell, and bitterness. The higher their content, the better the sensory properties of carrots (Zhang et al., 2005; Kreutzmann et al., 2008; Naczk and Shahidi, 2003). Therefore, the total content of phenolic components is a good indicator for assessing the quality of carrots during processing and storage (Gonçalves et al., 2010).

The TPC in the analyzed organic carrots in this experiment ranged from 47.05 mg GAE/100 g FW to 57.25 mg GAE/100 g FW, indicating high variability. Literature examples show a wide range of TPC values in carrots, varying from 1.5 to 126 mg/100 g (Raees-ul and Prasad, 2015). In some experiments, TPC levels in carrots were reported to be between 3.33 and 35.13 mg/100 g FW, with variations based on whether the concentration was measured immediately after yield or after storage (Gajewski et al., 2010). Other studies found TPC concentrations in carrots as high as 96 mg GAE/100 g FW (Marinova et al., 2005).

In this experiment, a statistically significant difference (LSD test, $P < 0.001$) was observed among the analyzed organic carrots grown at different locations (Table 3). The TPC level in carrots is influenced by various factors, including climate conditions, growing techniques, harvest timing, and genetic factors etc. (Ninfali and Bacchiocca, 2003, Zhang and Hamauzu, 2004, Alasalvar et al., 2005, Gebczynski, 2006, Gajewski et al., 2010, Alarcón-Flores et al., 2015). Seljåsen et al. (2013), comparing carrots grown in different climatic conditions, locations, and years, found that the phenol content can vary within the range of 28%. There is very little information about the impact of thermal processing on the total phenol content of carrots. It has been observed that more intense heat treatments lead to greater losses of phenol content in plant raw materials, according to Ismail et al. (2004), Turkmen et al. (2005), Gonçalves et al. (2010), Yao and Ren (2011) and Kapusta-Duch et al. (2017). In this study, thermal processing of carrot samples into juice and drying led to a decrease in the concentration of Total Phenolic Content (TPC). The lowest percentage of fall was found for pasteurisation of carrot juice at 70 °C and the highest by drying.

Tukey's test confirmed statistically significant differences ($P < 0.001$) in the level of TPC among fresh carrots, juice pasteurized at 70 °C and 90 °C, and

Table 3. Total phenols content (mg GAE/100 g FW) in carrot in fresh, dried and juice sample

Carrot growers	Total Phenols (mg GAE/100 g FW)				Tukey's test	Significant $P < 0.05; 0.01$
	Fresh	Juice 70 °C	Juice 90 °C	Dried		
SB	57.25	50.47	35.75	15.75	6.51	Yes
TS	57.00	47.25	36.15	16.15	18.55	Yes
GL	55.44	51.44	38.05	17.45	38.63	Yes
PD	47.05	37.35	32.05	11.25	12.03	Yes
KI	49.05	44.15	32.07	13.15	32.12	Yes
KS	55.00	51.05	35.45	15.25	20.09	Yes
$LSD_{0.05}$	1.573	1.983	2.301	1.819		
$LSD_{0.01}$	2.237	2.820	3.273	2.587		

dried slices (Table 3). The influence of temperature and treatment duration on changes in the TPC level in plant material was supported by previous studies (Kapusta-Duch et al., 2017; Yao and Ren, 2011). Lower temperatures, especially in prolonged processing such as drying, also have a negative impact on the total phenolic content (Gonçalves et al., 2010).

Total antioxidant activity (TAA)

Carrot is a good natural antioxidant, and it should be used instead of synthetic antioxidants, thereby reducing harmful health effects (Assous et al., 2014). The antioxidative activity in carrots is comprised of the synergistic effect of carotenoids, polyphenols, or phenolic acids, and vitamins (Varshney and Mishra, 2002; Gonçalves et al., 2010). Phenolic fractions are potent free radical scavengers, and β-carotene is considered a strong quencher of singlet oxygen (Schafer et al., 2002). Sun et al. (2009) suggest that phenols play a more significant role in overall antioxidative activity compared to carotenoids.

During the thermal processing of fresh carrots into juice and during drying, the TAA level decreases. The lowest loss of TAA was observed during juice pasteurization at 70 °C, while the highest loss occurred in the dried sample (Table 4). The results obtained in this experiment align with those from studies by Yao and Ren (2011) and Kapusta-Duch et al. (2017). Some research indicates that the TAA level during thermal processing can decrease from 5% to 53%. According to Yao and Ren (2011), the reduction in TAA directly depends on the thermal processing method and the duration of the process. Kapusta-Duch et al. (2017) state that during the warming of plant material, antioxidants oxidize, leading to chain reactions such as enzyme modification. These reactions contribute to the loss of antioxidants in vegetables, thereby reducing the potential for antioxidative activity.

Figure 1 shows the projection of variables based on Pearson correlation coefficients. In this study, a significant positive correlation was calculated between vitamin C, β-carotenoids, TPC, and TAA. These findings suggest a high additive and synergistic impact of phytochemical compounds on TAA. Principal Component 1 (PC1) explains 93.63% of the total variance, while the influence of PC2 on the total variance is considerably smaller at 4.55% (Figure 1). A high correlation between phytonutrients and TAA (total antioxidant activity) has been confirmed in studies by Heredia and Cisneros-Zevallos (2009), Yao and Ren (2011), and Ravichandran et al. (2012). Zhang and Hamauzu (2004) also found a good correlation between the total phenol content and TAA, as well as radical scavenging activity in carrots.

Table 4. Total antioxidant activity (mg AA/100 g) in carrot in fresh, dried and juice sample

Carrot growers	TAA (mg AA/100 g)				Tukey's test	Significant $P < 0.05; 0.01$
	Fresh	Juice 70 °C	Juice 90 °C	Dried		
SB	22.54	15.45	7.25	3.26	9.27	Yes
TS	28.75	17.25	8.25	3.75	17.72	Yes
GL	25.45	16.45	8.00	4.15	22.72	Yes
PD	23.35	15.35	7.78	1.78	8.46	Yes
KI	25.77	16.45	8.05	2.22	13.45	Yes
KS	29.05	18.35	9.24	3.45	4.99	Yes
$LSD_{0.05}$	1.383	0.428	0.306	0.374		
$LSD_{0.01}$	1.967	0.609	0.435	0.532		

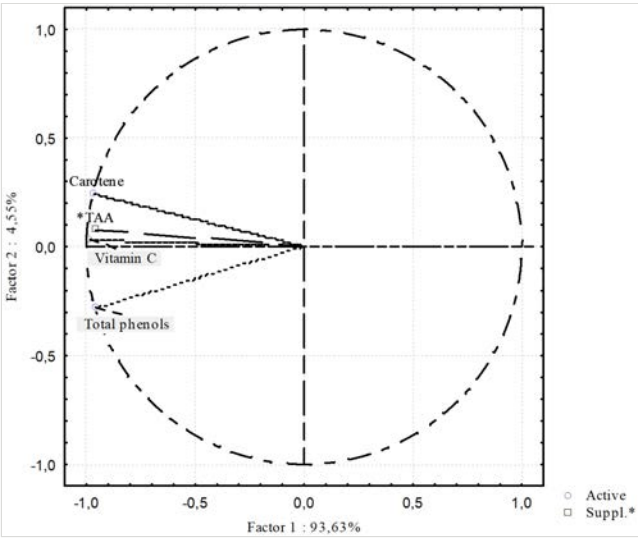

Figure 1. Pearson`s correlation figure of tested phytochemical components of carrot

CONCLUSION

This research provides valuable insights into the variation of phytonutrients in organic carrots concerning geographical origin, cultivation conditions, and thermal processing. The results indicate significant differences in the levels of vitamin C, β-carotene, and total phenols among different locations of organic carrot cultivation. Additionally, the study confirms that lower processing temperatures are associated with lesser losses of phytonutrients, especially in the case of β-carotene.

Thermal processing, such as pasteurization of juice at 70 °C, proves to be an effective way to preserve vitamin C. However, drying tends to cause more substantial losses of nutritional components. These findings underscore the need for careful selection of processing methods to preserve the nutritional value of organic carrots.

Furthermore, the conclusion emphasizes the significance of geographical origin in determining phytonutrient levels, highlighting the importance of local growing conditions as a factor contributing to the quality of organic carrots. This knowledge can provide guidance for improving cultivation practices and processing methods, supporting the production of nutritious organic produce.

ACKNOWLEDGEMENTS

The research was financed by the Ministry of Education, Science and Technological Development Republic of Serbia, project ref, number 451-03-66/2024-03/200088 and 451-03-66/2024-03/ 200217.

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