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POTENTIAL OF UNDERUTILIZED AMARANTH (*Amaranthus spp.*) IN IMPROVING FOOD SECURITY AND NUTRITION: A REVIEW

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ABSTRACT
Inadequate, affordable, healthy foods, loss of food biodiversity, economic issues, poverty, inequality, climate change, and other important factors drive global food insecurity and nutrition crises. In this context, achieving Sustainable Development Goal 2: Zero Hunger by 2030 is less likely. Addressing this challenge involves fostering a sustainable food system and diversification of crops, as well as utilizing neglected and underutilized crop species, which are considered highly nutritious and offer various health advantages. Amaranth (Amaranthus spp.), categorized as a superfood, is a versatile and drought-resistant crop that contains excellent nutrients such as carbohydrates, proteins, fiber, vitamins, and minerals. It also provides health-promoting properties due to its abundance in tocopherols, squalene, antioxidants, phenolic compounds, and flavonoids. Despite the adaptability of amaranth in extreme conditions, nutritional advantages, and health benefits, its exploration and utilization are still limited, especially in food production. Researchers should do more studies to promote amaranth in the food value chain, which may enhance food security and nutrition. The primary aim of this review is to present the potential of amaranth and its components in improving food security and nutrition based on its nutritional compositions, beneficial health effects, and current food applications.

KEYWORDS: *Amaranth; Underutilized Amaranth; Food Security; Nutrition; Global Food System; Nutrients from Amaranth; Health-Promoting Properties of Amaranth*

INTRODUCTION

In recent years, elevated hunger, food insecurity, and malnutrition rates have caused a regression in progress. These issues have derailed global efforts to achieve Sustainable Development Goal (SDG) Targets 2.1 and 2.2, which seek to eliminate these issues by 2030. Conflict, fluctuations in climate, and economic recessions and downturns substantially impact food insecurity and malnutrition. Well-known underlying contributors, including lack of access to healthy diets, unaffordability, unhealthy food environments, and persistent high inequality, compound these issues. (FAO, IFAD, UNICEF, WFP, and WHO, 2024). The World Health Organization (2023) reported that approximately 2.4 billion individuals lack reliable access to food, accounting for 29.6 percent of the worldwide population. This group includes 900 million individuals who are experiencing severe food insecurity. Our World in Data reported that one in ten people does not have enough food to eat (Ritchie et al., 2023). Africa boasts the highest proportion of its population facing hunger, at 20.4%, compared to Asia's 8.1%, Latin America and the Caribbean's 6.2%, and Oceania's 7.3%. Nevertheless, Asia still houses the most significant share: 384.5 million individuals, or over fifty percent of all people, experiencing hunger globally (FAO, IFAD, UNICEF, WFP, and WHO, 2024).

Hidden hunger is also associated with malnutrition, a food-related crisis. Experts estimated that in 2023, the number of people undernourished ranged from 713 to 757 million (representing 8.9 to 9.4 percent of the global population). Considering the midpoint of the estimated range (nearly 733 million), this amounts to an increase of 152 million people grappling with hunger in 2023 compared to 2019. (FAO, IFAD, UNICEF, WFP, and WHO, 2024). In middle- and low-income countries, infants, young children, and young women of childbearing age are at risk of devastating effects that impair vision and intellect, hinder development, and cause morbidity that limits the livelihoods of individuals, particularly smallholder farmers in rural areas (Aswal et al., 2016; Aderibigbe et al., 2020). Rural areas primarily host extreme poverty and hunger, where smallholder farmers and their families make up a significant proportion of the deprived and hungry population. As a result, eliminating hunger and poverty is closely connected to increases in food production, agricultural productivity, and rural incomes (FSNSA-DESA, n.d.). The agricultural sector faces immense pressure to produce 70% of the food required to nourish the anticipated 40% population growth, amounting to nine billion people globally by 2050 (Aderibigbe et al., 2020). Thus, the projected global population is a significant challenge in research, and it calls for persistent and focused exploration of underutilized edible crop

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species that may have great potential to improve food security and nutrition for the worldwide population.

Amaranth (*Amaranthus spp.*), often known as pigweed, is one of the most underutilized crops. It includes over 70 breeds classified as amaranth leafy vegetables, grainy, weedy, and ornamental (Achigan et al., 2014; Peter & Gandhi, 2017). Farmers cultivated amaranth in America between 6,000 and 8,000 years ago. Presently, it is grown worldwide (Achigan et al., 2014). Amaranth provides considerable advantages, such as excellent yield production, resilience to drought, and enhanced photosynthetic activity (Karamac et al., 2019). Different species of amaranth show significant genetic variation, allowing for improvements and adaptation to specific environments. They are often called weedy species and are largely undomesticated crops that adapt well to different geographical areas. Despite their strong adaptability, these species are not widely known or used as human food, and their production is limited, particularly in southern Africa (Mukuwapasi et al., 2024).

Researchers have reported that amaranth has valuable qualities as food and many valuable health-promoting properties (Karamac et al., 2019). Experts recognize amaranth as a highly nutritious food crop with great potential related to the nutritional benefits of its grains and leaves (Manyelo et al., 2020). Amaranth is primarily utilized as animal feed (Kamboh et al., 2016); however, amaranth leaves and grains contain abundant carbohydrates, dietary fiber, protein, vitamins, and minerals. Its fiber content can reduce cholesterol and promote gut health (Caselato-Sousa & Amaya-Farfán, 2012; Temel & Keskin, 2022; Sattar et al., 2024). This crop also contains significant amounts of tocopherols, squalene, antioxidants, phenolic compounds, flavonoids, vitamins, and inorganic minerals (Mustafa, Seguin, and Gelinas, 2011; Taylor et al., 2013; Soriano-García & Aguirre-Díaz, 2019; Sarker et al., 2020; Sarker et al., 2024). Amaranth possesses high antioxidant activity due to its polyphenols and phenolic acids (Paśko et al., 2008), and its squalene provides nutraceutical effects (He et al., 2001; Ryan et al., 2007; Kraujalis & Venskutonis, 2012). In this regard, amaranth may offer advantages in less developed areas, where undernutrition and food scarcity present significant challenges (Orona-Tamayo & Paredes-López, 2017).

As a result, the great nutritional value of amaranth and its health-promoting properties should motivate producers to create new, technologically advanced food products and exceptionally functional foods. Amaranth could also play a crucial role in alleviating hunger in developing nations. Although researchers should acknowledge amaranth as a promising nutritional and healthful crop with significant potential to nourish the global population, they have insufficiently explored its potential (Baraniak & Kania-Dobrowolska, 2022). Creating sustainable value chains for amaranth—from field cultivation to the production of various value-added products—and raising awareness of its many health benefits could provide a significant means of improving the lives of millions of rural and poor urban households in developing countries where malnutrition and its associated health effects are prevalent (Aderibigbe et al., 2020). Therefore, this review focuses on the state of the global food system and nutrition, the nutritional and health-promoting properties of amaranth, its applications in food products, and its benefits in improving food security and nutrition.

METHODOLOGY

The author used PubMed, Google Scholar, and Google databases to locate publications on Amaranth's potential to enhance food security and nutrition. This review article used the following keywords or phrases: "amaranth," "underutilized amaranth," "food security," "nutrition," "global food system," "nutrients from amaranth," and "health-promoting properties of amaranth."

CURRENT STATUS OF THE GLOBAL FOOD SYSTEM

Many countries around the globe have lost food diversity. The global food system currently depends on a limited variety of plant species (FAO, 2020). While researchers identify at least 7039 edible plant species globally, they classify only 417 as food crops. A mere 15 of these crop plants account for 90% of human consumption (FAO, 2023), with over four billion people relying on rice, maize, and wheat (Antonelli et al., 2020). In 2022, the primary crops produced worldwide were sugarcane, maize, wheat, rice, oil palm fruit, and potatoes (FAO, IFAD, UNICEF, WFP, and WHO, 2024). Maximizing crop output was the primary objective to provide sufficient calories for the growing global population, while there was less focus on the nutritional quality of the food (Knez et al., 2023). This situation is significantly affecting global nutrition security and dietary diversity. In 1991, several UN agencies acknowledged it as a significant barrier to human development (WHO, 1991). The Millennium Development Goals Report reiterated 14 years later that micronutrient deficiencies, or "hidden hunger," are primarily caused by simplified diets, especially among low-income people (UN, 2005).

The United Nations estimates that by 2050, the global population will reach 9.7 billion, representing a 19% increase from the current population of 7.9 billion (UNDESA, 2022). Thus, it requires finding new sustainable methods to feed the global population (Antonelli et al., 2020). However, the current food system, which is solely focused on increased yields and based merely on production intensification pathways, cannot be further expanded due to unsustainable resources and planetary boundaries (Knez et al., 2023). To provide all people with healthy and nutritious food by 2050 while ensuring sustainability and protecting the environment, agricultural and food systems must be more biodiverse. Moreover, more sustainable production of conventionally used plant species and reintroducing underutilized crops should enhance the sustainability of food systems and biodiversity (Kim & Baik, 2015).

According to the Food and Agriculture Organization (2021), reaching Sustainable Development Goal 2: Zero Hunger by 2030 involves boosting food production and guaranteeing fair distribution and access for everyone. Although the global population keeps growing, the food produced (around 5 billion tons in 2021/2022) is theoretically enough for everyone worldwide (FAO, 2022). Nonetheless, a considerable amount

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of this production is lost or wasted, and a large segment of the global population continues to lack sufficient access to food that meets quality standards (De Sousa et al., 2024). To sustainably feed the increasing global population, bringing about transformative changes in food systems worldwide, including agricultural production systems, is essential. Moreover, it is crucial to implement actions designed to lessen inequalities to guarantee that everyone can access food that is safe, nutritious, and adequate (UNDESA, 2021).

CURRENT STATUS OF GLOBAL NUTRITION

As the 2030 deadline approaches, the lack of improvements in food security and the inequalities in economic access to healthy diets raise questions about the feasibility of realizing Zero Hunger globally within six years. Projections show that by the decade's end, 582 million individuals will experience chronic undernourishment, with over half of them located in Africa. Global hunger, as indicated by the prevalence of undernourishment, rose sharply from 2019 to 2021 and has remained nearly constant for three years. In 2023, it still affected 9.1 percent of the population, up from 7.5 percent in 2019. In the aftermath of the COVID-19 pandemic, it has increased dramatically. In Africa, hunger continues to rise, while in Asia, it has remained relatively stable. Conversely, there has been significant improvement in the Latin American and Caribbean regions (FAO, IFAD, UNICEF, WFP, and WHO, 2024).

Malnutrition, in all types, poses serious dangers to human health. Currently, the world is confronted with a double burden of malnutrition, comprising both undernutrition and overweight, particularly in low- and middle-income countries. Malnutrition manifests in various forms, such as undernutrition (which includes wasting and stunting), insufficient vitamins or minerals, overweight and obesity issues, and diet-related noncommunicable diseases that arise from these conditions (WHO, 2019). In 2022, around 390 million adults aged 18 and over globally were classified as underweight, while 2.5 billion were overweight, with 890 million of them living with obesity. Among 5- to 19-year-olds, 390 million were classified as overweight, with 160 million of them living with obesity. An additional 190 million individuals were experiencing thinness (WHO, 2024). Researchers anticipate that by 2030, the percentage of children under five who are overweight will reach 5.7%, nearly twice the global target of 3% for that year. Recent projections also show that the number of obese adults has been continuously rising over the previous ten years, going from 12.1% in 2012 to 15.8% in 2022. The world is not on course to meet the 2030 goal of stopping this upward trend, with projections suggesting there will be over 1.2 billion obese adults by then (FAO, IFAD, UNICEF, WFP, and WHO, 2024).

Moreover, the worldwide prevalence of stunting in children younger than five years decreased from 26.3% in 2012 to 22.3% in 2022. In 2030, analysts expect 19.5 percent of all children under five will experience stunting. The prevalence of global wasting decreased from 7.5% in 2012 to 6.8% in 2022. Experts project that in 2030, 6.2% of children under five will be wasted, which exceeds the global target of 3% by more than double; thus, the world is not on track for this indicator (FAO, IFAD, UNICEF, WFP, and WHO, 2024). Malnutrition affects every country worldwide and is a significant barrier to achieving global food security, sufficient nutrition, and sustainable development (HLPE, 2017).

According to Gurinović et al. (2017), long-term factors such as significant shifts in eating habits, demographic expansion, urban growth, and globalization drive the global nutrition crisis. Although the production and consumption of vegetable oil from rapeseed, soybean, and sunflower (Tennant & Gosling, 2015), as well as primary crops like sugarcane, maize, wheat, rice, oil palm fruit, and potatoes have increased (FAO, IFAD, UNICEF, WFP, and WHO, 2024), global consumption of unhealthy foods—such as ultra-processed foods and sugar-sweetened beverages—has also risen substantially among pediatric populations (Markey et al., 2022). Cereals and pulses are most abundant in low- and middle-income countries, while meat, fish, oil, and sugar are more accessible in the middle- to higher-income countries (FAO, 2020). A daily consumption of three servings of vegetables and two servings of fruits is recommended. However, researchers believe global intake is low, often linking it to availability and cost issues, particularly in poor areas (Miller et al., 2016). According to Pries et al. (2019), early life consumption of unhealthy foods increases the risk of nutrient deficiencies, overweight or obesity, and associated chronic diseases in later life.

Most people worldwide cannot access or afford healthy food due to agricultural systems prioritizing calories over nutrition and the widespread availability and low prices of highly processed foods, with inequalities present both across and within countries (GNR, 2020). Policymakers and governments should prioritize and accelerate the transformation of global food systems to enhance their resilience against major drivers and resolve inequalities, ensuring that high-quality diets are accessible and affordable for everyone (Gurinović et al., 2017; FAO, IFAD, UNICEF, WFP, and WHO, 2024).

OVERVIEW OF AMARANTH (*Amaranthus spp.)*

Amaranth is part of the Amaranthaceae family, which comprises around 70 genera and over 800 species originating from tropical America and Africa. Amaranth has several reported species; however, the three main ones include *Amaranthus hypochondriacus*, *Amaranthus cruentus*, and *Amaranthus caudatus*, which farmers widely cultivate as edible amaranth species. They cultivate these species for their edible grains, called grain amaranths. As vegetable species grown for their leaves, *Amaranthus tricolor*, *Amaranthus lividus*, *Amaranthus blitum*, and *Amaranthus dubius* are cultivated (Sauer, 1967, 1993). *A. spinosus, A. viridis, A. retroflexus, A. graecizans, A. dubius*, and *A. hybridus* are categorized as weedy types (Das, 2011). Amaranth has become widely spread worldwide. It is grown and consumed in India, Nepal, China, Indonesia, Malaysia, the Philippines, Central America, Mexico, and Africa (Peter & Gandhi, 2017).

Furthermore, amaranth is recognized as a high-yielding vegetable crop among both rural and urban populations in various communities (Chelang'a et al., 2013). This adaptable crop is called multipurpose because it can endure drought, high temperatures, and pest infestations while adjusting more readily to challenging and unfamiliar conditions than conventional cereal crops. Its tolerance for weather conditions and short production cycles positions amaranth as a potential "golden" vegetable of significant economic value (Hoidal et al., 2020). Researchers classify it as a superfood, a popular category for natural, nutrient-rich, low-calorie foods that benefit health (Waisundara et al., 2019). Unfortunately, it has not yet become part of the mainstream industrial food processing sector (Bodroža-Solarov et al., 2022). This plant has only been grown and valued by certain regions or ethnic groups, and limited studies have been done on amaranth worldwide. Therefore, up-to-date information on their potential and applications is needed, as it may help address the world's food insecurity and nutrition issues.

NUTRITIONAL AND HEALTH-PROMOTING PROPERTIES OF AMARANTH

Amaranth is a dicotyledonous plant that is cereal-like (a pseudo-cereal) and not part of the grass family. Amaranth leaves and grains are staple foods in various forms, whether major or minor (Tang et al., 2016). Due to amaranth's excellent nutritional value, the diverse chemical composition of its seeds and leaves, and its health benefits, there has been a significant increase in scientific research on the properties and potential uses of preparations made from this plant (Baraniak & Kania-Dobrowolska, 2022). Amaranth is regarded by many as a highly nutritious food crop with great potential for nutritional benefits from its grain and leaves. (Manyelo et al., 2020). The amaranth species is an essential source of nutrition for both humans and animals due to its high content of carbohydrates, protein, fat, fiber, vitamins, and minerals (Shewry, 2016; Assad et al., 2017; Keskin et al., 2020; Petrova & Petrov, 2020; Sarker et al., 2020; Temel & Keskin, 2022; Sattar et al., 2024). According to Negro et al. (2008), the essential amino acids found in amaranth proteins are crucial for the formation of new cells and tissues. It includes omega-6 and omega-3 acids and palmitic and stearic acids (Peter & Gandhi, 2017). Additionally, it contains other nutraceutical components like squalene (Peter & Gandhi, 2017; Park et al., 2020). The lipid content of amaranth is noteworthy due to its fatty acid profile, which includes palmitic, oleic, and linoleic acids; the oil is highly unsaturated, with over 70% of its fatty acids being unsaturated (Nasirpour-Tabrizi et al., 2020). Moreover, amaranth contains a significant amount of fiber fraction compounds, both soluble (primarily pectins) and insoluble, which offer advantages for the digestive system (Ka'zmierczak et al., 2011; Bender & Schönlechner, 2021; Lăcătuş et al., 2024). The seeds and leaves of amaranth are good sources of vitamins and minerals (Januszewska-Jó´zwiak et al., 2008; Park et al., 2020). Amaranth leaves are abundant in vitamins from the B complex group, including riboflavin, niacin, folates, thiamin, and vitamin B6 (Randhawa et al., 2015). Regarded as a reservoir for potassium, calcium, iron, zinc, and magnesium, amaranth contains significant quantities of carotenes and vitamins A to C, which have been studied for their role in optimal health (Jimoh et al., 2018).

Similarly, in the comprehensive review of Lăcătuş et al. (2024), 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. 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 rich in polyunsaturated fatty acids, particularly linoleic acid. The nutritional value of amaranth species is summarized in Table 1.

Table 1. Nutritional value of Amaranth species based on database and literature data for 100 g (Lăcătuş et al., 2024).

Components	Unit	Average value
Water	%	44.520
Energy	kcal	371.000
Carbohydrate	g	65.250
Total dietary fiber	g	7.000
Total fat lipid	g	2.000
Protein	g	14.000
Ash	g	1.877
Starch	g	24.500
Lysine	g	0.525
Methionine	g	0.153
Leucine	g	1.074
Isoleucine	g	0.452
Thiamin	mg	0.076
Riboflavin	mg	0.524
Vitamin C	mg	112.933
Folic acid	mg	19.069
Calcium	g	0.748
Iron	mg	22.134

Magnesium	g	0.223
Phosphorus	g	0.326
Potassium	g	1.120
Zinc	mg	2.446
Copper	mg	0.447
Manganese	mg	1.552
Beta-carotene	mg	8.800

In addition to its nutritive value, amaranth grain comprises bioactive compounds with health-promoting effects. Amaranth species have vast and promising potential, making their investigation for health-related and industrial uses essential (Karamac et al., 2019). Amaranth grains and leaves possess substances with antioxidant properties, including flavonoids, phenolic acids, carotenoids, and tannins (Silva et al., 2021). Amaranth species comprises various polyphenols, potent antioxidants that aid in fighting oxidative stress; flavonoids with anti-inflammatory and antioxidant effects; saponins recognized for their antimicrobial and anti-inflammatory properties; and phytosterols that assist in lowering cholesterol. These compounds confer health benefits on amaranth, such as cardiovascular protection and immune support (Lăcătuş et al., 2024). Moreover, particular amaranth species possess multiple chemical components that exhibit strong effects, such as antiviral, anti-inflammatory, antihepatotoxic, antiulcer, and antiallergic activities (Reyad-ul-Ferdous et al., 2015). Amaranth shows astringent activity (Khare, 2004), as well as hypolipidemic and antihyperglycemic properties (Lakshman et al., 2011; Moszak et al., 2018; Hsiao et al., 2021) and anticancer effects (Al-Mamun et al., 2016). In the review of Sattar et al. (2024), some of the amaranth species' components and their pharmaceutical effects were summarized in Table 2.

Table 2. Amaranth's components and their pharmaceutical effects (Sattar et al., 2024).

Components	Pharmaceutical effects
Squalene	Hepatoprotective
Polyphenols and phenolic compounds	High antioxidant activity
Three-hydroxy-3-methylglutaryl-CoA reductase and fluid extract of heated amaranth foliage	Hypolipidemic and antihyperglycemic efficacy
Alcohol concentrations of *A. lividus* and *A. tricolor* leaves	Antidepressant and neuroprotective properties
Ethanolic and aqueous extracts of *A. caudatus*	Antibacterial and antiviral impact
Amaranth's oil	Cardioprotective impact
Ethanol and ethyl-acetate leaf extracts of *A. tricolor*	Duodenal peptic ulcer protection
Hexane, ethyl-acetate, and methanolic extracts of *A. tristis Roxb*	Anticancer impacts

Amaranth's remarkable nutritional value and health-promoting properties could benefit human and animal health. Nonetheless, the use of amaranth in the food value chain has not been extensively studied, which constrains its potential advantages for human and animal nutrition.

FOOD PRODUCTS DERIVED FROM AMARANTH

Farmers cultivate amaranth as a thriving crop relevant for both domestic and industrial use due to its exceptional nutritional profile and bioactive components that may be associated with positive health effects (Bodroža-Solarov et al., 2022). Experts categorize it among superfoods, a well-known classification for natural foods that are rich in nutrients, low in calories, and beneficial to health (Waisundara, 2020). Unfortunately, it has not become mainstream in industrial food processing (Bodroža-Solarov et al., 2022). Amaranth grain has been identified as a potential food ingredient for developing products suitable for celiac patients, aside from wheat and other cereals. This crop, which does not contain gluten, has gained popularity among those looking for gluten-free foods. For patients with celiac disease, the only currently available treatment is a gluten-free diet (Martınez-Villaluenga et al., 2020; Aderibigbe et al., 2020). Based on previous studies, amaranth leaves and grains can be incorporated into baked goods, pasta, and beverages. Despite its essential nutrients and health benefits, the use of amaranth in food production remains limited. If people give amaranth the needed attention, it may enhance food security and nutrition worldwide. Capuno et al. (2015) state that indigenous vegetables like amaranth are vital for food security, income generation, and food culture in poor rural communities. Their potential value has been underestimated and underutilized due to a lack of attention.

Baked Goods

Amaranth grain can produce extruded items, baked goods, breakfast products, and gluten-free foods independently or as part of composite flour. In the Himalayas and Latin America, people prepare flatbreads using amaranth flour. (Aderibigbe et al., 2022). Incorporating amaranth leaf powder in Ujeqe (steamed bread) significantly enhances its ash, protein content, and mineral levels in proportion to the amount of amaranth leaf powder used. However, increased amaranth leaf powder added results in a reduced consumer acceptability rate for the Ujeqe (Olusanya et al., 2023). Moreover, adding amaranth flour to wheat flour (up to 35%) enhanced the product's organoleptic properties, including its flavor, taste, color, and appearance.

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According to Buresova et al. (2017), the product with the best color and organoleptic properties substituted 25% of the flour with amaranth flour. Chaquilla-Quilca et al. (2024) examined the replacement of wheat flour with popped amaranth flour in bread formulation. Researchers observed that, at the highest substitution level, breads contained significantly more protein (approximately 12%) and raw fiber (over 100%), while they reduced their carbohydrate content (by about 6%) in comparison with wheat bread.

On the other hand, Aderibigbe et al. (2022) produced cookies using composite flours made from wheat and grain amaranth. The researchers reported that the cookies were still sensory acceptable with 100% grain amaranth used. Gebreil et al. (2020) showed that adding amaranth flour enhanced the chemical composition, physicochemical properties, essential amino acids, essential unsaturated fatty acids, and minerals of crackers and tortillas, thereby improving their nutritional value. The researchers confirmed that this is due to its significant source of protein and minerals, particularly calcium, magnesium, copper, zinc, iron, potassium, and phosphorus, and its abundance of bioactive compounds like phytosterols and polyphenols. Besides, it is a beneficial source of oils rich in omega fatty acids (linoleic and linolenic acids).

Pasta and Noodles

In the study of Islas-Rubio et al. (2014), a mixture of raw and ground popped amaranth grain (90:10) was partially used to substitute wheat semolina. Researchers assessed various blend combinations (amaranth blend: wheat semolina) for their suitability in pasta production, specifically at 25:75, 50:50, 75:25, and 100% ratios. A greater proportion of amaranth blended in the pasta resulted in a higher solid loss, reduced weight gain, and decreased firmness. Adding an amaranth blend enhanced the nutritional quality of pasta due to its increased dietary fiber content and superior-quality proteins.

Similarly, pasta's nutritional properties and antioxidant capacity improved with the partial replacement of wheat semolina with mixtures of amaranth flour and dried amaranth leaves studied by Cárdenas Hernández et al. (2016). Incorporating amaranth flour and dry leaves diminished cooking time and luminosity values while raising the percentage of cooking loss. Compared to control wheat pasta, including dried amaranth leaves resulted in higher levels of iron, zinc, magnesium, and potassium. After cooking the pasta, researchers measured the antioxidative activities, revealing higher values for pasta enriched with a combination of amaranth flour and dried amaranth leaves, confirming that the pasta has functional benefits.

Instant noodles were produced by Qumbisa et al. (2021) using amaranth leaf powder (ALP). The noodles' total glycemic carbohydrate, protein, fiber, and mineral contents were not significantly affected by increasing ALP from 0% to 3%. The addition of ALP significantly increased fat content (from 1.55% to 4.57%), contributing to an elevated energy value. Compared to standard noodles (control), which had a texture value of 609.08 g, noodle samples fortified with ALP exhibited a significantly softer texture (271.39 g). Additionally, the color was significantly greener with the inclusion of ALP. Researchers found every noodle sample to be equally acceptable as the control, indicating that ALP might enhance instant noodles' nutritional value.

The research conducted by Lawal et al. (2021) found that incorporating amaranth leaf powder into cassava pasta formulations led to a notable increase in dietary fiber (7.6–9.1 g/100 g) and protein (1.41–4.69 g/100 g) levels. The yellow cassava-amaranth pasta contained greater amounts of β-carotene (2.07 μg/g), iron (59 mg/kg), and zinc (9 mg/kg) compared to the white cassava-amaranth pasta. The researchers also reported that incorporating amaranth leaf powder improved the antioxidant capacity of pasta products. Adding amaranth leaf powder reduces cooking time and solid loss in gruel, which benefits consumers. Data indicated that amaranth-fortified yellow cassava pasta could contribute to a healthy diet in low- and middle-income countries by combining a biofortified crop with leafy vegetables through food-to-food fortification.

Beverages

Argüelles-López et al. (2018) developed a beverage based on amaranth and chai using extrusion and germination techniques. The protein content of germinated amaranth grains and chai seeds was higher than that of extruded seeds. Combining amaranth and chai flour at a 70:30 ratio made the drink. The panelists found the developed beverage to be highly acceptable. Moreover, the samples made with amaranth inclusion in the research conducted by Isaac-Bamgboye et al. (2019) were more acceptable than those that did not. A refreshing nonalcoholic drink in Nigeria, Kunu is made by fermenting grain amaranth for various lengths of time and is comparable to the well-known sorghum-based Kunu. The outcomes of the sensory assessment indicated that amaranth kunu had greater acceptability than sorghum kunu after a 48-hour fermentation period. The protein, lipid, and ash levels of amaranth-Kunu were higher than those of sorghum-Kunu.

Jamdar et al. (2023) developed a healthy drink by using different amounts of amaranth leaf juice in place of water and orange juice, sugar, citric acid, and other ingredients, following Ready-To-Serve (RTS) guidelines. Researchers produced five formulations, each substituting 10%, 20%, 30%, 40%, and 50% vegetable juice for water. The findings show that consumers found a healthy drink with 20% leaf juice instead of water more popular. Manufacturers can successfully add 20% red amaranth leaf juice to achieve the best organoleptic qualities in ready-to-serve orange beverages. *Amaranthus cruentus* leaves significantly increase the ascorbic acid and calcium content of nutrient-dense beverages since they are a rich source of both nutrients. Thus, the orange RTS beverage's use of one of the underutilized, incredibly nutrient-dense, and medicinally significant amaranth vegetable leaf juices will improve consumers' nutritional status.

Benefits of underutilized amaranth in improving food security and nutrition

Several factors hamper global food and nutrition security, including reliance on a few staple crops. This context is due in part to the fact that modern agriculture has deviated from adopting traditional food systems, which include the production and consumption of cash crops like cacao, coffee, oil palm, and soybeans, as well as conventional crops like maize, potatoes, rice, and wheat (AARINENA, 2021). Underutilized and neglected species are vanishing more and more in this context. Researchers, policymakers, and markets have undervalued the roles of neglected and underutilized species, also referred to as forgotten foods. These include cultivated, semi-domesticated, wild, and conventional varieties that have been produced and consumed for centuries or even millennia for their food, fiber, fodder, oil, and medicinal properties (Gruere et al., 2006; Ulian et al., 2020; AARINENA, 2021). Amid climate change, researchers acknowledge neglected and underutilized species as a promising way to solve hunger and nutrition issues. Consequently, it is crucial to discover potential natural resources, particularly plant ones (Zafar et al., 2023).

Amaranth is an old plant used for over 8000 years in many parts of the world. Young people stigmatize this climate change-resilient plant as "food for the poor or backward people," and it has been underutilized for many years (reviewed by Qumbisa et al., 2020). This crop has been overlooked despite its medicinal and nutraceutical uses, which may have led to its status as a food plant for people experiencing poverty (Achigan-Dako et al., 2014). It has not been as widely used or consumed by this group, although it has nutritional advantages (Qumbisa et al., 2021). Researchers have recently rediscovered Amaranth as one of the most promising plant genera. It contains phytochemicals, bioactive compounds, and other beneficial nutrients (Achigan-Dako et al., 2014; Qumbisa et al., 2021). Amaranth is also low in calories. Its essential vitamins and minerals, protein, fat, and fiber are considered crucial to the food and nutrition security of poorer communities in urban and rural areas (Ruth et al., 2021).

Amaranth is considered a superfood plant because it contains excellent nutrients and health-promoting bioactive compounds. Amaranth grains or leaves can be incorporated into a regular diet or utilized as a food ingredient in the food value chain. Consequently, they may help fight malnutrition, especially micronutrient deficiency issues and diet-related diseases, while promoting crop biodiversity and improving food security.

CONCLUSION

Amaranth is a neglected and underutilized crop with good sources of essential nutrients such as carbohydrates, protein, fiber, vitamins, and minerals. Amaranth species are also rich in bioactive compounds such as tocopherols, squalene, antioxidants, phenolic compounds, and flavonoids that promote health benefits in both human and animal nutrition. Amaranth has excellent potential to alleviate malnutrition and food insecurity in this context. Researchers have shown that Amaranth can be used in food product development, but it must expand its investigation and application. Therefore, exploring Amaranth further and disseminating scientific knowledge of its nutritional and health-promoting properties to various community groups such as local farmers, stakeholders, food producers, policymakers, and researchers is imperative. In this way, various industries, such as food, nutraceuticals, and medicine, can help commercialize Amaranth.

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