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Amaranth and quinoa as potential nutraceuticals: A review of anti-nutritional factors, health benefits and their applications in food, medicinal and cosmetic sectors

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ABSTRACT

Amaranth and quinoa are small-seeded grains with high nutritional and phytochemical profiles that promote numerous health benefits and offer protection against various chronic ailments including hypertension, diabetes, cancer, and cardiovascular disorders. They are classified as pseudocereals and possess significant nutritional benefits due to their abundance of proteins, lipids, fiber, vitamins, and minerals. Moreover, they exhibit an exceptional balance of essential amino acids. Despite having several health benefits, these grains have lost their popularity due to their coarse nature and are neglected in developed countries. Research and development activities are growing to explore these underutilized crops, characterizing and valorizing them for food applications. In this context, this review highlights the latest advancements in use of amaranth and quinoa as nutraceutical and functional foods, covering their bioactive substances, anti-nutritional factors, processing techniques, health benefits, and applications. This information will be valuable for planning novel research for efficient use of these neglected grains.

1. Introduction

Globalization of agriculture and consequently its industrialization appears to be unabated, with negative consequences (loss of biodiversity and health risks) perceived all over the world. These implications range from monoculture practices that reduce genetic variation in the agricultural field to biased technological development that uses only a few energy-demanding plant species (Srujana, Kumari, Suneetha, & Prathyusha, 2019). As a result, world food security is now mostly dependent on a small number of crops, including corn, rice, and wheat which are the principal cereals that supply more than half of the world's calorie demand. Even though these crops are a vital component of several diets, they lack important micronutrients. As a result, it is claimed that around 2 billion people have been affected by micronutrient deficiency globally (FAOSTAT, 2020), raising alarms for being heavily dependent on cereal crops. Since the agriculture sector is considered the backbone of a country, relying on a limited number of crops poses a threat to global food security. The agro-industry is currently experiencing enormous challenges to ensure an adequate food supply while also maintaining high productivity and quality standards in a world with a population of 7 billion people. Additionally, with the world population expected to exceed 10.9 billion people by 2050, combating the impending food crisis would be extremely difficult (Bekkering & Tian, 2019; FAOSTAT, 2018). To address this issue, an interdisciplinary strategy is required that not only improves the food basket but also increases access to high-quality food through bio-fortification, nutritional supplements, and enrichment, protecting the availability of nutritious food, a crucial component of food security. The aforementioned facts, which have negative environmental effects (loss of biodiversity, soil degradation as well as erosion) and concerns about the extinction of crop varieties, drive government organizations, institutions, and researchers all over the world to conduct research and circulate information on the cultivation and use of unused, unexplored, and novel plant species, or "alternative crops" (Pirzadah & Malik, 2020). The limited variety of agricultural products raises concerns about the ability of major crops to address food insecurity and alleviate poverty. To encounter such issues, exploiting the underutilized crop species is important to expand the scope of research and development. Due to the qualities of their products, such crops must also be able to reach high-value markets. Despite their nutritional value and historical importance as staple foods in many societies, ancient grain-rich crops that are high in micronutrients and/or phytonutrients are currently being neglected as they are only cultivated in a few niches

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of the global food system. Millions of people around the world depend on thousands of different plant species in supporting their livelihoods, health, and cultural traditions viz., they provide food, medicine, fiber, fuel, and other important resources that humans rely on for survival. From staple crops like rice, wheat, and maize to medicinal plants like quinine and artemisinin, plants have played a significant role in human history and continue to do so today. The majority of these plant species or crops are only significant locally or regionally, and as a result, are known under several common names, including minor, neglected, underutilized, or underexploited crops (Meena, Gora, Singh, Ram, Meena, & Pratibha, 2022). In this regard, it is essential in reviewing the cultivation and usage of underutilized crops that have good nutritional profiles and are regarded as 21st century crops. In addition, these underutilized crops (amaranth and quinoa) have gained international relevance in the nutraceutical sector owing to their high nutritional profile compared to traditional cereals whichhave led to increased research interest in these crops for their potential use in functional foods and nutraceuticals (Bhargava, Shukla, & Ohri, 2019). These crops have been designated as significant crops by United Nations Educational, Scientific and Cultural Organization (UNESCO) because of their diminishing cultivation and exploitation in the wild. These pseudocereals are supplemented with a variety of active components including; amino acids, vitamins, lignans, minerals, antioxidants, flavonoids, polyphenols, unsaturated fatty acids, dietary fibre, and other essential constituents such as fagopyritols (Pirzadah & Malik, 2020). Pseudocereals and underutilized grains provide around twice as much mineral content as other cereals, which has the potential to significantly reduce hidden hunger issues (Rodriguez, Rahman, Thushar, & Singh, 2020).

Amaranth (*Amaranthus spp.*) belongs to the family *Amaranthaceae*, while quinoa (*Chenopodium quinoa*) belongs to the family *Chenopodiaceae* are categorized as pseudocereals and do not belong to the Poaceae family despite having seeds that resemble cereal grains (Bekkering & Tian, 2019). When compared to staple cereals, underutilized grains have a different anatomy as they tend to have more embryos (which accumulate proteins and lipids) and less endosperm (which accumulates starch). It is important to emphasize that although a larger calorie content may be considered a disadvantage in food systems of developed countries where calorie inadequacies are a common problem, it can actually be a benefit in developing regions of the world where undernutrition and food insecurity are major challenges. Moreover, it is preferable that these underutilized grains have a higher protein content and a more well-balanced amino acid composition (Abugoch James, 2009). For instance, grains like quinoa and amaranth are rich in essential amino acids and showed a near-optimal protein composition that is similar to those found in cow's milk (Bekkering & Tian, 2019). Furthermore, these underutilized grains are also safe for celiac disease patients to consume due to the lack of gluten content. Despite being very nutritious, these grains have limited bioavailability due to the presence of anti-nutritional ingredients like phytic acid and saponins that bind with nutrients and render them unavailable to our body (Repo-Carrasco, Espinoza, & Jacobsen, 2003).

In this context, the current review focuses on bioactive composition, anti-nutritional factors, toxicity issues, processing treatments, health benefits, food, medicinal and cosmetic applications related to the consumption of amaranth and quinoa.

2. Overview of amaranth and quinoa

2.1. Amaranth

The genus *Amaranthus* in the *Amaranthaceae* family contains various cultivated species, including amaranth, that are primarily utilized as green vegetables and grains. The word "amaranth" refers to the group of about 60 species in this genus. Since ancient times, three species of amaranth have been grown entirely for grains: *A. cruentus* (red amaranth), *A. caudatus* (love-lies-bleeding), and *A. hypochondriacus* (Prince-of-Wales feather) (Cheng, 2018). Due to its multiple agronomic and nutritional benefits, amaranth—an underutilized crop has recently grown its popularity. Since it is known to be a drought-resistant crop, it may thrive in a variety of climatic and environmental conditions (Aderibigbe et al., 2022). Compared to other staple cereals like maize, wheat, and sorghum, amaranth has a higher protein level (14.0–15.5%), a lower fat content (7.5%), a higher carbohydrate content (60–68%), and less ash content (2.5–3.1%) (Table 1) (Grobelnik, Turinek, Jakop, Bavec, & Bavec, 2009). Most cereal grains generally lack the essential amino acid lysine and are rich in valine, leucine, and isoleucine while amaranth is high in lysine (5.2–6.1 g/100 g protein) and therefore has a well-balanced amino acid composition and meets the needs of the human diet for the majority of the essential amino acids namely, alanine, valine, leucine, arginine, phenylalanine, methionine, tryptophan, isoleucine, and serine which suggests that amaranth is a pseudo cereal which can be used as a substitute to nutrient cereal (Rastogi & Shukla, 2013). Amaranth protein contains a comparatively high amount of sulfur-containing amino acids, which are typically scarce in pulse crops (Grobelnik et al., 2009). It has been noted that the protein content

Table 1
Nutritional components of amaranth and quinoa.

Pseudocereals	Components	Values	References
	Proximate composition	(%)	
Amaranth	Protein	17.4–33.5	Akubugwo, Obasi, Chinyere, and Ugbogu (2007)
		13.1–21.0	Mlakar, Turinek, Jakop, Bavec, and Bavec (2009)
		12.5–17.6	Mburu, Gikonyo, Kenji, and Mwasaru (2012)
		15.2	Thakur et al. (2021)
	Fat	5.6–10	Mlakar et al. (2009)
		1.9–9.7	Berger et al. (2003)
		10.6	Akubugwo et al. (2007)
		8.0	Thakur et al. (2021)
	Ash	2.5–4	Mlakar et al. (2009)
		3.2	Thakur et al. (2021)
	Fiber	3.1–5.0	Mlakar et al. (2009)
		6.6	Njoki, Sila, and Onyango (2014)
	Carbohydrates	48–69	Mlakar et al. (2009)
		67.3	Thakur et al. (2021)
	Minerals	(mg/kg)	
	Magnesium	2300 to 3360	Thakur et al. (2021)
	Calcium	1300–2850	
	Sodium	160–480	
	Iron	72–174	
	Zinc	36.2–40	
Quinoa	*Proximate composition*	(%)	
	Protein	10–18	Bertazzo, Comai, Brunato, Zancato, and Costa (2011)
		16.7	Wright et al., (2002)
		13.3	Thakur et al. (2021)
	Fat	4.5–8.8	Bertazzo et al. (2011)
		6.3	Thakur et al. (2021)
		5.5	Wright et al. (2002)
	Ash	2.4–3.7	Bertazzo et al. (2011)
		3.8	Thakur et al. (2021)
		3.2	Wright et al. (2002)
	Fiber	2.1–4.9	Bertazzo et al. (2011)
		10.5	Wright et al. (2002)
		3.8	Thakur et al. (2021)
	Carbohydrates	54.1–64.2	Bertazzo et al. (2011)
		74.7	Wright et al. (2002)
		69	Thakur et al. (2021)
	Minerals	(mg/kg)	
	Magnesium	260–5020	Vega-Galvez et al. (2010)
	Calcium	275–1487	
	Potassium	6967–12000	
	Iron	14–168	
	Zinc	27–48	

of amaranth grain is relatively close to the guidelines recommended by the Food and Agriculture Organization/World Health Organization (FAO/WHO) because of its balanced amino acid profile. The FAO/WHO recommends a daily intake of 0.75 g of protein per kilogram of body weight for adults (Murya & Pratibha, 2018). The FAO listed amaranth as one of the most future promising crops for feeding the world's population. Among green leafy vegetables and cereals, *amaranthus* species are recognized as a storehouse for essential vitamins like vitamin B_6, C, folate, as well as carotene which is a precursor to vitamin A (Mekonnen, Woldesenbet, Teshale, & Biru, 2018). Amaranth contains remarkably higher levels of magnesium, calcium, sodium, zinc and iron than quinoa (Krkoskova & Mrazova, 2005). Amaranth is a gluten-free pseudo-cereal that might be included in gluten-free recipe formulations, thus providing a different food composition for celiac patients other than wheat and gluten-rich cereals (Shyam & Raghuvanshi, 2015).

2.2. Quinoa

Quinoa (*Chenopodium quinoa* Willd.) plant comes from the family of *Chenopodiaceae*. It is indigenous to the Andes, where it was successfully cultivated for human consumption between 3,000 and 4,000 years ago in Ecuador, Bolivia, Colombia, and Peru (Bhargava et al., 2019). *Chenopodium* species were cultivated and domesticated in North America as members of the Eastern Agricultural Complex before maize cultivation became popular (Mueller, White, & Szilagyi, 2019). Quinoa seeds are an excellent raw material for producing nutritious and healthy foods. They are considered easy to digest because they lack gluten and are an exceptionally complete food because they contain a well-balanced combination of essential amino acids for humans (methionine and lysine) and are a rich source of phosphorus, magnesium, iron, fibre, and proteins (Abugoch James, 2009; Tang & Tsao, 2017; Vega-Galvez et al., 2010). The protein content in quinoa varies between (13.8%–16.5%), carbohydrates (52%–69%), fats (2.05%), and ash content (3.4%) (Table 1) (Villacres, Quelal, Galarza, Iza, & Silva, 2022). The Andean people considered quinoa to be a gift from their gods and have consumed it as a sacred plant because of its high protein content and excellent balance of necessary amino acids (Filho et al., 2017). A large variety of antioxidant components, like vitamin C, carotenoids, and flavonoids are abundant in entire seeds (Vega-Galvez et al., 2010). Quinoa has a higher amount of calcium and iron compared to other commonly used grains. It contains about 0.26% magnesium, which is higher than wheat (0.16%) and corn (0.14%). The forms of calcium, magnesium, and potassium found in quinoa are considered biologically appropriate and the amounts present in the seeds are enough for a balanced diet (Repo-Carrasco et al., 2003; Vega-Galvez et al., 2010). The opportunity to substitute common cereal grains like wheat, rice, and corn with a pseudo-cereal of superior nutritional value like quinoa, is intrinsically advantageous to the interests of the general public (Ramos et al., 2021). Quinoa is a highly nutritious food that is rich in carotenoids, vitamins, and tocopherol, which are known to boost its antioxidant capacity and contribute to various essential physiological processes such as maintaining healthy bones and teeth, supporting the immune system, and aiding in energy production (Tang & Tsao, 2017). Quinoa is among the crops that have been evaluated as potential candidates for NASA's Controlled Ecological Life Support System (CELSS). The CELSS system utilizes plants like quinoa to extract carbon dioxide from the atmosphere and produces essential resources such as food, oxygen, and water for the crew during long-duration space missions. This is because quinoa is highly nutritious and can be grown in a variety of environmental conditions (Tang & Tsao, 2017).

3. Anti-nutritional factors

Plant-based foods are an excellent source of nutrients, but they also contain certain compounds derived from secondary plant metabolism that are commonly referred to as "anti-nutritional factors." These components are found in a variety of plant foods and can reduce the nutritional value of these foods by impeding the digestion, absorption, or utilization of nutrients and if consumed in large amounts, have a negative impact on health. Thus, it is important to conduct research on the antinutritional factors present in both conventional and unconventional plant foods to identify the specific compounds that can reduce their nutritional value (Filho et al., 2017). It has been established that cereal grains contain various anti-nutrients such as tannins, phytates, lectins, alkaloids, and protease inhibitors (Ram, Narwal, Gupta, Pandey, & Singh, 2020). On the other hand, amaranth has also been found to contain certain anti-nutrients, including tannins, saponins, phytate, oxalates, nitrates, and protease inhibitors (Aderibigbe et al., 2022). Small amounts of saponins are present in amaranth grains which vary from 0.9 to 4.91 mg/kg while phytic acid content ranges between 2.9 and 7.9 g/kg (Table 2) (Thakur, Kumar, & Dhaliwal, 2021). Comparing amaranth to other common cereals such as wheat and maize, only trace amounts of protease inhibitors (trypsin and chymotrypsin) are present, while nitrates are concentrated in the leaves rather than the grains which makes it a safer option for consumption (Rastogi & Shukla, 2013). These anti-nutritional substances have protective effects on plants, phytic acid, for example, acts as a way for plants to store phosphorous, however, they prevent nutrient absorption in humans (Aderibigbe et al., 2022). Phytate is indigestible for humans and is therefore not consumed as a source of phosphate or inositol, instead, it binds to proteins to form complexes which reduces its availability. Phytate and oxalate have been reported to not only interfere with mineral absorption but also impair the digestion of starch. Saponins can form complexes with minerals such as zinc and iron, while oxalate can bind to calcium, leading to a reduction in calcium absorption (Cuadrado, Takacs, Szabo, & Pedrosa, 2019).

Moreover, the anti-nutritional elements observed in quinoa seeds include saponins, tannins, phytic acid, oxalates, nitrates, and trypsin inhibitors. These chemicals are present in greater proportions in the outer layers of the grain (Filho et al., 2017). Quinoa seeds comprise only 6.27–692.49 mg/kg of saponin while phytic acid content ranges from 10.5 to 13.5 g/kg (Table 2) (Thakur et al., 2021). However, insufficient research has been done on the potential anti-nutrients in quinoa, and little is documented about its anti-nutritional effects that could impair its nutritional quality making it difficult to effectively incorporate it into the human diet (Petroski & Minich, 2020). Despite the existence of anti-nutritional components in the amaranth and quinoa grains, these components can be eliminated or decreased to levels that are safe for health when suitable methods are applied for food processing in industries or at home (Thakur et al., 2021).

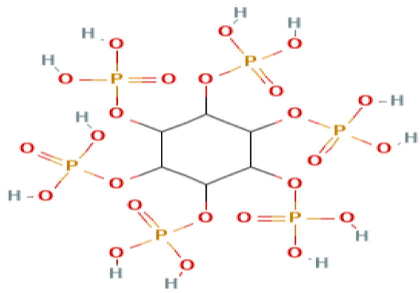
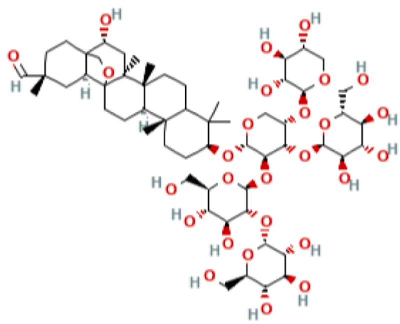
4. Toxicity issues

A single case of *A. paniculatus*-related systematic allergy has been recorded. A patient aged 19 developed symptoms of wheezing and vomiting after eating a chapatti made from gluten-free flour. It was the first recorded anaphylactic reaction to amaranth in the United States since he had a significant skin test-positive reaction and had previously developed a sensitivity to pigweed (Vaswani, Garg, Khim, Huang, & Vaswani, 2018).

In a different research, it was discovered that 5 min after eating a quinoa salad, a 29-year-old lady from the USA developed a rash on her arms and chest, itching on the palms and soles of her feet, urticaria, and angioedema in her lips. A skin prick test was used to identify the food allergy, and it gave favorable reports for quinoa. This was the country's first case report on quinoa allergy (Liu et al., 2018). Additionally, another instance involving a patient from France, 52 years old, who was identified as having a quinoa allergy was also recorded (Cox, Eigenmann, & Sicherer, 2021).

Overall, while amaranth and quinoa are generally considered safe for consumption and are not common allergens, rare cases of allergy have been reported. However, further research is needed to better understand

Table 2
Antinutritional components of amaranth and quinoa.

Anti-nutritional components	Structure	Pseudocereals	References
Phytic acid		2.9–7.9 g/kg in amaranth seeds 10.5–13.5 g/kg in quinoa seeds	Thakur et al. (2021)
Saponins		0.9–4.9 mg/kg in amaranth seeds 6.3–692.5 mg/kg in quinoa seed	Thakur et al. (2021)

the prevalence and mechanisms of amaranth and quinoa allergy.

5. Processing techniques and nutritional changes

Amaranth and quinoa are processed using various processing techniques including germination, extrusion, fermentation, and cooking to enhance their organoleptic and nutritional attributes. Table 3 shows the influence of various processing techniques on the nutritional and bioactive components of amaranth and quinoa. Following are the processing techniques used for increasing the nutritional quality of quinoa and amaranth.

5.1. Germination

Germination of quinoa seeds resulted in an increase in fiber and protein content, as well as higher levels of iron, zinc, and calcium. Additionally, germination led to a significant increase in phytase activity, which is an enzyme that breaks down phytic acid. As a result, the phytic acid content in the seeds decreased by 32% to 74% during the germination process. (Maldonado-Alvarado, Pavon-Vargas, Abarca-Robles, Valencia-Chamorro, & Haros, 2023). Liu et al. (2022) explored the impact of the germination period on the levels of antioxidants like ascorbic acid, phenolic components, tocopherol isomers, and antioxidant capacity in the seeds of quinoa. Compared to raw seeds, the total content of ascorbic acid and tocopherol enhanced after 72 h of germination. During the germination period, total phenolic compounds and antioxidant capacity increased significantly. Yadav et al. (2018) assessed the antioxidant capacity {ferric-reducing antioxidant power (FRAP) and 1,1-diphenyl-2-picrylhydrazyl (DPPH)}, vitamin C, polyphenolic compounds, and flavonoid contents of raw seeds and industrially processed seeds during the period of soaking and germination and concluded that raw seeds had a higher concentration of bioactive compounds such as antioxidant capacity, flavonoid content and total phenolic contents than industrially processed seeds. Similarly, there was a significant increase in crude protein, crude fiber, phenolic content, and antioxidant activity (7.01, 74.67, 126.62, and 87.47%) but a significant reduction of 32.30% and 29.57% in tannin and phytic acid contents in amaranth seeds during the germination process, respectively (Priyanka et al., 2021).

5.2. Fermentation

Fermentation is another traditional processing method used to improve nutritional quality in grains and seeds. Liu et al. (2022) explored the influence of fermentation on the levels of ascorbic acid, tocopherol isomers, phenolic components, and antioxidant capacity in the grains of quinoa. It was found that both the tocopherol and ascorbic acid contents were significantly reduced while phenolic compounds and antioxidant capacity increased significantly due to fermentation. As a result, fermentation turned out to be the most preferred method for improving the bioactive potential of quinoa. Likewise, Castro-Alba et al. (2019) demonstrated that lactic acid bacteria (LAB) are commonly used as starter cultures in food fermentation, and *Lactobacillus plantarum* has been found to be particularly effective in reducing anti-nutrients during the fermentation of quinoa flour. Aderibigbe et al. (2022) investigated the fermentation effect on the nutritional constituents of Ethiopian *Amaranthus caudatus* seed cultivars. The chemical characteristics of three cultivars were evaluated before and after the treatment of fermentation. Fermentation was found to increase the contents of fat, ash, and protein contents by 22, 14, and 3%, respectively. Similarly, Castro-Alba et al. (2019) observed that phytate content in amaranth is degraded during fermentation.

5.3. Extrusion

Extrusion cooking is a widely used food processing technique that involves subjecting food to high-temperature short-time treatment. This process can alter the molecular structure of starch and promote its interaction with other macromolecules by simultaneous application of high temperature and pressure (Jabeen et al., 2020). Abbasi, Moslehishad, and Salami (2022) conducted a study on amaranth hydrolysates and found that a longer hydrolysis period resulted in smaller-sized hydrolysates, indicating that hydrolysis time plays a crucial role in shaping the amaranth peptide profile. The extrusion process had a more

Table 3
Effect of different processing techniques on nutritional and bioactive components of amaranth and quinoa.

Processing techniques	Effects	References
Germination	Polyphenols and antioxidant activity get increased in amaranth seeds.	Alvarez-Jubete, Wijngaard, Arendt, and Gallagher (2010)
	There was a 78% increase in the antioxidant activity of quinoa as evaluated with FRAP assay and a 3% decrease with DPPH assay	Thakur et al. (2021)
	Significant reductions of 32.30% and 29.57% in tannin and phytic acid contents were observed in amaranth grains.	Thakur et al. (2021)
Fermentation	The chemical composition of fat, protein, and ash content increased by 3, 22, and 14% respectively in amaranth grains.	Amare, Mouquet-Rivier, Rochette, Adish, and Haki (2016)
	The antioxidant capacity of fermented quinoa seeds was greater than in raw seeds as measured by DPPH and ORAC.	Rocchetti, Miragoli, Zacconi, Lucini, and Rebecchi (2019)
	Lactic acid bacterial isolate −2 was found to be more efficient in reduction of phytic acid (from 11.06 to 1.00 mg/g) and tannins (from 4.92 to 2.05 mg/g of GAE). A significant reduction of saponin (from 11.2 to 0.13 mg/g) was recorded by lactic acid bacterial isolate −1 and Lactobacillus delbrueckii.	Sruthy, Suvarna, Puranik, and Vikram (2021)
Extrusion	Decrease in the content of total free phenolics in the extrudates of amaranth varieties was observed.	Repo-Carrasco et al., (2009)
	Extrusion had an impact on the release of bound phenolics from quinoa was also reported.	Song, Shao, Chen, and Li (2020)
Cooking and roasing	Significant increase in bioavailability of iron, calcium, and zinc after cooking (roasting and boiling), quinoa and amaranth seeds.	Repo-Carrasco-Valencia et al. (2010)
	An increase in TPC and ORAC radical scavenging was observed in quinoa seeds after the different cooking processes (i.e., boiling or toasting).	Rocchetti et al. (2019)
	Significant reduction in the anti-nutrient content (tannins, oxalates, and phytates) was observed in the case of cooking of amaranth grains as compared to roasting.	Njoki et al. (2014)

significant impact on the peptide profile, leading to the production of more biologically active peptides. Additionally, it has been found that raw and extruded amaranth flours are good sources of biologically active compounds specifically ACE (angiotensin-converting enzyme) inhibitor peptides which are linked to the protection of severe chronic disorders. Furthermore, Srujana et al. (2019) investigated that in the quinoa extrudates, higher extrusion temperatures reduce the amount of unsaturated fatty acids while increasing protein digestibility by inactivating antinutrients like lectin and antitrypsin inhibitors. Inactivation of these antinutrients may further enhance the nutritional quality of quinoa extrudates.

5.4. Cooking and roasting

Repo-Carrasco-Valencia, Encina, Binaghi, Greco, and Ronayne de Ferrer (2010) conducted research on the effects of boiling and roasting on quinoa and amaranth seeds. The results showed a significant increase in the bioavailability of essential minerals such as zinc, iron, and calcium after these processing treatments. Additionally, bioactive compounds including phenols, dietary fiber, and minerals (such as calcium, zinc, and iron) were found to increase when compared to untreated cereals. Dialyzability studies were conducted to estimate the potential bioavailability of nutrients. The findings revealed that boiling of grains increased the dialyzability of zinc, iron, and calcium. However, roasting had no significant effect on the mineral contents.

6. Bioactive composition

Amaranth and quinoa are potential sources of various bioactive compounds. Table 4 lists the main bioactive compounds found in amaranth and quinoa grains.

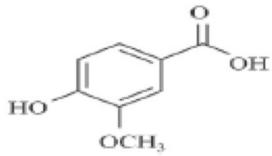
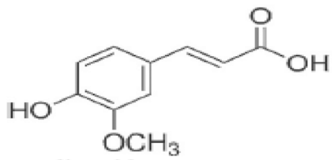
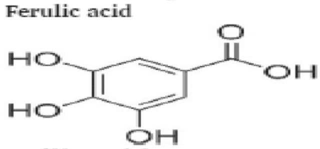
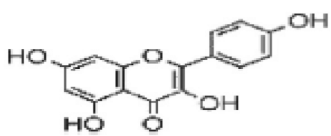
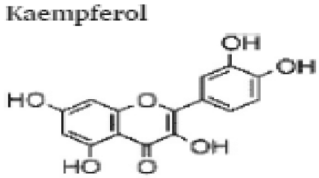
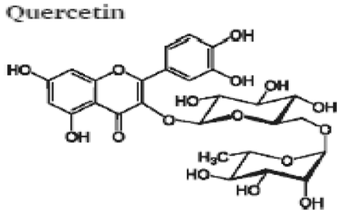
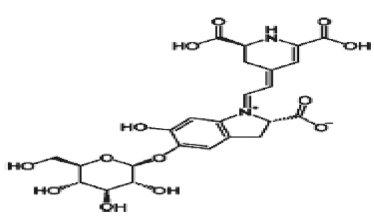
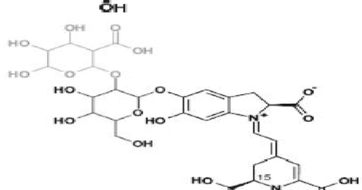
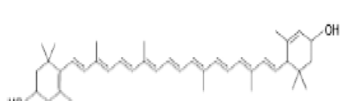
6.1. Phenolic acids

Amaranth and quinoa comprise bioactive phytochemicals in their outer layers functioning as a chemical defense against insects and microorganisms (Tang & Tsao, 2017). These components can be lipophilic or hydrophilic in nature. The seeds of amaranth and quinoa contain phenolic compounds, particularly phenolic acids, which are mainly located in the seed coat. Phenolic compounds are a class of relatively hydrophilic plant secondary metabolites that comprise phenolic acids, flavonoids, and tannins. These compounds are responsible for a wide range of physiological effects on the plant (Adetunji et al., 2021). Recent investigations have been conducted in quinoa on the identification of 23 phenolic components (vanillic acid, ferulic acid, and their derivatives) and flavonoids (kaempferol, quercetin, and their glycosides). Quinoa comprises phenolic substances like ferulic acid-4-glucoside in the proportion of 132–161 mg/kg of quinoa seeds, whereas vanillic and ferulic acids were found in conjugated forms (Tang et al., 2015; Tang et al., 2016). Amaranth is also a nutritionally essential pseudocereal and its sprouts and seeds have been shown to contain a variety of bioactive substances, including p-hydroxybenzoic acid, rutin, vanillic and gallic acids (Tang & Tsao, 2017). Phenolic acids like vanillic, 4-hydroxybenzoic, 4-syringic, and caffeoylisocitric acids (Vollmer et al., 2017), and flavonoids such as rutin, isoquercitrin, and nicotiflorine (Thakur et al., 2021) were present in amaranth varieties like '*Tulyehualco*', '*Nutrisol*', '*DGETA*', and '*Gabriela*'.

6.2. Betalains

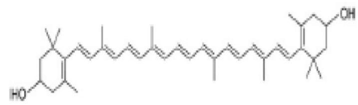
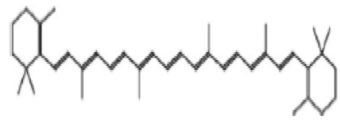
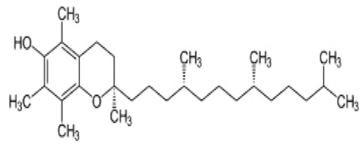
Pseudocereals are rich in betalains, the nitrogen-containing pigments. These are generated from tyrosine and they are later changed to L-3, 4-dihydroxyphenylalanine (L-DOPA). These can be divided into two subdivisions i.e. red-violet-colored betacyanins and yellow-orange-colored betaxanthins (Esatbeyoglu, Wagner, Schini-Kerth, & Rimbach, 2015). Betalains can be employed as a natural food coloring agent as well as effective scavengers to prevent DNA damage and oxidation of low-density lipoproteins (LDL) (Leong, Show, Lim, Ooi, & Ling, 2018). Amaranthine and isoamaranthine are two betacyanins found in amaranth while betacyanins such as betanin and isobetanin were the pigments found in red and black quinoa seeds (Tang & Tsao, 2017). Quinoa also contains betanins in the range of 1.5–61 mg per kg of grain and in amaranth seeds (19 mg/kg) as per estimations based on UV/Vis absorbance data (Cai, Sun, & Corke, 2003; Repo-Carrasco-Valencia et al., 2010).

Table 4
Bioactive components present in amaranth and quinoa.

Bioactive components	Sub-type	Source	Structure	Biological properties	References
Phenolic acids	Vanillic acid	Quinoa, Amaranth		Anti-cancer, anti-obesity, anti-diabetic, anti-bacterial, anti-inflammatory, and antioxidant properties	Kaur et al. (2022)
	Ferulic acid	Quinoa	 Ferulic acid	Antioxidant, anti-diabetic, hepato-protective, anti-atherosclerotic, neuro-protective, anti-neoplastic, and anti-bacterial properties.	Dędek, Rosicka-Kaczmarek, Nebesny, and Kowalska (2019)
	Gallic acid	Amaranth	 Gallic acid	Anti-inflammatory, anti-oxidative, anti-tumor, anti-bacterial, anti-diabetes, anti-obesity, anti-microbial, and anti-myocardial ischemia properties.	Bai et al. (2021)
Flavonoids	Kaempferol	Quinoa	 Kaempferol	Antioxidant, anti-inflammatory, antimicrobial, cardiovascular, and neuroprotective properties.	Singh, Kumari, and Ahmed (2022)
	Quercetin	Amaranth	 Quercetin	Antioxidant, antifungal, anti-carcinogenic, anti-inflammatory, hepatoprotective, and cytotoxic activity.	Bertazzo et al. (2011)
	Rutin	Amaranth		Anticancer, antioxidant, anti-diabetic, anti-inflammatory, antibacterial, antifungal, neuroprotective, cardioprotective, hepatoprotective, nephroprotective, and haematoprotective properties.	Prasad and Prasad (2019)
Betaline	Betanin	Quinoa		Antioxidant, antimicrobial, anticancer, anti-lipidemic, hepatoprotective, neuroprotective, antidiabetic, cardioprotective, and anti-inflammatory properties.	Sadowska-Bartosz and Bartosz (2021)
	Amaranthine	Amaranth		Antioxidant, antimicrobial, and cytotoxic properties	Roriz et al. (2021)
Carotenoids	Lutein	Quinoa, amaranth		Antioxidant, anti-diabetic, anti-inflammatory and anti-cancer properties.	Srividya and Vishnuvarthan (2014)

(continued on next page)

Table 4 (*continued*)

Bioactive components	Sub-type	Source	Structure	Biological properties	References
	Zeaxanthin	Quinoa, amaranth		Antioxidant, antiparasitic, anthelmintic activity, antiosteoporosis, anti-inflammatory, and anticancer properties.	Bouyahya et al. (2022)
	beta-carotene	Quinoa		Antioxidant, immune-regulator, anti-inflammatory, anti-apoptotic, and cardioprotective properties.	Anand, Mohan, and Bharadvaja (2022).
Tocopherols	α, β, γ, and δ tocopherols	Quinoa, amaranth		Antioxidant, cardioprotective, anticancer, antidiabetic, and antiobesity properties.	Shahidi and de Camargo (2016)

6.3. *Tocopherols*

Tocopherols are homologs of vitamin E. Four tocopherol isoforms including α, β, γ, and δ have been discovered in amaranth and quinoa (Alvarez-Jubete, Arendt, & Gallagher, 2009). The most abundant tocopherol in quinoa seeds is γ-tocopherol which ranges in concentration from 47 to 53 mg/kg dry weight (DW) followed by α-tocopherol which ranges from 17 to 26 mg/kg DW and β as well as δ tocopherols found in trace amounts i.e. less than 5 mg/kg DW (Bruni, Guerrini, Scalia, Romagnoli, & Sacchetti, 2002; Tang et al., 2015). Other investigations recorded that in amaranth seeds, the most prevalent tocopherols are α-tocopherol which ranges from 1.40 to 31.6 mg/kg, β-tocopherol varies from 0.53 to 43.86 mg/kg, γ-tocopherol varies from 0.06 to 8.69 mg/kg, and δ-tocopherol varies from 0.01 to 48.79 mg/kg (Lee, Bi, & Henry, 2022). Vitamin E analogs possess potent antioxidant properties and play important physiological roles such as controlling blood clotting, regulating metabolic processes, reducing inflammation, and combating cancer in humans (Joana Gil-Chavez et al., 2013).

6.4. *Carotenoids*

Carotenoids are important compounds found in many fruits and vegetables that act as antioxidants and can potentially be converted into vitamin A by the body. They have a range of benefits, including enhancing the activity of certain enzymes, improving communication between cells, regulating gene expression, supporting the immune system, and aiding in plant photosynthesis as a photosensitizer (Tang & Tsao, 2017). Lutein, which ranges from 3.96 to 12.01 mg/kg, zeaxanthin, which ranges from 0.31 to 5.37 mg/kg, and beta-carotene varies from 0.26 to 1.07 mg/kg are the other carotenoids found in quinoa seeds (Tang et al., 2016). Amaranth seeds contain a lower amount of zeaxanthin and lutein i.e. 0.14–0.30 and 3.55–4.44 mg/kg, respectively (Estivi, Pellegrino, Hogenboom, Brandolini, & Hidalgo, 2022).

6.5. *Proanthocyanidins*

Proanthocyanidins (PAs) also known as condensed tannins are a significant class of oligomeric flavonoids that are abundant in cereal and pseudocereal grains, including amaranth and quinoa. PAs have been found to have antioxidant, anti-inflammatory, anti-diabetic, and anticancerous properties and have been linked to a decrease in the prevalence of various chronic diseases. These may be employed to develop foods with functional properties that enhance human health (Zhu, 2019). Mudgil, Omar, Kamal, Kilari, and Maqsood (2019) conducted a study to investigate the potential bioactive properties of hydrolysates derived from protein isolates of quinoa and amaranth. They used enzymes such as chymotrypsin, bromelain, and protease to hydrolyze the proteins at various time intervals and examined their antibacterial, antioxidant, and anti-hemolytic properties. They concluded that these hydrolysates could serve as an excellent source of bioactive peptides.

7. Potential health benefits

7.1. *Anti-diabetic activities*

The metabolic disorder known as diabetes mellitus (DM), which is characterized by a persistent increase in blood glucose levels, affects millions of people globally. DM affects a number of physiological processes, including enhancing peripheral tissues' consumption of glucose and reducing hepatic glucose production and adipocyte fat storage (Shahwan, Alhumaydhi, Ashraf, Hasan, & Shamsi, 2022). According to the Centers for Disease Control and Prevention's study, DM is becoming increasingly widespread with 8.3% of Americans having diabetes, and an estimated 35% having pre-diabetes (Association, 2016). The anti-hypertensive and anti-hyperglycemic characteristics of amaranth and quinoa have been assessed for their capacity to lower the incidence of type II diabetes by using in vitro enzyme assays (Tang & Tsao, 2017), thus suggested that amaranth and quinoa can be used as natural remedies or dietary supplements for individuals at risk of developing type II diabetes. α-Glucosidase and pancreatic lipase are important enzymes for the digestion of complex carbohydrates and the absorption of triglyceride lipids, respectively. Food bioactive that inhibit these two enzymes raises the possibility of beneficial effects on blood sugar, thus, ultimately type 2 diabetes. The phenolic components of quinoa strongly inhibited the activities of α-glucosidase and pancreatic lipase (Chen, He, Sun, & Wang, 2022). Amaranth seeds have a limited preventive effect against diabetes caused by fructose. Amaranth seeds are helpful for treating hyperglycemia and reducing diabetes complications because the amaranth grain and its oil component have been found to be effectively lowered serum glucose and raised serum insulin levels in diabetic rats (Tang & Tsao, 2017).

7.2. *Antioxidant activities*

Numerous nutrients that are not required for life such as phenolics and carotenoids offer a variety of health-promoting qualities such as anti-inflammatory, anti-viral, and antioxidant qualities (Samtiya, Aluko, Dhewa, & Moreno-Rojas, 2021). Antioxidants are abundant in the seeds of quinoa and amaranth. The lipophilic and hydrophilic constituents of quinoa seed significantly inhibited glutathione, tyrosinase, MMP (matrix metalloproteinases), and catalase capacities and intracellular ROS generation in cultured cells and were believed to help in preventing the oxidation-related process of skin aging (Pasko et al., 2010). Quinoa seeds incorporated into the diet decreased oxidative stress in the heart, liver, lungs, plasma, kidney, spleen, testis, and pancreas of rats given with fructose and suppressed plasma lipid peroxidation as evidenced by a marked decline in the plasma malondialdehyde (MDA) content. Some antioxidant enzymes such as CAT (catalase), SOD (superoxide dismutase), and GPx (glutathione peroxidase) were able to maintain their regular activity when quinoa seeds were also administered (Tang & Tsao, 2017). They also demonstrated that rats treated with quinoa extracts had higher SOD and GPx activity in their livers, as well as higher levels of 12-hydroxy-eicosatetraenoic acid (12-HETE) in their lungs. Another signaling molecule that counteracts oxidative stress is nitric oxide (NO), which is crucial for healing ROS-related damage. In cell models, amaranth seed extracts demonstrated potent antioxidant action, especially against the superoxide radical, and they prevented RAW 264.7 macrophages that had been activated by lipopolysaccharides from producing NO. Some components, such as betanins and quercetin were recognized anti-inflammatory and antioxidants agents, and the composition of the extracts was recorded; nevertheless, the study could not demonstrate a link between these substances and the antioxidant effects (Sharma, Usmani, Gupta, & Bhat, 2021).

7.3. Anti-inflammatory activities

Polyphenols isolated from quinoa has been shown to reduce IL-1 (interleukin-1), IL-8 (interleukin-8), and TNF (tumor necrosis factor) cytokines in cultured colonic epithelial Caco-2 cells, inhibit obesity-induced inflammation and support gastrointestinal health in mice (Shahbaz et al., 2022). Additionally, it has been demonstrated that the saponins in quinoa seeds block the overproduction of NO , TNF-α (tumor necrosis factor-alpha), and IL-6 (interleukin-6) which are involved in the inflammatory response, suggesting that quinoa saponins may be a useful dietary component for the treatment and prevention of inflammation (Tang & Tsao, 2017). It was discovered that the hydromethanolic extract of amaranth seeds decreased NO generation in mouse macrophage-like cell line RAW264.7 and increased NO_3^- and NO_2^- contents in the mouse body after a single oral administration of amaranth extract for eight hours (Liberal et al., 2016). People who engage in strenuous physical activity or sports may show decreases in NO levels as well as increases in NO_3^- and NO_2^- levels. The significantly decreased levels of the pro-inflammatory cytokine IL-6 in RAW 264.7 macrophages and suppression of NFkB (Nuclear factor kappa B) translocation to the cell nucleus showed the anti-inflammatory characteristics of edible amaranth seed sprouts, which comprise selenium and betacyanins (Tyszka-Czochara et al., 2015). This showed that amaranth and quinoa grains have anti-inflammatory and NO-regulating effects.

7.4. Cardiovascular diseases

Diet is one of the key risk factors for cardiovascular disorders (CVDs) which is the leading cause of mortality and disability worldwide (Roth et al., 2020). The risk factors for CVDs include LDL cholesterol (LDL-c), total cholesterol, and triglyceride concentrations. In students aged 22 to 45, the impact of dietary quinoa on markers for CVD risk was assessed 30 days after ingestion. Blood pressure and body weight were observed to be lowered in 42.2 and 40.7% of the people, respectively (Tang & Tsao, 2017). When hypercholesterolemic rabbits were fed an extruded amaranth diet and a diet containing amaranth oil, their levels of LDL-c, triglycerides, total cholesterol, and very low-density lipoprotein cholesterol (VLDL-C) were shown to be lowered by around 50% compared to rabbits on the control diet (Madadi et al., 2020). They were divided into two groups: extremely low resistance group 1 included those with significantly low heart rate variability (HRV) (Total Power (TP) 400 ms^2), and low resistance group 2 included those with somewhat higher HRV (TP > 400 ms^2). Group 3 consisted of regional and national competitors with TPs between 3500 and 7000 ms^2 (Yelisyeyeva et al., 2012). Significant reductions in LDL, triglycerides, total cholesterol, and VLDL cholesterols were seen in human subjects who consumed 18 mL of amaranth oil per day for 3 weeks. Total blood cholesterol above 200 mg/dl, high-density lipoprotein (HDL) cholesterol below 35 mg/dl, and LDL above 130 mg/dL are indicators of problematic cholesterol (Martirosyan, Miroshnichenko, Kulakova, Pogojeva, & Zoloedov, 2007). High-quality polyunsaturated fatty acids, lutein, and tocopherols can be found in both quinoa and amaranth seeds (Tang & Tsao, 2017), however more studies are required to confirm their effects on potential CVD prevention in humans. According to De Carvalho et al. (2014), postmenopausal women who consumed 25 g of quinoa flakes daily had lower levels of LDL-c and total cholesterol and higher levels of GSH.

8. Recent advances in application of amaranth and quinoa

8.1. Applications in foods

Amaranth and quinoa grains have been claimed as "super" grain-producing plants that have a tremendous prospect and huge economic viability for product development, especially in the baking area of food sectors. Unlike wheat, amaranth and quinoa are gluten-free, thus, making them ideal replacement raw materials for the development of gluten-free items. Amaranth and quinoa grains can be processed to add value so that they can be used as food and provide customers with the nutrition they need (Table 5).

At the household level, amaranth grain can be cooked and consumed as porridge, as well as malted to make beer (Yang & Gao, 2022). It has been demonstrated that popping or roasting the amaranth grain will provide amaranth flour, which can be used alone or in combination with other components to prepare products including breakfast cereals, spaghetti, biscuits, crackers, bread, pancakes, and muffins (Aderibigbe et al., 2022). Unpopped grain can be prepared into a thin porridge by mashing it and adding groundfish or the flour of other grains including millet, sorghum, and maize (Janet, 2015). Amaranth grain can be used to make extruded products, bread goods, breakfast foods, and foods that are gluten-free either on their own or in composite flour. A variety of flatbreads are made with amaranth flour in the Himalayas and Latin America (Aderibigbe et al., 2022). Amaranth flour was added to wheat flour by up to 35%, according to Buresova et al., (2017). The organoleptic characteristics of the product were improved (flavor, taste, color, and appearance). The best product in terms of colour and organoleptic properties was found to have 25% amaranth flour substitution. Aderibigbe et al. (2022) produced cookies with wheat-grain amaranth composite flours and noticed that the products were sensory acceptable even when 100% grain amaranth was used.

There are many uses for quinoa. It has the potential to replace protein in food and fodder as well as in the pharmaceutical sector because it is one of the best sources of leaf protein concentrate. The entire plant can additionally be used as green fodder for livestock such as cattle, horses, pigs, sheep, and poultry (Hancock, 2022). Quinoa can be used in place of rice, as a hot breakfast cereal, or for making infant cereal by boiling it in water. The seeds can even be popped like popcorn. Seeds can be sprouted or pulverized and used as flour. Sprouts must turn green before being put into salads (Artes-Hernandez, Miranda-Molina, Klug, & Martinez-Hernandez, 2022). Quinoa flour can be combined with maize or wheat flour. There have been reports of quinoa flour substitution at various concentrations such as 10%–13% quinoa flour in bread, 30%–40% quinoa flour in noodles and pasta, and 60% quinoa flour in sweet biscuits (Sezgin & Sanlier, 2019). Additionally, quinoa flour can be extruded and drum-dried to produce products with great nutritional, sensory, and physical properties. Quinoa could be successfully used in the beverage sector to develop formulations for malted drinks. It can be used to feed animals or fermented to make beer (Singh et al., 2021). Quinoa is solid-state fermented with *Rhizopus oligosporus Saito* to produce high-quality tempeh (Christensen, Garcaa-Bejar, Bang-Berthelsen,

Table 5
Functional food products made from amaranth and quinoa.

Functional food products	Product constituents and preparation	References
Bread	• Partial substitution of amaranth flour with wheat flour significantly enhanced bread's nutritional value by increasing protein and ash content, as well as mineral content and sensory evaluation revealed higher scores for the acceptability of the bread.	Cotovanu, Stroe, Ursachi, and Mironeasa (2023)
	• Partial substitution of quinoa flour (30%) with maize flour (70%) significantly increased nutritional quality by increasing protein, ash, fibre contents as well as mineral content and had no changes in the sensory properties.	Dhillon, Bhise, and Goel (2022)
Cakes	• Incorporation of amaranth flour (40%) in the conventional sponge cake formulation improved its nutritional value.	Shyam and Raghuvanshi (2015)
	• Incorporation of quinoa flour in the gluten-free cake formulation showed that 100% wheat flour amounts could be replaced by the same amounts of quinoa meal still providing the good quality cake.	Atef, Abou-Zaid, Wafaa, and Emam (2012)
Cookies and biscuits	• Amaranth oat sugar cookies were developed using gluten-free amaranth flour (25%) containing essential amino acids and minerals improved their nutritional and physical quality.	Inglett, Chen, and Liu (2015)
	• Wheat flour was fortified with quinoa flour in different ratios and it was found that biscuits with ratio (60:40) were acceptable as it contains high fibre content and high ash content as compared to other samples. On the basis of sensory evaluation, whole wheat flour biscuits and 10% fortified biscuits scored highest among all samples. Fortified quinoa seed flour biscuits were found to be highly nutritious.	Puri, Sarao, Kaur, and Talwar (2020)
Pasta	• Pasta prepared from quinoa flour (60%) is a promising product in the market with good acceptability for its consumption, given its sensory characteristics and high protein content.	Vargas, González, and Loaiza (2021)
	• Substitution of whole wheat flour partly with amaranth flour (30%) improved nutritional and functional properties of pasta with acceptable quality.	Martinez, Ribotta, Anon, and Leon (2014)
Beverages	• Fermentation of quinoa beverages significantly increased proteins, total phenolic content, and antioxidative activity as well as enhanced overall acceptability.	Karovicova et al. (2020)
	• Amaranth-based beverages enhanced the cycling performance compared to participants consuming commercial sports beverage.	Espino-Gonzalez et al. (2018)

& Hansen, 2022).

Amaranth and quinoa grains may significantly improve food security and nutrition, as well as supply raw and intermediate materials for companies to expand their scope of production and create employment if they receive the necessary care from cultivation to storage.

8.2. Applications in medicine

Amaranth has been suggested as a dietary supplement that can promote bone health due to its high calcium content, can assist blood sugar regulation due to its high manganese levels, and can help cure folic acid shortage in pregnant women to prevent spina bifida and heart problems in newborns (Soriano-Garcia et al., 2018). In the Himalayan region, 78 plant species have been found to have aphrodisiac qualities. According to a Kashmiri ethnobotanical study, *A. spinosus* decoction is administered orally to cure premature ejaculation and erectile dysfunction (Ganie, Tali, Shapoo, Nawchoo, & Khuroo, 2019). In some villages of Sivagangai district in Tamil Nadu, India, shoot infusion of *A. spinosus L.* is administered to eczema until it is cured (Gandhi, Samarth, & Peter, 2020). In the silent valley of Kerala, India, traditional healers utilize a decoction of the leaves as a bath additive to treat skin allergies (Gandhi et al., 2020). Similarly, in the Alagar hills of Madurai district, Tamil Nadu, India, traditional healers employed an extract of *A. spinosus L.* whole plant to treat jaundice and liver enlargement (Sundaram & Suresh, 2019). In Africa, leaves of amaranth are used as a nutraceutical or functional food to treat tooth emergence in infants. It is also used as a diuretic to treat worms and to treat stomachaches and constipation (Gandhi et al., 2020).

It has also been stated that quinoa is used medicinally (Shah, Khan, & Yan, 2022). The plant is reportedly used as an analgesic, to treat inflammation, and to clean the urinary tract. Additionally, it is utilized as an insect repellant, for internal hemorrhaging, and fractures (Lapez-Cervantes, Sánchez-Machado, de la Mora-Lopez, & Sanches-Silva, 2021). Recently, ethanol-induced acute gastric lesions in rats led to the cell wall polysaccharides viz., arabinan and arabinan-rich pectic polysaccharides to exhibit gastroprotective effects (Cordeiro, Reinhardt, & Baggio, 2012). These reports might provide new opportunities for growing quinoa for medical purposes. It is believed that dietary flavonoids have positive health effects because they have antioxidant and anti-inflammatory characteristics (Yi, Ma, & Ren, 2017). Among cereals and pseudocereals, quinoa seeds are the most efficient food as a source of flavonoids. Large levels of flavonoid conjugates, including kaempferol and quercetin oligomeric glycosides, have been found in quinoa seeds in recent investigations (Melini & Melini, 2021). Quinoa is also a good source of vitamin E (Pathan & Siddiqui, 2022). In areas where there is a protein deficiency, the highly nutritive quinoa flour could be utilized to complement the protein-deficient wheat flour that is frequently used for human consumption. Quinoa's low fructose and glucose content makes it a good choice for people with maturity-onset diabetes. For consumers with celiac disease, quinoa flour can be used in tiny amounts in place of wheat flour to make bread. This has been found to improve the quality of bread (Xu, Luo, Yang, Xiao, & Lu, 2019).

8.3. Applications in cosmetics

A new study has revealed that amaranth has tremendous cosmetic potential in addition to its significant role as a nutritious meal. *Amaranthus* spp. seed extracts were shown to have potential skin-whitening properties due to the presence of myoinositol and squalene because they have the ability to reduce melanin formation in vitro even more than the common arbutin (Gandhi et al., 2020). UVA (ultraviolet A) is known to inhibit collagen biosynthesis in skin fibroblasts. Oil from seeds of *A. cruentus* was discovered to provide pre-and post-UVA protection in skin fibroblasts, and as a result, it can be used in cosmetic formulations of anti-aging creams and as a natural sun protection factor (SPF) component (Wolosik, Zareba, Surazynski, & Markowska, 2017). In another study, a hydrogel nano-delivery system based on amaranth oil (nanostructured lipid carriers) allowed for sustained release of the antioxidant hesperidin and entrapment of UVA and UVB filters (diethylamino-hydroxy benzoyl hexyl benzoate, 2-ethylhexyl salicylate) which ensured the absorption of 99% UVB radiations (SPF ¼ 46/50.5) and had the ability to combat 83% of UVA radiation in the formulation. The amount of UV filters employed in the formulation was drastically lowered when compared to the measure present in commercial creams because of the entrapment with Amaranth oil. With continued usage, it is anticipated that the improved antioxidant qualities and superior photo-protection in the sunscreen formulation may lower the incidence of skin cancer and postpone the effects of photoaging (Lacatusu et al., 2018). The aqueous extract of *A. cruentus* L. was used to create a formulation for herbal lipstick, another cosmetic product that performed well according to the parameters assessed and was reasonably priced. This was done to encourage the use of natural formulations and natural dyes in order to prevent the negative effects of using synthetic ones (Karanje, Doijad, & Bhosale, 2020). *A. tricolor* is also cited in the literature to be used as a possible ingredient in beauty care for face spa in Bangladesh (Haque & Uddin, 2018). According to Busa and Getalado (2019), A. gangeticus leaf extract which is anthocyanin-rich, can be utilized as a natural hair colorant and can be a good replacement for synthetic hair dyes which are toxic. Additionally, there have been few reports of quinoa being used for cosmetic purposes. The main anti-nutritional components in quinoa's seed coat are saponins. Shampoos, detergents, and soaps are all made with saponins. In addition to being used to treat foul breath, quinoa saponins can also be found in toothpaste and mouthwashes (Heliawati, Lestari, Hasanah, Ajiati, & Kurnia, 2022). Seeing the cosmetic potential of amaranth and quinoa, efforts should be made towards the utilization of amaranth and quinoa for this purpose.

9. Conclusion

Grains with essential nutrients are required to address micronutrient deficiency and related ailments resulting from malnutrition. Amaranth and quinoa are truly superior to other cereals because they are rich in proteins and polyphenolic compounds such as flavonoids, carotenoids, and tocopherols which are responsible for numerous health benefits. In addition, these contain a variety of anti-nutritional constituents such as phytic acid and saponins which bind micro and macronutrients and render them inaccessible to our body. However, by using different processing techniques like fermentation, germination, extrusion, and cooking, their bioavailability can be enhanced. Although they are neglected in some regions of the world, but not underestimated because substantial attempts are being made to enhance their utilization in products with commercial value. With emerging research, these grains are being already developed as one of the ingredients or functional food to be incorporated with cereals in bread, cakes, pasta, and cookies, up to different levels but the horizon needs to be widened. Therefore, it is imperative to investigate the bioactive properties of amaranth and quinoa in order to effectively exploit them for commercialization in a variety of industries including natural health supplements, pharmaceuticals, packaged food, and the cosmetic industry.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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