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The Utilization of Vegetable Powders for Bread Enrichment—The Effect on the Content of Selected Minerals, Total Phenolic and Flavonoid Content, and the Coverage of Daily Requirements in the Human Diet

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Abstract: The aim of this study was to evaluate the content of selected minerals and total phenolic and flavonoid content of wheat bread and bread enriched with varying amounts of carrot powder (CP) and pumpkin powder (PP). In addition, the coverage of daily requirements of selected minerals was evaluated after the consumption of 100 g of each type of bread. The research included seven types of bread: wheat bread (WB) and bread enriched with 10%, 20%, and 30% CP and PP. The vegetable powders were obtained by freeze-drying. The concentrations of minerals—sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn)—were determined by atomic absorption spectroscopy (AAS) method. Coverage of daily requirements after consumption of a serving of bread was determined based on Recommended Daily Allowance (RDA) and Adequate Intake (AI) ratios for minerals, according to the nutritional standards for the Polish population. The addition of 10% PP led to a greater increase in Na, K, Mg, and Cu in the bread compared to CP, while for Ca, Fe, Zn, and Mn a greater increase was observed with the addition of 10% CP than PP. Among macronutrients, the greatest changes in content were recorded for Ca—the addition of 10 and 20% CP and PP resulted in increases of 66, 113, 51 and 59%. Among micronutrients, the addition of CP and PP to wheat bread caused the largest changes in Cu (46–150% increase) and Mn (25–99% increase) content. Additionally, there was a tenfold increase in total phenolic content (TPC) when 30% CP was added to the bread. Consuming 100 g of bread with CP and PP provided the greatest coverage of K (41–60%), Cu (8–17.5%), and Mn (6–17%). These findings suggest that fortification of bread with vegetable powders has the potential to be a useful method of enriching the mineral composition and increasing the proportion of selected minerals in the human diet.

Keywords: food fortification; bread; carrot powder; pumpkin powder; minerals; mineral requirements

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Citation: Purkiewicz, A.; Gul, F.H.; Pietrzak-Fiećko, R. The Utilization of Vegetable Powders for Bread Enrichment—The Effect on the Content of Selected Minerals, Total Phenolic and Flavonoid Content, and the Coverage of Daily Requirements in the Human Diet. *Appl. Sci.* **2024**, *14*, 10022. https://doi.org/10.3390/app142110022

Academic Editors: Monica Gallo and Wojciech Kolanowski

Received: 21 September 2024
Revised: 24 October 2024
Accepted: 31 October 2024
Published: 2 November 2024

1. Introduction

Bread is a fundamental component of diets worldwide [1]. Its consumption varies across regions, depending on the availability and cost of cereals [2]. It is recognized as a source of essential vitamins and minerals that are crucial for proper development [3]. Nutritionally, bread constitutes a significant part of a balanced human diet, offering a rich energy source due to its high carbohydrate (starch) content and low-fat composition [4].

Bread provides a substantial supply of both macro- and micronutrients [3]. Wheat bread contains key minerals such as calcium (Ca), phosphorus (P), potassium (K), iron (Fe), magnesium (Mg), and sodium (Na) [5]. In the human body, these minerals play vital structural and regulatory roles [6]. Adequate calcium intake is essential for maintaining the bone and dental density [7]. Similarly, Mg is crucial for nerve impulse transmission, blood pressure regulation, calcium metabolism, glucose control, and nucleic acid synthesis [8]. Na and K, both electrolytes, are responsible for regulating fluid balance and blood pressure, with sodium also aiding in nerve impulse transmission in conjunction with potassium [9]. Iron's (Fe) primary role lies in oxygen transport to cells and the synthesis of hemoglobin. Iron deficiency anemia remains the most prevalent type of anemia worldwide [3]. Zinc (Zn), on the other hand, is essential for brain enzyme synthesis, and its deficiency can result in impaired physical development and weakened immune function [10]. The mineral composition of bread is largely influenced by the type of flour used in its production. For instance, the typical mineral content in wheat bread includes the following: Ca—26 mg/100 g; K—345 mg/100 g; Zn—1.7 mg/100 g; Fe—3.4 mg/100 g; P—205 mg/100 g; Ca—381.0 mg/100 g; Cu—0.3 mg/100 g; and Mn—2.1 mg/100 g [11]. However, these values can vary depending on the wheat variety, growing conditions, and additives introduced during production [12]. There is a growing trend in enriching bakery products with additives to enhance their taste, flavor, and nutritional value. Several studies have demonstrated the benefits of enriching white wheat flour with other cereals or pseudo-cereals. More recent research has explored the supplementation of wheat flour with plant-based ingredients, such as fruit and vegetable fibers, dried fruits and vegetables, nuts, seeds, and vegetable powders [13,14]. From a nutritional perspective, fortifying wheat bread is important, as it typically utilizes only the endosperm, excluding the germ and bran, rendering it less nutritious compared to whole wheat bread [5]. The enrichment of bread significantly affects its antioxidant profile. While wheat bread contains small amounts of bioactive compounds, the addition of vegetables can significantly increase the amount of bioactive compounds while increasing the nutritional value of wheat bread [15]. A particularly popular method for mineral enrichment in baked products is the addition of vegetable powders. These powders serve as concentrated sources of micro- and macrominerals and represent a cost-effective, low-calorie addition to bakery products [16]. The freeze-drying process used to create vegetable powders results in minimal loss of bioactive compounds compared to conventional drying techniques [17]. Minerals have low volatility and are less affected by heat treatments, thus preserving the ash content [18]. Previous studies have fortified bread with eggplant and radish powder [16], leafy vegetable powders [19], and powders from vegetables such as broccoli, cauliflower, and zucchini [20]. Orange vegetables, such as pumpkins and carrots, are relatively cheap in the Polish market, particularly during the autumn season [21]. These vegetables also offer significant nutritional value, with high levels of carotenoids, vitamin A, and minerals like Ca, K, Na, and Mg [22,23]. Due to their availability, affordability, and nutrient density, these vegetables are ideal candidates for inclusion in bakery products [24].

Fortifying bread with minerals has a positive impact on its nutritional quality. Studies suggest that the diet of the Polish population does not adequately meet the recommended intake for certain macro- and micronutrients [25,26]. Bread consumption in Poland has significantly decreased over the years. While the monthly bread consumption per capita in 2010 was approximately 5 kg, it dropped to 2.5–3 kg by 2022 [27]. This decline may be attributed to shifts in dietary recommendations, which advocate reducing cereal product consumption in favor of vegetables and fruits, largely due to concerns over excessive salt intake. It is reported that Polish people consume up to 13 g of salt per day through food, which is more than twice the safe level set by the World Health Organization (WHO) [28,29]. The increasing popularity of dietary trends, such as gluten-free diets, has resulted in a decline in the consumption of grain-based products [28]. Nevertheless, bread remains a staple in Poland, with a signification proportion of the population consuming it daily. Therefore, it is concluded that bread is a rich source of minerals in the diet and is an important source of nutrition [2]. Despite increasing interest in whole grain and multigrain bread, many Polish consumers still prefer wheat bread [30,31].

The aim of this study was to enhance traditional wheat bread with carrot powder (CP) and pumpkin powder (PP) and to evaluate the effects of this enrichment on the levels of selected macrominerals (Na, K, Ca, Mg), microminerals (Fe, Zn, Cu, Mn), and total phenolic and total flavonoid content. In addition, this study examined the extent to which the consumption of these breads could contribute to meeting the Recommended Daily Allowance (RDA) and Adequate Intake (AI) of these minerals for adults based on average daily bread consumption.

2. Materials and Methods

2.1. Materials

Wheat flour type 680, fresh yeast, milk, sugar, and salt were purchased at a supermarket in Olsztyn (Poland). Carrots (*Daucus carota* L. cv. Flakkee) and pumpkin (*Cucurbita maxima* Duchesne—'Gomez') were purchased at a local fruit and vegetable store in Olsztyn (Poland).

2.2. Production of Vegetable Powder from Carrots and Pumpkins

Fresh carrots and pumpkins were pre-treated (sorting, washing) and then cut into thin slices and dried in the laboratory vacuum freeze dryer Chaist Alpha 1-2 LD (Christ/Sigma, Osterode, Germany). Frozen samples (at −70 °C for 20 h) were placed in the freeze dryer, and the drying step was carried out at a pressure of 0.04 mbar at a temperature of −50 °C for 40 h. The dried carrots and pumpkins were ground into a fine powder using the multifunction device Thermomix MT31, Vorwerk (Wuppertal, Germany). The resulting powder was tightly placed in Ziplock foil bags intended for freezing food products, and stored in a dry, dark place at room temperature (22 °C) until further use (Figure 1).

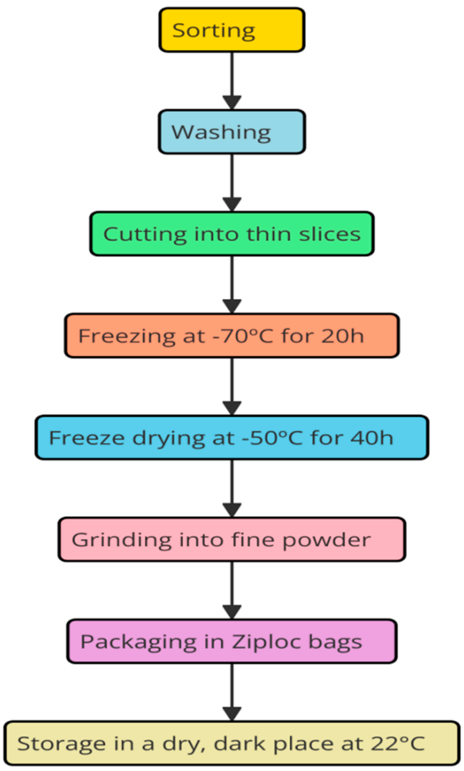

Figure 1. Production of vegetable powder from carrots and pumpkins.

2.3. Bread Preparation

In the present study, the research material consisted of seven types of bread prepared according to the recipe. Table 1 shows the amount of individual ingredients used in the preparation of each type of bread. The control bread included wheat bread made using the single-phase method according to Wójcik et al. [32] with modifications. Yeast was liquidized with milk (35 ± 2 °C) with the addition of sugar. The remaining water, previously sieved flour, and the prepared salt-water solution were added to the yeast starter. The dough was kneaded in a multifunction device Thermomix MT31, Vorwerk, Germany, for 6 min. After the dough was formed, it was transferred to a separate container and remained for 2 h for fermentation. After fermentation, the dough was divided into equally sized pieces, transferred to baking pans, and baked at 230–250 °C for 30 min. Bread with 10%, 20%, and 30% vegetable powders were prepared analogously, replacing the appropriate parts of the flour with vegetable powders. The selection of concentrations of vegetable powders added to bread was conducted based on the review of the studies of other authors performing similar enrichment treatments [15,33,34].

Table 1. The proportion of the various ingredients for the bread preparation.

Ingredient	Control Bread (WB) Sample	Bread Containing Carrot Powder			Bread Containing Pumpkin Powder		
		CB10%	CB20%	CB30%	PB10%	PB20%	PB30%
Wheat flour type 680, g	330	297	264	330	297	264	330
Water, ml	220	220	220	220	220	220	220
Milk, ml	50	50	50	50	50	50	50
Sugar, g	5	5	5	5	5	5	5
Fresh yeast, g	11	11	11	11	11	11	11
Salt, g	4	4	4	4	4	4	4
Carrot powder (CP), g	-	33	66	99	-	-	-
Pumpkin powder (PP), g	-	-	-	-	33	66	99

2.4. Determination of Minerals

The mineralization of the samples was carried out according to the method described by Whiteside and Miner [35]. Standardized milk samples (10 mL) were weighed into quartz crucibles and dried in a laboratory dryer (Memmert UF30, Schwabach, Germany) for 8–12 h at a temperature of 60 °C. The samples were then carbonized on an electric cooker for 8 h at 480 °C and then placed in a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) to obtain a white-gray ash (with the temperature rising gradually from 100 °C to 500 °C).

The ashes were heat dissociated in 1M HNO_3 (Merck, Darmstadt, Germany), transferred to 25 mL volumetric flasks, and filled with deionized water. Reagent samples were prepared in parallel to the test samples. The mineral content was determined in the mineralization obtained (directly or after their dilution).

The contents of copper (Cu), manganese (Mn), iron (Fe), zinc (Zn), calcium (Ca), and magnesium (Mg) were determined by the flame atomic absorption spectroscopy (AAS) method (acetylene–air flame). Analyses were conducted using an atomic absorption spectrometer iCE 3000 SERIES-THERMO (Thermo-Scientific, Hemel Hempstead, Hertfordshire, UK) equipped with a GLITE data station, background correction (deuterium lamp), and suitable cathode-ray tubes. To determine the Ca content, the addition of a 10% heptahydrate lanthanum chloride $LaCl_3*7H_2O$ (Merck, Darmstadt, Germany) in an amount providing a final concentration of La^{+3} of 1% was used.

Sodium and potassium (Na and K) contents were determined by the emission technique (acetylene/air flame). Analyses were conducted using an atomic absorption spectrometer iCE 3000 SERIES-THERMO (Thermo-Scientific, Hemel Hempstead, Hertfordshire, UK) equipped with a GLITE data station and operating in the emission system.

The average mineral content was expressed as the mean of three replications with a standard deviation of 1 kg of fresh bread.

2.5. Preparation of Extracts

For the analysis of phenolic and flavonoid compounds, 5 g of bread (previously dried) was diluted five times with distilled water and then centrifuged in an Eppendorf-type centrifuge (Eppendorf AG, Hamburg, Germany) (4000 rpm/10 min). The prepared extracts were used to determine total phenolic content (TPC) and total flavonoid content (TFC).

2.6. Determination of Total Phenolic Content (TPC)

The modified method described by Ribereau-Gayon et al. [36] was used to determine the total phenolic compounds in the bread. In a 10 mL volumetric flask, 0.5 mL of prepared extract was transferred, and 0.5 mL of Folin–Ciocalteu reagent (diluted 1:2 with distilled water) was added and mixed. Subsequently, 3 mL of 14% sodium carbonate solution was added and mixed again. The flask was refilled with distilled water and mixed again. The prepared solutions were left for 60 min in a dark place and then the absorbance of the solutions was measured at 720 nm using a FLUOstar OMEGA BGM LAB (BMG Labtech, Ortenberg, Germany). Tech spectrophotometer against the reagent sample. The reagent sample contained distilled water instead of the extract to be analyzed. The total phenolic compound content was expressed as mg catechin/g bread relative to the standard curve prepared for the catechin solution.

2.7. Determination of Total Flavonoid Content (TFC)

The method developed by Herald et al. [37] and Yafang et al. [38] was used to determine the total flavonoid content of the tested bread. To a 15 mL polypropylene tube, 4 mL of deionized water, 1 mL of the extract to be analyzed, and 0.3 mL of a 5% $NaNO_2$ solution were added. The mixture was mixed thoroughly and left to react for 5 min. Subsequently, 0.6 mL of 10% $AlCl_3$ $6H_2O$ solution was added to the mixture and left to react for 6 min. Once the reaction was complete, 2 mL of 1 M NaOH solution and 2 mL of deionized water were added. The mixture was centrifuged in an Eppendorf centrifuge type 5810R (Eppendorf AG, Hamburg, Germany) at 4000 rpm for 10 min. The absorbance of the mixture was measured at 415 nm using a UV/Vis UV2 spectrophotometer (Unicam, Ortenberg, Germany) against the reagent sample. The reagent sample contained distilled water instead of the extract analyzed. Flavonoid content was expressed as mg catechin/g of bread, relative to the standard curve prepared for the catechin solution.

2.8. Coverage of Daily Mineral Requirements After Consumption of Bread

Calculations of coverage of daily requirements for selected minerals were conducted using the intake standards included in the norms of nutrition for the Polish population [39,40]. Two indicators—Recommended Daily Allowance (RDA) and Adequate Intake (AI)—were used for conversion. Mineral requirements were recalculated for adult men and women aged 18–65 years after consuming a particular portion of bread.

2.9. Statistical Analysis

Results were presented as mean ± standard deviation (SD). One-way ANOVA and Tukey's test were utilized to determine statistical differences in the content of individual minerals, total phenolic, and total flavonoid content in different types of bread. Statistical calculations were performed using Statistica 13.1 software (Tulsa, OH, USA).

3. Results and Discussion

3.1. Minerals in Carrot Powder (CP) and Pumpkin Powder (PP)

Bread is not usually considered a significant source of antioxidants or dietary fiber, fortification with vegetable powders is a reasonable approach to increase its nutritional value. According to the nutritional value of wheat flour as reported by the United States Department of Agriculture (USDA) [41], its Na, K, Ca, Mg, Fe, Zn, Cu, and Mn content is lower than that of the two sheaths tested.

3.1.1. Macroelements

Figure 2 shows the macroelements content of vegetable powders. The macronutrient content in CP was Na > Ca > K > Mg, while in PP, it was Na > K > Ca > Mg. Singh Purewal et al. [42], investigating the mineral profile of carrot flour, found the highest K content in orange, red, and black carrot flours. Kamel et al. [43] identified higher contents of Ca (880 ± 3.0 mg/100 g vs. 301.88 ± 4.95 mg/100 g), Na (615.0 ± 4.0 mg/100 g vs.

530.83 ± 9.07 mg/100 g), K (532.7 ± 0.2 mg/100 g vs. 208.01 ± 5.78), and Mg (171.7 ± 0.2 mg/100 g vs. 108.29 ± 3.23 mg/100 g) in comparison to our study. The differences in mineral content may be due to the carrot variety included as study material, the soil profile on which the carrots were grown (soil type, soil mineral content), and environmental factors [44,45]. The content of Ca and Mg in PP was 179.08 ± 3.59 mg/100 g and 90.21 ± 0.02 mg/100 g and was similar to the values of these elements in 'Gomez' pumpkin determined by Kulczyński et al. [46] (119.08 ± 0.17 and 111.11 ± 0.19 mg/100 g dm). These authors also report that the content of Ca and Mg varies in pumpkin depending on the variety and can range from 92.12 ± 0.19 mg/100 g in Hokkaido pumpkin to 264.89 ± 0.59 mg/100 g dm in Yellow Melon pumpkin (Ca) and 79.97 ± 2.18 mg/100 g dm in Blue Kuri pumpkin to 135.35 ± 0.08 mg/100 g dm in Bambino pumpkin (Mg) [46]. In the case of Na, the determined content (775.94 ± 10.52 mg/100 g) was more than twice as low as determined by Besaar et al. [47]. The same authors indicate a higher Mg content in PP (146 mg/100 g) compared to our study. In contrast, Assenova et al. [48] indicate a similar Mg content (94.5 mg/100 g) as in our study. Comparing the two powders, PP contained higher Na and K quantities, while CP contained Ca ($p < 0.05$). According to the literature, the Ca content of PP is significantly lower than that of CP [49,50].

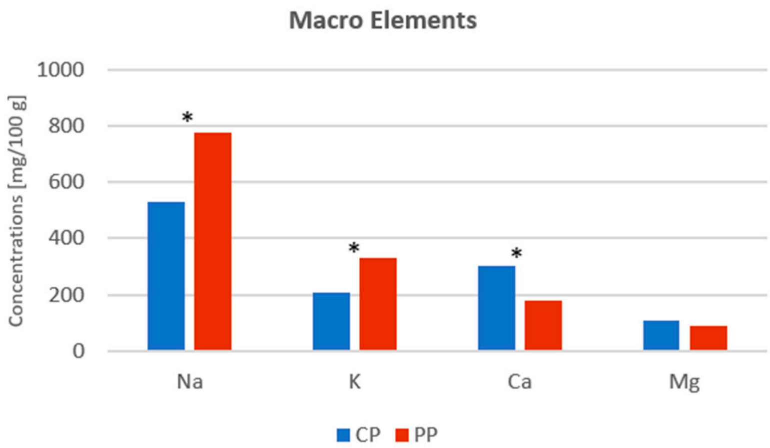

Figure 2. The content of individual macro minerals in vegetable powders. Abbreviations: Na—sodium, K—potassium, Ca—calcium, Mg—magnesium, CP—carrot powder, PP—pumpkin powder. Means with * is significantly different at $p < 0.05$.

3.1.2. Microelements

Figure 3 presents the microelements content of the vegetable powders tested. The present study identified Cu and Mn in CP at 0.35 ± 0.03 mg/100 g and 0.39 ± 0.04 mg/100 g; these values were much lower than those reported by Assenova et al. [48] (0.98 mg/100 g of Cu, 4.03 mg/100 g of Mn). The Fe (0.474 mg/100 g) and Zn (0.347 mg/100 g) contents determined by Hashmi et al. [51] in carrot pomace were lower than those in our study (2.21 ± 0.02 and 1.85 ± 0.07 mg/100 g). Also, Assenova et al. [48] showed a lower Fe content in CP (0.653 mg/100 g). While the Fe content of both powders was the same, the Zn content was higher in CP ($p < 0.05$). In the study from Besaar et al. [47] on pumpkin pulp meal, the Fe and Zn contents were 3.55 mg/100 g and 2.40 mg/100 g, respectively, and were higher than those obtained in our study. On the other hand, in the study of Adubofour et al. [52], the Fe content of PP was also high (3.74 ± 0.00 mg/100 g), while the Zn content (1.24 ± 0.00 mg/100 g) was lower than that determined by us. The Fe and Zn content of PP may vary depending on the drying method used. El Khatib and Muhieddine [53] indicate that Zn content was highest in oven-dried powder and lowest in enhanced solar. In contrast, the highest Fe content was identified in open sun-dried powder. In the production of PP, the use of appropriate pretreatment plays an important role in improving product quality and inhibiting enzymatic browning. Depending on the pretreatment carried out, which included hot water blanching, steam blanching, or dipping in 0.1% citric acid, the Fe content of the pumpkin flours ranged from 5.078 ± 0.00 to 22.54 ± 0.05 mg/100 g [53]. PP contained twice as much Cu and Mn compared to CP. It should be noted that the content of heavy metals, including copper, manganese, or zinc, in vegetables may depend on the type of pesticides used, soil and weather conditions, and the location of the growing areas [54].

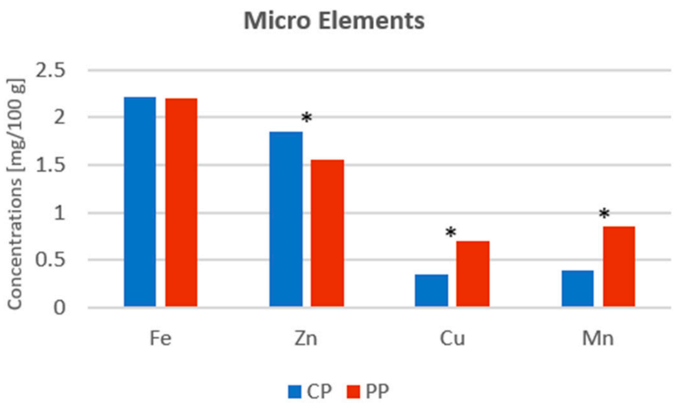

Figure 3. The content of individual macro minerals in vegetable powders. Abbreviations: Fe—iron, Zn—zinc, Cu—copper, Mn—manganese, CP—carrot powder, PP—pumpkin powder. Means with * is significantly different at $p < 0.05$.

3.2. Minerals Content in Bread Samples

In each type of bread, eight different minerals were determined. The contents of individual macrominerals (Na, K, Ca, Mg) and microminerals (Fe, Zn, Cu, Mn) are summarized in Table 2. It was found that the enrichment of wheat bread with CP and PP affected the content of each of the determined minerals.

Table 2. Mineral content of bread samples, mg/kg.

Mineral Elements	Control Bread (WB)	Bread Containing Carrot Powder CB10%	CB20%	CB30%	Bread Containing Pumpkin Powder PB10%	PB20%	PB30%
				Macroelements			
Na	900.75 ± 57.71 [b]	949.22 ± 21.54 [b]	1277.00 ± 60.42 [a]	1295.31 ± 123.15 [a]	1158.06 ± 12.18 [a]	1211.61 ± 3.22 [a]	1337.08 ± 101.55 [a]
K	1434.73 ± 43.91 [d]	1532.54 ± 23.17 [d]	1692.19 ± 59.14 [c]	1792.47 ± 38.29 [b]	1593.23 ± 56.47 [d]	1739.19 ± 32.45 [b]	2099.82 ± 93.34 [a]
Ca	261.25 ± 37.87 [d]	336.74 ± 13.63 [c]	433.29 ± 2.42 [b]	557.28 ± 23.94 [a]	335.56 ± 1.15 [c]	395.85 ± 14.64 [b]	416.06 ± 4.86 [b]
Mg	150.79 ± 21.92 [a]	169.43 ± 18.88 [a]	178.52 ± 10.05 [a]	203.60 ± 5.00 [a]	173.07 ± 27.84 [a]	191.82 ± 20.48 [a]	209.63 ± 3.83 [a]
				Microelements			
Fe	5.56 ± 0.09 [d]	6.46 ± 0.03 [c]	6.89 ± 0.17 [b]	7.89 ± 0.35 [a]	6.00 ± 0.09 [c]	6.85 ± 0.24 [b]	7.48 ± 0.08 [a]
Zn	5.41 ± 0.12 [c]	6.43 ± 0.06 [b]	6.54 ± 0.29 [b]	7.49 ± 0.06 [a]	5.65 ± 0.13 [c]	5.75 ± 0.23 [c]	5.91 ± 0.15 [b]
Cu	0.76 ± 0.05 [b]	1.11 ± 0.01 [b]	1.17 ± 0.13 [b]	1.26 ± 0.06 [b]	1.29 ± 0.14 [b]	1.58 ± 0.03 [a]	1.90 ± 0.38 [a]
Mn	1.55 ± 0.06 [b]	2.19 ± 0.01 [b]	2.44 ± 0.02 [b]	2.79 ± 0.04 [a]	1.94 ± 0.29 [b]	2.87 ± 0.02 [a]	3.09 ± 0.16 [a]

Abbreviations: Na—sodium, K—potassium, Ca—calcium, Mg—magnesium, Fe—iron, Zn—zinc, Cu—copper, Mn—manganese, WB—wheat bread, CB10/20/30%—bread with 10/20/30% addition of carrot powder, PB10/20/30—bread with 10/20/30% addition of pumpkin powder. Means with different letters (a, b, c, d) are significantly different at $p < 0.05$. Means a, b, c, d specify differences between the mineral composition of wheat bread and bread enriched with 10, 20, and 30% carrot and pumpkin powder.

Carrots and pumpkins are among the vegetables rich in minerals, especially P, K, and Ca, and contain moderate amounts of Fe [55]. It should be noted that the chemical composition of vegetables is largely dependent on the species, maturity, climatic and soil conditions, and storage method [12]. On the other hand, the amount of mineral elements in vegetables is largely dependent on the heat treatment used, the fineness of the raw material, and the form of the minerals [56].

3.2.1. Macrominerals

Each of the different types of bread contained the highest Na (900.75–1337.08 mg/kg) and K (1434.73–2099.82 mg/kg), and the lowest Mg (150.79–209.63 mg/kg). In the case of Na, the addition of even 10% PP caused a significant increase in the content of this element.

Compared to control bread (WB), bread with the addition of 10% PP (PB10%) contained 257.31 mg/kg more Na. Further addition of PP increased Na content, but no significant statistical differences were indicated. The addition of 10% CP to bread increased Na by about 5%, while in the study of Mohammed et al. [16], the increase was about 12%. For bread with the addition of CP, a significant increase in Na, compared to WB, was observed only in bread with the addition of 20% CP (CB20%). Based on the analysis, it is concluded that PP is a 25% richer source of Na compared to CP. The Na content of raw pumpkin can range from 50 to as much as 100 mg/100 g, depending on the variety of the vegetable [57], while in raw carrots, the content is lower at around 50 mg/100 g [58].

In the wheat bread studied a similar amount of K was identified to that determined by Czarnowska-Kujawska et al. [12]. The addition of both types of powders caused an increase in the K content of the bread; however, significant differences were noted only at 20% CP and PP. The addition of 20 and 30% of CP increased the K content of bread by 15 and 20%, while PP increased the K content of bread by 18 and 32%. PP had almost 40% higher potassium content than CP. As PP had a higher K content, less of this type of powder was needed to increase the K content compared to CP. In the present study, bread with 30% CP and bread with 20% PP contained the same amounts of K. On the other hand, bread fortified with 30% PP contained a distinctive K content. The K content of pumpkin ranges depending on the variety. Demina et al. [59] report that 100 g of pumpkin contains 204 mg of K, while Karanja et al. [57] report that the content ranges from 172.3 to 199 mg/100 g. Lyophilized pumpkin contains significantly higher amounts of K, which exceeds the content of the raw vegetable by almost eight times (about 1610.7 mg/100 g). The authors also point out that the K content of PP is significantly higher than that of apricot powder (1051.5 mg/100 g) or berry powder (strawberry—703.6 mg/100 g; raspberry—866.4 mg/100 g; black currant—923.9 mg/100 g) [59]. McArthur-Floyd and Brako [60] incorporated powdered pumpkin into cookies and noted that with an increase in the percentage of powdered pumpkin, there was a significant rise in potassium content.

The Ca content of WB was 261.25 mg/kg, which was more than twice as high in the studies of Zlateva et al. [61] and Winiarska-Mieczan et al. [27]. Ca content can fluctuate depending on the type of flour used for baking. In a study by Winiarska-Mieczan et al. [27], commercially available wheat bread contained 620 mg/kg Ca, indicating a value more than twice higher than that determined in this study. While bread is not the finest source of dietary Ca, fortification can significantly increase the contribution of this element. The addition of both CP and PP significantly increased the Ca content of bread ($p < 0.05$). Raw carrots and pumpkin do not represent a rich source of Ca (33 mg/100 g; 21 mg/100 g, respectively) [62,63]; however, in processed form (powders, pulps) they are more concentrated sources of this element. Both types of bread, CB10% and PB20%, contained more than 20% more Ca than WB. The addition of further portions of CP significantly increased the Ca content of CB20% and CB30%. Compared to the control sample, CB30% contained more than two times more Ca. A different trend was observed in bread with the addition of PP. The addition of PP at 20% caused a significant increase in Ca in the bread, though increasing its contribution by another 10% did not cause significant differences in Ca content. CB30% bread contained 25% more Ca than PB30% ($p < 0.05$). This is attributable to the higher percentage of Ca in CP.

The bread showed the lowest changes in its Mg content concerning the addition of vegetable powders. The addition of CP and PP caused an increase in its content in breads; however, no significant changes in its amount were noted in both cases. The content of Mg in bread with the addition of both powders fluctuated within similar limits (169.43–203.60 mg/kg for bread with CP; 173.07–209.63 mg/kg for bread with PP). Despite the Mg content of vegetable powders at about 90–110 mg/100 g, their addition at 10, 20, and 30% was not sufficient to significantly increase the Mg content of the final bread. Vegetables are not a good source of Mg and fortification toward increasing Mg content with the addition of CP and PP in wheat bread would not be effective. For more effective fortification, an alternative could be the addition of other flours—rye, whole wheat, or oat flour—and additives—seeds or nuts—which are rich sources of magnesium [64,65].

3.2.2. Microminerals

It was noted that the content of selected micronutrients depends on the type and amount of vegetable powder added.

Based on the data presented in Table 2, it is concluded that the most significant differences resulting from the addition of vegetable powders were noted for Fe. The lowest Fe content was observed in WB, with 5.56 ± 0.09 mg/kg; it was lower than that determined by Zlateva et al. [61]. In contrast, Czarnowska-Kujawska et al. [12] indicated a Fe content of 6.8 mg/kg in toasted wheat bread. The addition of both vegetable powders caused a significant increase in Fe content in the bread ($p < 0.05$). In bread with CP addition, there were increases in Fe content of 15, 20, and 30% in CB10%, CB20%, and CB30%, respectively. On the other hand, the addition of PP resulted in a slightly smaller increase in Fe in bread, by 8, 19, and 26% in PB10%, PB20%, and PB30%, respectively. The Fe content of pumpkin fluctuates depending on the variety. Karanja et al. [57] indicated that the Fe content of thirteen different pumpkin varieties (in pulps) ranged from 3.15 mg/100 g dry weight basis in light green pumpkin to 11.08 mg/100 g dry weight basis in yellow-orange plain pumpkin. In contrast, compared to fresh pumpkins, the PP contains three and a half times more Fe [66]. In contrast, Fe can be found in carrot pulp in amounts as high as 11.66 mg/100 g. Although these vegetables in raw form are not a good source of Fe, in processed form they can contain higher amounts of this element. In the case of bread, both types of vegetable powders resulted in a significant increase in Fe relative to wheat bread, indicating efficient fortification.

There was also a large difference between WB and bread enriched with CP and PP in the percentage of Zn. The addition of 10 and 20% CP increased Zn content significantly, from 5.41 ± 0.12 mg/kg in CB to 6.43 ± 0.06 mg/kg and 6.54 ± 0.29 mg/kg in CB10% and CB20%. In contrast, 30% CP increased Zn content by almost 30% ($p < 0.05$). There was no difference in the amount of Zn relative to WB in bread with 10% and 20% PP. On the other hand, there was a significant increase in Zn content in PB30% bread; however, it was much lower than in the case of 30% CP addition and amounted to only 4%. This is a result of the higher amount of Zn in the CP tested than in the PP. Mohammed et al. [16] analyzed the Zn content of vegetable powders from carrot, eggplant, and radish and indicated that the highest content of this element was in carrot powder.

The Cu content also depended on the addition of CP or PP to wheat bread. In WB, the Cu content was 0.76 ± 0.05 mg/kg. The content of this micronutrient changed more dynamically in bread with the addition of PP. The addition of 20 and 30% PP increased the Cu content in bread by 50 and 60% ($p < 0.05$). The addition of CP to bread did not cause significant changes in Cu content. The addition of PP to bread at 10% caused a similar increase in Cu percentage (1.29 ± 0.14) to the addition of CP at 30% (1.26 ± 0.06). The reason for this is that the Cu content of PP was two times higher than that of CP. According to data from the United States Department of Agriculture (USDA), the Cu content of raw pumpkins is almost three times higher than that of raw carrots (0.127 vs. 0.045 mg/100 g) [62,63].

The Mn content in WB was 1.55 ± 0.06 mg/kg. This value was significantly lower than the amount determined by Zlateva et al. [61]. The rationale for these differences is the different Mn content of wheat flour, ranging from 3.9 ± 0.2 to 14.7 ± 1.8 mg/g [61]. These differences are mainly due to the species and variety of wheat, growing conditions, and the degree of grinding of the flour. When 10% CP and PP were added to the bread, the Mn content increased to 2.19 ± 0.01 mg/kg and 1.94 ± 0.29 mg/kg of bread, and in both cases, the addition did not cause a significant increase in this element. The addition of PP to bread at 20% resulted in a 46% increase in Mn content compared to wheat bread ($p < 0.05$). In contrast, significant changes in the Mn content of bread with CP were noted only when the powder was added at 30%. After enriching the bread with this amount of CP, the Mn content increased by 50% compared to wheat bread ($p < 0.05$).

3.3. Total Phenolic Content (TPC) and Total Flavonoid Content (TFC)

3.3.1. Total Phenolic Content (TPC)

Figure 4 shows the effect of adding CP and PP on the bread's total phenolic content (TPC). Carrots and pumpkins are raw products that are particularly rich in bioactive compounds, including carotenoids, phenolic compounds, terpenoids, and sterols [67]. The results indicate that the addition of both CP and PP affects the total phenolic content of the bread ($p < 0.05$). While wheat bread without additives contained 2.65 mg/g of phenolic compounds, bread with 10%, 20%, and 30% CP contained 6.67, 18.28, and 26.11 mg/g, respectively. The TPC of bread with a 10% PP and CP addition did not differ; however, significant differences in amounts were noted with greater additions of bread powders.

Bread enriched with 20% CP contained 30% more phenolic compounds than bread with the same amount of PP. Wahyono et al. [68] indicated a higher TPC in wheat bread enriched with 20% PP (16.16 mg/g). The differences in content may have been mainly due to the different species and origin of the pumpkin, as well as the different methods used to prepare PP (freeze-drying vs. traditional drying). Klava et al. [69] showed in their study that PP obtained by freeze-drying contained significantly fewer total phenolic compounds than those obtained by the conventional drying method (at 40 to 80 °C). When phenolic compounds were analyzed, it was shown that treatment at higher temperatures and shorter drying times produced a dried product with a higher content of phenolic compounds [69]. Aydin and Duygu [70] also report that bioavailable phenolic content is increased with conventional drying compared to freeze-drying.

Begum et al. [71] reported a significant increase in the content of phenolic compounds in bread enriched with freeze-dried carrot pomace powder, thus recognizing carrots as a valuable raw material for increasing the nutritional value of wheat bread. In our study, a 30% addition of PP to bread resulted in an almost tenfold increase in the content of phenolic compounds compared to the control bread ($p < 0.05$).

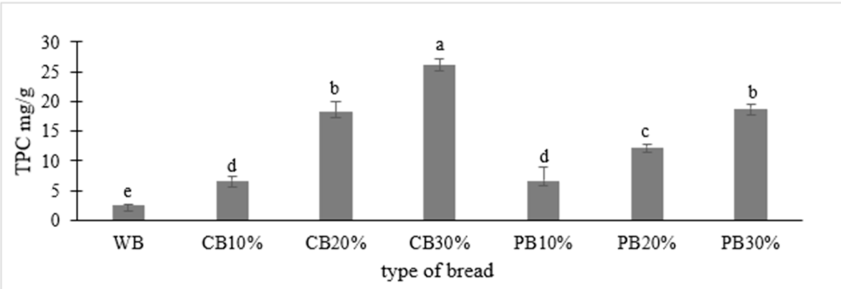

Figure 4. Total phenolic content (TPC) in each type of bread. Abbreviations: WB—wheat bread, CB10/20/30%—bread with 10/20/30% addition of carrot powder, PB10/20/30—bread with 10/20/30% addition of pumpkin powder. Means with different letters (a, b, c, d, e) are significantly different at $p < 0.05$. Means a, b, c, d, e specify differences between the total phenolic content (TPC) of wheat bread and bread enriched with 10, 20, and 30% CP and PP.

3.3.2. Total Flavonoid Content (TFC)

Figure 5 shows the total flavonoid content (TFC) of the different bread types. As with phenolic compounds, there was an increasing trend in flavonoid content with increasing proportions of both vegetable powders. In contrast to TPC, TFC values showed less variability. The lowest flavonoid compounds were determined in the control bread (0.47 mg/g) and the highest in CB30% (2.99 mg/g). Higher TFC values were recorded for bread with CP (1.53–2.99 mg/g) compared to bread with PP (1.29–2.02 mg/g). However, these differences were only significant for PB10%, which contained fewer flavonoids than the other enriched breads ($p < 0.05$). A similar trend was observed by Ivanova et al. [72], indicating smaller differences in flavonoid content than polyphenols when increasing the proportion of PP in the bread. In our study, flavonoids in PP-enriched bread accounted for 11–19% of the TPC, depending on the percentage of powder, while in the study by Ivanova et al. [72], they accounted for about 15%. Hussain et al. [73] report that flavonoids account for up to 60% of the phenolic compounds in pumpkin pulp powder. Differences in content are mainly due to the proportion of vegetable powder. In addition, differences may be due to the different types of solvents used to prepare the extracts (water, methanol) [72].

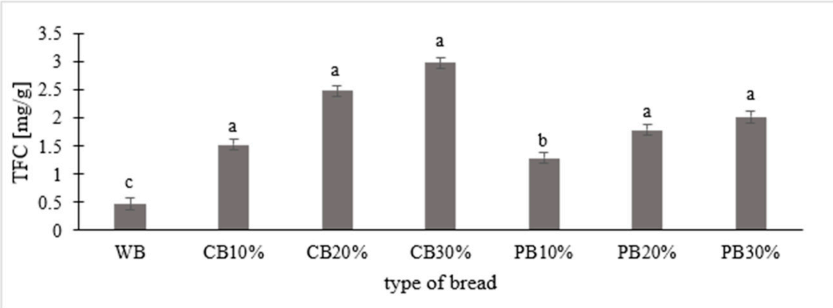

Figure 5. Total flavonoid content (TFC) in each type of bread. Abbreviations: WB—wheat bread, CB10/20/30%—bread with 10/20/30% addition of carrot powder, PB10/20/30—bread with 10/20/30% addition of pumpkin powder. Means with different letters (a, b, c) are significantly different at $p < 0.05$. Means a, b, c specify differences between the total flavonoid content (TFC) of wheat bread and breads enriched with 10, 20, and 30% carrot and pumpkin powder.

3.4. Coverage of Mineral Requirements After Consumption of 100 g of Bread

Since the proportion of wheat bread in the diet of Polish people is still relatively high, enriching this product with vegetable powders can be a good solution to enhance the mineral composition and increase the nutritional value. Table 3 shows the coverage of daily requirements for selected minerals calculated based on nutrition standards for the Polish population—RDA (Recommended Daily Allowance) and AI (Adequate Intake) after consumption of 100 g of bread per day.

Table 3. The coverage of selected minerals after consuming 100 g of wheat bread and bread with carrot and pumpkin powder, %.

Mineral Elements	Sex; Age (Years)	RDA/AI mg/Day	Control Bread (WB)	Bread Containing Carrot Powder CB10%	CB20%	CB30%	Bread Containing Pumpkin Powder PB10%	PB20%	PB30%
Na	M/W 19–65	1500	6.01	6.33	8.51	8.64	7.72	8.08	8.91
K	M/W; 19–65	3500	40.99	43.79	48.35	51.21	45.52	49.69	59.99
Ca	M; 19–65	1000	2.61	3.37	4.33	5.57	3.36	3.96	4.16
	W; 19–50	1000	2.61	3.37	4.33	5.57	3.36	3.96	4.16
	W; 51–65	1200	2.18	2.81	3.61	4.64	2.80	3.30	3.47
Mg	M; 19–30	400	3.77	4.24	4.46	5.09	4.33	4.80	5.24
	M; 31–65	420	3.59	4.03	4.25	4.85	4.12	4.57	4.99
	W; 19–30	310	4.86	5.47	5.76	6.57	5.58	6.19	6.76
	W; 31–65	320	4.71	5.29	5.58	6.36	5.41	5.99	6.55
Fe	M; 19–65	10	5.56	6.46	6.89	7.89	6.00	6.85	7.48
	W; 19–50	18	3.09	3.59	3.83	4.38	3.33	3.81	4.16
	W; 51–65	10	5.56	6.46	6.89	7.89	6.00	6.85	7.48
Zn	M; 19–65	11	4.92	5.85	5.95	6.81	5.14	5.23	5.37
	W; 19–65	8	6.76	8.04	8.18	9.36	7.06	7.19	7.39
Cu	M/W; 19–65	0.9	8.44	12.33	13.00	14.00	14.33	17.56	21.11
Mn	M; 19–65	2.3	6.74	9.52	10.61	12.13	8.43	12.48	13.43
	W; 19–65	1.8	8.61	12.17	13.56	15.50	10.78	15.94	17.17

Abbreviations: Na—sodium, K—potassium, Ca—calcium, Mg—magnesium, Fe—iron, Zn—zinc, Cu—copper, Mn—manganese, M—men, W—women, RDA—Recommended Daily Allowance, AI—Adequate Intake, WB—wheat bread, CB10/20/30%—bread with 10/20/30% addition of carrot powder, PB10/20/30—bread with 10/20/30% addition of pumpkin powder.

3.4.1. Microelements

After consuming a portion of 100 g of bread, high coverage of the demand for selected micronutrients was noted. Depending on the percentage of vegetable powders, the consumption of 100 g of bread allows the coverage of Cu requirements of 12.33–14.00% (bread with CP) and 14.33–21.11% (bread with PP), both among men and women. Cu is an essential element for, among other things, collagen and elastin synthesis and the transition of iron to hemoglobin [59]. Its deficiencies can lead to growth disorders in children; in addition, deficiency of this element can cause anemia [74].

The fortified breads were also a good source of Mn. After consuming a serving of CP-enriched bread, Mn requirements are covered by 9.52–12.13% among men and 12.17–15.50% among women. In contrast, a serving of bread with PP allows to cover the Mn requirement in the amount of 8.43–13.43% among men and 10.78–17.17% among women. Although Mn deficiencies are not common in Poland due to the prevalence of this element in many foods, it is important to have a proper supply of this element. Mn regulates blood glucose levels, influences brain activity, and plays an important role in lipid metabolism by preventing fat deposition in the liver [59].

Bread enriched with CP covered Zn requirements to a higher degree (5.85–6.81% men; 8.04–9.36% women) than bread with PP (5.14–5.37% men; 7.06–7.39% women). Zinc increases the body's resistance to infectious diseases and participates in the synthesis and breakdown of carbohydrates, proteins, and fats. It is indicated that zinc deficiency promotes the development of diabetes, certain types of cancer (e.g., esophageal, breast, colorectal), neurodegenerative diseases, and intestinal diseases [75].

In the case of Fe, the coverage of the requirement after consumption of selected types of bread was dependent on sex and age. Due to the lower Fe requirement among men, the consumption of 100 g of bread with CP and PP covered the Fe requirement by 6.46–7.89% and 6.00–7.48%, respectively. In contrast, among women aged 18–50, 100 g of bread consumed covered the Fe requirement of 3.59–4.38 mg/100 g and 3.33–4.16 mg/100 g in bread with CP and PP, respectively. Fe participates in the formation of hemoglobin in the blood and determines normal muscle function. Its deficiencies primarily promote the development of anemia, which can result in functional impairment affecting cognitive development or immune mechanisms [76].

3.4.2. Macroelements

Among macronutrients, 100 g of bread with added vegetable powders covered the daily requirement for K to the highest extent. Consumption of 100 g of bread with added CP covered the K requirement by 43.79–51.21%. Higher coverage of K requirements was recorded for bread with PP additives (45.52–59.99%). The study found that PP was richer in K than CP. Demina et al. [59] report that the consumption of 100 g of PP covers the K requirement by 64%. An adequate supply of potassium in the diet is essential for maintaining normal muscle activity, maintaining water balance, osmotic pressure, and acid-base balance within the body [77].

A portion of bread with 20% and 30% CP and PP covered more than 8% of Na requirements. In the case of Na, its consumption among Polish people is reported to be excessively high. Although Na plays an important role in the human body—it is involved in the formation of nerve impulses, muscle contractions, and regulation of blood glucose levels [59]—its excess can lead to hypertension, increased risk of cardiovascular disease, kidney dysfunction, and oxidative stress [78]. The salt content of bread can vary depending on the type of bread and the additives used during baking. Al Jawaldeh and Khamaiseh [79] report that the salt content of bread ranges from 4.28 g/kg to 12.41 g/kg, while the average Na content is 3.0 g/kg. In contrast, the contribution of bread to daily salt intake ranges from 1.3 g (12.5%) to 3.7 g (33.5%), depending on the country, which is higher than in the studies presented.

The coverage of Mg requirements was the most variable, due to different daily requirements for this element according to sex and age. The consumption of 100 g of bread, both with CP and PP, covers the demand to the highest degree among women aged 19–30 years (5.47–6.76%) and 31–65 years (5.29–6.55%). Due to the higher demand for Mg among men, their Mg coverage after consuming 100 g of bread with CP and PP would be covered at 4.03–4.99% and 4.24–5.24%, respectively. Mg is involved in the transmission of neuromuscular impulses, which promote muscle relaxation; in addition, this element is an essential element of ribosomes and participates in protein synthesis [80].

The types of bread studied covered the lowest degree of Ca requirements (up to about 6%). Commonly, bread is not considered a good source of Ca. On the other hand, considering the coverage of this element after consuming 100 g of wheat bread (2.18–2.61%), it is indicated that enriching bread with CP and PP increases the amount of this element, corresponding to a coverage of more than double (more than 5%), after consuming a 100 g serving.

3.5. Limitations of the Study

In the conducted study, the focus was on the production of wheat bread enriched with CP and PP at three different concentrations: 10%, 20%, and 30%. Although the mineral content was assessed, an important limitation of this study is the lack of a bioavailability analysis of these ingredients, which determines the actual uptake of the minerals by the body. Future studies are recommended to include methods to assess the bioavailability of minerals from bread enriched with vegetable powders, which would allow a more precise determination of the extent of mineral absorption by the human body.

Furthermore, the present study was limited to basic antioxidant tests, such as TPC and TFC. In future studies, it would be important to apply methods for the determination of individual phenolic compounds, carotenoids, and other bioactive substances, which could provide important information on the mechanisms of antioxidant activity and potential health benefits associated with regular consumption of enriched bread.

Another limitation is the lack of sensory evaluation of the bread in the present study. The authors plan to conduct a detailed sensory analysis in future studies to assess the consumer acceptability of the different bread variants. Determining the optimum concentration of CP and PP in terms of taste, aroma, and textural qualities will allow the products to be adapted to consumer expectations.

4. Conclusions

The present study was designed to evaluate the mineral content of breads enriched with CP and PP. Subsequently, the coverage of daily mineral requirements after consuming 100 g of each bread was estimated. PP was richer in Na, K, Cu, and Mn compared to CP. Bread enriched with CP and PP was shown to contain significantly higher contents of individual macro- and micronutrients. Among macrominerals, the highest changes were observed in the content of Ca, with amounts after the addition of 30% CP and PP containing 113% and 59% more than in wheat bread. Among micronutrients, the highest increases relative to WB after the addition of both vegetable powders were recorded in the contents of Cu (46–66% and 70–150% increase after the addition of CP and PP) and Mn (41–80% and 25–99% increase after the addition of CP and PP). With the addition of 30% CP and PP, the TPC increased by almost ten and seven times, respectively. The coverage of the daily mineral requirement was met to the highest extent for potassium (K). Consumption of 100 g of bread with CP and PP would allow the K requirement to be covered by up to 60%. Based on this study, it was concluded that vegetable powders have great potential as an additive for bakery products. Future research on the enrichment of bread with vegetable powders would need to be extended to include sensory evaluation to determine the acceptability of the products. In addition, further research on the health-promoting potential of enriched breads is planned to include a broader analysis of bioactive compounds.

Author Contributions: Conceptualization, A.P.; methodology, A.P. and R.P.-F.; validation, A.P. and R.P.-F.; formal analysis, A.P.; investigation, A.P. and R.P.-F.; resources, A.P. and R.P.-F.; data curation, A.P.; writing—original draft preparation, A.P. and F.H.G.; writing—review and editing, F.H.G. and

R.P.-F.; visualization, A.P. and F.H.G.; supervision, R.P.-F.; funding acquisition, R.P.-F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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