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Professional paper

COMPARATIVE ANALYSIS OF IRON LEVELS IN CABBAGE AND EGGPLANT FROM THE VELES AND BITOLA REGIONS IN R. N. MACEDONIA

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Abstract

Iron (Fe) is a crucial micronutrient involved in oxygen transport, cellular respiration, as well as various metabolic processes in humans, including DNA synthesis, electron transport, vital enzymatic activities, and cellular energy generation. The aim of this study was to determine the iron concentration in cabbage (*Brassica oleracea* var. *capitata* F. *alba*) and eggplant (*Solanum melongena* L.) from different locations within two regions. Iron concentrations were determined in cabbage and eggplant samples collected from six locations within the Veles and Bitola regions of R. N. Macedonia. Quantitative analysis of Fe was performed using inductively coupled plasma - optical emission spectrometry (ICP-OES). The results are expressed on both a dry weight (DW) and fresh weight (FW) basis. The percentage of dry matter and water content in the samples is also presented. The estimated daily intake of iron from these vegetables for adults and children was calculated. The concentration of Fe in cabbage ranged from 7.44 to 33.57 mg/kg DW and 0.58 to 2.35 mg/kg FW, while in eggplant, it ranged from 4.29 to 30.35 mg/kg DW and 0.35 to 2.72 mg/kg FW. The estimated daily iron intake ranged from 0.07 to 0.67 mg/day for adults and 0.041 to 0.464 mg/day for children. Variations in iron concentration were observed in both cabbage and eggplant depending on the cultivation location The ANOVA test revealed a statistically significant difference in iron concentration between cabbage and eggplant, as well as between the two cultivation regions.

Keywords: cabbage, eggplant, iron, dry matter, microelements, daily intake

1. Introduction

Iron is a micronutrient that plays a significant structural and functional role in all organisms. Iron is predominantly found in erythrocytes as a heme complex within hemoglobin (approximately 2.5 g for average adult – 70 kg). The remaining iron is stored in forms such as ferritin, hemosiderin, and myoglobin. These are primarily located in the liver, bone marrow, muscles, and spleen (Perera et al., 2023; Rolic et al., 2024).

In addition to its essential role in critical biological functions like oxygen transport and cellular respiration, iron is required for various metabolic processes in humans, including DNA synthesis, electron transport, essential enzymatic activities, and cellular energy generation (Roemhild et al., 2021; Charlebois & Pantopoulos, 2023; Perera et al., 2023). Iron deficiency is one of the most common nutritional deficits and disorders worldwide, leading to one of the most prevalent medical conditions, iron deficiency anemia (Kumar et al., 2022; Kulik-Rechberger & Dubel, 2024). Despite the essential role of iron in the human body, high iron intake can lead to various physical abnormalities and impair organ function due to oxidative damage, inflammation, apoptosis, and necroptosis (Huang et al., 2021).

Dietary iron exists in heme and non-heme forms. Heme iron is found in foods of animal origin, such as meat, poultry, and fish, whereas non-heme iron is found in foods of plant origin, like

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cereals, legumes, nuts, fruits, and vegetables. Heme iron has higher bioavailability (15–35%), while non-heme iron has lower bioavailability, around 10%, and is strongly influenced by other components affecting its absorption (Perera et al., 2023; Piskin et al., 2022).

Non-heme iron, found mainly in legumes, cereals, and vegetables, includes various organic forms such as iron citrate, iron gluconate, iron fumarate, and ferritin, and inorganic forms like iron sulfate, carbonate, and chloride. Each form of iron exhibits different absorption patterns and efficiencies (Miramontes et al., 2018). According to Bukva et al. (2019), vegetables have a higher iron content (6.33 to 107 mg/kg) than fruits (2.91 to 39.27 mg/kg). A study by Rodrigues-Ramiro et al. (2019) on the bioavailability of iron from leafy vegetables using *in vitro* digestion model showed that cabbage had the highest iron bioavailability at 16.2%, whereas iron from spinach had the lowest bioavailability at 6.6%. According to the authors, cabbage was the best source of bioavailable iron due to the formation of complexes with fructose derivatives, which contribute to increasing its bioavailability.

Cabbage (*Brassica oleracea var. capitata F. alba*) is one of the most widespread vegetables globally, belonging to the *Brassica* genus. Cabbage has positive effects on human health due to its rich nutritional composition, containing glucosinolates, polyphenols, vitamins, and minerals with antioxidant, anti-inflammatory, and anticarcinogenic properties (Stefan & Ona, 2020; Rokayya et al., 2013). Eggplant (*Solanum melongena* L.) is a fruiting vegetable and one of the most important plant crops due to its nutritional benefits. It is a source of various bioactive compounds such as proteins, polyphenols, flavonoids, vitamins, and minerals that preserve and promote human health (Sharma & Kaushik, 2021; Mauro et al., 2022).

The aim of this study was to determine the iron content in cabbage and eggplant in order to assess their nutritional value as dietary sources of this essential mineral. Furthermore, by comparing samples from two different regions, the study sought to evaluate the regional variability in iron concentrations. These vegetables are commonly consumed in the local diet, making the findings relevant for understanding their contribution to iron intake in the studied population.

2. Materials and Methods

Sample Selection and Preparation. Two types of vegetables were analyzed: cabbage (*Brassica oleracea* var. *capitata* F. *alba*) and eggplant (*Solanum melongena* L.) from the Bitola and Veles regions in R. N. Macedonia. The samples for analysis were collected from three locations in the vicinity of the city of Bitola: Novaci, Gneotino, and Porodin, and three locations in the vicinity of the city of Veles: Bashino Selo, Rechani, and Dolno Kalaslari (Темелковска Ристевска, 2024; Temelkovska Ristevska et al., 2024). Ten cabbages and ten eggplants were collected from each location. The outer leaves were removed from the cabbage samples, while the eggplant samples were washed with distilled water and left to air-dry at room temperature. The vegetables were chopped, and a representative sample of cabbage and eggplant was weighed on an analytical balance (BRS-1000-C1, d=0.001g, MRC manufacturer) and placed in a drying oven (DRY-line manufactured by VWR) at 105°C to dry to a constant mass. Subsequently, the samples were cooled in a desiccator, homogenized with a porcelain mortar and pestle, and stored in polyethylene bags until analysis. The percentage of water and dry matter was calculated as described in the study by Heghedus-Mindru et al. (2023).

Quantitative Iron Analysis. Sample preparation for analysis involved wet digestion with 65% nitric acid (Sigma-Aldrich). Quantitative analysis of iron (Fe) was performed using inductively coupled plasma - optical emission spectrometry (ICP-OES, ARCOS FHE12, SPECTRO, Germany). Three replicates of the analysis were performed for each sample. The iron concentration was initially determined based on the dry weight of the samples. The equation provided by the USDA (2011) was used to calculate the concentration based on fresh weight.

Daily Intake Rate (DIR). The Daily Intake Rate (DIR) estimates the total daily intake of iron through each vegetable. It was calculated using the following formula (Chauhan & Chauhan, 2014):

$$DIR = C \times D$$

Where:

- C - concentration of iron in vegetables (mg/kg) on a fresh weight basis.
- D - daily intake of vegetables (kg per person per day on a fresh weight basis).

Data for the average daily vegetable intake used in these calculations were obtained from USEPA (2018).

Statistical Analysis. The statistical significance of iron concentration differences between the two vegetable types, and between the cultivation locations, was analyzed using a two-way Analysis of Variance (ANOVA) with replications. Statistical analysis was performed using Microsoft Excel, with a significance level of $p < 0.05$ (Levine, 2020).

3. Results and Discussion

Table 1 shows the percentage of dry matter (DM) and water (W) in cabbage and eggplant from all locations.

Table 1. Percentage of dry matter and water in cabbage and eggplant

Location	Cabbage*		Eggplant	
	% DM	% W	% DM	% W
Bashino selo	6.39	93.61	9.45	90.55
Rechani	7.01	92.99	8.95	91.05
Dolno Kalaslari	7.79	92.21	7.70	92.30
Novaci	6.90	93.10	6.86	93.14
Gneotino	7.80	92.20	8.30	91.70
Porodin	7.77	92.23	8.52	91.48

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Results indicated that the dry matter content in cabbage ranged from 6.39% to 7.80%, while the water content ranged from 92.20% to 93.61% (Table 1). Eggplants exhibited a higher dry matter content (6.86% to 9.45%) and a lower water content (90.55% to 93.14%); however, these differences in dry matter and water content between the two vegetables were not substantial. These results are consistent with the dry matter content in cabbage reported by Duarte et al. (2019), which was 7.62% and 6.53%. Shabetya et al. (2020) reported a dry matter content ranging from 7.8% to 8.7% in four eggplant types, while Sharma & Kaushik (2021) found a range of 4.69% to 6.7% in different eggplant varieties**.** Figure 1 shows the concentration of iron (on a dry weight basis) in cabbage and eggplant samples from six cultivation locations.

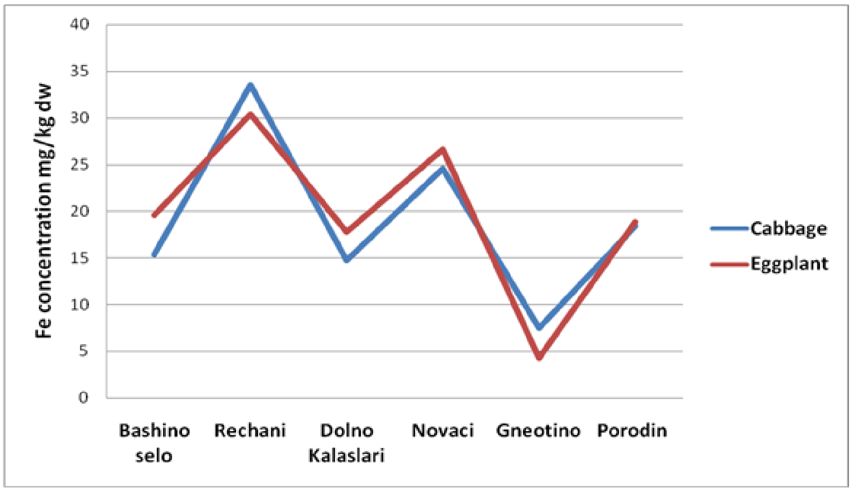

Figure 1. Concentration of iron in cabbage and eggplant (mg/kg dw)

The lowest iron concentrations were observed in cabbage and eggplants from Gneotino (Bitola region), whereas the highest concentrations were found in cabbage and eggplants from Rechani (Veles region) and Novaci (Bitola region) as presented in the Figure 1. Ahmad et al. (2015) reported higher iron concentrations in the dry weight of cabbage (32.3 and 60.1 mg/kg), while Haliu et al. (2019) reported lower concentrations (9.31 mg/kg). According to Atamaleki et al. (2021), there are variations in the iron concentration in the dry weight of eggplants ranging from 2.22 to 96.72 mg/kg. Table 3 shows the concentration of iron in the fresh weight of cabbage and eggplants.

Table 2. Iron (Fe) concentration in fresh weight of cabbage and eggplants (mean ± standard deviation mg/kg, n=3)

Location	Cabbage	Eggplant
Bashino selo	0.98 ± 0.01	1.84 ± 0.01
Rechani	2.35 ± 0.02	2.72 ± 0.03
Dolno Kalaslari	1.15 ± 0.08	1.37 ± 0.07
Novaci	1.69 ± 0.01	1.83 ± 0.07
Gneotino	0.58 ± 0.02	0.36 ± 0.01
Porodin	1.43 ± 0.08	1.61 ± 0.04

From Table 2, it can be observed that the concentration of Fe is higher in the fresh weight of eggplants compared to cabbage from all locations, except in Gneotino, where the Fe concentration in cabbage is 0.23 mg/kg higher than in eggplants. The largest difference in iron concentration between the analyzed vegetables is in Bashino Selo, where the Fe concentration in eggplants is 0.86 mg/kg higher than the Fe concentration in cabbage. In the remaining locations, there are no significant differences in iron concentration between cabbage and eggplants, ranging from 0.17 to 0.36 mg/kg.

Our results are consistent with the iron concentration results in cabbage (3.0, 2.92, and 2.75 mg/kg fw) reported by Lere et al. (2021) and the iron concentration in cabbage (1.91 to 8.6 mg/kg) reported by Anunciacao et al. (2011). According to the literature, the Fe concentration in fresh weight of eggplants was 2.63 to 3.58 mg/kg (Mauro et al., 2022), 2.02 to 3.7 mg/kg (Ayaz et al., 2015), 0.18 to 7.74 mg/kg (Atamaleki et al., 2021), 1.16 mg/kg (Davidson & Monulu, 2018), etc.

Iron absorption by vegetables from the soil is influenced by several factors. Iron availability is largely dependent on the soil's redox potential and pH. In soils with a higher pH, Fe readily oxidizes and is predominantly found as insoluble oxides. Conversely, at a lower pH, Fe is released from these oxides, becoming more available for root absorption. Furthermore, divalent metal ions such as Cd, Mn, Ni, Co, and Zn can also influence Fe absorption and metabolism in plants. The genotype of the vegetable also significantly influences iron uptake from the soil. Other factors affecting iron absorption and availability in plants include its redox reactions with nitrogen, phosphorus, calcium, and sulfur, which can decrease Fe bioavailability. Conversely, the presence of organic matter, particularly organic acids, can form chelates with iron, thereby increasing its availability (Fodor, 2024; Morrissey & Guerinot, 2009; Ning et al., 2023; Liu et al., 2024).

Table 3. Daily iron intake in adults and children (mg/day).

Location	Vegetable	Adults	Children
Bashino selo	Cabbage	0.12	0.07
	Eggplant	0.46	0.31
Rechani	Cabbage	0.29	0.17
	Eggplant	0.67	0.46
Dolno Kalaslari	Cabbage	0.14	0.08
	Eggplant	0.34	0.23
Novaci	Cabbage	0.21	0.12
	Eggplant	0.45	0.31
Gneotino	Cabbage	0.07	0.04
	Eggplant	0.09	0.06
Porodin	Cabbage	0.17	0.10
	Eggplant	0.40	0.28

*****Recommended Daily Intake (RDI) according to EFSA
Adults: 11-16 mg/day
Children: 7 - 11 mg/day

Based on Table 3, the estimated daily iron intake from cabbage and eggplant is notably low for both adults and children, remaining under 0.7 mg/day. As expected, adults showed a higher daily intake from these vegetables compared to children. The highest average daily iron intake was observed from eggplants sourced from Rechani, contributing 4.2-6.1% of the recommended daily intake (RDI) for adults and 4.2-6.6% for children. For cabbage, the highest estimated daily iron intake was also from Rechani, meeting 1.7-2.6% of the RDI for adults and 1.5-2.4% for children. Conversely, the lowest estimated iron intake for both adults and children was from Gneotino, which consistently corresponded with the lowest iron concentration found in the vegetables from that location.

Considering the inherently low bioavailability of iron from plant-based sources, cabbage and eggplant contribute only a small fraction to the total daily iron needs of adults and children. Therefore, it is recommended to consume these vegetables alongside foods with higher iron concentrations and those known to have better iron bioavailability to ensure adequate intake.

Foods of animal origin generally have higher iron bioavailability compared to plant sources (Richard & Ines, 2010). The bioavailability of iron from plant sources is significantly influenced by the presence and concentration of both promoters and inhibitors of its absorption. Inhibitors of iron absorption include phytates, tannins, polyphenols, calcium salts, and oxalates, among

others. Conversely, promoters of iron absorption include ascorbic acid, citric acid, other organic acids, and certain vegetable processing methods (Malhotra et al., 2023).
Given these factors, it is crucial to conduct further research on the bioavailability of iron from plant-based foods, particularly using in-vitro methods (Sulaiman et al., 2021). The bioavailability of iron from plant-based foods is especially important for vegetarians, vegans, and individuals whose diets are primarily plant-based. Careful meal planning that considers both promoters and inhibitors of iron absorption is therefore necessary for these groups (Wonderen et al., 2023). According to the literature, vegetarians and vegans often exhibit lower blood hemoglobin concentrations compared to non-vegetarians and are consequently more susceptible to developing iron-deficiency anemia (Tong et al., 2019; Pawlak et al., 2016; Haider et al., 2016).

Table 4. Results of ANOVA test for iron variability in vegetables.

Source of Variation	F	P-value	F critical
Vegetables	22.83	7.30E-05	4.26
Locations	2990	1.03E-32	2.62
Interaction	93.61	6.14E-15	2.62

According to the results from the ANOVA test (Table 4), which assessed for a statistically significant difference in iron concentration between cabbage and eggplant, the obtained p-value (7.30E-05) is much lower than 0.05, and the F-value (22.83) is higher than the F-critical value (4.26). This decisively indicates a statistically significant difference in iron concentration between cabbage and eggplant. Regarding cultivation location, the obtained p-value (1.03E-32) is significantly lower than 0.05, and the F-value (2990) is substantially higher than the F-critical value (2.62). We can therefore conclude that there is a statistically significant difference in iron concentration between different regions**.** Furthermore, a statistically significant interaction exists between vegetable type and location**.** The p-value (6.14E-15) is much lower than 0.05, and the F-value (93.61) is higher than the F-critical value (2.62). This suggests that the influence of vegetable type on iron concentration is not uniform across all locations. In other words, the difference in iron concentration between the two vegetable types varies depending on the location, which is clearly illustrated in Figure 1.

4. Conclusions

This study determined the iron concentration in cabbage and eggplant samples collected from six different cultivation locations. Both cabbage and eggplant exhibited high water content and consequently lower dry matter content, ranging from 6.39% to 7.80% in cabbage and 6.86% to 9.45% in eggplant. Significant differences in iron concentration were observed in the analyzed vegetables depending on their cultivation location. The highest fresh weight iron concentrations were found in samples **f**rom Rechani (cabbage: 2.35 mg/kg; eggplant: 2.72 mg/kg), followed by Novaci (cabbage: 1.69 mg/kg; eggplant: 1.83 mg/kg). Conversely, the lowest iron concentrations were detected in vegetables from Gneotino (cabbage**:** 0.58 mg/kg; eggplant: 0.36 mg/kg). The estimated daily iron intake from cabbage and eggplant was very low for both adults and children, meeting only a small fraction of their total daily requirements. Nevertheless, further research on the bioavailability of iron from these vegetables is essential. Statistical analysis of the data revealed a statistically significant difference in iron concentration between cabbage and eggplant, as well as significant variations in iron concentrations based on the cultivation region.

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