

NITRATE AND VITAMIN C CONTENT IN RADISH (*RAPHANUS SATIVUS*) FROM DIFFERENT PRODUCERS: INFLUENCE OF VARIETY, SOURCE, AND SEASONALITY

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<https://doi.org/10.55251/jmbfs.12517>

ARTICLE INFO

Received 12. 3. 2025
Revised 19. 5. 2025
Accepted 22. 5. 2025
Published 1. 8. 2025

Regular article



ABSTRACT

The aim of the study was to analyze the content of nitrates and vitamin C in radish (*Raphanus sativus*) from different producers and to evaluate the influence of variety, origin, and seasonality on these parameters. The red and white varieties of radish were purchased regularly each month over a 12-month period from the same two producers at a local marketplace and from a retail chain. The conventional Tillmans titration method was used to determine vitamin C content, while nitrate levels were measured using the direct potentiometric method with a nitrate ion-selective electrode (ISE). The results of the annual analyses monitoring nitrate content in the red and white varieties of radish from different producers showed that the average nitrate concentration was higher in the red variety, reaching 1308 mg/kg, while the white variety contained 1246 mg/kg. Regarding the origin, the highest nitrate content was found in red radishes purchased from the retail chain (1463 mg/kg). During the spring months, higher nitrate levels were detected in both radish varieties, though in the red variety, the difference was not statistically significant ($p > 0.05$). Over the annual monitoring period, the red variety contained more vitamin C (18.5 mg/100g) compared to the white variety (14.6 mg/100g). Radishes sold in the retail chain had slightly higher vitamin C content (18.9 mg/100g) compared to those from the marketplace vendors. Additionally, it was confirmed that the summer months represent a significantly ($p < 0.05$) greater source of vitamin C compared to the winter and autumn periods.

Keywords: radish, nitrate, vitamin C, analysis, producer

INTRODUCTION

Radish (*Raphanus sativus*) is a root vegetable with light, crisp flesh, a pungent taste, and a variable skin color. Radishes differ in shape and size (ranging from short and round to long and narrow) as well as in skin color, which can be red, black, yellow, white, purple, or pink (WebMD, 2022). The surface color of radishes may vary depending on the geographical and climatic conditions of a given region. White radish varieties are predominantly found in Asian regions, whereas red varieties are more common in Europe. Despite this variability, the flesh of radishes in most European and Asian countries is predominantly white (Manivannan et al., 2019). Radish is an annual or biennial horticultural crop. *Raphanus sativus* is generally the domesticated parent species for all radish types, with color and shape being the main distinguishing factors among different varieties. Some of the most well-known varieties include the red radish, also referred to as the round radish or globe radish, and daikon, or Japanese radish, which is white and resembles a carrot or parsnip in shape. Recently, lesser-known varieties have gained attention, such as the watermelon radish, which has pink green skin and a pink interior, and the black radish, characterized by its dark-colored skin (Aboyeji et al., 2019).

Radish roots are characterized by low-calorie content and serve as a good source of calcium, copper, manganese, magnesium, potassium, vitamin B6, vitamin C, and folic acid. Radish roots are mostly consumed raw but can also be cooked, preserved, dried, or salted together with other vegetables. The leaves and sprouts of radish are also edible and can be cooked like spinach or consumed raw as part of salads. Radishes are typically cultivated as annuals and harvested before flowering (Umamaheswari, 2021). Radish represents a significant source of vitamins, fiber, antioxidants, and minerals, demonstrating beneficial health effects, including the prevention of several lifestyle-related diseases. However, it is also one of the major dietary sources of nitrates. Nitrates are a natural component of the environment and, as part of the nitrogen cycle, are predominantly found in plant-based foods (Almasi et al., 2015; Karwowska & Kanoniuk, 2020).

Nitrates accumulate primarily in root vegetables, short-season crops, and early cultivars of vegetables (Walkowiak-Tomczak et al., 2011). The increased nitrate content in the stem of *Raphanus sativus* may result not only from intensive fertilization but also from transportation and storage conditions, as well as the way

radishes are stored by consumers at home. Plants with yellowing and decaying leaves pose a potential source of nitrates and N-nitroso compounds (Stepowska, 2000). The elimination of nitrates from vegetables is influenced by post-harvest processes, which can modulate nitrate and nitrite levels in plant products. Nitrate content in vegetables can be reduced using mechanical and physical methods such as washing and peeling, with their reduction further facilitated by their high-water solubility. Studies have shown that blanching vegetables for three minutes can decrease nitrate content by 12–31% (Chen, 2010). Under conditions of low solar radiation intensity and lower temperatures, typical of the autumn-winter season, greenhouse cultivation, and higher latitudes, controlling nitrate levels becomes more challenging. Maintaining nitrate concentrations within legally established limits therefore requires effective cultivation strategies and nutrient management (Signore et al., 2021).

Vitamin C is one of the key quality indicators for many types of horticultural crops (Schlueter & Johnston, 2011). Its concentration in fruits and vegetables is influenced by multiple factors, including post-harvest climatic conditions, genetic variability, ripeness stage, harvesting methods, and post-harvest processing practices. Research suggests that higher light intensity during the growing season promotes the accumulation of vitamin C in plant tissues. In contrast, conditions that favor water loss after harvest lead to its rapid degradation. Another negative factor affecting vitamin C stability is an increased concentration of carbon dioxide, which can accelerate its breakdown (Paciolla et al., 2019). The vitamin C content in fruits and vegetables is also closely related to the post-harvest ripeness stage. Studies indicate that early-harvested crops may contain higher concentrations of ascorbic acid compared to later-harvested ones. The stability of ascorbic acid decreases with increasing temperature, pH value, and light exposure. Due to differences in pH between fruits and vegetables, vitamin C is more stable in fruits, as they generally have a lower pH (Jeney-Nagyfű & Fodor, 2008). Regarding the vitamin C content in radish, all its varieties, including the leaves, represent a significant source of this vitamin. The vitamin C content in 100 grams of the edible portion ranges from 14 to 25 mg, with radish leaves containing on average up to six times higher amounts than the root portion. In India, radish roots and leaves are used not only for preventing vitamin C deficiency but also as a diuretic, a remedy for gastrointestinal disorders, and a laxative. However, it is important to emphasize

that thermal processing significantly reduces the vitamin C content in radish roots (Murray & Pizzorno, 2005).

The aim of this study was to analyze the nitrate and vitamin C content in radish (*Raphanus sativus*) from different producers and to evaluate the influence of variety, origin, and seasonality on these parameters.

MATERIAL AND METHODS

Material and design of experiment

The red and white cultivars of radish (*Raphanus sativus*) were regularly purchased every month over a 12-month period in batches of three bunches from the same two local producers at a farmers’ market and additionally from a retail chain. For experimental purposes, the edible radish roots were analyzed, as they represent the most consumed part of this vegetable. Each average sample was created from three bundles of radishes (purchased at the same time from a specific seller), with each bundle containing approximately 5–8 individual roots.

The samples were collected one day before analysis and originated from three different sources (Table 1):

- Local Producer 1 (LP1): Radish cultivated in a greenhouse in Slovakia (stable conditions regarding temperature, humidity, and light intensity; ripening time 20–25 days; temperature 15–22 °C during the day, 8–12 °C at night).
- Local Producer 2 (LP2): Radish cultivated in a tunnel type greenhouse in Slovakia (slower ripening, 30–35 days; higher temperature fluctuations: 10–25 °C during the day, 5–10 °C at night).
- Retail Chain (RC): Radish sourced from Italy (no specific cultivation data available).

Over the 12-month period, a total of 324 samples of *Raphanus sativus* were analyzed.

Table 1 Designation and description of radish samples

Producer	Variety of radish	Cultivar	No. of collected samples /year	Cultivation conditions	Origin
LP1	red	Felix F1	54	Greenhouse-grown radish	Slovakia
	white	Blanka	54	Greenhouse-grown radish	Slovakia
LP2	red	Felix F1	54	Polytunnel-grown radish	Slovakia
	white	Blanka	54	Polytunnel-grown radish	Slovakia
RC	red	Ester	54	Not-given	Italy
	white	Blanka	54	Not-given	Italy

Note: LP1 – local producer 1, LP2 – local producer 2, RC – retail chain, Greenhouse-grown radish (for LP1) with the controlled indoor cultivation, Polytunnel-grown radish (for LP2) was cultivated under plastic tunnels.

Radish was stored for a maximum of 24 hours in the dark at 4 °C prior to analysis.

Sample preparation and analytical procedures

Radish samples without any visible damage were prepared before each analysis by removing the leaves and coarse impurities. They were then washed with potable water and dried using paper towels. White radish was peeled before analysis. A homogeneous consistency was achieved by blending the samples in a container using a Grindomix GM200 chopper knife (Retsch GmbH & Co. KG, Germany).

Determination of nitrate content: The nitrate content in the filtered radish extracts was determined by direct potentiometry using a nitrate ion-selective electrode (ISE). This method is based on measuring the electric potential generated at the nitrate ISE membrane, which depends on the activity of nitrate ions in the solution. 10 g of homogenized material was weighed directly into 200 mL laboratory beakers using a Kern PLE-3n laboratory scale (Kern & Sohn GmbH, Balingen, Germany). A leaching solution composed of 1% Al₂(SO₄)₃ and 0.1% Ag₂SO₄ (both of analytical purity 99.5%, purchased from Centralchem s.r.o., Bratislava, Slovak Republic) was added in an amount of 60 mL to the beakers. The mixture was stirred, maintained in a water bath at 100 °C for 5 minutes, and then filtered into volumetric flasks, followed by cooling to laboratory temperature. The total volume was adjusted to 100 mL using the leaching solution (1% Al₂(SO₄)₃ and 0.1% Ag₂SO₄). Measurements were performed at laboratory temperature.

The dry matter content in radish was determined using a moisture analyzer Kern DAB 100-3 (Kern & Sohn GmbH, Balingen, Germany) at 105 °C.

For the determination of nitrates in the radish extracts, the SI Analytics Lab meter 845 (Fisher Scientific Ltd., Germany), equipped with a nitrate ion-selective electrode (type 25–312, electrochemical detectors, Ltd., Turnov, Czech Republic),

was used. The calibration curve was prepared from a KNO₃ calibration solution (c = 0.1 mol/L, Hach Company, Loveland, USA) by dilution with the leaching solution (1% Al₂(SO₄)₃ and 0.1% Ag₂SO₄) and the addition of 1 mL of NaH₂PO₄ (1 mol/L, purchased from Centralchem s.r.o., Bratislava, Slovak Republic) to each 100 mL volumetric flask, ensuring a calibration range of 10–200 mg NO₃⁻/L. Data was recorded as measured potential in mV and used to generate the calibration curve and calculate concentrations using Excel with Equations 1 and 2. Calibration dependence (Eq. 1):

$$EMS = k \times \log c(\text{NO}_3^-) + b \tag{Eq. 1}$$

Where: EMS is measured voltage in mV; k is a calibration slope and b means a shift of calibration curve.

Thus concentration of nitrates is calculated from the equation (Eq. 2):

$$c(\text{NO}_3^-) = 10^{(EMS-b/k)} \tag{Eq. 2}$$

Concentration in sample solutions were expressed in mg/L. The results were then converted to the nitrate concentration in fresh matter (mg/kg) and in the dry matter of the sample (mg/kg). The measurement of the nitrate content using an ion selective electrode (ISE) was repeated 3 times in each of the prepared samples.

Determination of vitamin C content: The conventional Tillmans titration method was used to determine the vitamin C content. This method is based on the titration with 2,6-dichlorophenolindophenol, exploiting the reducing properties of ascorbic acid. The reaction does not require an external indicator for the titration endpoint, as 2,6-dichlorophenolindophenol, after quantitatively reacting with ascorbic acid in the sample, colours the titrated solution pink in an acidic environment.

For the determination of vitamin C in radish samples, 10 g of prepared homogenate was accurately weighed (±0.01 g) on an analytical balance and transferred directly into a 50 mL polypropylene centrifuge tube.

Prior to the analysis, the 2,6-dichlorophenolindophenol standard solution was calibrated against a standard solution of L-ascorbic acid, and a blank test was performed using 10 mL of a 5% trichloroacetic acid solution. The measured blank value and the standard volume were incorporated into the result evaluation.

After the blank test, 10 mL of filtrate was titrated with 2,6-dichlorophenolindophenol solution until a persistent light pink coloration was observed for at least 30 seconds. The vitamin C content in radish samples was then calculated using Equation 3 based on the results obtained.

Calculation of vitamin C:

$$\text{Content of ascorbic acid (mg)} = \frac{40 \cdot (V_a - V_c)}{V_b} \tag{Eq. 3}$$

Where:

40 – total titration volume (10 mL sample + 30 mL extraction reagent, 5% TCA)

V_a – volume of titrant consumed for sample titration (mL)

V_b – volume of titrant consumed for titration of the L-ascorbic acid standard (mL)

V_c – volume of titrant consumed for blank titration (mL)

Statistical evaluation

None of the tested variables followed a normal distribution, as determined by the Shapiro-Wilk and Kolmogorov-Smirnov tests. Consequently, the Kruskal-Wallis and Wilcoxon tests were conducted to identify significant differences between the tested variables. To enhance the interpretation of the results, each month was compared with the median value (horizontal line) using the Wilcoxon test. The Spearman correlation test was applied to assess relationships between nitrate content across the tested months. Descriptive statistics and normality tests were performed using MS Excel with the XLSTAT package, while the Kruskal-Wallis and Wilcoxon tests were conducted in RStudio software, version 1.2.5033.

RESULTS AND DISCUSSION

Nitrates in radish (*Raphanus sativus*)

Nitrates primarily accumulate in root vegetables, crops with a short vegetative cycle, and early cultivars. Radish (*Raphanus sativus*), as a representative of root vegetables, exhibits a high capacity for nitrate accumulation, which can subsequently be reduced to potentially toxic nitrites (Walkowiak-Tomczak et al., 2011). The degree of nitrate accumulation in fresh vegetables is highly variable and influenced by multiple environmental and agronomic factors. Excessive application of nitrogen fertilizers leads to increased nitrate concentrations in various vegetable species, with accumulation depending on several variables. Key factors include soil composition, the genetic predisposition of the plant species, the frequency and amount of nitrogen fertilizer application, the plant’s ability to fix atmospheric nitrogen, cultivation conditions (traditional vs. greenhouse), temperature and light intensity, seasonal effects, weather conditions, harvest timing, moisture stress, the ontogenetic phase of the plants, soil pH, post-harvest

storage methods, and the concentration of carbon dioxide in the surrounding environment (Mensinga et al., 2012; Salehzadeh et al., 2020).

To protect consumer health, the European Union has implemented Commission Regulation (EU) No. 1258/2011, amending Regulation (EC) No. 1881/2006 concerning the maximum allowable concentrations of nitrates in food (Kiani et al., 2022). However, this regulation does not establish maximum nitrate content limits for radish, including those cultivated in greenhouses or under forced growing conditions.

Slovak legislation still enforces Decree No. 2/1997 Coll., which establishes hygiene requirements for the content of foreign substances in foodstuffs. This decree also includes provisions regarding the maximum allowable levels of nitrates (NaNO₃) in vegetables, including radish. According to the decree, the nitrate content in radish grown in open fields can reach a maximum of 1500 mg/kg, while in radish cultivated in greenhouses and under forced growing conditions, the limit is set at 3000 mg/kg. It is important to emphasize that these limits apply exclusively to vegetables cultivated under Slovak conditions and do not apply to imported produce.

The results of annual analyses monitoring nitrate content in red and white radish cultivars from different producers indicated that the average nitrate concentration was higher in the red cultivar, reaching 1308 mg/kg, whereas the measured value in the white cultivar was 1246 mg/kg (Figure 1).

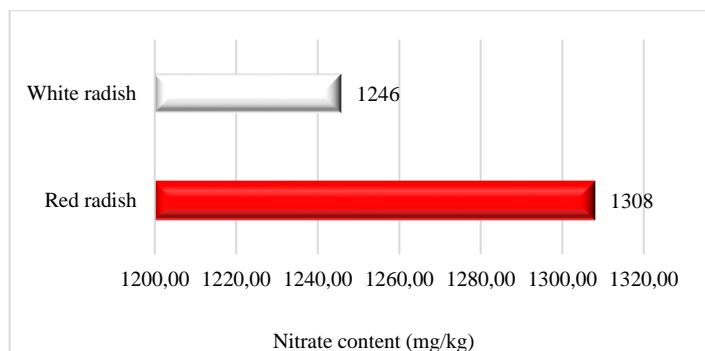


Figure 1 Comparison of the average nitrate content in white and red radish cultivars during annual monitoring

A comparison of individual producers yielded the following findings. The average nitrate content in red radish from Local Producer 1 (grown in a greenhouse) during the monitored period reached 1247±277 mg/kg. The lowest concentration was recorded in the summer month of July (948 mg/kg), while the highest value was observed in September (1938 mg/kg).

In the case of red radish grown under polytunnels (Local Producer 2), the average nitrate content was 1213±443 mg/kg, with a high variability in measured values, as confirmed by the coefficient of variation (37%). Significant differences in nitrate content were observed between the spring and autumn periods. In March, nitrate concentration peaked at 2310 mg/kg, whereas in October, it was significantly lower (702 mg/kg).

The average nitrate content in red radish purchased from a retail chain was 1463±532 mg/kg, with values exhibiting considerable variation across different months. The highest nitrate concentration was recorded in April (2456 mg/kg), while the lowest was observed in January (712 mg/kg).

A complete comparison of the measured nitrate concentrations in the red radish cultivar based on their origin is illustrated in Figure 2. During the monitored period, the highest concentrations were recorded in radishes purchased from the retail chain (1463 mg/kg). Radishes from Local Producer 1 contained 1247 mg/kg of nitrates, whereas samples from Local Producer 2 showed an average content of 1213 mg/kg.

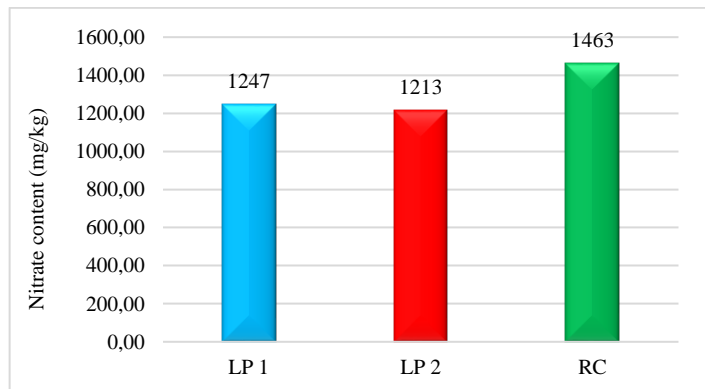


Figure 2 Comparison of the average nitrate content in red radish from different sources

In the white radish cultivar, the average nitrate content was 1459±416 mg/kg, with an annual variability of 29%. A notable observation was a significant decrease in nitrate content over two consecutive months – while the concentration in April was 2302 mg/kg, it dropped to 781 mg/kg in May. In radishes purchased from the retail chain, nitrates were detected; however, their average content over the monitored period was 29% lower compared to producers from the marketplace. The lowest concentration was recorded in January (645 mg/kg), whereas the highest value was observed in October (2655 mg/kg). Interestingly, in April, the retail chain offered white radish with a nitrate content of 650 mg/kg, which was 28% lower compared to local producers. In May, the values between the retail chain and local producers were comparable (780 mg/kg vs. 718 mg/kg).

For statistical comparison of differences between individual months of radish analyses, the Kruskal-Wallis test was applied at a significance level of $p < 0.05$. Figure 3 illustrates statistically significant differences in nitrate content during the monitored period. Statistically significant differences were identified between radish samples analyzed in January and August.

Table 2 Statistical comparison of nitrate content (mg/kg) by month and radish cultivar

Sample	Month	Measured value	Sample	Month	Measured value
	January	994±210 ^{ef}		January	1049±432 ^{cd}
	February	1030±153 ^e		February	1066±136 ^e
	March	1678±495 ^a		March	1302±374 ^{bc}
	April	1639±535 ^{ab}		April	1605±714 ^{ab}
	May	1565±437 ^{abc}		May	1550±49 ^d
Red radish	June	1275±115 ^{bcd^{ef}}	White radish	June	1452±495 ^{abc}
	July	1291±671 ^{bcd^{ef}}		July	1237±552 ^{bcd}
	August	1254±168 ^{cdef}		August	1213±406 ^{bc}
	September	1332±469 ^{abcde}		September	967±211 ^{cd}
	October	945±185 ^f		October	1272±778 ^a
	November	1371±188 ^{abcd}		November	1146±115 ^{bcd}
	December	1009±177 ^{def}		December	1078±222 ^{bcd}

Note: The different letters ^{a,b,c,d,e,f} listed with the mean values in the columns represent statistically significant differences between the observed varieties ($p < 0.05$)

Table 2 indicates that in red radish, regardless of its origin, the highest nitrate levels were recorded in March, April, and May, with no statistically significant difference between these months ($p > 0.05$). The lowest nitrate content was observed in October (945±185 mg/kg).

In the white radish cultivar, a statistically significant difference ($p < 0.05$) was identified between the group of months with the highest nitrate content (April, May, June; 1536±778 mg/kg) and the group of months with significantly lower values (January, September; 750±49 mg/kg).

Zeleňáková et al. (2022) analyzed head lettuce from various producers and evaluated the results in terms of seasonality. Their findings indicated that the highest nitrate content was detected in fresh lettuce in November (2039 mg/kg), whereas in May, the value was significantly lower (775 mg/kg). Additionally, differences were observed between local producers and retail chains. Brkić (2017) also investigated head lettuce and confirmed a higher nitrate content in the autumn months (1264 mg/kg) compared to spring (704 mg/kg).

However, our results suggest an opposite trend – the highest average nitrate content was recorded in the spring months (1627 mg/kg), while the lowest values were measured in winter (1002 mg/kg).

Several factors may contribute to this phenomenon. One key aspect is the botanical classification of the studied crops – radish belongs to root vegetables, whereas head lettuce is classified as a leafy vegetable. These morphological and physiological differences can influence nitrate accumulation (Vollmannová et al., 2018; Boros, 2020). Another significant factor is the growing conditions. Leafy vegetables typically have a shorter growing cycle and faster growth rate, while root vegetables have a longer growth cycle and are often cultivated in late summer and autumn, when temperature conditions are more favorable for their development. These differences in vegetation length and climatic conditions during cultivation may significantly impact nitrate accumulation in different vegetable types (Tyksinski et al., 2006).

Additionally, root vegetables may be less efficient in utilizing available nitrogen from the soil during winter due to less favorable light and temperature conditions. This may lead to increased nitrate accumulation in warmer and more humid months, when nitrogen uptake conditions are more favorable (Mirecki et al., 2015). As noted by Najera & Urrestarazu (2019), light plays a crucial role in

nitrate accumulation, and there is a well-established relationship between nitrate levels in vegetables and light intensity, as photosynthesis facilitates nitrate uptake and assimilation in plants.

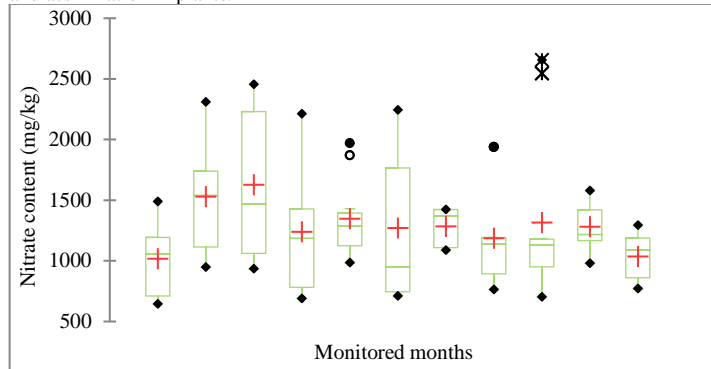


Figure 3 Statistically significant differences in nitrate content in both varieties of radishes during annual monitoring

Vitamin C in radish (*Raphanus sativus*)

Fruits and vegetables are significant dietary sources of vitamin C (ascorbic acid). However, its content can be influenced by various factors, including post-harvest treatments, storage conditions, oxidative stress, and the application of nitrate fertilizers. Post-harvest treatments include surface and thermal processing, as well as irradiation. As for storage conditions, improper temperature control can negatively affect the nutritional quality of products, with vitamin C loss accelerating at higher storage temperatures (Mditshwa et al., 2017).

Radish (*Raphanus sativus*) is an important source of ascorbic acid, with its average content ranging from 15 to 40 mg per 100 grams. Higher concentrations of this vitamin have been recorded in cultivars with pink skin (Hadley & Fordham, 2003). Annual analyses monitoring vitamin C content in red and white radish varieties (Figure 4) from different producers revealed higher concentrations of this vitamin in red radishes (18.5 mg/100g) compared to white ones (14.6 mg/100g).

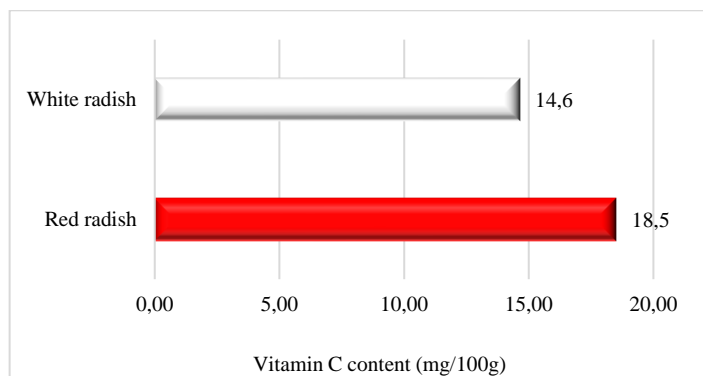


Figure 4 Comparison of the average vitamin C content in white and red radish cultivars during annual monitoring

The average vitamin C content in red radishes purchased from Local Producer 1 (greenhouse cultivation) during the 12-month monitoring period was 18.0±4.9 mg/100g of fresh weight. The highest concentration was recorded in July (27.2 mg/100g), but in October, a significant decrease was observed, dropping to 11.9 mg/100g. For red radishes grown in a plastic tunnel (Local Producer 2), the vitamin C content was slightly higher (18.1±3.9 mg/100g), with the maximum value also recorded in July (24.0 mg/100g). In the fall months, the vitamin C content again reached its lowest levels, with October showing a value of 12.0 mg/100g.

For red radishes purchased from a retail chain, the average vitamin C content throughout the monitoring period was 18.9±5.3 mg/100g. However, the results showed considerable variation between months – the maximum vitamin C concentration was recorded in August (27.6 mg/100g), while the lowest value was observed in November (8.4 mg/100g). A comparison of the average vitamin C content in red radishes from different producers is illustrated in Figure 5.

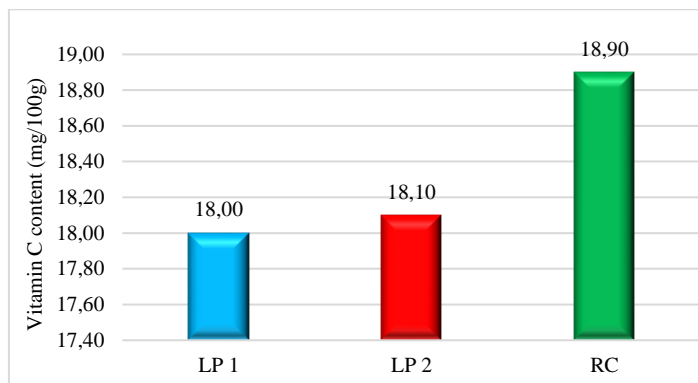


Figure 5 Comparison of the average vitamin C content in red radish from different sources

The vitamin C content in white radishes reached 14.1±4.1 mg/100g, with an annual variability of 28.9%. The highest concentration of vitamin C was recorded in March (21.4 mg/100g), while the lowest value was measured in September (7.8 mg/100g).

White radishes purchased from a retail chain, with an origin from Italy, contained slightly higher amounts of vitamin C (15.2±2.8 mg/100g) compared to radishes purchased from local vendors. Regarding seasonal differences, it was notable that radishes bought in November had a higher vitamin C concentration (19.8 mg/100g) than samples analyzed in July (10.4 mg/100g).

To statistically assess differences between the months in terms of the overall comparison of radish samples, the Kruskal-Wallis test was applied at a significance level of $p < 0.05$. The results of the statistical analysis (Figure 6, Table 3) demonstrated significant differences in vitamin C content throughout the annual monitoring. Statistically significant differences were found between the samples analyzed in January and August.

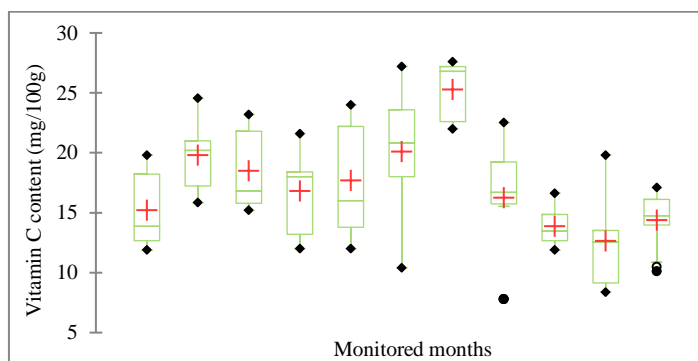


Figure 6 Statistically significant differences in vitamin C content in both varieties of radishes during annual monitoring

For red radishes, regardless of their origin, the highest concentration of vitamin C was measured in the months of August, July, April, March, and June, with no statistically significant difference found between these months ($p > 0.05$). The lowest vitamin C content in red radishes was recorded in November (11.7±1.9 mg/100g).

In white radishes, the highest vitamin C values were measured in March and May ($p < 0.05$), while lower concentrations were observed in the months of January, December, and September ($p < 0.05$).

Table 3 Statistical comparison of vitamin C content (mg/100g) by month and radish cultivar

Sample	Month	Measured value	Sample	Month	Measured value
Red radish	January	17.0±2.5 ^{bcd}	White radish	January	12.5±0.6 ^b
	February	18.1±2.9 ^{bc}		February	13.9±0.8 ^{bc}
	March	20.6±3.2 ^{ab}		March	18.6±1.9 ^a
	April	23.2±1.6 ^a		April	16.2±0.9 ^{ab}
	May	15.9±4.4 ^{cde}		May	18.2±0.3 ^a
	June	20.5±3.5 ^{ab}		June	13.4±0.9 ^{ab}
	July	23.6±2.7 ^a		July	14.8±4.0 ^{ab}
	August	18.9±2.6 ^{bc}		August	13.8±3.5 ^{ab}
	September	15.9±1.9 ^{de}		September	12.2±4.9 ^b
	October	13.9±1.9 ^e		October	13.9±0.9 ^{ab}
	November	11.7±1.9 ^e		November	14.1±5.9 ^{ab}
	December	15.7±1.1 ^{cde}		December	12.4±2.2 ^b

Note: The different letters ^{a,b,c,d,e} listed with the mean values in the columns represent statistically significant differences between the observed varieties ($p < 0.05$)

Lee & Kader (2000) report that higher light intensity during the growing season correlates with increased vitamin C content in plant tissues. Kováčik et al. (2017) analyzed the content of vitamin C and nitrates in radish roots, noting that a negative correlation is typically observed between these two qualitative parameters. Their analysis confirmed that the application of nitrogen fertilizers leads to an increased accumulation of nitrates and a simultaneous reduction in vitamin C content. Additionally, they found that the highest nitrate concentration was present in the upper root portion, while the lowest was in the subleaf area. Conversely, the vitamin C content was highest in the subleaf region and lowest in the upper root area. Zhang et al. (2021) state that the negative effects of nitrates on the human body are significantly reduced by the presence of ascorbic acid. Experiments aimed at quantifying the inhibitory effect of L-ascorbic acid on nitrosation reactions demonstrated that when the ratio of vitamin C to nitrates exceeds 2:1, the formation of N-nitroso compounds does not occur.

CONCLUSION

This study confirmed that radish (*Raphanus sativus*) is a valuable source of vitamin C and at the same time exhibits a significant capacity for nitrate accumulation, depending on variety, source, and seasonality. Our experimental results showed that red radishes contained a higher average nitrate content (1308 mg/kg) compared to white radishes (1246 mg/kg). The highest nitrate concentrations were recorded in radishes from the retail chain (1463 mg/kg), while local producers presented lower values (LP1: 1247 mg/kg, LP2: 1213 mg/kg). Seasonality strongly affected nitrate levels, with peak concentrations observed in spring months (average 1627 mg/kg) and the lowest values in winter (average 1002 mg/kg). Vitamin C content was also variety- and season-dependent, with red radishes exhibiting higher average values (18.5 mg/100 g) compared to white radishes (14.6 mg/100 g). The highest vitamin C concentrations were detected during the summer months, particularly in July and August, confirming that this period provides a significantly greater source of vitamin C compared to winter and autumn. Our findings further emphasize that cultivation system, environmental conditions, and nutrient management practices considerably influence the nitrate and vitamin C content in radishes. Monitoring and optimizing these factors is therefore essential to maximize the nutritional quality and health safety of radishes. Appropriate fertilization management, careful control of soil nitrate levels, and adapted cultivation strategies can effectively contribute to reducing nitrate accumulation without compromising vitamin C content.

Acknowledgments: This work was supported by project KEGA no. 013SPU-4/2023 „Innovation of the methodologies for the development of combined education in food disciplines “and KEGA no. 002SPU-4/2025 „Innovative education in food-oriented study programs as a pathway for the employability of Generation Z graduates in the job market “.

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