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A comprehensive review of *Amaranthus spp*. as a nutrient-dense food supplement: focus on mineral composition and health benefits

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Abstract

The purpose of the study is to highlight that the Amaranthus spp. plant contains a significant amount of nutrients that are beneficial to human health and, when included in a balanced diet, can improve or even combat certain diseases. The plant is an important source of proteins, crude fiber, carbohydrates, energy, and minerals.

Amaranthus spp. belongs to the Amaranthaceae family. There are about 65 to 70 species of amaranth, known commonly as amaranth. It is about 8000 years old and was originally considered a sacred food with ceremonial uses due to its nutritional and healing properties before modern times. All parts of the plant can be consumed.

The nutritional value of amaranth is very high, the leaves contain more protein and lysine than corn or other cereals, and more methionine than soy, both essential amino acids. It also contains significant amounts of beta-carotene, omega-6, and powerful antioxidants.

The amaranth plant (specifically its species) is rich in vitamins, particularly A, K, B1, B3, B5, B6, B17, C, E, riboflavin, folic acid, and folate, as well as minerals like calcium, iron, magnesium, phosphorus, potassium, zinc, copper, and manganese. Amaranth contains significant amounts of provitamin A (beta-carotene) and is also rich in polyunsaturated fatty acids, particularly linoleic acid.

Amaranthus spp. contains a variety of valuable bioactive compounds, which are good for our health: polyphenols – powerful antioxidants that help combat oxidative stress; flavonoids – with anti-inflammatory and antioxidant properties; saponins – known for their antimicrobial and anti-inflammatory effects; dietary fiber – beneficial for digestive health; phytosterols – help reduce cholesterol. These compounds provide amaranth with health benefits, including cardiovascular protection and immune support.

Keywords: weed, healthy food, nutrients, and bioactive compounds

1. Introduction

Because of the high weed overgrowth in organic and non-organic farms, and in conventional, conservation, and no-till production systems with conventional herbicides, which leave weed seeds at the surface and select for herbicide-resistant populations, the weed problems have amplified [32].

The information on genetic nutritional diversity among the species and their wild-related species is fundamental for the effective use of plant-like genetic resources such as crop development of Amaranth [7, 33].

The food science scientific community [6], has recently been attracted to the amaranth species because it is a convincing nutritional alternative to cereals with a significant potential food benefit. Domesticated as leaf vegetables, aromatic herbs, or as ornamentals. Characterized by a high level of diversity, the amaranth species have a wide spectrum of adaptability to diverse environmental conditions.

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Due to influences of environment, genotype, and adaptation to specific agroecological areas under which different species of the plant have adapted and evolved, the nutritional values are likely to vary [15]. The increasing ignorance among people regarding the existence of Indigenous herbs and vegetables that are rich in nutrients is causing a decline in their consumption, leading to inadequate nutrition in certain rural and urban areas, for example in Africa [11].

Therefore, containing a large amount of energy, protein, fat, fiber, vitamins, and minerals, makes the amaranth species an important source of human and animal nutrition [3, 9, 35]. Some studies have shown that amaranth species compared to some plants used as cereals and forage crops, are more nutritious [18]. Besides the fat and protein contents of amaranth species, it was determined that quality components such as amino acids and fatty acids, are also high [8, 20].

Because it is a gluten-free pseudo cereal, in addition to being a relevant source of vegetable proteins, amaranth can be considered a superfood, because it offers the human diet a balanced content of essential amino acids, significant amounts of calcium, dietary fiber, omega-3, omega-6, vitamin, minerals, and antioxidants [28, 16].

The seeds hold a substantial quantity of high-quality proteins, carbohydrates, lipids, dietary fiber, minerals, and vitamins. Amaranth seeds help with a balanced protein diet, an important nutritional fact, because they contain a large amount of protein and provide more amino acids, can include amaranth seeds in their diet. Amaranth also counts with the presence of a high amount of protein in the leaves. In the seeds, in addition to omega-6, omega-3, palmitic, and stearic acids, as well as other nutraceutical components such as squalene [25].

The biologically active components [27] like tannins, saponins, phenols, flavonoids, cardiac glycoside, steroids, and triterpenoids [30], are reported in the phytochemical extract from leaves of *Amaranthus spp*. Also, some of *Amaranthus spp*. contains several chemical constituents that present strong activities like antiviral actions, anti-inflammatory, anti-hepatotoxic, antiulcer, and antiallergic [30]; is a crop that suffered ignorance, even though holds many nutraceuticals and medicinal potentials, which possibly resulted in it becoming a poor man's food plant [1].

The study aims to answer two main questions: is it rich in minerals and if yes, is it a dense nutrient food?.

2. Materials and methods

To compare and recognize the most nutrient-dense forms of Amaranthus (plant, seeds, flour, and cooked seeds), multiple databases such as USDA, FoodB, and scientific papers were reviewed. The analyzed materials are included in the text, tables, and references. The analysis of data was performed by direct comparison (table, treemap), ranking by nutrient content, and using Principal Component Analysis (PCA). All data are presented in Tables 1 and 2 and different graphs. For direct comparison was used treemap from a data fingerprint.

For creating the ranking chart the method used is called „Line Plot with an Inverted Y-axis" suggested to visually exemplify rankings. Meanwhile, rankings are better when they are lower (with 1 being the best), the y-axis is inverted to highlight those lower values are better ranks. The lines simplify the observation of the products that regularly perform well or poorly based on various metrics.

PCA is a mathematical model which is reducing the number of data, to form clusters showing the most important correlations. The joint plot graph helps visualize how the samples can be compared based on multiple variables and which variables contribute most to their variance. It's a powerful way to understand the key factors distinguishing these samples and their compositions.

3. Results and discussions

To answer the main questions, based on the studied literature data and database information the following table was constructed and the results were analyzed using mathematical models. The data are presented in Table 1 and the fingerprint of the data in Figure 1.

The treemap illustrates clearly the pictures in Table 1 dataset, highlighting the different components and their proportions in an easily understandable way. The size of each rectangle represents how significant the component is compared to others. The higher values are shown in the bigger rectangles and indicate a more substantial contribution. The created treemap proves the strengths of Amaranthus spp. as a superfood. It is a great appliance for promoting Amaranthus and its dietary and health benefits.

Table 1. Nutritional value of A. spp based on database and literature data for 100 g F.W.

Components	Symbol	Unit	A. Plant Average value [36]	A. seed	A. flour	A. seeds cooked
Water	H_2O	%	44.520	11.290 [17]	9.490 [38]	75.200 [37]
Energy	EN	Kcal	371.000	371.000 [17]	384.000 [38]	371.000 [37]
Carbohydrate	CARB	g	65.250	65.250 [17]	68.800 [38]	18.700 [37]
Sugars	Sug	g	1.690	-	-	-
Sucrose	Suc	g	0.700	-	-	-
Maltose	Mal	mg	5.000	-	-	-
D-Fructose	Fruc	mg	5.000	-	-	-
Total dietary fiber	TDF	g	7.000	67.000 [17]	90.400 [38]	2.100 [37]
Total fat lipid	TFL	g	2.000	7.020 [17]	6.240 [38]	1.580 [37]
Protein	Prot	g	14.000	13.560 [17]	13.200 [38]	3.800 [37]
Ash	sh	g	1.877	2.880 [17]	2.290 [38]	0.770 [37]
Starch	Starch	g	24.500	57.270 [17]	55.700 [38]	16.200 [37]
K	K	g	1.120	0.508 [34]	0.396 [38]	0.135 [37]
Ca	Ca	g	0.748	0.159 [34]	0.135 [38]	0.047 [37]
Mg	Mg	g	0.223	0.248 [34]	0.233 [38]	0.065 [37]
P	P	g	0.326	0.557 [34]	0.425 [38]	0.148 [37]
Fe	Fe	mg	22.134	7.610 [34]	7.560 [38]	2.100 [37]
Na	Na	mg	33.390	4.000 [34]	2.500 [38]	6.000 [37]
Zn	Zn	mg	2.446	2.870 [34]	3.000 [38]	0.860 [37]
Cu	Cu	mg	0.447	0.530 [34]	0.518 [38]	0.149 [37]
Mn	Mn	mg	1.552	3.330 [34]	2.300 [38]	0.854 [37]
Se	Se	mg	7.391	0.018 [34]	0.021 [38]	0.005 [37]
Mo	Mo	mg	-	-	0.035 [38]	-
Thiamin	Thi	mg	0.076	0.120 [34]	0.059 [38]	0.015 [37]
Riboflavin	Rib	mg	0.524	0.200 [34]	0.175 [38]	0.022 [37]
Niacin	Nia	mg	-	0.920 [34]	0.748 [38]	0.235 [37]
Vitamin B-6	B6	mg	-	0.590 [34]	0.387 [38]	0.113 [37]
Biotin	Bio	mg	-	-	0.025 [38]	-
L-Ascorbic acid	AscA	mg	112.933	4.200 [34]	-	-
L-Aspartic acid	AspA	g	1.376	1.261 [17]	0.071 [5]	0.084 [4]
L-Leucine	L-Leu	g	1.074	0.880 [17]	0.058 [5]	0.060 [4]
L-Lysine	L-Lys	g	0.525	0.747 [17]	0.082 [5]	0.044 [4]
L-Isoleucine	L-Isol	g	0.452	0.580 [34]	0.030 [5]	0.033 [4]
L-Threonine	L-Thr	g	0.401	0.560 [34]	0.027 [5]	0.035 [4]
L-Histidine	L-His	g	0.242	0.389 [17]	0.025 [5]	-
L-Methionine	L-Meth	g	0.153	0.230 [34]	0.036 [5]	0.023 [4]
L-Serine	L-Ser	g	0.624	1.148 [17]	0.054 [5]	0.059 [4]
L-Alanine	L-Alan	g	0.568	0.799 [17]	0.034 [5]	0.038 [4]
L-Tyrosine	L-Tyro	g	0.283	0.329 [17]	0.063 [5]	0.048 [4]
L-Cystine	L-Cyst	g	0.126	-	0.036 [5]	0.029 [4]
L-Tryptophan	L-Tryp	g	0.127	0.180 [34]	0.018 [5]	-
(±) Leucine	Leu	g	0.879	0.879 [17]	-	-
(±) Valine	Val	mg	0.679	0.680 [34]	32.000 [5]	40.200 [4]
(±) Phenylalanine	Phen	g	0.542	0.540 [17]	63.000 [5]	41.400 [37]
Glycine	Glyc	g	0.832	1.380 [7]	0.067 [5]	0.093 [4]
Arginine	Argi	g	0.616	1.060 [17]	0.083 [5]	0.088 [4]
Proline	Prol	g	0.698	0.698 [17]	0.037 [5]	0.113 [4]
Glutamic acid	GlutAc	g	2.259	2.259 [17]	-	-
Retinol	Ret	IU	0.666	-	-	-
Choline	Chol	mg	69.800	69.800 [34]	-	-
Betaine	Bet	mg	67.600	67.600 [34]	-	-
alpha-Linolenic acid	αLinAc	mg	42.000	-	-	-
Folic acid	FoAc	mg	19.069	-	-	-

beta-Carotene	βCar	mg	8.800	-	-	-
Nicotinic acid	NicAc	mg	1.848	-	-	-
D-Aspartic acid	D-As	g	1.261	1.261 [17]	-	-
Pantothenic acid	PanAc	mg	0.818	-	-	-
Phytosterol	Phyt	mg	24.000	24.000 [17]	-	-
alpha-Tocopherol	αToc	mg	0.735	0.960 [34]	-	0.190 [37]
beta-Tocopherol	βToc	mg	0.770	0.690 [34]	-	0.380 [37]
d-Tocopherol	d-Toc	mg	0.506 [36]	0.690 [17]	-	0.240 [37]

The data fingerprint is presented in Figure 1.

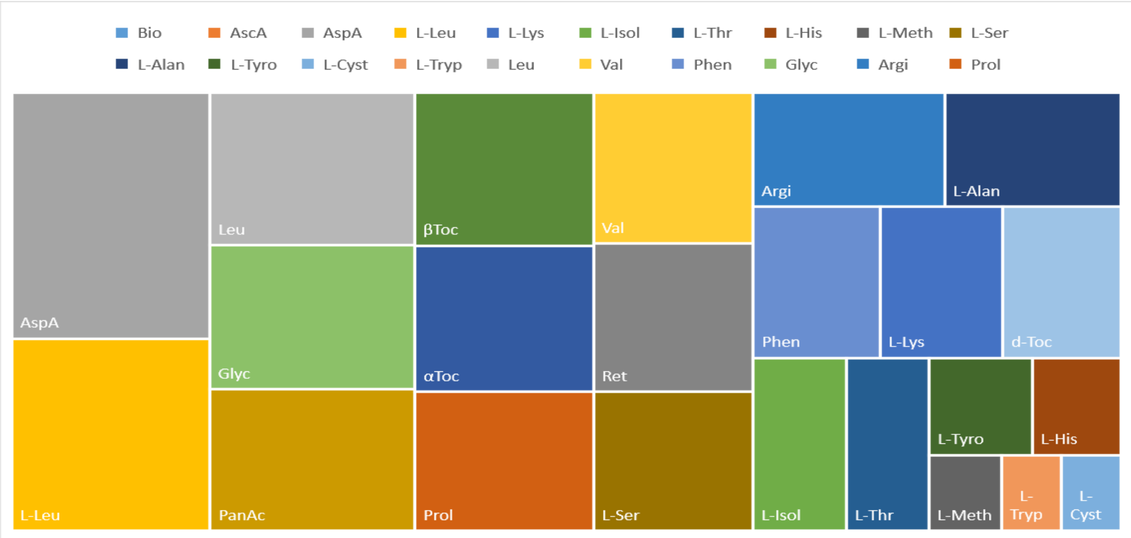

Figure 1. Data fingerprint

To create the ranking chart, we evaluated directly the data values by comparing the minimum and maximum of the values.

- **Energy:** *A.flour > A.seed / A.Plant Average value / A.seeds cooked* (same energy content)
- **Carbohydrates**: *A.flour > A.seed/A.Plant Average value > A.seeds cooked*
- **Fiber**: *A.flour > A.seed > A.Plant Average value > A.seeds cooked*
- **Protein**: *A.Plant Average value > A.seed > A.flour > A.seeds cooked*
- **Total Minerals:** *A.Plant Average value > A.seed > A.flour > A.seeds cooked*

We can observe that after the food processing (cooking) the seeds lose a large amount of minerals, fibers, and proteins.

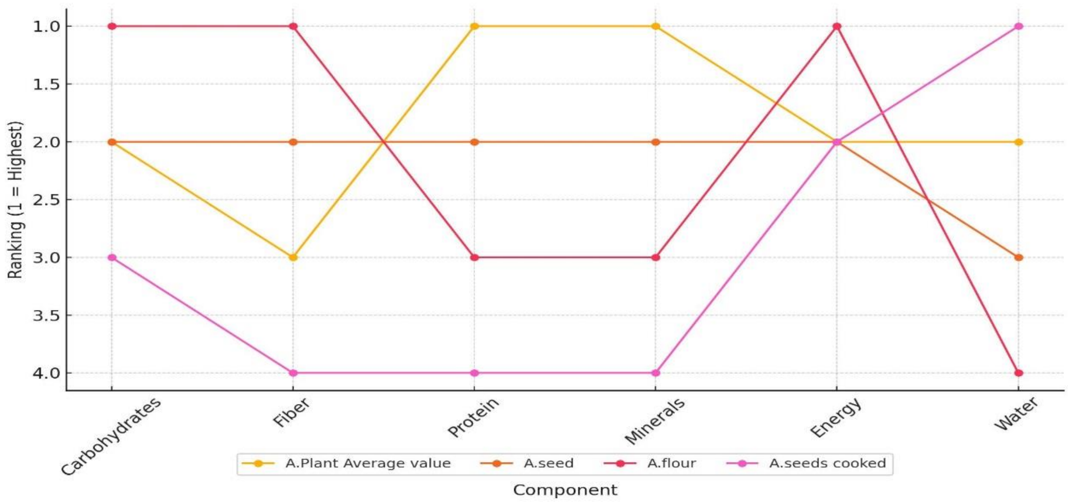

Figure 2. Ranking of Nutritional Components across Products (The ranking chart was generated with the help of an AI-based solution).

- **A.flour** is regularly ranked in the middle for most components, showing stable properties but lower water content.
- **A.seed** is constantly ranked in the middle for most components, showing balanced properties but with lower water content.
- **A. plant** Average value average values accomplish best in protein and minerals contents, signifying a more nutrient-dense profile.
- **A. seeds** cooked have the highest water content but rank last in fiber, protein, carbohydrates, and minerals, probably due to nutrient loss during boiling of the seeds.

The chart highlights the nutritional strengths and weaknesses of the analyzed samples and helps to how each different component acts in key areas. The connecting lines help reveal this contrast, making it easier to spot patterns of nutrient retention and loss across the different analyzed forms.

The Principal Component Analysis (PCA), helps to simplify complex information. The Eigenvalues resulting after applying PCA mathematical protocol are presented in Table 2.

Table 2. Eigenvalues of PCA data

	Axis 1	Axis 2	Axis 3
Eigenvalues	35.469	16.715	8.816
Percentage	58.145	27.402	14.453
Cum. Percentage	58.145	85.547	100

The PCA joint plot representation demonstrates the relationships among variables and samples in reduced dimensions.

The graph presents two principal components: PC1 (Axis 1) and PC2 (Axis 2), showing the most significant variance in the dataset. The directions and length of the vectors specify the involvement and strength of the variable quantity, related to the principal components. The direction of each vector shows the connection between the variable and the principal components. The longer the vector is, the more it contributes to the variance lengthwise that principal component. The vectors going in the same direction designate a positive correlation, while vectors distributed at opposite ends specify a negative correlation. For example, variables like moisture content and L-cystine are negatively correlated with Phenylalanine and Valine.

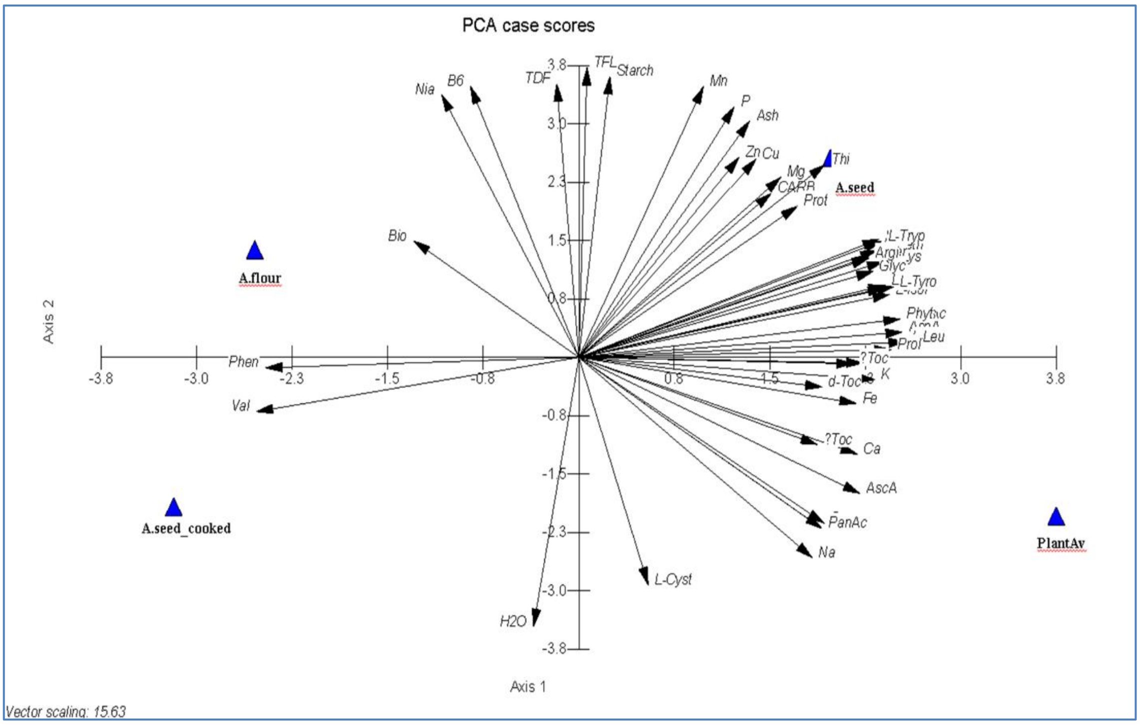

Figure 3. PCA Joint Plot representation of analyzed data

Observations:

- A. flour is located closer to Phenylalanine and Valine, suggesting a higher content of these components.
- A. seed positioned near Magnesium, Zinc, and Protein, indicating high content of these components.
- A. seed_cooked is positioned lower, practically closer to the basis, showing a smaller variation of the measured variables.
- Plant Av is near Cysteine and Ascorbic Acid, suggesting a high concentration of the mentioned variables.

The amaranth plants are beneficial sources of food, contributing to the nutritional well-being of rural populations, by providing essential nutrients and for the prevention of diseases associated with nutritional disorders (e.g. blindness due to vitamin A deficiency) [11].

Information about the nutritional and chemical composition of amaranth leaves and grains, unlike conventional vegetables, is less well documented [2].

The A.spp gains interest, being rediscovered as a traditional vegetable, with beneficial protective and curative properties, which are mainly attributed to its phytochemical properties [22, 25]. Considered a cost-effective and sustainable food, *Amaranthus*, like other varieties of food plants, has been recognized to supply most of the dietary needs [29, 26].

By introducing Amaranth plants into our daily diet, we can benefit from the multitude of health benefits. The consumption of Amaranth's seeds offers a high-quality protein, and many of the necessary amino acids, which are essential molecules that build new cells and tissues facilitating proper neuronal function, helping the immune system and recovery of muscles [21].

It has been presented that the consumption of Amaranth could help to avoid chronic diseases caused by inflammation, by reducing the expression of several pro-inflammatory markers by the extruded Amaranth protein and activation of bioactive peptides [19].

Another key compound is calcium which maintains bones healthy and supports mineralization [14]. An amaranth seed possesses more calcium than other seeds, which leads to a beneficial food that helps to obtain a healthy growth of bones aiding in the prevention of osteoporosis [13, 31].

Due to its substantial amount of manganese, contained within a diet, *Amaranth* presents a good alternative for regulating sugar levels in the organism. When manganese is consumed in a sufficient amount it is possible to prevent diabetes [12].

Even if calciferous vegetables such as: cabbage, cauliflower, broccoli, lettuce, spinach, celery, etc. are quite sought after and preferred among consumers, the popularity of the *Amaranthus* plant is increasing, and it is currently considered among superfoods with numerous health benefits. *Amaranthus spp*. vegetables promote health benefits because is attributed to the nutritional and bioactive compounds enhanced in the plants. Studies on the *Amaranthus spinosus* for example, offer a vast and variety of information regarding its pharmacological actions (high antioxidant activity, hepato-protective effects, important immune-stimulating activity of the plant water extract). The extracts had been used as antidiuretic, antiviral, antibacterial, anti-inflammatory, antimicrobial, and anti-hepatic disorders [10].

Free radicals can cause toxic effects in the organism when are accumulated in an abnormal way producing oxidative stress which can cause the development of diseases. Preventing or limiting the negative effects of oxidative stress, can be done by consuming rich nutrients foods that contains antioxidants like: polyphenols, ascorbic acid, phenolic acids and tocopherols [24].

4. Conclusions

Amaranth flour is an exceptional source of energy and carbohydrates, but it has less water and only moderate amounts of other nutrients. Amaranth leaves show high protein and mineral content, showing that leaves are the most nutrient-dense when eaten fresh. Amaranth seeds provide a mix rich in both fiber and protein. However, cooked Amaranth seeds tend to lose a lot of their nutrients, which reflects how food processing can impact and change the nutritional values of a food product. To get the most benefits of Amaranth, we can consume it in raw and minimally processed forms preserving more of their nutritional benefits.

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Compliance with Ethics Requirements.
Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human or animal subjects (if exist) respect the specific regulation and standards.

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