Review Article

Amaranth Seeds: A Promising Functional Ingredient for Gastronomy– A Review

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Abstract | Amaranth (*Amaranthus* spp.) is a nutritious gluten-free pseudocereal that has been consumed for years in South and Central America. Amaranth plants are well adaptable in different climatic conditions, and easy to grow. Amaranth grains have several beneficial features such as high-quality protein, high content of fiber and micronutrients such as iron and calcium. Furthermore, amaranth seeds are a good source of phytochemical compounds with health-promoting effects such as squalene, phytosterols, and polyphenols. Amaranth seeds have gained popularity in recent years due to their perceived health benefits and dubbed as superfood. The food industry is formulating new products adding amaranth to cereal-based food and gluten-free products such as bread, muffins, cookies, pasta, breakfast, beer, and beef. This comprehensive review is focused on the important aspects of amaranth such as the taxonomic and origin, proximal composition, phytochemical composition, and amaranth as food ingredient added to common foods.

Received | August 02, 2023; **Accepted** | November 17, 2023; **Published** | January 22, 2024
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Citation | Lopez-Martinez, J.M. and I. Ahmad. 2024. Amaranth seeds: A promising functional ingredient for gastronomy– A review. *Sarhad Journal of Agriculture,* 40(1): 39-53.
DOI | https://dx.doi.org/10.17582/journal.sja/2024/40.1.39.53
Keywords | Amaranth, Gluten-free, Food addition, Applications

Introduction

Amaranth or pigweed (*Amaranthus* spp.) is a dicotyledonous plant that belongs to the order *Caryophyllales*, family *Amaranthaceae*, subfamily *Amaranthoideae*, genus *Amaranthus* that includes approximately 60-69 species (Dabija *et al*., 2022; Martinez *et al*., 2013). Three amaranth species are mainly used for seed production; these are *Amaranthus Caudatus*, *Amaranthus Cruentus*, and *Amaranthus Hypochondriacus*. While leafy varieties are less extent such as *Amaranthus hybridus* and *Amaranthus tricolor* (Akin-Idowu *et al*., 2017; Bang *et al*., 2021). Authors reported that amaranth seeds possess a diameter of 0.9-1.7 mm, weight varying of 0.6 to 1.3 g in 1000 lenticular shape seeds (Bojórquez-Velázquez *et al*., 2018; Dabija *et al*., 2022). Figure 1 shows the amaranth seeds of the *Amaranth hypochondriacus* specie harvested in Atlacomulco, Estado de Mexico, Mexico.

Amaranth is an ancient plant (4000 B.C). In the past, people of communities believed that this plant had mystical qualities and utilization of the plant

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provided endurance and strength; it was unknown as the food of the Gods (Adekunle, 2001). The word amaranth was originated from a Greek word which meaning "everlasting" or "immortal" (Dabija *et al*., 2022). It is believed that amaranth originated from Central and South America (Amare *et al*., 2016; Becket *et al*., 1987; Bodroza-Solarov *et al*., 2008). This pseudocereal had great value for the most important civilizations of Mexico such as Mayan, Aztec, and Incas. Amaranth was cultivated as main crop, but it was prohibited during the Spanish Conquest, due the spiritual connection of indigenous with plants (Bojórquez-Velázquez *et al*., 2018).

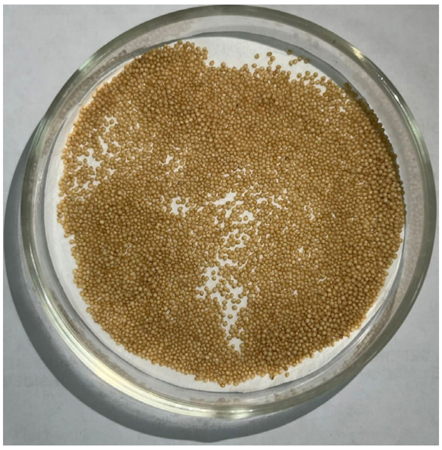

Figure 1: *Amaranth seeds (Amaranth hypochondriacus).*

Currently, amaranth is a plant that it is cultivated all over the world, but principally in Mexico, Canada, Peru, Russia, Nepal, Nepal, China, Argentina, Malaysia, Indonesia, Philippines, and Australia. The world's largest producer of amaranth is China, while Germany is the principal consumer market for amaranth seeds (Dabija *et al*., 2022). The entire Himalayan region of India used amaranth as a valuable ingredient in food, while in Peru, seeds are fermented to make amaranth beer (Chauhan and Singh, 2013). México consumes amaranth grains after popping, which is mixed with sugar cane and makes a suitable and popular snack called "Alegria" (Calderon de la Barca *et al*., 2010).

Amaranth is an adaptable plant to the soil, and it's easily grown in cool temperature to tropical regions at altitudes in a range between sea level and 3000 m (Amare *et al*., 2016; Bang *et al*., 2021; Dabija *et al*., 2022). However, amaranth can withstand extreme climates, requires little cultivation and it is resistant to biotic and abiotic stress (Becket *et al*., 1987; Dabija *et al*., 2022; Martinez *et al*., 2013; Sindhuja *et al*., 2005).

Amaranth seeds are conformed mainly by carbohydrates and contain higher quantities of dietary fiber (Akin-Idowu *et al*., 2017; Bojórquez-Velázquez *et al*., 2018; Globelnik Mkalar *et al*., 2009). Moreover, amaranth is good source of protein comprising all the essential amino acids and is also gluten free, these characteristics gives a complete protein source (Adekunle, 2001; Amare *et al*., 2016; Becker *et al*., 1987). Researchers have been reported that the amaranth oil (squalene) is the highest source of squalene in the plant world (Bojórquez-Velázquez *et al*., 2018; Skwarylo-Bednarz *et al*., 2020). In addition, amaranth seeds possess nutraceutical properties that contribute to improved human health. For this reason, the nutritional composition of amaranth seeds makes it attractive for use as ingredient or food for processed foods to increase the biological value. Several studies investigate new applications of amaranth seeds in food products to improve nutritional quality.

Amaranth proximal composition

Amaranth seeds chemical composition is dominated by carbohydrates, where starch is the principal component of these carbohydrates (29-38%) (Akin-Idowu *et al*., 2017; Amare *et al*., 2016; Bojórquez-Velázquez *et al*., 2018; Globelnik Mkalar *et al*., 2009). The starch conformed the bulk of seeds, and it has small granules (0.5–2 μm), where these granules are located mainly in the seed endosperm (Adekunle, 2001; Alvarez-Jubete *et al*., 2010; Malganve *et al*., 2022). Amaranth starch granules possess a polygonal structure and have a great swelling power (Dabija *et al*., 2022). Amaranth starch seeds are conformed principally of amylopectin, 7.6–34.4%, while the amylose content is lesser (5–7%) than other cereal starches (0.2% and 11.0%) (Cotovanu and Mironeasa, 2022). Starch possesses granules characteristics, such as great solubility, water binding capacity, higher absorption capacity due the moisture activity, which gives functional attributes for the interest in food applications (Bojórquez-Velázquez *et al*., 2018; Dabija *et al*., 2022; Liu *et al*., 2019).

Moreover, amylose from amaranth seed has been linked with rheological properties such as texture (starch gelatinization) and rheology (thermal and pasting properties) (Capriles *et al*., 2008; Cotovanu and Mironeasa, 2022).

Dietary fiber is comprised mainly of plant cell walls and fiber contains indigestible oligosaccharides, polysaccharides, and lignin (Bunzel *et al*., 2005). Amaranth grains possess good quantities of dietary fiber (4.0–8.1%) than those found in most cereals such as wheat, rice, sorghum, oat, and barley (Dabija *et al*., 2022; Raghuvanshi and Bathi, 2019; USDA, 2019). Fiber intake is an important part of human nutrition;

furthermore, fiber intake has been linked to prevention of colon cancer. Amaranth has a high soluble fiber content (1.46 g/100 g), and it is an excellent source of insoluble fiber (3.6 g/ 100 g) (Ojedokun *et al*., 2020). Authors have been published that amaranth fiber could be related in the control of blood cholesterol level in serum and it could prevent the development of atherosclerosis (Bojórquez-Velázquez *et al*., 2018).

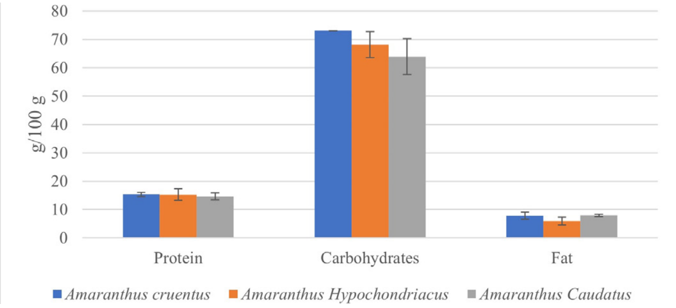

Figure 2: *Macronutrients content of three different amaranth species used for the seed production (Akin-Idowu et al., 2017; Amare et al., 2016; Bojórquez-Velázquez et al., 2018; Globelnik Mkalar et al., 2009).*

The nutritional quality of proteins in amaranth grains is higher than the most cereal grains (Martinez *et al*., 2013). Amaranth grains are a great source of proteins, and they have concentrations from 13.8 to 16.7 g/100 g of proteins, depending on the plant variety (Figure 2) (Amare *et al*., 2016; Bojórquez-Velázquez *et al*., 2018; Globelnik Mkalar *et al*., 2009).

According to Osborne's classification, amaranth proteins contain values of 39% albumin, 19.9% globulin, 24.9–29.9% glutelin, and 2–3% prolamin (Cotovanu and Mironeasa, 2022). Since the proteins in this grain don't include gluten, amaranth flour is recommended for those with celiac disease or gluten intolerance. Moreover, the biological value of protein in amaranth protein is estimated to be around 75-90%, depending on factors such as processing, cooking methods and individual metabolism (Dabija *et al*., 2022). High level protein content presents a unique functional attribute such as water absorption property and high foaming of amaranth flour (Amare *et al*., 2016).

Furthermore, seeds possess a complete protein source due their content of all the essential amino acids (Table 2) (Cardenas-Hernandez *et al*., 2016). It contains a great concentration of lysine, 0.74% to 0.83%, of the total protein. The main grains, like wheat and corn, are deficient in the important amino acid lysine (Adekunle, 2001; Amare *et al*., 2016; Becker *et al*., 1987). In addition, amaranth grains have a good concentration of sulfur-containing amino acids (2-5%), which are limiting in some crops (Chauhan and Singh, 2013).

Table 1: *Proximal composition of amaranth grain species.*

Proximal composition	Amaranthus cruentus	Amaranthus hypochondriacus	Amaranthus caudatus
Moisture (g/100 g)	11	11.5	10.9 – 11.1
Ash (g/100 g)	2.8 - 3.1	2.9 - 4.2	2.6 - 3.7
Starch (g/100 g)	31.2	37.7	29.4
Sugar (g/100 g)	1.7	1.9	1.6
Crude Fiber (g/100 g)	2.5 - 3.5	2.4 - 3.9	4.0
Squalene (% in oil)	2.2 – 6.9	1.9 – 4.6	3.8 – 6.7

Akin-Idowu et al., 2017; Amare et al., 2016; Bojórquez-Velázquez et al., 2018; Globelnik Mkalar et al., 2009.

Amaranth seed contains 2–3 times more lipids than most conventional cereals such as rye or wheat grains, and twice in maize grains (Amare *et al*., 2016; Barba de la Rosa *et al*., 2009). The lipid content in amaranth seeds is in a range from 4.9% to 8.9% depending of the specie (Figure 2) (Akin-Idowu *et al*., 2017; Amare *et al*., 2016; Bojórquez-Velázquez *et al*., 2018). The seeds possess values from 6% to 10% oil. The oil is found principally within the germ, which it has a good concentration of unsaturated oils (75%) such as oleic (19–35%), palmitic (12–25%), linoleic (25–62%), and linolenic acids (0.3–2.2%) (Bodroza-Solarov *et al*., 2008; Caselato-Sousa and Amaya-Farfan, 2012). Due to high oxidative stability, the amaranth seed oil has potential to develop beneficial products for human health with a longer shelf life (Cotovanu and Mironeasa, 2022; Dabija *et al*., 2022). Researchers have been reported that the amaranth oil is the richest source of squalene in the world (Martinez *et al*., 2013). Amaranth squalene concentration varied between 0.2 until 0.8 g/100 g of grains and the relation of this concentration oil content varies from 2.8 to 4.9 g/100 g oil (Table 1) (Bojórquez-Velázquez *et al*., 2018; Skwarylo-Bednarz *et al*., 2020). Squalene is a precursor of sterol, and it improves the oxygen supply to the cells of the human body and this function of oxygen-carrying acts as a key role in decreasing low-density lipoprotein blood cholesterol (Bodroza-Solariv *et al*., 2008). Likewise, squalene has a good concentration of antioxidants, which inhibits oxidative damage produced by free radicals which can potentially prevent skin cancer and has cholesterol-lowering properties (Adekunle, 2001; Amare *et al*., 2016).

Amaranth seeds contain large amounts of pyridoxine (0.52–0.60 mg/100g) and folic acid (0.44–0.96 mg/100g) (Skwarylo-Bednarz *et al*., 2020).

Furthermore, grains being a good source of vitamins such as niacin (1.16–1.44 mg/100 g), thiamine (0.07-0.16 mg/100 g), riboflavin (0.19-0.41 mg/100 g), ascorbic acid (4.2-4.9 mg/100g) and biotin (42.5 mg/100g) (Cardenas-Hernandez *et al*., 2016; Dabija *et al*., 2022; Skwarylo-Bednarz *et al*., 2020).

Table 2: *Essential aminoacid composition of amaranth seeds.*

Amino acid	Content (g of amino acid/ 100 g protein)
Alanine	0.53 – 0.79
Arginine	1.06 - 1.47
Aspartic Acid	1.22 – 1.23
Glycine	1.38 – 1.63
Isoleucine	0.55 – 3.3
Leucine	0.86 – 6.6
Glutamic Acid	2.23 - 2.51
Lysine	0.83 – 7.5
Metionine + Cysteine	0.3 – 7.2
Phenylalanyne + Tyrosine	1.2 – 8.3
Threonine	0.38 – 4.8
Proline	0.69 – 0.70
Valine	0.60 – 3.9
Histidine	0.38 – 0.39
Serine	0.88 – 1.14

Barba de la Rosa et al., 2009; Palombini *et al*., 2013*;* USDA, 2019. *g, grams.*

Table 3: *Mineral composition of amaranth grain species.*

Minerals	Content (mg/kg)
Iron	118-172
Zinc	43-59
Cooper	3-7
Sodium	1-9
Manganese	64-136
Potassium	4281-5362
Phosphorus	4681-6680
Calcium	1287-2480
Magnesium	2035-3260
Aluminum	48-111
Selenium	0.8-0.27

Akin-Idowu et al., 2017; Sarker and Oba, 2020*; USDA, 2013. mg, milligram; kg, kilogram.*

In addition, the mineral concentration of amaranth grains (calcium and iron) is about twice as high as cereals like wheat and maize (Adekunle, 2001; Amare *et al*., 2016; Capriles *et al*., 2008) (Table 3). Amaranth seeds are rich in calcium (1300–2850 mg/kg), sodium (161-479 mg/kg, iron (72–174 mg/kg), magnesium (2299–3361 mg/kg), and zinc (36.1-39 mg/kg) (Akin-Idowu *et al*., 2017; Dabija *et al*., 2022). Nevertheless, their bioavailability would varied on the of antinutritional factors, such as phytic acid, which sometimes it could form insoluble complexes (Amare *et al*., 2016; Martinez *et al*., 2013). Phytate content in amaranth has been reported from 4.8 to 2.11 μmol/g. However, investigations have suggested that phytate has beneficial effects in health, such as antioxidant with anticarcinogenic effect and in the prevention of heart diseases (Miranda-Ramos *et al*., 2019).

Amaranth phytochemical composition

Over the past of years, many studies have been conducted on related topics like the antioxidant capacity of foods, polyphenol bioavailability and metabolism. The antioxidants effects in plants are an effect of the presence of polyphenolic compounds as phenolics compounds (flavonoids, tannins, phenolic acids, phenolic diterpenes) (Ahmed *et al*., 2013). Polyphenols are secondary plant metabolites that give protection of plants against herbivores, pathogens, and ultraviolet radiation (Alvarez-Jubete *et al*., 2010). Antioxidants shield cells from damage brought on by free radicals (Ahmed *et al*., 2013). The attention in polyphenols in the past years has been increasing due results from epidemiological investigations between the consumption of diets with good source of antioxidants and the reduced risk of diseases associated with oxidative stress, such as inflammation, cancer, and cardiovascular disease (Ahmed *et al*., 2013; Alvarez-Jubete *et al*., 2010).

Determination of the antioxidant capacity is a common practice for the measurement of the scavenging capacity of foods against ROS (Reactive Oxygen Species). Various assays used to evaluate antioxidant capacity in food are 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2, 2-azobis (3-ethyl-benzothialzoline-6-sulfonic acid) (ABTS), oxygen radical absorption capacity (ORAC), and ferric reducing antioxidant power (FRAP) (Jacobo-Velazquez and Cisneros-Ceballos, 2009). However, data variation in the phytochemical content and antioxidant capacity of cereals (amaranth) is expected, as many causes such as agrotechnical processes, environment conditions, and, genetics, that have an effect on the phenolic compounds content (Akin-Idowu *et al*., 2017).

Amaranth is a valuable pseudo cereal; seeds contain nutraceutical properties that contribute to improved human health. Several of studies demonstrated that the consumption on amaranth grains could be beneficial for the health and chronic degenerative diseases related with the oxidative stress (cancer, cardiovascular diseases, and lipid metabolism) (Chmelik *et al*., 2019). The amaranth could provide health benefits through its bioactive composition. Amaranths grains contain flavonoids and antioxidants that give protection to the cells and tissues from free radicals and oxidative stress (Ahmed, 2013). Antioxidant activity of amaranth seeds has been recognized for their concentration of anthocyanins, flavonoids, tocopherols, and polyphenols (Akin-Idowu *et al*., 2017). The principal phenolic compounds found in amaranth grains are gallic acid (11–44 mg/kg), caffeic acid (6.42–6.44 mg/kg), *p*-hydroxybenzoic acid (8.5–20.9 mg/kg) and ferulic acid (119–621 mg/kg) (Table 4). The conjugated fraction is composed of ferulic acid (80% of total bound phenolic acids), *p*-hydroxybenzoic acid, vanillic acid and coumaric acid. In addition, other phytochemical compounds in amaranth seeds are synaptic acid and protocatechuic acid (Venskutonis and Kraujalis, 2013). Amaranth oil is composed of α, β, ϒ, δ tocopherol which have great antioxidant activity and hypocholesterolemic agents (Table 4). In the same way, seed oil has good source of tocotrienols (ability to inhibit HMG-CoA reductase activity) and phytosterols (Skwarylo-Bednarz *et al*., 2020).

Table 4: *Phytochemicals compounds in amaranth seeds.*

Phytochemicals	Concentration (mg/kg)
p-Hydroxybenzoic acid	8.5 – 20.9
3,4 – Dihydroxybenzoic acid	4.7 - 136
2,4 – Dihydroxybenzoic acid	4.68 – 5.11
Vanillic acid	15.5 – 69.5
Gallic acid	11.0 - 440
p-coumaric acid	1.2 – 17.4
Ferulic acid	120 - 620
Caffeic acid	6.41 – 6.61
Quercentin	214 - 843
Quercentin 3-rutinoside	7 - 592
Kaempferol	22.4 – 59.7
Myricetin	1.8 – 12.53
Rutin	8.54-27.53
Isorhametin	142 - 600
Amaranthine	151.3
Isoamaranthine	58.7
Betanin	17.7
Isobetanin	5.0
α- Tocopherol	2.97 – 34.81
β - Tocopherol	5.92 – 211.8
ϒ- Tocopherol	0.95 – 57.07
δ- Tocopherol	0.01 – 48.79
α- Tocotrienol	10.2 – 20.6
β- Tocotrienol	35.4 – 48.5
ϒ- Tocotrienol	2.0 – 4.0
δ- Tocotrienol	15.5 – 18.4
Lutein	3.55 – 4.29
Zeaxanthin	0.14 – 0.32

Sarker and Oba, 2020; Tang and Tsao, 2017; Caselato-Sousa and Amaya-Farfan, 2012; Venskutonis and Kraujalis, 2013. *mg, milligram; kg, kilogram.*

Several authors evaluated the concentration of different antioxidants in some species of amaranth with various experimental conditions. Amare *et al*. (2016) determined that *Amaranth caudatus* contain polyphenols such as galloyls (93–143 mg TAE/100 g) and catechols (24–54 mg CE/100 g). Akin-Idowu *et al*. (2017) studied the bioactive compounds concentration and antioxidant activity of amaranth seeds (*Amaranth cruentus*, *Amaranth hybridus*, *Amaranth caudatus*, *Amaranth hypochondriacus* and *Amaranth hybrid*) using different techniques. *Amaranthus caudatus* seeds contain the highest tannin contents (0.14 g/100g) and good Fe chelating capacity (66.72%) compared with other studied amaranth species, while *Amaranthus hybridus* grains have the highest phytate content (1.6 g/100g), total polyphenol (30.8 mg GAE/100 g), DPPH scavenging activity (93.4%), ferric reducing power (0.19g /100g), total antioxidant (199.9 mg AAE/100 g) and ABTS (201.6 mmol TE/100 g). Tannin concentration of the five amaranth species varied from 0.10 – 0.14 g/100g. Characterization of phenolic acid and flavonoids of amaranth seeds (*Amaranth hypochondriacus*) grow in arid zones were analyzed by Barba de la Rosa *et al*. (2009). Authors identified and quantified three polyphenols in amaranth seeds using a HPLC-UV; these bioactive compounds were rutin, isoquercitrin, and nicotiflorin with concentrations of 4.0–10.1 μg/g, 0.3–0.5 μg/g, and 4.8–7.2 μg/g, respectively. In addition, they identified three phenolic acids; vanillic acid (1.5- 1.8 μg/g); 4-hydrozybenzoic acid (1.7 – 2.2 μg/g), and syringic acid (0.7-0.8 μg/g). Palombini *et al*. (2013) observed that grains of amaranth (*Amaranthus cruentus*) had values of α-tocopherol of 1.15 mg/100 g and the sums of β- and γ-tocopherols are 1.35 mg/100 g. Total phenolics content found in this studied was 21.8 mg GAE/ 100 g. Results from different research can be difficult to compare due the variability in the experimental environment amongst the techniques utilized and the varieties of amaranth species. However, seeds of amaranth species have a great concentration of phenolic acids and an excellent antioxidant capacity, making these qualities a good potential for food biofortification (Alvarez-Jubilete *et al*., 2010; Akin-Idowu *et al*., 2017). Amaranth seed also contains anti-nutritional phytochemicals such as tannins and phytic acid, however these compounds also exhibit protective effects. Ahmed *et al*. (2013) found that extracts of amaranth seeds have a concentration of tanins of 5.65%, saponnins of 32%, and glycosides of 32%.

Amaranth as a food ingredient and current food applications

The extraordinary nutritive composition of amaranth seeds makes it attractive for use as an ingredient to blend with food to improve the biological value of processed foods (Bodroza-Solarov *et al*., 2008). Several researchers investigate new applications of amaranth seeds in some food products as it can act as a promise food crop for the nutritional quality and because it can be used to complement with cereals as a supplement for adding nutritional value to foods (Sindhuja *et al*., 2005).

Amaranth grains can be subject in different treatments such as popping, cooking, toasting, flaking, roasting, extruding or griding to be consumed as suspensions or mixed with other cereal flour for making bread, biscuits, cookies, pasta, beef, beer and other food products to improved food products nutritional quality (Amare *et al*., 2016; Martinez *et al*., 2013).

Conversely, gluten proteins from grains like rye, barley, and wheat can cause celiac disease, an inflammatory condition affecting the small intestine (Calderon de la Barca *et al*., 2010; D'Amico *et al*., 2015; Garcia-Caldera and Velazquez-Contreras, 2019). Celiac patients must have a life-long gluten free diet, and they may have difficulty finding gluten free food products because the major cereal-based foods available in market have gluten (Alvarez- Jubete *et al*., 2010; Garcia-Caldera and Velazquez-Contreras, 2019; Meo *et al*., 2011). Gluten free food products are predominantly based on flour from maize or rice with low concentration of quality proteins and they need to include additives to increase their viscoelastic properties of baking (Calderon de la Barca *et al*., 2010). For this reason, amaranth seeds are an excellent choice to include in these gluten-free food products.

Amaranth bread

Bread is the main component of the diet in the world (Bodroza-Solarov *et al*., 2008). Refined wheat flour is the most important ingredient to manufacture the bread and bakery products, however this kind of flour has a reduced nutritional value due its lower concentration of fibers, vitamins (Lysine and threonine), and minerals (Cotovanu *et al*., 2023; Miranda-Ramos *et al*., 2019). In addition, the elimination of the pericarp and aleuronic layers through milling affects the protein concentration in refined flours of wheat bread (Estivi *et al*., 2022). Amaranth captures growing interest due of its great nutritional quality and technological properties, especially in the baking process (Miranda-Ramos *et al*., 2019).

However, the substitution of gluten in cereal-based products (bread, cake, and biscuit) represents a technological challenge, due to the fundamental role of this protein in breadmaking and mediocre quality food (Estivi *et al*., 2022). Gluten is an essential structural protein that offers viscoelasticity to the dough, good crumb structure, and good gas-holding ability as the result of baked products (Alvarez-Jubete *et al*., 2010). Amaranth is not regularly used in making bread, but it can be useful in the diet treatment of celiac disease (Chlopicka *et al*., 2012). Specialized studies literature highlights the enhancement of nutritional characteristics of wheat flour incorporating new ingredients such as amaranth (Alvarez-Jubete *et al*., 2010; Cotovanu *et al*., 2023; Estivi *et al*., 2022; Machado *et al*., 2015). Bread formulations with the substitution of 10g/100g of amaranth flour significantly improves the protein, lipid, and ash content in bread formulated with this cereal compared with quinoa bread (Machado *et al*., 2015). Cotovanu *et al*. (2023) reported the nutritional improvement of wheat bread by adding amaranth flour. Adding 7-9% of amaranth flour to the formulation (varied particle size) increases protein, lipid, and ash content in bread. The mineral content (K, Ca, and Mg) was two times higher in the optimal bread compared to the control bread. Small and medium-sized amaranth particle sizes present a lower α-amylase content, whereas dough development time was high compared to wheat flour.

Similar results were obtained by Bodroza-Solarov *et al*. (2008), who determined the nutritional composition of wheat bread with the addition of popped amaranth seeds. The substitution of popped amaranth in bread significantly increases the protein, fiber and ash compared with control bread. Mineral content improves in major concentrations of zinc (42.6 to 74.6%), manganese (51.7% to 90.8%), magnesium (75.7% to 88.0%), and calcium (57% to 171%) when they add 10 to 20% of amaranth grain. Squalene content was higher in bread supplemental with amaranth (8-12 times higher) compared with the control. The addition of popped amaranth seeds on bread improved the crumb moisture content, crumb hardness, denser crumb structure, and enhanced crust color and flavor compared with the control. However, the amaranth addition gives thicker walls to the bread. The amaranth process of popping and fermentation seeds were studied by Amare *et al*.

(2016). Popping amaranth grains increase fat (12%), acid fiber (15%), and neutral detergent fiber (67%), while seed fermentation caused more protein (3%), fat (22%,) and ash (14%) compared with control. In addition, popping and fermentation reduce the level of three types of phytates (IP6, galloyl, catechol) that act as inhibitors of mineral absorption improving mineral bioavailability. Furthermore, popping process of amaranth seeds increases the rheological properties of food products (Calderon de la Barca *et al*., 2010).

In the same way, the inclusion of amaranth (25 g/100 g) improves the nutritional composition of bread such as protein (10.2 to 14.8%), lipid (1.08 to 6.94%), ash (0.09 to 2.77%) and myo-inositol phosphate contents (n.d. to 21μmol/g). The increase of moisture in the bread with amaranth seeds flour caused hydroxyl groups in the fiber structure, allowing water interaction thorough hydrogen bonding than in control flour caused a significantly increase of fiber from 3.9 to 7.9 g/100 g (Miranda-Ramos *et al*., 2019). Liu *et al*. (2019) formulated a nutritive gluten-free bread using amaranth seed flour mixed with soybean, lupin or navy bean flour (15% of 30%). This bread contains more proteins, minerals, and vitamins than whole wheat. Additionally, inclusion amaranth flour to soybean, lupin and navy bean flours increases the springiness in comparison with the control (wheat bread) caused by their high protein content and water holding capacity.

The effect of amaranth grain flour on quality of bread had been investigated to improve the sensory values. Formulation of bread with a composition of 50% of amaranth flour and 50% wheat flour increase the water absorption compared with the control (2.55 to 3.65%), nevertheless loaf volume decreases from 3.3% to 1.9% because of the flour lack gluten (responsible for a good formulation of dough in bread production). Amaranth bread moisture increases from 22% to 42%, caused by the small particles that increase the absorption of water. However, authors reported intrinsic compounds in this cereal at elevated temperature that taste as a nutty flavor which could be unpleasant in amaranth baked products (Adekunle, 2001).

Another study about the baking properties of amaranth in gluten-free bread was performed by Alvarez-Jubete *et al*. (2010). Amaranth bread had the softest crumb compared with other kinds of bread such as quinoa bread and buckwheat bread. Higher fat concentration in amaranth could have linked in relation of crumb texture and structure. Amaranth lipid content was 2-3 times higher than buckwheat and wheat. On the other hand, authors found that amaranth starch has a lower content of amylose compared with starch cereals (quinoa and buckwheat) and this can be related to weak crumb composition when processed into bread compared with the control (buckwheat flour). Analysis of images of amaranth crumb structure indicated that flours present a smaller number of alveoli but giving structure with larger alveoli in bread compared with the gluten-free bread with a starch-based formulation (Machado *et al*., 2015). Bread elasticity improves with the substitution of amaranth seeds flour in wheat bread (1:1) caused by the elevated lipid concentration in amaranth that could have an effect in the functionality like gas-stabilizing agent during breadmaking (Miranda-Ramos *et al*., 2019).

However, adding 60-70% popped amaranths to the formulation of natural amaranth seeds flour gave loaves with higher specific volume (3.6 ml/g) and homogeneous crumb than other gluten-free bread (Calderon de la Barca *et al*., 2010).

On the other hand, the product election by consumers on the market is influenced by the relation of non-sensory factors such as sensory factors and personal health (Machado *et al*., 2015). Chlopicka *et al*. (2012) reported the effect of adding 15% or 30% of amaranth seed flour in wheat bread on antioxidant content bread, and authors compared it with buckwheat and quinoa flours. Bread baked with 15% amaranth flour had similar phenol and flavonoid content that wheat bread (1.7 mg/g, 20.3 mg/g), this is caused because antioxidant compounds presented in flour could be degraded due the high temperature during baking process. Conversely, adding 30% of amaranth flour to wheat bread increased the phenol (2.61 mg/g) and flavonoid concentration (34.9 mg/g) in the bread. Antioxidant activity by FRAP method in bread was higher for bread baked with 30% amaranth flour compared with quinoa bread and wheat bread (control).

Sensory qualities of bread are important because taste, flavor and smell of baking products are qualities that give influence in the consumer preferences of products and some extend its physicochemical properties (Adekunle, 2001; Chlopicka *et al*., 2012). Adding 50% of amaranth flour to einkorn flour in a biscuit formulation improved the antioxidant content in baking. Biscuits baking with amaranth flour content high concentration of β-tocopherol (29.16 mg/kg), p-hydroxybenzoic acid (43.30 mg/kg), p-coumaric acid (5.41 mg/kg) and ferulic acid (54.30 mg/kg) compared with einkorn wheat (5.70 mg/kg, 2.51 mg/kg, 2.98 mg/kg and 36.49 mg/kg, respectively). However, the conjugated phenolics content are better in other formulations with buckwheat and quinoa biscuit. The highest chroma value was observed in amaranth whole meal after baking (Estivi *et al*., 2022). In the same way, Hozova *et al*. (1997) determined that biscuits made with wheat flour in addition to amaranth flour (20%) was evaluated favorable in terms of taste regarded as harmonic, which reflects a high scoring evaluation. In addition, the influence of sweeteners (sucrose, sucralose, acesulfame-K) in amaranth bread doesn't affect the quality parameters of gluten-free bread formulations compared with demerara sugar, so it can be a good opportunity to formulated gluten-free breads with no sugar to population with special needs (Machado *et al*., 2015).

One of the most popular products in bakery industry are cookies, due some factors such as long shelf life and ready-to-eat (Sindhuja *et al*., 2005). Wheat flour is the principal ingredient in cookies. However, this ingredient is deficient in some essential amino acids such as tryptophan and lysine, while amaranth grains are good source in these kind of essential amino acids (Chauhan *et al*., 2016).

The incorporation of amaranth flour in wheat flour to make cookies was tested (0, 5, 10, 15, 20, 25, 30, 35%) to measure the quality of cookies. Integration of amaranth seeds flour enhanced the color of cookies from pale cream (10%) to golden brown (30%). Furthermore, incorporation of 25% of amaranth seeds flour to the formulation was optimum considering the color, taste, and surface appearance of cookies (Sindhuja *et al*., 2005). Physical, sensory characteristics and textural, in six types of amaranth seeds flour (20, 40, 60, 80, and 100%) cookies were studied by Chauhan *et al*. (2016). Whole amaranth seeds flour cookies required t a snap force of 71 M compared with wheat flour cookies (144 N). Hardness cookies decreased with the substitution of amaranth. Spread ratios and diameter were superior in whole amaranth seeds cookies (52 mm and 6.5), comparing with other formulations such as 20% (51.9 mm and 6.13) and 80% (51.92 mm and 6.36). Cookies' lightness (L*) value decreased with the increasing of amaranth seeds flour. Formulation of amaranth cookies at 60% was acceptable in sensory data results. Calderon de la Barca *et al*. (2010) obtained a great formulation of amaranth cookies with the addition of 20% popped amaranth seeds flour and 13% of the whole grain popped amaranth to rice flour. Hardness was similar like other glute-free cookies (10.88 N) and expansion factor had results like starch-bases controls. The gluten concentration of cookies was 12ppm.

Amaranth pasta

A popular worldwide cereal-based food product is the pasta due to its palatability, convenience, and nutritive composition (Martinez *et al*., 2013). Wheat semolina is the principal ingredient in pasta products, due to durum wheat proteins that its characteristics such as an optimal dough formation and networking of the matrix (Islas-Rubio *et al*., 2014). Different varieties of pasta are present in the food industry due the production process (lamination or extrusion) giving food products with different kind of color, composition, shape, and uses (Del Nobile *et al*., 2008). In recent years, different grains from wheat have been explored in the formulation of non-conventional pasta with the objective to create a pasta with healthy characteristics (Del Nobile *et al*., 2008; Martinez *et al*., 2013). However, substitution of different ingredients to wheat pasta formulation requires inclusion of additives and processing adjustments, due the poor characteristics in terms of cooking quality and texture compared to traditional wheat semolina pasta (D'Amico *et al*., 2014; Islas-Rubio *et al*., 2014). Popularity of non-convectional pasta products like gluten-free pasta has impulse to pasta food industry to formulate and development of production technologies (Del Nobile *et al*., 2008). Several authors studied the incorporation of seed flour amaranth in different matrices of pasta to improve the functional meal. Amaranth flour was added in concentrations of 15, 30, 40 and 50% in wheat flour to make a pasta. Amaranth flour used in this research was higher in protein, fiber, fat, and ash than the control (wheat flour). However, pasta formulated with amaranth flour showed weaker structure with the increasing of substitution levels, while firmness result was lower with the incorporation level of 40% (Martinez *et al*., 2013). The study of semolina substitution with raw: Popped amaranth seeds flour (90:10) on texture and cooking quality pasta were investigated by Islas-Rubio *et al*. (2014). Amaranth incorporation in gluten-free pasta enhances the fiber and high-quality content with adequate cooking quality (solid loss of 3.5 g/100 g higher than acceptable in solid loss control (semolina pasta). Adding white powder (9g/100g) to the amaranth blend showed an excellent effect on cooking quality resulting in form and texture (Islas-Rubio et a., 2014). While D'Amico *et al*. (2015) incorporated 6 g/100 g to amaranth pasta and obtain good results in texture and good quality of pasta. This is caused by the integration of protein aggregates (insoluble and large) responsible of improving texture, firmness, and elasticity of the pasta. The addition of 5% or 10% of amaranth flour to a pea flour formulation pasta improves the effect on the maximum consistency and dough development time from 513 to 535 FU and 4.5 to 5.2 min, respectively. On the other hand, higher sensory scores were designated for color, texture quality, and firmness of pasta formulated with 10% amaranth flour (Sudha and Leelavathi, 2012).

Enhancing with 9% of tapioca starch and 8% corn starch in the formulation of amaranth pasta presented a good stability time during blending, pasta can be laminated and dried at 80 °C for 45 min to obtain a ready cook pasta. Authors informed that this formulation is firm after oven cooking and soft at mouthfeel participants in a sensory test (acceptability and buying intention of the final product) (Garcia-Caldera and Velazquez-Contreras., 2019).

Several heat treatments have been studied to increase the quality of amaranth pasta. Islas-Rubio *et al.* (2014) informed that drying conditions (95 °C for 45 min) used in the formulation of the replacement of raw: popped flour blend pasta (90:10) extend the shelf life of the pasta and facilitate the production of good cooking quality pasta. As similar results, D'Amico *et al.* (2015) reported that amaranth pasta exposed to a higher temperature (100 °C) improves the properties (texture) and quality of pasta. Combined the extrusion-cooking with rice-based pasta (75g) enrich with amaranth flour (25g) improves the textural characteristics (firmness: 7.2 N) and increases the protein (129 g/kg), fat (30 g/kg), fiber (59.7 g/kg) and mineral content such as Zinc (0.071 g/kg), Fe (0.075 g/kg), Calcium (0.29 g/kg) in pasta compared with rice-pasta (100 g protein, 3.5g fat, fiber 30.5 g/kg, Zinc 0.007 g/kg, Fe 0.017 g/kg, Calcium 0.03 g/kg) (Cabrera-Chavez *et al.*, 2012).

Pasta is an optimal vehicle for the inclusion of nutrients such as amaranth, increasing the prevention of health disorders (Estivi *et al.*, 2022).
Valdez-Meza *et al.* (2019) studied the sensory, technological, and antihypertensive properties of pasta enrichment with amaranth. Semolina pasta added with 15% and 20% of amaranth hydrolysate have an optimum cooking time (7.5 and 5.5 min) and cooking loss decreased (8.9 and 7.3 g/100 g). Firmness increases in the formulation of 20% amaranth hydrolysate compared with control (100% semolina). Control pasta has more acceptability ($p < 0.05$) compared with the other treatments. Pasta products added with amaranth hydrolysates exhibited antihypertensive properties after 3 h of supplementation in rats.

On the other hand, fresh pasta is easily perishable due it has high moisture content. Products made from pasta are easily contaminated by microorganisms like bacteria, yeast, and mold (Del Nobile *et al.*, 2008). Pasta is being researched as a new method of food safety as well as synthetic food additives and environmentally friendly items. Del Nobile *et al.* (2008) studied the antimicrobial activity of natural compounds such as grapefruit seed extract, thymol, chitosan and lemon extract on amaranth-based homemade fresh pasta. Amaranth pasta formulated with these compounds, and it was stored at 4°C for 25 days. Chitosan and grapefruit seed extract increases the microbial acceptability limit of total coliforms, mesophilic and psychotropic bacteria, *Staphylococcus* spp., mold, and yeasts. Thymol reduces the growth of *Staphylococcus spp.*, psychotropic and mesophilic bacteria.

Amarant breakfast as cereal
Breakfast is the most important meal of the day (Ojedokun *et al.*, 2020). It is recommended that each person should consume around 15-25% of daily energy at breakfast (Raghuvanshi and Bathi, 2019). Development of high fiber content ready-to-eat food (<6 g fiber/100 g product) could be provide numerous healthy benefits (Tobias-Espinoza *et al.*, 2019). Amaranth provides a better nutritional balance compared with cereal renders due to its high protein concentration, higher lysine content, and balanced amino acid profile (Bunzel *et al.* 2005). Furthermore, amaranth products are better accepted for breakfast of snack item due it is soft consistency (Raghuvanshi and Bathi, 2019). Snacks and meals using amaranth seeds for pre-scholars' celiac subjects were formulated by Raghuvanshi and Bathi (2019). Researchers developed laddoo, kheer (sweet puffed amaranth grains) and upma, khichri (salty raw amaranth grains). Protein content was higher in khichri (15.11%) while fiber content was greater in Upma compared with the other breakfast products that contains 5.14–14% and 2.4 -3.2%, respectively. Organoleptically all the products were acceptable. Breakfast meals produced with roasted sesame flour and processed malted amaranth flour were studied to determinate quality and sensory parameters. The flour blends had a protein concentration from 11.07 to 15.04%, while total fiber content between 4.62 to 6.37 g/100 g. Soluble fiber and insoluble fiber of extruded food products obtained values from 1.87 – 2.28 g/100 g and 3.3 to 3.78 g/100 g respectively. Panelists determined that amaranth based meals (100%) were acceptable in terms of all

the assess attributes (Ojedokun *et al*., 2020).

Tobias-Espinoza *et al*. (2019) developed instant-extruded breakfast food products with amaranth seeds and flaxseed. Authors created six formulations with amaranth seeds (19–33 %), maize grits (56–67%) and flaxseed (7–9%). The extruded food products formulations showed high protein concentration (<12%), which is better protein content than commercial breakfast cereals. Extruded food products with high amount of amaranth and flaxseed obtained the best concentration of dietary fiber and hardness value (5.2 N), while soluble and insoluble fiber concentration in extrudates food improved as the proportions of amaranth increase.

Amaranth beer

One of the most consumed alcoholic beverages in the world is the beer. Nevertheless, in recent years the consumers are concerned about the nutritional composition benefits and the environment, demanding value-added food products and sustainable (Cadenas *et al*., 2021). Amaranth can be used as a partial replacement for malt in the formulation of new beers (Davija *et al*., 2022). Authors reported that for effective beer fermentation, the wort must have a good chemical composition (carbon, nitrogen, and vitamins) and it should contain mineral elements such as Zinc, Calcium, and Magnesium. Mineral content and high level of nutrients in amaranth grains improve the performance of fermentation rate and brewing yeast (Kordialik-Bogacka *et al*., 2019). Other authors reported that the utilization of amaranth as an adjunct in the elaboration of beer increases the ratio of Mg2+/ Ca2+, required for effective fermentation of carbohydrates from beer wort into alcohol, even at 10% of amaranth (Cadenas *et al*., 2021).

The highest polyphenol content in amaranth beer was reported with the addition of 10% of amaranth flakes (117 mg/L). A challenge in amaranth beer production is the β-glucan and its viscosity in the wort and beer filtration. However, the use of β-glucanase can be the solution to these problems (Bogdan and Kordialik-Bogacka, 2016). Amaranth grains have a high starch concentration, which can be altered into sugars by the malting process. Amaranth grains soaked for a time interval of 16 h for 3 days show a high amylase activity (850 protein/mg/min) and high reducing sugars (19.7 mg/g). The addition of 1 % α-amylase could produce the highest reducing sugars (91.4 mg/g) in incubation at 65°C for 24 h (Malganve *et al*., 2022).

On the other hand, malt quality was investigated in different cereals as amaranth to produce a gluten-free beer. Meo *et al*. (2012) studied the alternative to use amaranth with alkaline steeping to improve the free amino nitrogen and total soluble nitrogen to obtain a brew. Alkaline steeping is a variable related to the process of optimization of malt quality.

Amaranth obtained a lower water content (33–35%). Amaranth seeds showed a high fermentability of 56% and good values of extract. The authors concluded that the amaranth malting process could be optimized to obtain a quality malt, and suitable for gluten-free beer production. On the other hand, Montenegro (2016) reported that using amaranth malt produces a degree of 4.9% alcohol in beer elaboration, ranging in the values of strong beers (4.8%-5.5%). 40% of amaranth final product result were acceptable in physicochemical, and sensorial tests, while unmalted amaranth results in the least appreciated by consumers (Cela *et al*., 2022).

Amaranth used in animal meat

The food industry is constantly looking to create new recipes to enhance nutrient quality and food safety (Longato *et al*., 2017). Meat products contain high amounts of saturated fats and salts which the regular consumption causes chronic degenerative diseases. For this reason, it is important to develop healthy meat (Faid, 2019). Natural raw ingredients rich in dietary fiber and high antioxidant capacity serve as functional components for the meat industry (Longato *et al*., 2017). There are many alternatives to producing healthy meat products. Amaranth could be utilized as a fat replacer in a formulation of whole-meal beef burgers. Beef burgers were formulated with amaranth in different concentrations (2.5, 5.0, 7.5, and 10%) with 10% germinated red beans. Using amaranth at different levels in the production of beef burgers increases the protein content, fiber, and total carbohydrate. Beef burgers with amaranth at 10% gave the most significant value of water holding capacity (2.88 cm2), plasticity (2.95 cm2), shrinkage (11.27%), cooking lost (20.41%, and cooking yield (82.23%) compared with the other formulations. Furthermore, adding 10% to the beef formulation has good results in sensory evaluation (improvement in color, odor, juiciness, and taste) (Faid, 2019). Furthermore, the incorporation of amaranth seeds (1 and 2%) in the formulation of chicken burgers was studied by Longato *et al*. (2017. Chicken nuggets with amaranth seeds improve the cooking characteristics and lipid stability during storage (P > 0.05) compared with the control.

On the other hand, quality attributes in beef sausages with amaranth incorporation were reported. Whole amaranth meal (20%) increased total carbohydrate (9.57%) and ash (3.75%), however other chemical compositions (moisture, protein, and fiber) were decreased compared with the other formulations. The whole amaranth meal increased cooking yield (93%) and decrease frying and cooking loss (90.7%) (Sharoba, 2009).

The inclusion of binders in the sausage formulation is essential. Legumes and cereals are utilized as binders due to their ability to improve fat and water preservation caused by the starch and protein content (Muchekeza *et al*., 2021). Soya protein, maize starch, and non-fat dried milk are the most common binders used in most sausages (USDA, 2013). Sausages added with amaranth flour are high in protein content (16.6%), fat (5.52%), and ash (3.06%) comparable with corn starch (6.7%, 0.27%, and 0.26%, respectively) and quinoa flour (12.5%, 3.3% and 1.9%, respectively). On the other hand, amaranth sausage had a higher emulsion activity and thermal diffusivity (0.27) than quinoa and corn starch sausages (0.25). However, sausages with amaranth dislike in the sensory test (Muchekeza *et al*., 2021).

Frying battered products are used to improve the quality such as crispness, texture, moisture, porosity, color, flavor, and nutrition. Wheat flour is the common ingredient in batter; however, partial, or complete substitution of wheat flour has been contemplated to reduce dependency on wheat. The substitution of amaranth flour in wheat flour on chicken nuggets was studied by Tamsen *et al.* (2017). Inclusion of amaranth flour improved minerals, fat, protein and fiber content in chicken nuggets. Nuggets with amaranth flour have a high pH and emulsion stability compared with the other treatments. Substitution of amaranth flour in chicken nuggets does not have effect on the overall acceptability of the chicken nuggets in the sensory evaluation, however, amaranth flour darkened the chicken nuggets. Similarly, goat meat nuggets breaded with refined wheat flour were replaced with amaranth flour (1.5 and 3%). Addition of amaranth flour (3%) increases the dietary content and fat content compared with the control ($P > 0.05$), while moisture decreases in goat nuggets formulations. Treatment with amaranth flour at 3% had a low hunter color lightness value, however, high values for sensory parameters were obtained in amaranth meat products (Verma *et al*., 2019).

Factors to consider while incorporating amaranth into food products

The addition of amaranth to baked products is a good option to improve the nutritional composition of the food. Amaranth baked products improve the content of protein, lipids, fiber, zinc, manganese, magnesium, calcium, phenolic compounds, squalene, and antioxidant activity compared with wheat bread (Amare *et al*., 2016; Bodroza-Solarov *et al*., 2008; Chlopicka *et al*., 2012; Estivi *et al*., 2022). However, replacement of amaranth flour with cereal-based food products such as bread, cookies, and pasta represent a technological challenge. Supplementation of popped amaranth grain is the best option for increasing the rheological properties of food products and it could reduce phytates (Amare *et al*., 2016; Alvarez-Jubete *et al*., 2010; Islas-Rubio *et al*., 2014).

On the other hand, it is important to consider that while more concentration of amaranth in baked products, products could change their color, aroma, and flavor, caused by intrinsic compounds of this cereal at high temperatures producing a slightly pungent with bitter aftertaste (Adekunle, 2001).

Other potential applications

Other potential applications of Amaranth are tortillas. Amaranth tortillas could enhance the nutritional status of tortilla consumers. Adding 30% of amaranth to tortillas mix increases the protein and fiber. Furthermore, amaranth tortillas could have an effect as antihypertensive and hypoglycemic (Gamez-Valdez *et al*., 2020). Furthermore, incorporation of popped amaranth has become a trendy addition to various dishes, such as toppings for salads, desserts, yogurt, or as an ingredient in pop corns, energy bars and snack bars. Another way to add amaranth to food is into beverages, such as smoothies, shakes and plant-based milks.

Edible films are other use of amaranth flour due its functional and unique properties of their starch (smaller granular size, moderated viscosity, great paste, good gelatinization, and elastic properties (Chandla *et al*., 2016). On the other hand, oil amaranth looks promising with opportunities in food supplements, aroma industry, personal care, and pharmaceuticals. However, more research is needed to obtain better products in the market.

Amaranth seeds are an excellent ingredient to include in different food preparations due to their technological value as starch properties on low amylose content, slow starch retrogradation, high viscosity, and low gelatinization. Furthermore, amaranth grains possess emulsification property, high water-soluble index, and water absorption capacity. These properties could help in the good formulation of food products (Bender and Schönlechner, 2021).

Conclusions and Recommendations

Amaranth is a highly nutritious grain-like seed that has gained popularity in recent years as a superfood due to its many health benefits. Since amaranth is a complete protein source, it has all the important amino acids that the body requires. This grain has considerable amounts of vitamins and minerals, including calcium, iron, potassium, magnesium, and vitamins A, B, and C. It also has a high content of dietary fiber. Furthermore, amaranth facilitates variety and availability of bread, cookies, pasta, breakfast, beer, beef products, especially for consumers with celiac disease or gluten sensitivity. A notable concern about healthy eating is gradually increasing in the market for foods products with special purposes and has been driving force for the food industry to formulate or modify food preparations. Amaranth is an excellent choice to develop gluten-free food products with high nutritional quality ingredients.

Novelty Statement

A comprehensive review paper on the gastronomic potential of amaranth seeds covers an in-depth description of taxonomy, proximal composition, and phytochemical attributes for its suitability as a functional ingredient in gluten-free products.

Author's Contribution

Julieta M Lopez-Martinez: Conceptualization, writing-original draft.
Imran Ahmad: Review and editing.
Both authors have read and agreed to the published version of the manuscript.

Conflicts of interest
The authors have declared no conflict of interest.

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