Chapter

Current Production Scenario and Functional Potential of the Whole Amaranth Plant: A Review

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Abstract

Amaranth grain is a pseudocereal that has been widely studied, standing out as a gluten-free seed and plant-based protein source. Amaranth seeds have been associated with functional properties and attractive medical benefits. Besides the seeds themselves, various other parts of the plant possess significant nutritional and functional value. Thus, on one hand, this chapter summarizes an overview of amaranth seeds, leaves, and flowers. Apart from this, recent research and studies have reported on amaranth's composition, its uses, and potential benefits for human health. This chapter also offers insight into the global socioeconomic scenario of farmers and producers. Possible strategies that include biotechnology, ingredient innovation, and ethical biotrade have been proposed here. These three fronts, acting synergistically, would exploit the considerable diversity of these species and promote programs to improve the value chain and, therefore, the life quality of their communities.

Keywords: amaranth, nutrition, pseudocereal, biotrade, functional ingredients

1. Introduction

Amaranth has been consumed throughout history as a staple food by the Inca, Maya, and Aztec civilizations like quinoa and chia seeds [1]. In the 1980s, an increase in interest in amaranth appeared as the US National Academy of Sciences conducted research on the grain and described its high nutritional value and agronomic potential [2]. Because of the growing demand for healthy foods, amaranth has gained recognition in countries where its consumption was not traditional. This recognition has been further supported by recent literature reviews focused on aspects such as the adaptation of amaranth to traditional cuisines [3, 4] as well as the functional and nutraceutical properties of this pseudocereal [5].

Amaranthus or amaranth comes from the Greek amarantos (Αμάρανθος or Αμάραντος), meaning the "one that does not wither," or the never-fading (flower) [6]. Several species of the genus are commonly referred to as weeds, while other species are used as leafy vegetables in many parts of the world [7]. Grain amaranth belongs to the order Caryophyllales, the amaranth family Amaranthaceae, which comprises 65 genera and 850 species, subfamily Amaranthoideae, genus *Amaranthus,* which includes 50–60 species cultivated for leaf (greens) and grains. It equally includes a few wild species. The important leaf amaranth species are *Amaranthus tricolor* (syn. *A. gangeticus, A. tristis, A. mangostanus, A. polygamous, and A. meloncholicus)*, *A. dubius*, and *A. lividus* (*Amaranthus blitum*). In recent years, *A. caudatus L., Amaranthus hypochondriacus L., and A. cruentus L.* are the species that have created a strong interest in seed production [8].

All the grain of amaranth's real origin is traced to Central and South America. Notwithstanding, with some species such as *Amaranthus tricolor* are believed to be a native of India or southern China; *A. lividus* is reported to be a native of south or Central Europe, whereas *A. dubius* is from Central America [9]. It makes sense that the key producers are mostly in several South American countries, along with China, India, Russia, and Kenya [10].

Although amaranth production is not registered by the UN's Food and Agriculture Organization (FAO), it is currently widely cultivated in several countries, including Nepal, Indonesia, Malaysia, Central America, Mexico, and Southern and Eastern Africa [11].

The data shows the strong influence of worldwide amaranth cultivation and the socioeconomic impact generated on farm families. This situation is overshadowed by the brightness of a food gem, which raises interest in its nutritional and functional properties. It should be noted that the leaves and flowers of amaranth have a high antioxidant activity compared with other parts of the plant and many other traditional leafy greens [12, 13].

This review begins with a summary of the composition, the functional properties, and the uses of the different anatomical parts of amaranth. Then, a comparative discussion among the results found in seeds, leaves, and flowers is presented. Finally, the current farmer scenario is analyzed.

2. Functional properties of different parts of the Amaranth plant

Overall, amaranth is a highly nutritious plant that can provide a range of important nutrients when consumed in its various forms. It is well known that the amaranth seed has been reporting outstanding nutritional and health properties. It is significant to note that other parts of the plant have also shown interesting functional potential. Therefore, the nutritional and functional aspects of the amaranth seed, leaves, and flowers are described separately below.

2.1 Amaranth seed

Amaranth seeds are a great source of plant-based protein, fiber, and several essential vitamins and minerals. They are high in lysine, an essential amino acid that is often lacking in grains. Amaranth seeds are also a good source of iron, calcium, magnesium, and phosphorus. Amaranth seeds contain antioxidants, such as vitamin E and phenolic compounds, which may help to protect against cellular damage.

Amaranth seed is a dicotyledonous pseudocereal that has been consumed for thousands of years. It is known for its many health benefits. The protein content of the amaranth seed is superior to that of cereals, making it a highly nutritious food.

Extensive research has shown that amaranth seeds are also well-balanced. They are rich in protein content of between 12% and 16% and have an excellent balance of essential amino acids in their peptides. These peptide-rich fractions exhibit various health benefits, including antioxidant, antihypertensive, hypocholesterolemic, anticoagulant, antidiabetic, anticancer, anti-inflammatory, and antiviral activities [12]. This leads to a reduction in plasma cholesterol levels. It also has antitumor effects, lowers blood sugar levels, and treats anemia [1].

In addition to being rich in protein, amaranth seeds are good sources of crude fiber, dietary fiber, and minerals, especially calcium, iron, and potassium [13]. This translates into a remarkable nutritional profile, and it can be used in a variety of dishes, including salads, soups, and baked goods, making it an excellent option as an additive to improve the nutritional profile of other foods [8]. Finally, as a gluten-free ingredient for people with coeliac disease or gluten intolerance, the flour obtained from milling amaranth seeds has become a great alternative.

Amaranth seeds have been shown to improve the antioxidant potential of baked cookies [14, 15], and they have been used to make functional cookies with antithrombotic and antihypertensive activities [16]. Even after thermal and enzymatic treatments, end-consumer products derived from amaranth showed antioxidant capacity, which further increased after *in vitro* digestion [17]. Altogether, amaranth seeds exhibit antioxidant activity attributed to their content of polyphenols, anthocyanins, flavonoids, and tocopherols [18], which can help to prevent damage to cells and reduce the risk of chronic diseases. This proves once again the high potential of amaranth seeds as a source of functional ingredients.

2.2 Amaranth leaves

Amaranth leaves are a highly nutritious vegetable that is commonly eaten in many parts of the world. They are rich in vitamins A, C, and K, with a higher content of vitamin C than spinach and cabbage. These essential vitamins are involved in the healthy functioning of the immune system and can help to prevent the spread of infectious diseases.

While amaranth leaves and stems contain high levels of several vitamins, they also contain riboflavin (vitamin B2), vitamin B6, folate, and niacin. Amaranth leaves also contain minerals such as calcium, iron, and magnesium [19]. Amaranth leaves are a nutritious vegetable with many health benefits when incorporated into a balanced diet, making it a healthy and nutrient-dense food [20].

It has been reported that amaranth leaves and their products are a valuable source of protein, calcium, iron, and ß-carotene [21]. Certain baked goods made with amaranth leaves were found to have significantly higher protein, fat, ash, and fiber content than their counterparts, while all fortified products had notably higher levels of calcium, magnesium, iron, and zinc [22].

Compared to other edible leaves, amaranth leaves are known for their high protein content. Furthermore, studies have shown that extracts derived from the leaves possess a superior antioxidant capacity compared to those obtained from the seeds [23]. This has been confirmed *in vitro* in both the leaves and flowers of the amaranth plant [24].

Specifically, high concentrations of hydroxycinnamic acid derivatives, such as caffeoylaldaric and -isocitric esters, have been found in amaranth leaves, although flavonoids and carotenoids were found in moderate concentrations compared to other leafy vegetables [25]. These unique compounds have been linked to potential health [26] and cosmetic benefits [27], including controlling lipids and obesity.

Additionally, tannins extracted from amaranth leaves have been identified as a promising source of antioxidants that may be used as food-preserving agents or as dietary supplements [28].

Concerning the unique antioxidant components found in amaranth vegetables, betalains (beta-cyanins and betaxanthins) and their physiological functions such as antioxidant, anti-lipidemic, anticancer, and antimicrobial activities are also emphasized [29].

Amaranth leaves are a versatile ingredient. They can be used in a variety of dishes, including soups, stews, and salads. Amaranth leaf infusions have also been used for treating anemia, chronic fatigue, diarrhea, coughing, and heavy menstrual bleeding, and even for soothing itchy, burning skin, and cleaning wounds [30]. The consumption of amaranth vegetables is also considered medicinal for young children, breastfeeding mothers, and patients suffering from constipation, fever, hemorrhage, anemia, and renal problems [31]. In this sense, some studies have proposed the incorporation of amaranth leaf flour in processed foods such as pasta, resulting in higher levels of iron, zinc, magnesium, potassium, and higher antioxidant capacity values after cooking [32]. Consumer acceptance of pasta made with amaranth leaf flour was found to be like that of pasta made with spinach. Once again, amaranth leaves have demonstrated their innate potential to increase the functional benefits of food and to improve human nutrition.

2.3 Amaranth flowers

Amaranth flowers are often used for ornamental purposes in gardens and floral arrangements. Furthermore, they are a good source of several important nutrients. They contain vitamin A, folate, and potassium, and they are particularly rich in vitamin C. Amaranth flowers also have certain health benefits due to their high antioxidant capacity. This depends on the flavonoid content.

Purple amaranth flowers contain higher levels of flavonoids than red amaranth flowers, which makes them particularly beneficial [33]. It is known that amaranth species are attractive sources of betalain because of the broad range of pigmentation [34]. Due to the global status of amaranth as a food, one of the major applications of amaranth flowers is as a natural food coloring agent.

Phenolic compounds found in the flowers include gallic acid, chlorogenic acid, protocatechuic acid, 2,4-dihydroxybenzoic acid, genistein, ellagic acid, feluric acid, and salicylic acid. Rutin, quercetin, and kaempferol-3-rutinoside are also found. It is worth noting that although all parts of the plant have been analyzed, chlorogenic acid is the only compound detected in flowers [35]. Moreover, even though the tannin content is higher in the leaves, the amounts of it found in the flower still represent a potential antitumor agent [28].

Similarly, although the inflorescence of amaranth contains only half the amount of rutin compared to the leaves, the amaranth plant could still be an excellent source of this antioxidant in the human diet [36]. Food additives with a high content of betacyanin, obtained from amaranth flowers, showed higher stability, even after they were incorporated into biscuits [37].

Despite its potential health benefits, the amaranth flower has not been widely used as a foodstuff, so its properties have been studied only to a limited extent. However, the flowers have been used as a remedy for diarrhea, dysentery, coughs, and bleeding [38].

An important finding is that extracts from the flower of the amaranth plant have a valuable potential as an antimicrobial agent. Amaranth stem and flower showed higher antimicrobial activity than root and leaves against five strains of bacteria including *Staphylococcus* sp., *Escherichia coli*, *Pseudomonas* sp., *Klebsiella* sp., *Paracoccus* sp., and three strains of fungi including *Fusarium* spp., *Aspergillus* spp., and *Alternaria* spp. [38]. Furthermore, the globe amaranth flower was reported to have antibacterial bioactivity against *P. aeruginosa* [39]. This indicates great potential for its use in medical applications and the food and agricultural industry.

3. Comparative discussion

Amaranth has been extensively employed in food products throughout history due to its favorable nutritional value, as shown in **Table 1**. Despite anatomical and species variations in the *Amaranthus* plant, numerous studies have consistently shown that it contains various bioactive compounds (as listed in **Table 2**) and functional properties (as described in **Table 3**) that support human health. Recent research has further reinforced these findings, providing additional evidence of the beneficial effects of amaranth on human health.

	Amaranth **seeds d.b.**	**Scientific references**	*Amaranth* **leaves w.b.**	**Scientific references**
Main nutrient (g/100 g)				
Proteins	13.5–17.5	[10, 15, 23, 39–53]	3.5–4.6	[23, 31, 43, 44, 54–56]
Carbohydrates	63.0–75.8	[10, 15, 39, 40, 42, 44–46, 49, 53, 57]	3.8–6.5	[23, 31, 44, 54]
Fiber	6.0–8.8	[10, 15, 23, 39, 40, 44–53, 57]	1.3–1.9	[23, 31, 44, 54–56]
Fat	5.8–10.2	[15, 23, 39, 40, 44–52, 58]	0.3–0.6	[23, 31, 44, 54, 55]
Minerals (mg/100 g)				
Calcium	159–240	[10, 39, 40, 44, 46, 47, 52, 53, 57]	140–350	[31, 43, 44, 55, 59]
Iron	760–1000	[10, 39, 40, 44, 46, 47, 52, 53, 57]	330–1000	[31, 44, 55, 56, 59]
Magnesium	235–303	[10, 39, 40, 46, 47, 52, 53, 57]	150–450	[31, 55, 59]
Phosphorus	455–580	[39, 44, 47, 52, 53, 57]	430–1000	[31, 55, 59]
Potassium	508–595	[10, 39, 40, 47, 52, 53, 57]	460–920	[31, 44, 55, 59]
Zinc	287–390	[10, 39, 40, 46, 47, 52, 53, 57]	0.67–2.0	[31, 43, 55, 59]
Vitamins (mg/100 g)				
Vitamin A	Unknown	—	1.70–5.7	[31, 43]
Vitamin C	298–705	[45, 53, 57]	36.0–78.0	[56, 59]
Thiamin (B1)	7.2–24	[45, 53]	0.03–0.06	[31]
Riboflavin (B2)	18–27	[45, 53, 57]	0.08–0.18	[31]
Niacin (B3)	89–100	[45, 57]	0.5–1.1	[31]

Table 1.
Nutritional value of Amaranth spp.

Plant part	Bioactive compounds	Scientific references
Seeds	1-Naphtalenol, 4-methyl	[23, 35, 45, 48–51, 53, 58, 60–68]
	2,4-Dihydroxybenzoic acid	
	3,4-Dihydroxybenzoic acid	
	24,25-Dihydroxyvitamin D	
	2H-1,2-Oxazine, 6-(4-chlorophenyl) tetrahydro-2-methyl	
	4-Hydroxybenzoic acid	
	9-Octadecenoic (2-phenyl-1,3-dioxolan-4-Yl)	
	Acid methyl ester	
	Alkaloids	
	Amaranthine	
	Betacyanins	
	Betanin	
	Caffeic acid	
	Caffeine	
	Ferulic acid	
	Flavonoids	
	Gallic acid	
	Gentistic acid	
	Isoamaranthine	
	Isobetanin	
	Isoquercitrin	
	Isorhametin	
	Kaempferol	
	Kaempferol dirhamnoside	
	Myricetin	
	Nicotiflorin	
	p-Coumaric acid	
	p-Hydroxybenzoic acid	
	p-OH-Benzoic acid	
	Phenolic acids	
	Protocatechuic acid	
	PUFAs	
	Quercetin	
	Quercetin 3-rutinoside	
	Rutin	
	Salicylic acid	
	Saponins	
	Sinapic acid	
	Squalene	
	Syringic acid	
	Tannins	
	Tocopherols	
	Tocotrienols	
	Triterpenes	
	Vanillic acid	
	Zeaxanthin	

Plant part	Bioactive compounds	Scientific references
Leaves	2-Methoxy-4-vinylphenol	[23, 24, 31, 35, 55, 59, 64, 69, 70]
	2-Propenoic, 3-(2,3-dimethoxyphenyl)-acid	
	2,4-Dihydroxybenzoic acid	
	24,25-Dihydroxyvitamin D	
	5-Methyl-2-(N-ethyl-p-chlorophenylamino)-2-thiazoline	
	Alkaloid	
	Carotenoid	
	Chlorogenic acid	
	Ferulic acid	
	Flavonoids	
	Gallic acid	
	Gentistic acid	
	Hydrocyanic acid	
	Kaempferol	
	Nitrates	
	Phenol-4-(2-(dimethylamino)ethyl)	
	Phenolic acids	
	Phytic acid	
	Protocatechuic acid	
	Quercetin	
	Retinoic acid, methyl ester	
	Rutin	
	Salicylic acid	
	Saponins	
	Steroids	
	Tannins	
	Terpenoids	
Flowers	2,4-Dihydroxybenzoic acid	[24, 35, 71–73]
	Betacyanins	
	Betalain (amaranthine, isoamaranthine)	
	Betaxanthins	
	Chlorogenic acid	
	Ferulic acid	
	Gallic acid	
	Gentistic acid	
	Isoquercetin and rutin	
	p-Coumaric acid	
	Protocatechuic acid	
	Salicylic acid	
	Syringic acid	
	Vanillic acid	

Table 2.
Biochemical studies validating bioactive compounds of Amaranthus spp.

Apart from the anatomical parts of the plant discussed earlier, studies have also investigated the functional properties of whole plant extracts. The entire plant has been found to possess numerous beneficial properties such as wound-healing

Plant part	Functionality	Scientific references
Seeds	Antibacterial	[46]
	Anti-inflammatory	[12, 45, 46, 62, 72, 74, 75]
	Antidiabetic	[12, 45, 46, 74, 76, 77]
	Antifungal	[12, 78]
	Antihypertensive	[12, 43, 46, 53, 60, 79, 80]
	Antimicrobial	[46, 81]
	Antioxidant	[1, 12, 15, 23, 35, 45, 46, 50, 53, 60, 62–64, 66–68, 74, 76, 79, 82–85]
	Antitumoral activities	[1, 12, 46, 53, 62, 72, 74, 79, 85]
	Cardiovascular disease	[43, 45, 46, 60, 72]
	Hepatoprotective	[46, 53, 74, 82, 86]
	Hypocholesterolemic	[1, 12, 45, 53, 60, 86]
	Immunomodulatory	[52, 53, 72, 79]
	Neuroprotective	[46]
Leaves	Antioxidant	[23, 24, 35, 44, 62, 64, 70, 82]
	Emollient	[44]
	Anti-inflammatory	[44, 74]
	Hepatoprotective	[74]
	Diuretic	[44]
Flowers	Antioxidant	[24, 35, 82]
	Antidiabetic	[72, 74]
	Anti-inflammatory	[72, 74]
	Hepatoprotective	[74]
	Immunomodulatory	[72]

Table 3.
Biochemical studies validating functional and health properties of Amaranthus spp.

acceleration and antimicrobial activities [81, 87] gut modulatory and bronchodilator effects [88], anti-inflammatory, analgesic, and anthelmintic activities [75, 89], and even anticancer properties [90], among others.

Although the current data suggests significant potential for functional properties in the seeds and leaves of the amaranth plant, additional research is needed to explore the potential antibacterial, antioxidant, and antifungal properties of the flower. These properties could have promising applications in fields such as phytosanitary and pharmaceuticals. Furthermore, while extensive research has been conducted on the nutritional potential of the grain and leaves, there are no available reports on the nutrient profile of the flower.

Amaranth, particularly the vegetable variety, is commonly consumed as a source of protein in sauces, soups, or cooked with other vegetables as a side dish or stand-alone meal [91]. It is also utilized in processed foods such as pasta [92], biscuits, and snacks [22]. Furthermore, extracts from the flower and leaves have been integrated into active and smart packaging films [22]. While traditionally consumed in infusions, flower extract has also been used as a food additive [37].

Amaranth seeds can be processed in various ways such as popping, flaking, extruding, and grinding into flour. The resulting flour can be combined with wheat or other flour to make a variety of baked goods [91]. Other interesting proposals include using amaranth as a food supplement [93], a binder for meat burgers, cream soups, and sauces [94], and as an alternative like cow's milk in beverages [94].

Further research is necessary to comprehensively explore the nutritional and functional properties of all parts of the amaranth plant, especially the flower, which remains relatively underexplored. Nonetheless, based on the available information, amaranth offers multiple health benefits and has various potential applications, notably in its leaves and seeds. Despite this, research on the flower has been limited, despite its potential health benefits that may rival those of the leaves.

4. Current scenario of amaranth farmers

The global situation of amaranth producers is diverse. While amaranth's high nutritional value and versatility in cooking are driving an increase in demand and production in some countries, there are also concerns regarding the sustainability of its production and its potential negative impact on the environment and small-scale farmers' livelihoods. The economic and social conditions of amaranth farmers differ based on the size and location of production.

Small-scale farmers operating in areas affected by migration, economic instability, and environmental degradation often belong to the rural poor. A 2008 report presented at the IFOAM Organic World Congress [95] indicated that amaranth was viewed as an alternative crop and livelihood that could provide valuable resources to these farmers in addressing these challenges. Amaranth is adaptable to extreme conditions such as drought and saline soils, making it particularly valuable for small farmers in the central and southern regions of Mexico. Nevertheless, the economic and social status of amaranth farmers varies depending on the region and the scale of production.

Small amaranth farmers face several limitations, one of which is the monopolization practices developed by certain associations. These practices include the transfer of knowledge and technology, seed distribution, and contact with potential national and foreign buyers. To support small-scale livelihoods, the government can take a more proactive role by establishing stricter requirements for cooperatives to ensure that small farmers are included as true partners or co-owners.

It is important to consider the entire value chain when promoting sustainable livelihoods in amaranth. Therefore, national consumer associations, particularly in European markets, can play a vital role by demanding more active and tangible participation of small farmers associated with cooperatives that control the amaranth value chain. This can ensure that small farmers are included as true partners or co-owners and can benefit from the knowledge, technology, and seed distribution practices developed by these cooperatives. By doing so, consumer associations can contribute to the promotion of fair and sustainable trade practices that benefit small-scale amaranth farmers and their communities.

According to a study carried out in Kenya, the production of amaranth faces several economic and environmental challenges. These challenges include droughts, limited awareness about crop utilization, inadequate seed supply, lack of market access, competition with other cereals, insufficient value-added equipment, low and unstable prices, limited knowledge about packaging, inadequate capital, and pest and disease pressure. The study indicated that farmers' knowledge, attitudes, and practices related to amaranth production, value addition, and utilization were relatively low due to insufficient technical support.

Studies have shown that crop diversification through intercropping can lead to yield increases in amaranth production, compared to monoculture. However, despite its benefits, only around half of Kenyan farmers practice intercropping [96]. Intercropping also serves other purposes such as medicinal, commercial, and animal feed purposes. Gender and education levels were found to have a significant positive effect on the adoption of intercropping in amaranth crops, with women being more likely to adopt the practice since they provide most of the agricultural labor for food production. However, women face several challenges in accessing key productive resources such as land, labor, and capital, and are often disadvantaged in terms of education and knowledge. Cultural factors also limit women's access to extension meetings and the transfer of knowledge.

In contrast to the previous study, a study conducted in Kampala found that more men were involved in the cultivation of amaranth than women, suggesting a potential shift in gender roles [97]. While female farmers primarily grew amaranth for personal consumption, male farmers focused on generating income. This study also highlighted the economic, employment, and social benefits of amaranth cultivation. Specifically, improved land use and increased empowerment of women were observed as potential social impacts. Social capital in the form of social groups is another way to empower women in agricultural production, leading to greater gender equality and increased income. It was noted that women have access to social capital, and households can acquire more assets such as land, livestock, and irrigation. Extension programs and services, such as training and mentoring, should consider the triple role that women play in creating equal opportunities.

Amaranth is a more competitive crop compared to others, primarily due to its short growth cycle, which enables farmers to obtain income quickly. The additional income generated is used for subsistence and to improve amaranth production by purchasing better agricultural inputs, resulting in greater capital obtained from the sale of products. The adoption of modern agronomic practices, including domestic agriculture and the use of small spaces, could promote sustainable and better land use. However, the overall observation shows that most households are growing amaranth using rudimentary technology [10]. This is combined with existing agricultural challenges in developing countries, such as limited land access, high labor costs, lack of irrigation facilities, fertilizer scarcity, poor transportation, poor market channels, and lack of financial support exacerbate the situation.

Various recent studies have come to a similar conclusion that amaranth can enhance household livelihoods owing to several benefits, including high productivity and stress tolerance, high nutritional and bioactive content, and significance for both household and industrial purposes. Nonetheless, the cultivation of amaranth grain confronts challenges such as inadequate availability of high-quality seeds, insufficient awareness of effective agronomic practices, and weak farmer organizations resulting in weak connections with political bodies, extension services, and research institutions.

The cultivation of protein crops and support for farmers is encouraged by the European Union (EU). The EU has implemented many initiatives including Protein2Food, the Green Deal, or the Common Agricultural Policy [98]. Protein2Food, for instance, aims to increase the production of selected protein crops such as quinoa, amaranth, buckwheat, lupin, fava beans, chickpeas, and lentils by improving their quality and quantity.

According to the report from MarketsandMarkets, the protein ingredients market offers several opportunities [99], including the following:

- Growing demand for protein ingredients from various end-use industries such as food & beverage, pharmaceutical, and animal feed.

- Increasing consumer interest in plant-based protein ingredients due to concerns over health, sustainability, and animal welfare.

- Rising demand for functional protein ingredients that offer health benefits beyond basic nutrition.

- Growing awareness about the benefits of protein-rich diets among consumers and athletes, driving demand for protein supplements.

- Emerging markets in Asia-Pacific, Latin America, and Africa offer significant growth potential for protein ingredient manufacturers.

- Technological advancements in protein extraction and processing led to improved efficiency and higher-quality products.

- Increasing focus on research and development to create innovative protein ingredients with enhanced functionality and nutritional profiles.

In this sense, the growing demand for plant-based ingredients in natural cosmetics and finished food products is expected to drive the amaranth grain market expansion. This growth is further enhanced by opportunities arising from the popularity of international cuisines, creating marketing opportunities for pulses, and promoting "new" ancient grains such as natural breakfast cereals, pasta, bakery, and healthy snacks [100]. However, research and development into industrial uses of underutilized crops are mainly taking place in developed countries, with the support of their policies, which may not be appropriate for developing countries. Therefore, there is an urgent need for the promotion of appropriate scales of development in line with local conditions in these countries.

Developing a network for stakeholders in grain amaranth is imperative. The goal of this network should be to facilitate knowledge and resource sharing and coordinate actions. One effective approach would be to include ethical biotrade practices [101], which promote good practices for companies and their suppliers in harvesting, collecting, or cultivating biodiverse ingredients in a way that is respectful of the local environment and communities. Moreover, in addition to generating new knowledge and technologies, researchers must also prioritize technology transfer, leveraging new knowledge and technology to enhance processes and empower stakeholders. Recognizing the crucial role of farmers in amaranth production, it is essential to involve them throughout the entire process.

Collaboration among all stakeholders involved in the production, marketing, and sale of amaranth products is crucial to fully realize the potential of this crop. This requires a joint effort from farmers, researchers, extension workers, processors, marketers, and policymakers to promote amaranth cultivation, develop value-added products, and create effective marketing channels to increase the demand and sale of amaranth products. By working together, they can maximize amaranth's economic, social, and health benefits, ultimately improving the livelihoods of those involved in its production and consumption. Moreover, it is important to establish unanimous policies and regulations to raise awareness and generate support for amaranth production and consumption, while aiming to achieve the Sustainable Development Goals.

5. Conclusions

During this review, we discussed the composition and functional properties of the different parts of the amaranth plant, including the seeds, the leaves, and the flowers. While most research has focused on the seeds due to their high nutritional content and versatility, recent studies have shown that the leaves and flowers exhibit even greater antioxidant activity. However, research on the flower has been limited in the past and should receive more attention in upcoming studies. Developing and promoting amaranth species that are both highly nutritious and resilient to environmental stress is essential for achieving sustainable agricultural systems.

To ensure the sustainability of amaranth farming and construct a resilient food system for future societies, it is crucial to consider the economic and social situation of amaranth farmers, which varies depending on the region and scale of production. However, initiatives to support and promote these farmers can positively impact their livelihoods and well-being. Achieving a sustainable food system requires ensuring the availability of high-quality and nutritious food for present and future generations, while also promoting the well-being of farmers and minimizing environmental impacts. This can be accomplished by distributing nutritious and healthy foods using ethical biotrade practices and through balanced and synergistic work among all stakeholders, including political and research entities.

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Conflict of interest

The authors declare no conflict of interest.

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