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BIOACTIVE COMPOUNDS AND NUTRITIONAL CHARACTERISTICS OF SELECTED FUNCTIONAL FOOD PRODUCTS

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ABSTRACT

As a result of the presence of essential nutrients and bioactive constituents, functional foods are gaining recognition for their role in nutrition and health. The nutritional profiles and some bioactive compounds of six categories of functional foods (berries, fermented dairy products, leafy vegetables, legumes and soy products, nuts and seeds, whole grains) were compared in this study. The descriptive statistics, Kruskal–Wallis testing, Spearman correlation analysis, and principal component analysis were used for the evaluation of the macronutrients, minerals, carotenoids, and antioxidant-related vitamins. The nutritional and bioactive variables showed significant variations between different food categories for all the main variables. The protein content was the highest in legumes and soy products, and the energy, fat, dietary fibre, magnesium, phosphorus, potassium, zinc, and vitamin E content was highest in nuts and seeds. Whole grains had high levels of carbohydrates, fibre, and iron. The leafy vegetables showed the best carotenoid profile, with more beta-carotene and lutein + zeaxanthin and a moderate amount of vitamin C. There were also significant positive associations between fibre and magnesium, protein and magnesium, and beta-carotene and lutein plus zeaxanthin, and principal component analysis also indicated good compositional separation between the food categories. The results provide an insight into the complementary nutritional and bioactive properties of various functional foods.

Keywords: Functional foods; Bioactive compounds; Carotenoids; Nutritional composition; Antioxidant nutrients

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1.Introduction

Functional foods have been getting more attention because they offer nutritional benefits beyond the basic nutrition needs of the population and may be beneficial in the prevention and/or management of chronic diseases. The foods are typically rich in essential nutrients and also in biologically active components like carotenoids, phenolic compounds, anthocyanins, isoflavones, vitamins, minerals, dietary fibre and unsaturated fatty acids. As their significance continues to rise, demand for nutrition intervention strategies that promote long-term health, metabolic control, and disease risk reduction is growing. Many types of functional foods have been identified, including whole grains, legumes, soya foods, nuts, seeds, fruits and vegetables, and fermented foods, which are unique in their nutritional profile of macronutrients, micronutrients and phytochemicals. For instance, speciality seeds are known to be rich in vitamins, minerals, healthy fats, and some bioactive compounds that could have physiological benefits, in addition to being high in protein and dietary fibre (Alasalvar et al., 2021).

Additionally, legumes and soy products are important functional foods due to their quality plant protein and related nutraceutical properties. Legume proteins and bioactive peptides could be beneficial for their nutritional value and some physiological functions, suggesting their potential use in healthy food habits (Carbonaro & Nucara, 2022). Legumes are also gaining increasing importance as a food source in sustainable nutrition due to their high protein, fibre, mineral and other beneficial food content, and their relatively low environmental resource requirements compared to many animal protein sources (Singh et al., 2022). One of the most remarkable is the presence of isoflavones in soy foods, which have received a tremendous amount of research for their possible cardiovascular, metabolic, hormonal, and other health effects (Jang et al., 2021; Messina et al., 2022).

Similarly, whole grains are important functional foods due to their bran, germ and endosperm, which help to provide dietary fibre, vitamins, minerals, antioxidants, and several phytochemicals. Their functional components have been linked to beneficial results in metabolic health, gut function and the prevention of chronic diseases (Guo et al., 2022). The glycaemic regulation and activity of gut microbiota are especially important for the quality of dietary carbohydrates and the presence of cereal fibres (Seal et al., 2021). Observational studies also provide evidence of benefits of whole grain consumption for health, including lower risk for multiple non-communicable diseases (NCDs) (Tieri et al., 2020).

Carotenoids and polyphenolic compounds are important bioactive compounds in fruits and vegetables. Carotenoids like beta-carotene, alpha-carotene, lycopene, beta-cryptoxanthin, lutein and zeaxanthin not only impart colour to food but also exhibit important physiological functions. The nutritional importance of their ability to be converted into vitamin A, protection against oxidative stress, visual function, immune function, and cell health (Meléndez-Martínez et al., 2022). Dietary carotenoids have both concentration in food and extraction, stability, food matrix interaction, and bioavailability that affect the health effects of dietary carotenoids (Saini et al., 2022). Leafy vegetables are especially rich in beta-carotene, lutein, and zeaxanthin while other fruits and vegetables provide varying amounts of lycopene and other carotenoid compounds.

The rich anthocyanins, phenolic compounds, vitamins, and phytochemical content in berries also provides excellent functional food properties. The biological activities have been linked to their antioxidant, anti-inflammatory, cardiometabolic, and neuroprotective properties (Golovinskaia & Wang, 2021). Lingonberries and other berry species may have a health-promoting potential due to their content of many bioactive components (Kowalska, 2021). Anthocyanins are especially interesting due to their molecular structure, metabolism, and bioavailability, which affect their biological activity and possible effect on reducing processes of oxidative and inflammatory stress (Jokioja et al., 2021). Further, evidence from systematic assessments has correlated anthocyanin consumption with some desirable health effects (Sandoval-Ramirez et al., 2022), and research on berry anthocyanins has highlighted the role of absorption, metabolism and interactions with food in the biological activity of anthocyanins (Xue et al., 2022).

It is well recognized that individual functional-food groups are important, but a direct comparison of their nutritional and bioactive profiles is still needed. Different food types can offer complementary nutritional benefits; for instance, different types of protein, minerals, carotenoids, vitamins with antioxidant properties, fibre and lipids are higher in different foods. A systematic comparison can thus reveal differences and relationships in composition and therefore a better understanding of the nutritional and bioactive components. This type of information can help determine foods with unique nutrient-density patterns and can aid in developing evidence-based dietary recommendations and functional foods.

The aim of the present study was thus to comparatively assess bioactive compounds and nutritional properties of selected functional food products.

Objectives

1. Compare macronutrient, mineral, vitamin and selected bioactive compound profile of various categories of functional food.
2. Analyze the interactions between nutritional components, carotenoids and antioxidants nutrients.
3. Recognize significant compositional patterns and differentiate functional – food groups by comparative and multivariate statistical methods.

2. Methodology

2.1 Research Design and Data Source

A quantitative comparative research design was used in this study with secondary food-composition information gathered from the USDA National Nutrient Database for Standard Refer (Georfed, 2023). It has a large amount of data on macronutrients, micronutrients, vitamins, minerals, fatty acids and some carotenoid compounds, and it has been standardized. The data set was found suitable for comparison of the nutritional and bioactive properties of selected functional food products.

2.2 Selection of Functional Food Products

The functional food products were chosen from the USDA database with adequate compositional data and health or nutrition benefits. Fruits and berries, vegetables, legumes and soy products, whole grains, nuts and seeds, and dairy products were the food categories of interest. Duplication, little-relevant highly processed foods were omitted from the comparative analysis, as were records with significant missing values.

2.3 Nutritional Variables

Selected food's nutritional properties were assessed based on the available variables such as energy, protein, total fat, carbohydrates, dietary fibre, sugars and ash content. The micronutrient variables were calcium, iron, magnesium, phosphorus, potassium, sodium, zinc, copper, manganese and selenium. Where adequate data were available, selected vitamins were also added: A, C, D, E and K as well as B-group vitamins.

2.4 Assessment of Bioactive Compounds

Compounds reported in the USDA National Nutrient Database for Standard Reference (Nutrient Database) were used in bioactive profiling. The active ingredients that were found in the principal section were alpha-carotene, beta-carotene, beta-cryptoxanthin, lycopene and lutein plus zeaxanthin. Other nutritional constituents were also taken as antioxidants, such as vitamins A, C and E. The total phenolics, total flavonoids, DPPH, ABTS, and FRAP assays were not available, so the assessment of bioactive compounds was limited to those carotenoids and micronutrients in the data set that were related to antioxidants.

2.5 Data Screening and Preprocessing

Before statistical analysis, the data set was checked for duplication, missing data, inconsistencies and irrelevant variables. Nutrient values were left in the standardised units reported by the USDA, typically those per 100 g edible portion. Only records that contained large amounts of missing data for the main study variables were not used in the relevant analyses. Checks were made of extreme observations, and these were kept if they were biologically feasible differences between food products.

2.6 Descriptive and Comparative Statistical Analysis

All the main nutritional and bioactive variables were computed using descriptive statistics such as mean, standard deviation, median, minimum and maximum. When assumptions of normality and homogeneity of variance were met, differences among functional-food groups were evaluated with one-way analysis of variance (ANOVA). For significant results, appropriate post hoc comparisons were done. If the assumptions of the parametric tests were not met for the variables, the Kruskal–Wallis test was used. A p-value of < 0.05 was regarded as statistically significant.

2.7 Correlation Analysis

Correlation analysis was performed to investigate relationships between nutritional components and some bioactive compounds. Pearson's correlation coefficient was applied to approximately normally distributed variables, and Spearman's rank correlation coefficient was used for non-normally distributed variables. Special focus was placed on the correlation of carotenoids and other antioxidant vitamins, as well as dietary fibre, minerals and other important nutritional parameters.

2.8 Multivariate Analysis

Principal component analysis (PCA) was done to determine the overall trend of the selected functional foods regarding their nutritional and bioactive profile. Due to the different numerical scales and measurement units the variables were standardized before analysis. In addition, when appropriate, hierarchical cluster analysis was also applied to classify foods based on nutrient and bioactive similarities and to determine groups with unique nutrient composition.

2.9 Data Presentation

The results were presented in tabulated and graphical format, using well-structured tables. The major nutritional and bioactive properties were presented in comparative tables, differences and relationships among the selected functional food products were presented in bar charts, correlation heatmaps, PCA plots and clustering visualizations.

2.10 Ethical Considerations

The study was based on a secondary food-composition data set that was publicly available, and included no human participants, personal information, clinical records, or animal experimentation. Hence, ethical approval and informed consent were not necessary. Nutrient composition data for the analysis were from the USDA National Nutrient Database for Standard Reference.

3. Results

3.1 Distribution of Selected Functional Food Products

After applying the food inclusion criteria that were defined in advance, 680 foods in the USDA National Nutrient Database for Standard Reference were retained. The foods were divided into six categories of functional foods. Whole grains formed the largest group, accounting for 32.2% (n = 219), followed by berries with 21.3% (n = 145), nuts and seeds with 14.1% (n = 96), legumes and soy products with 12.1% (n = 82), leafy vegetables with 11.8% (n = 80), and fermented dairy products with 8.5% (n = 58). Table 1 shows the distribution of the selected functional foods.

Table 1. Distribution of selected functional food products

Functional food category	n	Percentage (%)
Whole grains	219	32.2
Berries	145	21.3
Nuts and seeds	96	14.1
Legumes and soy	82	12.1
Leafy vegetables	80	11.8
Fermented dairy	58	8.5

3.2 Macronutrient Characteristics

A significant difference in the macronutrient composition of the functional foods selected was found. As shown in Table 2, nuts and seeds had the highest mean energy value (512.94 ± 174.07 kcal/100 g) and total fat content (37.35 ± 24.99 g/100 g). The highest dietary fibre concentration was also found in them (6.50 ± 5.60 g/100 g). Foods with the highest mean protein (12.64 ± 10.27 g/100 g) and highest carbohydrate (57.05 ± 25.31 g/100 g) concentrations were legumes and soy products, respectively. Sugars had relatively higher mean concentrations in berries and fermented dairy products than in leafy vegetables and legumes.

Table 2. Macronutrient characteristics of selected functional food categories

Category	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	Fibre (g)	Sugars (g)
Berries	179.00 ± 142.90	3.07 ± 3.43	3.60 ± 5.07	34.81 ± 26.67	2.76 ± 3.42	18.49 ± 14.26
Fermented dairy	123.74 ± 107.09	4.31 ± 2.82	3.42 ± 10.06	19.24 ± 17.74	0.62 ± 1.24	13.86 ± 11.66

Leafy vegetables	99.65 ± 96.44	5.72 ± 4.71	2.98 ± 4.11	13.08 ± 13.85	2.26 ± 1.52	1.72 ± 1.46
Legumes and soy	151.09 ± 117.07	**12.64 ± 10.27**	6.42 ± 7.23	12.97 ± 14.26	3.95 ± 4.01	1.95 ± 2.23
Nuts and seeds	**512.94 ± 174.07**	10.56 ± 6.62	**37.35 ± 24.99**	39.58 ± 25.52	**6.50 ± 5.60**	17.38 ± 16.45
Whole grains	342.63 ± 145.27	7.95 ± 4.63	10.36 ± 12.19	**57.05 ± 25.31**	5.52 ± 4.14	**19.37 ± 16.80**

The comparison of macronutrient patterns is shown in Figure 1, which reflects the higher fat and fibre content of nuts and seeds, and the relatively high protein content of legumes and soy products.

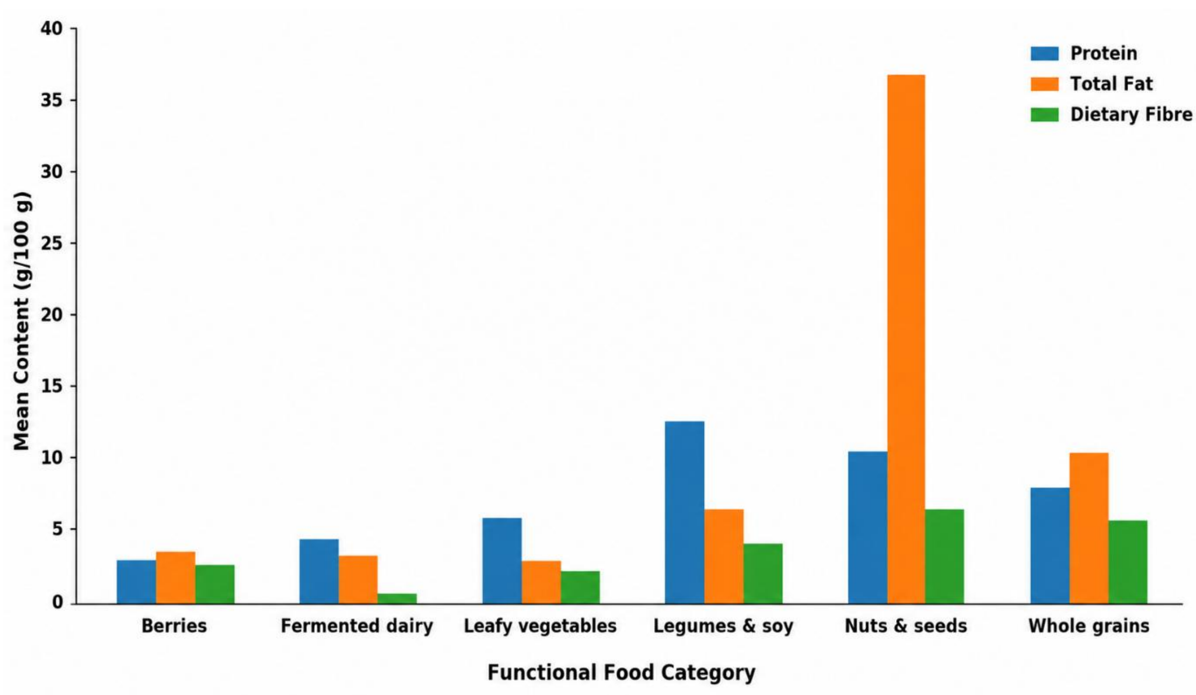

Figure 1. Comparative macronutrient profiles of selected functional foods

3.3 Mineral Composition

There was also a significant variation in the mineral composition. According to Table 3, nuts and seeds had the highest mean magnesium (126.32 ± 107.55 mg/100 g), phosphorus (270.92 ± 192.02 mg/100 g), potassium (384.76 ± 261.89 mg/100 g), and zinc (2.46 ± 1.88 mg/100 g) concentrations. Legumes and soy products had relatively high concentrations of calcium and potassium, while whole grains had the highest mean iron concentration (6.70 ± 11.00 mg/100 g). The calcium and potassium content was also significantly contributed by leafy vegetables. These results suggested that nuts and seeds were especially mineral-rich and whole grains were found to be higher in iron.

Table 3. Selected mineral composition of functional food categories

Category	Calcium (mg)	Iron (mg)	Magnesium (mg)	Phosphorus (mg)	Potassium (mg)	Zinc (mg)
Berries	68.57 ± 148.24	2.45 ± 5.60	18.48 ± 26.52	78.20 ± 100.30	118.00 ± 137.47	0.72 ± 1.89
Fermented dairy	136.40 ± 91.15	0.65 ± 3.33	16.73 ± 11.06	109.40 ± 57.90	187.71 ± 104.06	0.58 ± 0.33
Leafy vegetables	115.01 ± 56.63	1.56 ± 0.74	38.67 ± 29.12	80.34 ± 65.97	259.85 ± 131.94	0.65 ± 0.55
Legumes and soy	163.74 ± 290.98	2.60 ± 2.40	65.24 ± 55.65	177.43 ± 130.78	358.64 ± 356.30	1.53 ± 1.30
Nuts and seeds	171.48 ± 222.25	4.31 ± 5.18	126.32 ± 107.55	270.92 ± 192.02	384.76 ± 261.89	2.46 ± 1.88
Whole grains	111.74 ± 166.63	6.70 ± 11.00	73.03 ± 60.29	222.08 ± 155.94	255.74 ± 141.23	2.21 ± 2.80

3.4 Bioactive Compounds and Antioxidant-Related Nutrients

The nutrient profiles of the selected functional-food categories were significantly different about carotenoids and antioxidants. As shown in Table 4, the mean concentration of beta-carotene and lutein plus zeaxanthin in leafy vegetables was the highest (2914.85 ± 3018.36µg/100g and 5511.07 ± 6233.10µg/100g, respectively). They also showed the highest mean alpha-carotene (11.21 ± 27.75 µg/100 g) and vitamin C (19.87 ± 29.71 mg/100 g) concentrations. Nuts and seeds showed the highest mean vitamin E concentration (7.88 ± 11.02 mg/100 g) as compared to other foods. In fact, there are significant variations in the carotenoid content of various food groups, as seen in Figure 2, where leafy vegetables are clearly the richest sources of carotenoids.

Table 4. Bioactive carotenoids and antioxidant-related nutrients

Category	α-Carotene (µg)	β-Carotene (µg)	β-Cryptoxanthin (µg)	Lycopene (µg)	Lutein + Zeaxanthin (µg)	Vitamin C (mg)	Vitamin E (mg)
Berries	2.07 ± 5.94	24.40 ± 40.29	3.50 ± 20.48	0.04 ± 0.36	48.69 ± 50.79	15.98 ± 17.15	0.73 ± 1.46
Fermented dairy	0.28 ± 1.03	44.62 ± 156.26	3.24 ± 18.07	0.00 ± 0.00	12.11 ± 45.19	15.23 ± 42.87	0.42 ± 1.37
Leafy vegetables	11.21 ± 27.75	2914.85 ± 3018.36	5.50 ± 13.91	79.44 ± 154.44	5511.07 ± 6233.10	19.87 ± 29.71	1.07 ± 0.84
Legumes and soy	4.97 ± 16.45	40.67 ± 65.88	1.93 ± 4.05	24.82 ± 96.41	60.54 ± 305.54	3.78 ± 6.20	0.71 ± 1.27
Nuts and seeds	0.31 ± 1.43	20.91 ± 51.93	0.31 ± 1.33	0.00 ± 0.00	141.33 ± 471.22	7.24 ± 26.14	7.88 ± 11.02
Whole grains	2.87 ± 11.29	47.79 ± 242.36	0.86 ± 3.79	9.10 ± 58.86	102.71 ± 169.96	4.61 ± 19.09	2.18 ± 6.60

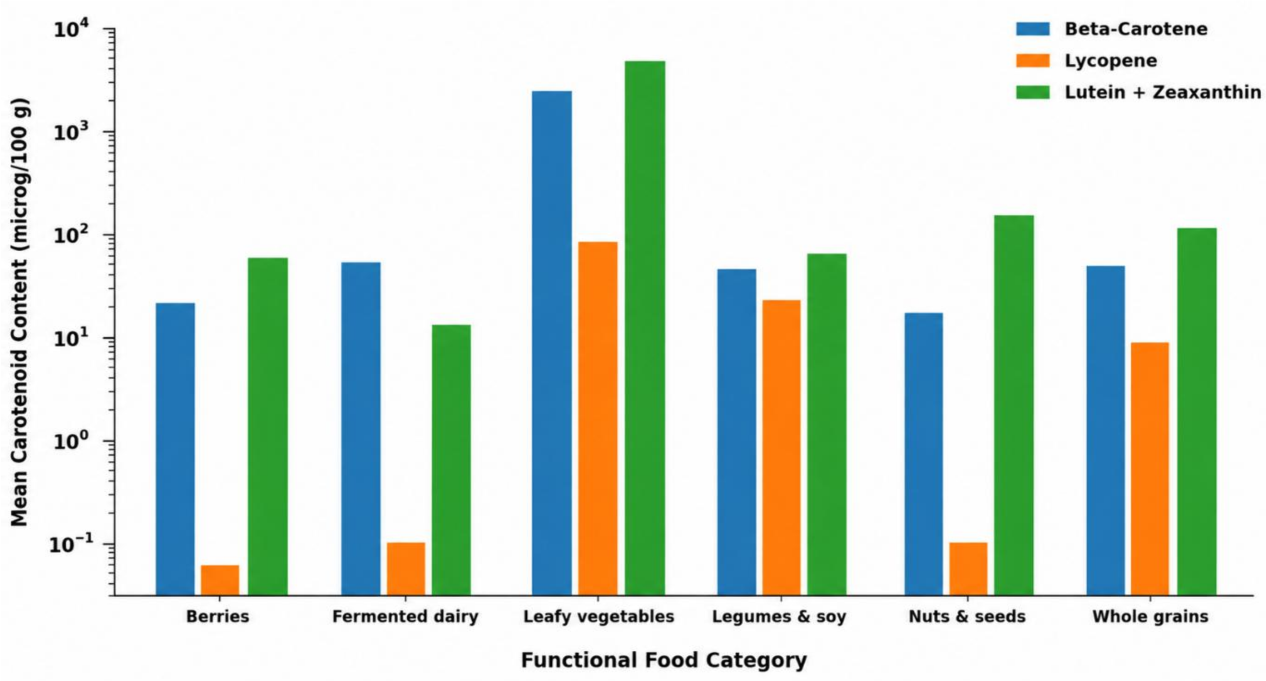

Figure 2. Carotenoid profiles of selected functional food categories

The comparison also showed significant differences among the major functional-food categories across all major nutritional and bioactive variables. As shown in Table 5, energy exhibited the largest between-group variation ($H = 310.84$, $p < 0.001$), followed by total fat ($H = 271.69$, $p < 0.001$) and carbohydrate ($H = 225.11$, $p < 0.001$). Significant differences were also observed for beta-carotene ($H = 162.49$, $p < 0.001$), lutein plus zeaxanthin ($H = 153.10$, $p < 0.001$), vitamin C ($H = 149.89$, $p < 0.001$), and vitamin E ($H = 135.45$, $p < 0.001$).

Table 5. Kruskal–Wallis comparison of nutritional and bioactive characteristics

Variable	H statistic	p-value
Energy	310.84	<0.001
Protein	197.89	<0.001
Total fat	271.69	<0.001
Carbohydrate	225.11	<0.001
Dietary fibre	168.34	<0.001

Total sugars	178.24	<0.001
Calcium	101.11	<0.001
Iron	202.96	<0.001
Magnesium	200.07	<0.001
Phosphorus	163.48	<0.001
Potassium	142.29	<0.001
Zinc	185.65	<0.001
Alpha-carotene	22.38	<0.001
Beta-carotene	162.49	<0.001
Beta-cryptoxanthin	12.73	0.026
Lycopene	61.07	<0.001
Lutein + zeaxanthin	153.10	<0.001
Vitamin C	149.89	<0.001
Vitamin E	135.45	<0.001

3.5 Correlation Among Nutritional and Bioactive Variables

Significant associations were found between the nutritional and bioactive variables by using Spearman correlation analysis. Dietary fibre showed a strong positive correlation with magnesium ($\rho = 0.726$, $p < 0.001$), and protein was also strongly correlated with magnesium ($\rho = 0.724$, $p < 0.001$). The relationships between beta-carotene and lutein plus zeaxanthin and vitamin C were moderate and positive (rho = 0.437, $p < 0.001$; and rho = 0.436, $p < 0.001$, respectively). Lutein plus zeaxanthin was positively correlated with vitamin E ($\rho = 0.324$, $p< 0.001$). However, lycopene did not have a significant association with vitamin C ($\rho = -0.037$, $p = 0.489$). Figure 3 depicts the general trend of the relationships between the various nutritional, mineral, carotenoid and antioxidant-related variables.

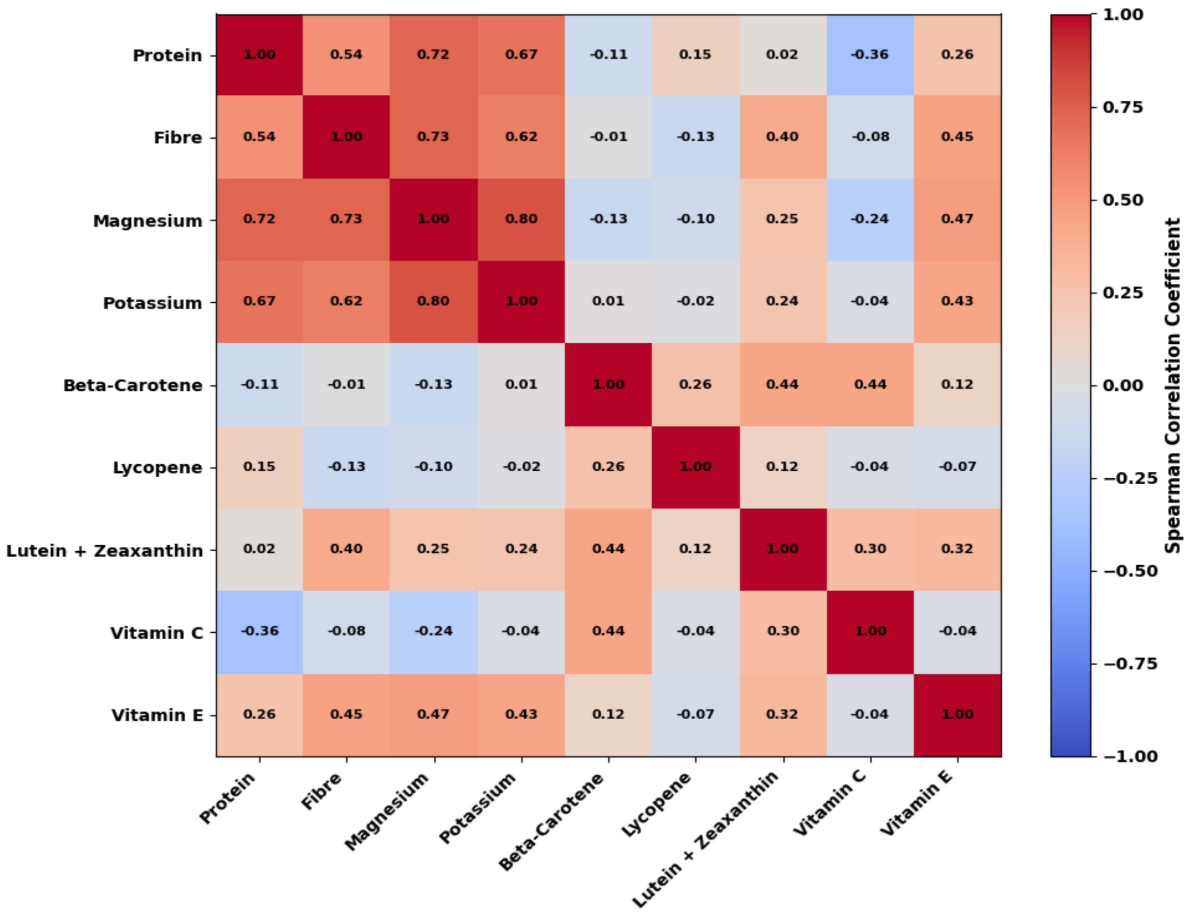

Figure 3. Correlations among nutritional and bioactive variables

3.6 Principal Component Analysis

The principal component analysis (PCA) showed that the functional-food categories were well separated from each other based on their nutritional and bioactive properties. The first principal component (PC1) accounted for 27.06% of the total variance and the second principal component (PC2) accounted for 15.94% of the total variance, and the cumulative explained variance was 42.99%. Protein, dietary fibre, magnesium, potassium and other nutrient-density variables were the longest, most dominant contributors to PC1, while beta-carotene and lutein plus zeaxanthin were the longest, most dominant contributors to PC2. Nuts and seeds were mainly grouped towards the PC1 positive region due to their relatively high energy, fat, fibre, mineral, and vitamin E contents. The high carotene content of leafy vegetables caused them to be separated along PC2. Legumes and soy were intermediate, and most of the other berries and fermented dairy products clustered in the lower area of PC1. The multivariate separation of the chosen food classes is shown in Figure 4.

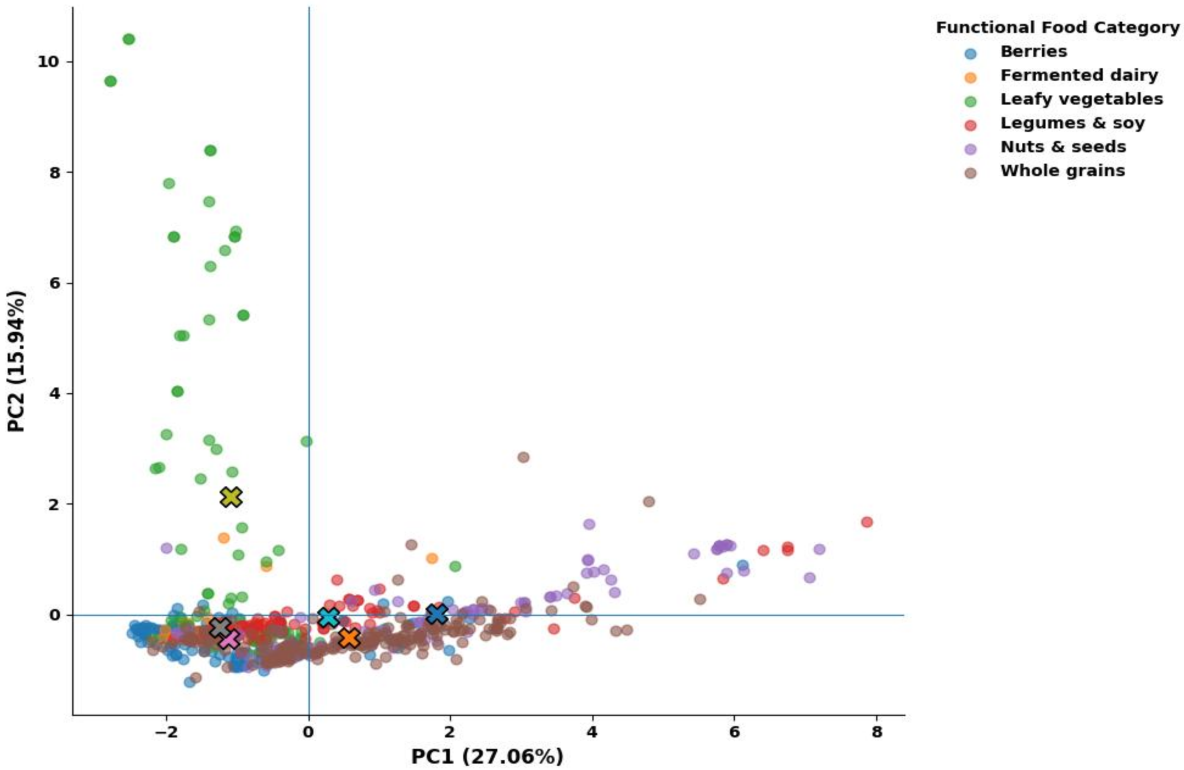

Figure 4. PCA of nutritional and bioactive profiles

3.7 Summary of Results

Overall, the results indicated high differences in nutritional and bioactive attributes for the chosen categories of functional foods. Nuts and seeds contained high levels of energy, dietary fibre, magnesium, phosphorus, potassium, zinc, vitamin E and protein. Protein content was high in legumes and soy products, while energy, fat, and dietary fibre, magnesium, phosphorus, potassium, zinc and vitamin E were high in nuts and seeds. Comparatively, whole grains were good sources of carbohydrates, fibre and iron. Among food groups, the nutritional and bioactive variables were statistically different for all of the main variables, with more than half of the comparisons having $p < 0.001$ for leafy vegetables; the remaining statistically lower values were for fruit, grains, oils, nuts, legumes, fish, and milk. The highest bioactive profile was for leafy vegetables, particularly for beta-carotene, lutein plus zeaxanthin, and vitamin C, with significant differences present among food groups for all main nutritional and bioactive variables; more than half of the comparisons had $p < 0.001$. The results of the correlation analysis showed key positive correlations among fibre, protein, minerals and carotenoids, and PCA results provided evidence of the compositional clusters between functional food categories.

4. Discussion

In the present study, significant differences were observed among the selected categories of functional foods, in terms of their nutrient and bioactive profile, highlighting the different combination of macronutrients, minerals, vitamins and carotenoids provided by different food groups. It revealed a particularly high nutrient density in nuts and seeds, a higher level of protein in legumes and soya products, a higher level of carbohydrate and fibre in whole grains, and higher concentrations of carotenoids in leafy vegetables. The results in this study suggest that there is no need to think of functional foods as nutritionally similar, as the health benefits of foods are linked to the type and quantity of nutrients, as well as the bioactive compounds, they contain.

Nuts and seeds had the highest energy and total fat content, and were also a major source of dietary fibre, magnesium, phosphorus, potassium, zinc and vitamin E. The nutritional profile is comparable to that of speciality seeds, which are known for their high levels of unsaturated lipids, fibre, minerals and various bioactive compounds (Alasalvar et al., 2021). Nuts are also reported as nutritionally dense foods rich in nutritious fatty acids, proteins, minerals, tocopherols and phytochemicals that have been reported to be beneficial to cardiometabolic health (Gonçalves et al., 2023). The relatively high concentration of vitamin E and minerals also aligns with previous findings on the nut composition of almonds and other nuts as key factors shaping nutritional quality of the food, such as processing, fat content, phenolics content and micronutrient density (Özcan, 2023). There is further supporting evidence for the impact of walnut consumption on beneficial health outcomes, via its association with nutrients (Lockyer et al., 2023).

Legumes and soy products had the highest mean protein content and had good levels of calcium, magnesium, phosphorus, and potassium. The results are anticipated, as legumes are a valuable source of plant protein and useful peptides and other functional molecules (Carbonaro & Nucara, 2022). Besides, soy-derived products are also a good source of isoflavones and other bioactive substances that may have cardiometabolic and endocrine-related effects (Li et al., 2020). As a result, the nutrient profile of the present analysis confirms the suitability of legumes and soy as functional ingredients of nutritionally balanced and vegetarian diets.

Whole grains had high levels of carbohydrates, fibres and iron. This agrees with the presence of bran, germ and endosperm fractions which contain complex carbohydrates, dietary fibre, vitamins, minerals and phytochemicals (Guo et al., 2022). The relatively high fibre content is especially important since whole-grain fibre has been shown to exert beneficial effects on gut microbial composition and function

(Tangestani et al., 2020). Furthermore, the consumption of whole grains has been associated with better levels in inflammatory markers and other health outcomes, highlighting their importance in preventive nutrition (Milesi et al., 2022).

The vegetables with the highest levels of bioactive carotenoids were leafy vegetables, especially beta-carotene and lutein+zeaxanthin. The antioxidant activity, provitamin A activity and application in visual, immune and cellular health make these carotenoids important (Meléndez-Martínez et al., 2022). The food matrix characteristics, processing, absorption, and bioavailability have a profound effect on their concentration and biological effectiveness (Saini et al., 2022). The separation of the leafy vegetables in the multivariate analysis, therefore is likely due to their high carotenoid content compared with the other food groups.

Berries showed a different functional profile, with relatively higher relevance to antioxidant-related compounds as compared to macronutrient density. Berries are known sources of antioxidants and anti-inflammatory phytochemicals including vitamins, phenolic acids and anthocyanins (Golovinskaia & Wang, 2021). Lingonberries and related berry species are rich in various health-promoting compounds which add to their functional-food properties (Kowalska, 2021). Beyond their relatively small macronutrient contributions, the metabolism and bioavailability of anthocyanins in the human body further highlight the importance of berry consumption in the human body (Xue et al., 2022).

Fermented dairy products had lower levels of several plant-derived bioactive compounds and despite this, are also of nutritional significance for the content of protein, calcium, fermentation-derived metabolites and probiotic effects. In the cardiometabolic health domain, fermented milks have been shown to have beneficial effects (Companys et al., 2020), and cultured milk products, such as yoghurt, have been linked to digestive and metabolic health benefits related to microorganisms in milk fermentation (Savaiano & Hutkins, 2021). The same functional properties have been reported for kefir and its derived products (Egea et al., 2022; Yerlikaya, 2023).

In general, the high level of significant correlations and PCA results show that the functional-food categories have different rather than the same nutritional benefits. The results of the combined data indicate that dietary diversity is important, because certain nutrient and bioactive properties of functional foods may complement each other and play a role in health and disease prevention.

5. Conclusion

It was concluded from the present study that the nutritional content of selected functional food groups is different and their bioactive components showed significant variation. The energy, fat, dietary fibre, magnesium, phosphorus, potassium, zinc and vitamin E content of nuts and seeds was high, while the protein content was high with appreciable mineral contents in legumes and soy products. Legumes had higher levels of carotene and iron, and leafy vegetables had the greatest amounts of carotene, with relatively high vitamin C content, and the highest levels of lutein and zeaxanthin. The legumes had the highest levels of carotene and iron, the leafy vegetables had the highest levels of carotene, with relatively high vitamin C content, and the highest levels of lutein and zeaxanthin. Berries added a unique antioxidant profile, and fermented dairy products gave complementary nutritional properties related to protein, calcium and fermentation-related functional properties. The observed differences in the nutrient content of food categories, as well as the correlations between fibre, protein, minerals, carotenoids and antioxidant-related nutrients, reinforce the idea that the functional foods do not all have the same nutritional values or benefits. The results of the principal component analysis also showed a clear differentiation in the composition of the major food groups. The results overall highlight the importance of taking into the diet a wide variety of functional foods that provide a larger spectrum of nutritional and bioactive values. The study is also used as a comparative tool to recognize nutrient-rich foods which can be utilized in future dietary planning, functional food formulation, and nutrition-related research.

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