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Quinoa and amaranth as functional foods: A review of their nutritional composition and applications in health-promoting diets

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Abstract

Amaranth and quinoa, two highly nutritious pseudocereal seeds, have garnered attention for their versatile applications in food products, particularly for individuals with gluten sensitivity, such as those with celiac disease. Both grains are rich in essential nutrients like proteins, dietary fibers, vitamins, and minerals, making them ideal candidates for enhancing the nutritional value of various foods. Their gluten-free nature allows them to be used as alternatives to wheat and other grains in a range of products, including bread, cookies, and breakfast cereals. Amaranth and quinoa are also incorporated into traditional dishes, particularly in Indian cuisine, and are increasingly being explored in plant-based meat substitutes. Additionally, quinoa can be used to create milk and tempeh, further expanding its utility in the food industry. The incorporation of quinoa and amaranth into food formulations not only improves the nutritional profile of the products but also offers potential health benefits, such as anti-inflammatory, anti-obesity, and antioxidant activities. This review highlights the growing potential of quinoa and amaranth as functional foods and their promising applications in the food industry.

Keywords: Amaranth, quinoa, pseudocereals, gluten-free, functional foods, celiac disease, anti-inflammatory, anti-obesity, antioxidant, nutritional value, dietary fibres, vitamins, minerals

Introduction

Agriculture's modernization and the ensuing globalization appear to be unabated, with negative consequences (such as the loss of biodiversity and health risks) being felt everywhere. These effects include monoculture practices that reduce genetic variety in the agriculture sector and biased technical improvements that only use a few energy-demanding plant species (Srujana *et al.*, 2019) ^[74]. As a result, achieving global food security is now extremely difficult due to factors including climate change, population growth, and the increased demand for agricultural products.

As a result, global food security largely depends on a small number of staple crops, particularly maize, rice, and wheat. These three cereals supply more than half of the world's total caloric intake. Historically, cereal grains have been a fundamental component of the human diet, with maize, wheat, and rice ranking as the most widely grown and consumed cereals worldwide (Zamaratskaia *et al.*, 2021) ^[94]. Despite being an essential part of many diets, these crops are deficient in critical micronutrients. Over 2 billion people are expected to be vitamin deficient globally as a result (FAOSTAT, 2020) ^[31], underscoring the concerning effects of their excessive reliance on grain crops.

In light of these challenges, government agencies, institutions, and researchers around the world are conducting research and disseminating information on the cultivation and use of underutilized, unexplored, and novel plant species, or "alternative crops" (Pirzadah & Malik, 2020) ^[60]. These efforts aim to address issues such as negative environmental effects (such as biodiversity loss, soil degradation, and erosion), as well as concerns about crop variety extinction.

Therefore, it is important to focus on the cultivation and use of underutilized crops, often regarded as crops of the 21st century, due to their impressive nutritional value. These crops offer promising benefits in terms of enhancing food security, improving public health and nutrition, generating income, and supporting sustainable environmental practices. However, their potential remains largely untapped.

Quinoa and amaranth are key examples of such crops. Commonly referred to as “ancient grains,” they are rich in high-quality protein, essential vitamins and minerals, and various bioactive compounds. In addition to their nutritional qualities, they are resilient to extreme environmental conditions such as drought, poor soil fertility, salinity, and frost, making them suitable for cultivation in arid and semi-arid regions. While the label “ancient grains” lacks a strict scientific definition, it generally applies to cereal-like plants that have remained relatively unchanged through centuries of traditional farming. Crops like amaranth, quinoa, and millets have recently gained increased attention from both researchers and health-conscious consumers (Taylor *et al.*, 2017) [82].

2. Overview of Amaranth and Quinoa

Quinoa and amaranth, both are an indigenous to the Andes and belong to the Amaranthaceae family. The botanical identity and historical background of these crops are closely related. For more than 5,000 years, people in Central and South America have consumed amaranth and quinoa seeds, which were vital to the diets of ancient societies, including the Aztec, Mayan, and Incan civilizations (Kojiol, 1992; Maurya *et al.*, 2018) [50]. Due to its remarkable nutritional richness, quinoa was dubbed the “mother grain” (Taylor *et al.*, 2002) [81], and the Inca people considered it a gift from their gods. Despite being a staple food along with potatoes and maize, the cultivation of quinoa and amaranth was restricted to a much smaller scale during the Spanish invasion, which also led to a decrease in their production and consumption (Berghofer *et al.*, 2002) [9].

Although quinoa and amaranth are often referred to as pseudo-cereals in botany—since they are dicotyledonous rather than monocots like true cereals—these seeds share many qualities with cereal grains. According to Mlakar *et al.* (2009) [54], amaranth seeds are lenticular, small (0.9-1.7 mm in diameter), and weigh between 0.6 and 1 g per 1,000 seeds. The seed coat can be pink, black, brown, gold, or white. While several species of amaranth are cultivated for their seeds and leaves, three species—*A. caudatus*, *A. cruentus*, and *A. hypochondriacus*—are most commonly grown for their seeds.

Quinoa (*Chenopodium quinoa*) is a yearly herbaceous plant that typically reaches a height of 1 to 2 meters and features a robust root system that extends deep into the soil. It produces small, round, and slightly compressed seeds, each about 1.5 mm in diameter, with approximately 350 seeds weighing around 1 gram (Varriano-Marston *et al.*, 1984) [86]. These seeds vary in both size and color, with black, red, and light yellow being the most widely recognized and cultivated types.

2.1 Ancient Grain Quinoa and Amaranth's Nutritional Value and Health Benefits

Ancient grain-rich crops, high in micronutrients and/or phytonutrients, are currently being neglected despite their nutritional value and historical significance as staple foods in many communities. These crops are primarily grown in a few niches within the global food chain. Millions of people worldwide depend on thousands of different plant species for food, medicine, fibre, fuel, and other essential resources needed for survival, health, and cultural traditions. Herbs have played a significant role in human history and continue to do so, from medicinal herbs like quinine and artemisinin

to staple crops like rice, wheat, and maize. Many of these plant species or crops are referred to as small, neglected, underutilized, or underexploited crops because they are primarily important on a local or regional scale (Meena, Gora, Singh, Ram, Meena, & Pratibha, 2022) [52].

Furthermore, due to their superior nutritional profiles compared to traditional cereals, quinoa and amaranth have gained global relevance in the nutraceutical industry, sparking increased interest in research on their potential applications in functional foods and nutraceuticals (Bhargava, Shukla, & Ohri, 2019) [10]. Celiac disease, which has an estimated mean prevalence of 1% of the general population, is one of the most common lifelong illnesses worldwide. The only recognized treatment for celiac disease is strict lifetime avoidance of gluten in the diet (Catassi & Fasano, 2008) [17]. According to Zevallos *et al.* (2014) [96], quinoa was well-tolerated and did not worsen celiac disease when incorporated into a gluten-free diet.

As gluten-free pseudocereal grains, quinoa and amaranth seeds have attracted significant attention due to their remarkable nutritional content and potential health benefits. Both quinoa and amaranth exhibit a high degree of genetic polymorphism, enabling them to adapt to a variety of environmental conditions in most of the world's arable regions, from tropical to temperate climates (Ruiz, *et al.*, 2014) [66].

2.1.1 Quinoa

The nutritional value of quinoa seeds is higher than that of most cereals (Matiacevich *et al.*, 2006). Quinoa seeds typically contain a greater protein content than conventional cereals like rice, wheat, and barley, ranging from 8% to 22%. Albumins and globulins make up the majority of the protein in pseudocereals like quinoa (44-77% of total protein), which is higher than that of prolamins (0.5-7.0%). Since quinoa has little to no prolamins, it is regarded as a gluten-free grain.

Quinoa's proximate composition varies, with crude fat ranging from 4.5% to 8.75%, ash content from 2.4% to 3.65%, carbohydrates from 54.1% to 64.2%, crude fibre from 2.1% to 4.9%, and protein from 10% to 18%. Due to the relatively higher levels of lysine, the first limiting amino acid, quinoa seeds have a superior amino acid balance compared to wheat or maize (Vilche *et al.*, 2003) [87]. The tiny granule-sized starch (< 1 micron) is the primary component of amaranth and quinoa (Caussette *et al.*, 1997) [18]. According to Comai *et al.* (2007) [21], 52-60% of the grain weight is made up of starch, and quinoa starch contains 7.1% amylose. Quinoa starch granules have 35.0% relative crystallinity (Tari & Singhal, 2002) [83].

Between 67% and 74% of the dry matter in quinoa is composed of carbohydrates, with starch making up 52% to 60%. Quinoa contains between 2% and 10% fat. Because the fatty acid contents of quinoa and soy oils are similar, quinoa provides a rich source of essential fatty acids, including linoleic acid (18:2n-6: 52%) and linolenic acid (18:3n-6: 40%) (Valencia-Chamorro, 2003) [85]. The whole quinoa seed and hulls contain relatively high concentrations of free fatty acids, which make up 18.9% and 15.4% of total lipids, respectively. The predominant portion, making up more than half of the neutral lipids, is triglycerides. Diglycerides account for 20% of the neutral lipid fraction and are found in the entire seed. Lys phosphatidylethanolamine is the most prevalent

phospholipid among those analyzed, accounting for 45% of all polar lipids.

Quinoa is also rich in minerals. Compared to other cereals, it has higher levels of calcium, magnesium, iron, and zinc, with iron content being especially high. Polishing and washing quinoa seeds result in a 12-15% decrease in the concentration of iron, zinc, and potassium, as well as a 27% loss of copper and a 3% loss of magnesium. Quinoa also has higher levels of α -tocopherol and riboflavin (B2) than wheat, barley, or rice (Michala *et al.*, 2009).

2.1.2 Amaranth

Proteins, which make up 14.0-16.5% of amaranth's nutritional value, are a significant class of biomacromolecules involved in physiological processes (Gorinstein *et al.*, 2002) [37]. About 40% of amaranth's proteins are albumins, 20% are globulins, 25% to 30% are glutelins, and 2-3% are prolamins (Schoenlechner *et al.*, 2008) [70]. Although amaranth protein is an excellent source of amino acids, leucine is present in slightly lower amounts compared to other cereals. This suggests that amaranth may need to be combined with other cereals to meet the recommended amino acid requirements (Becker *et al.*, 1981; Grobelnik *et al.*, 2009) [6, 39].

Amaranth starch is found in the perisperm, where amyloplasts produce characteristic compounded starch particles that can reach up to 90 μ m in diameter. Carbohydrates contribute 50-70% of dietary energy. According to Schoenlechner *et al.* (2010) [69], amaranth starch has a lower amylose percentage than other grain starches, ranging from 0.1% to 11.1%. Dodok *et al.* (1997)

[28] and Grobelnik *et al.* (2009) [39] report that between 75% and 77.1% of the fatty acids in amaranth oil are unsaturated. The most prevalent fatty acid in amaranth oil is linoleic acid (47.5-47.8%), followed by oleic acid (23.7-32.9%) and palmitic acid (12.3-20.9%) (Alvarez *et al.*, 2009; Bruni *et al.*, 2002) [1, 2, 13].

Furthermore, amaranth is a good source of riboflavin (0.19-0.23%) and ascorbic acid (4.50%). According to Becker's (1981) [6] analysis, the ascorbic acid levels in amaranth samples ranged from 3.36 to 7.24 mg/100 g. The levels of polyphenols in amaranth range from 14.72 to 14.91 mg/100 g. The hulls of grains and legumes contain high levels of tannins, which are polyphenolic secondary metabolites found in higher plants (Schoenlechner *et al.*, 2008) [70].

The Table No.1 represents the macronutrient composition of *Quinoa* and *Amaranth*, two pseudo-cereals known for their high nutritional value. The data includes the content of protein, fat, carbohydrates (CHO), ash, and crude fibre, expressed per 100 grams of dry weight. For each nutrient, a typical value, the reported range, and reference sources are provided. The values vary across different studies due to factors such as cultivar differences, environmental conditions, and analytical methods used. Overall, both grains demonstrate considerable nutritional potential, with amaranth showing relatively higher crude fibre content, while quinoa offers a balanced profile with a slightly higher carbohydrate content. The references cited include studies by Dini *et al.* (1992) [25], Copeland *et al.* (2009) [22], Koziol (1992) [46], Bressani *et al.* (2003) [12], and recent findings by Sattar *et al.* (2024) [68], among others.

Table 1: Macronutrients Quinoa, Macronutrients Amaranth

Macronutrients	Quinoa	Reference
Protein	13.7 9.5-16.7 16.5	(Dini A <i>et al</i> 1992) Copeland <i>et al</i> (2009) Koziol (1992) [22, 25, 46]
Fat	5-10 14.5 6.3	Copeland <i>et al</i> (2009) Dini A. <i>et al</i> (1992) Koziol (1992) [22, 25, 46]
CHO	61-74 65.7 69.0	Copeland 2009 Dini A <i>et al</i> (1992) Koziol (1992) [22, 25, 46]
Ash	3 3.5 3.8	Copeland <i>et al</i> (2009) Dini A <i>et al</i> 1992 Koziol (1992) [22, 25, 46]
Crude fibres	2-3 2.6 3.8	Copeland <i>et al</i> (2009) Dini A <i>et al</i> (1992) Koziol (1992) [22, 25, 46]
Macronutrients	Amaranth	Reference
Protein	13-18 12.5-17.6 14.6	Bressani <i>et al</i> (2003) Mburu, <i>et al</i> (2012) [51] Sattar M. <i>et al</i> (2024) [12, 68]
Fat	6.04 6-8 5.6-10	Sattar M. <i>et al</i> 2024 Bressani <i>et al</i> (2003) Mlakar <i>et al.</i> (2009) [12, 54, 68]
CHO	68.1 63 48-69	Sattar M. <i>et al</i> (2024) Bressani <i>et al</i> (2003) Mlakar <i>et al.</i> (2009) [12, 54, 68]
Ash	2.40 3-4 2.5-4	Sattar M. <i>et al</i> (2024) Bressani <i>et al</i> (2003) Mlakar <i>et al.</i> (2009) [12, 54, 68]
Crude fibres	4-14 3.1-5.0 6.7	Bressani <i>et al</i> (2003) Mlakar <i>et al.</i> (2009) Sattar M. <i>et al</i> 2024 [12, 54, 68]

3 Principal Bioactive Ingredients in Amaranth and Quinoa Seeds

The outer layers of quinoa and amaranth seeds contain the majority of the bioactive phytochemicals, which act as a chemical barrier against insects and microbes. The seed coats of quinoa and amaranth are rich in phenolic compounds, particularly phenolic acids. Phenolics are secondary metabolites in plants that contribute to various physiological effects. They are highly hydrophilic and include phenolic acids, flavonoids, and tannins. The extractables from these seeds have been the primary focus of phenolic characterization.

Research has reported two kaempferol glycosides and other free phenolics in the polar extract of quinoa (De Simone *et al.*, 1990). Recent studies have identified twenty-three phenolic compounds in quinoa seeds, both in free and conjugated forms. These include flavonoids such as quercetin and kaempferol, along with their glycosides, as well as phenolic acids like vanillic acid, ferulic acid, and their derivatives. Among these, ferulic acid-4-glucoside is the most abundant free phenolic compound, present at 132-161 mg/kg of quinoa seeds. The two most abundant extractable phenolics in conjugated forms are vanillic acid and ferulic acid, which are found at concentrations of 207-250 mg/kg in quinoa seeds.

In amaranth seeds, the percentage of extractable phenolic acids (in free, conjugated, and bound forms) varies from 7% to 14% of the total phenolic acids. The overall amount of phenolic acids in amaranth seeds ranges from 168 to 329 mg/kg. Phenolic acids, such as gallic acid, p-hydroxybenzoic acid, and vanillic acid, along with rutin, have been detected in amaranth seeds and sprouts (Woodhead *et al.*, 1974; Klimczak *et al.*, 2002; Pa'sko *et al.*, 2008) [44, 92]. The three main free phenolics found in amaranth seeds are gallic acid, protocatechuic acid, and p-hydroxybenzoic acid, with concentrations ranging from 11.0 to 440, 4.7 to 136, and 8.5 to 20.9 mg/kg dry seed, respectively. Following alkaline and enzyme hydrolysis, amaranth seeds were found to contain bound ferulic acids, primarily trans-ferulic acid (620 mg/kg) and cis-ferulic acid (203 mg/kg) (Bunzel *et al.*, 2005) [14].

3.1 Betalains

Betalains are nitrogen-containing pigments derived from tyrosine and L-3,4-dihydroxyphenylalanine (L-DOPA), and they are classified into two subgroups: red-violet betacyanins and yellow-orange betaxanthins. As a natural food coloring, betanin serves not only as a pigment but also as an effective scavenger of reactive oxygen species (ROS). This helps inhibit DNA damage and low-density lipoprotein (LDL) oxidation. Additionally, betanin stimulates phase II enzymes and enhances antioxidant defense mechanisms (Esatbeyoglu *et al.*, 2015) [30].

Among the primary betacyanins found in amaranth are isoamaranthine and amaranthine. Due to the lack of standard references for individual betanin and isobetanin, the total amounts of betanins in amaranth seeds (19 mg/kg) and quinoa seeds (1.5-61 mg/kg) have been determined using UV/Vis absorbance data (Repo-Carrasco *et al.*, 2010; Cai *et al.*, 2003) [15, 63].

3.2 Fatty Acids and Lipids

The primary lipophilic bioactives in amaranth and quinoa seeds were first studied by Wood *et al.* (1993) [91], who

analyzed the compositional aspects of lipophilic phytochemicals in quinoa. Unsaturated fatty acids (UFAs) make up the majority of the 9.7% fat content in quinoa seeds, comprising 84.83-89.42% of the total fat. Within the UFAs, polyunsaturated fatty acids (PUFAs) account for approximately two-thirds, while monounsaturated fatty acids (MUFA) make up the remaining third.

Amaranth seeds contain the primary fatty acids palmitic acid (21.4-23.8%), oleic acid (22.8-31.5%), and linoleic acid (39.4-49.1%). The total UFAs in amaranth oil range from 71.4% to 73.2% (Jahanval *et al.*, 2000). In comparison to cereal grains such as wheat (2.0%), rice (1.9%), millet (2.9%), corn (3.9%), and sorghum (3.3%), quinoa and amaranth seeds exhibit significantly higher lipid yields (Charalampopoulos *et al.*, 2002) [19].

Since the human body cannot synthesize linoleic, oleic, or linolenic acids, they are classified as essential fatty acids.

3.3 Tocopherols

Tocopherols and tocotrienols are homologs of vitamin E. All four forms of tocopherol have been identified in quinoa and amaranth seeds, with α -tocopherol (47-53 mg/kg DW) being the most prevalent, followed by β -tocopherol (17-26 mg/kg DW), and trace amounts of γ - and δ -tocopherols (<5 mg/kg DW) (Ruales *et al.*, 1993 [65]; Alvarez, 2009) [1, 2]. In amaranth seeds, the predominant tocopherols were α -tocopherol (1.40-31.6 mg/kg), γ -tocotrienol (0.53-43.86 mg/kg), δ -tocotrienol (0.06-8.69 mg/kg), and β -tocopherol (0.01-48.79 mg/kg) (Tang *et al.*, 2016 [76]; Lehmann *et al.*, 1994; Bruni *et al.*, 2002) [13, 48]. Quinoa seeds also contain trace amounts of tocotrienols and other vitamin E isomers (Tang *et al.*, 2015) [77]. According to Joana *et al.* (2013) and Ju *et al.* (2009), vitamin E analogs are potent antioxidants with several vital physiological roles, including anticoagulant, metabolic, inflammatory, and anticancer functions in humans.

3.4 Carotenoids

Carotenoids are well-known for their role as provitamin A precursors and potent antioxidants. They also play a key role in modulating cellular gene transcription, improving gap junction communication, inducing phase II enzymes, and enhancing immune functions. Additionally, carotenoids are crucial as photosensitizers in plants' photosynthesis process. In quinoa seed oils, total carotenoid content (TCC) varies from 1.69 to 17.61 mg/kg (Tang *et al.*, 2025; Prakash *et al.*, 1993 [61]; Bhargava *et al.*, 2007; Dini *et al.*, 2010) [11, 26]. The primary carotenoids identified in quinoa seeds include lutein (3.96-12.01 mg/kg), carotene (0.26-1.07 mg/kg), and zeaxanthin (0.31-5.37 mg/kg). Amaranth seeds, on the other hand, contain lower amounts of lutein (3.55-4.44 mg/kg) and zeaxanthin (0.14-0.30 mg/kg) (Tang *et al.*, 2016) [76].

4 Anti-nutritional Factors in Quinoa and Amaranth

4.1 Saponins and Phytates

The seeds of both amaranth and quinoa are rich in saponins, which are triterpenoids and glycosides of aglycones, or sapogenins. The total saponin concentration in quinoa seeds ranges from 6.27 to 692.49 mg/kg, whereas amaranth seeds have a much lower saponin content, ranging from 0.9 to 4.91 mg/kg (Yao *et al.*, 2014 [93]; Gomez *et al.*, 2012; Olezek *et al.*, 1999). According to studies (Mizui *et al.*, 1990; Ridout *et al.*, 1991 [64]; Dini *et al.*, 2001 [26, 53]; Woldemichael *et al.*, 2002; Villa *et al.*, 2014) [88, 90], quinoa

and amaranth seeds contain at least 16 and 6 saponins, respectively. These saponins can be categorized into three distinct subgroups, with aglycones such as oleanolic acid, hederagenin, or phytolaccagenic acid.

While certain saponins can form insoluble complexes with minerals like iron and zinc, impairing their intestinal absorption and bioavailability (Jancurov *et al.*, 2009), dietary saponins in typical consumption amounts are generally considered harmless and pose no significant health risks to humans (Oleszek *et al.*, 1999)^[56].

4.2 Phytic Acid

Quinoa and amaranth also contain varying amounts of myoinositol hexaphosphoric acid (phytic acid), with quinoa having 10.5-13.5 g/kg and amaranth containing 2.9-7.9 g/kg (DeRuiz *et al.*, 1990; Koziot *et al.*, 1992)^[23]. While these amounts are lower compared to other foods such as peanuts, rice (uncooked and unpolished), soy protein concentrate, sesame seeds (toasted), and unleavened maize bread (Kumar *et al.*, 2010)^[47], phytic acid still has the potential to form strong chelates with cations like calcium, magnesium, zinc, copper, iron, and potassium, resulting in insoluble salts known as phytates. These phytates can reduce the bioavailability and absorption of these essential minerals, thus negatively impacting the nutritional value of the seeds (Kumar *et al.*, 2010)^[47].

5 Health Benefits of Amaranth and Quinoa

5.1 Anti-inflammatory Activities

Quinoa has demonstrated significant anti-inflammatory effects in overweight postmenopausal women. After consuming quinoa flakes for four weeks, there was a reversal of elevated IL-6 levels, a pro-inflammatory cytokine, whereas those consuming corn flakes did not show this effect. This suggests that quinoa may help modulate inflammatory processes by lowering IL-6 levels in postmenopausal women (Carvalho *et al.*, 2015)^[16].

Similarly, amaranth has shown anti-inflammatory properties. A study with amaranth extract administered to mice showed increased levels of NO₃ and NO₂, while also inhibiting the formation of nitric oxide (NO) in macrophage-like cells (Liberal *et al.*, 2016)^[49]. Additionally, amaranth seed sprouts, rich in betacyanins and selenium, significantly reduced IL-6 levels and inhibited NF-κB translocation in RAW 264.7 macrophages, indicating anti-inflammatory effects (Tyszka-Czochara *et al.*, 2016)^[84]. These findings highlight the potential anti-inflammatory and nitric oxide-regulating properties of both quinoa and amaranth grains.

5.2 Anti-obesity and Anti-diabetic Activities

The prevalence of obesity and diabetes is rising globally. The Centers for Disease Control and Prevention report that 8.3% of Americans have diabetes, and over 600 million adults worldwide are obese (Association *et al.*, 2016; WHO, 2015). Amaranth and quinoa have been assessed for their potential in reducing the risk of type 2 diabetes and obesity. *In vitro* enzyme assays and a hyperglycemic mouse model have shown that quinoa and amaranth seeds exhibit antihyperglycemic, antihypertensive, and anti-obesity properties (Pasko *et al.*, 2011; Tang *et al.*, 2016)^[76]. Specifically, amaranth seeds have demonstrated the potential to prevent obesity and diabetes caused by fructose consumption. The amaranth grain and its oil component significantly lowered serum glucose levels and increased

insulin levels in diabetic rats (Tang *et al.*, 2017)^[75], suggesting that amaranth could be useful in managing hyperglycemia and preventing diabetic complications.

5.3 Antioxidant Activities

Amaranth and quinoa are excellent sources of antioxidants, including carotenoids and phenolics, which contribute to their anti-inflammatory, antiviral, and antioxidant properties (Dziki *et al.*, 2014)^[29]. Oxidative stress, caused by an imbalance between reactive oxygen species (ROS) and antioxidant defenses, is linked to various health conditions. Studies have shown that quinoa, particularly its free phenolic and polyunsaturated fatty acid (PUFA) fractions, exhibits potent antioxidant capacity. These fractions protected Caco-2 cells from oxidative damage induced by hydrogen peroxide (H₂O₂) and demonstrated a dose-dependent effect (Tang *et al.*, 2015)^[77].

5.4 Gluten-Free (Celiac Disease Safety)

Celiac disease (CD) is an autoimmune disorder triggered by the consumption of gluten, found in wheat, barley, and rye. Individuals with CD experience inflammation and damage to the small intestine's mucosal lining. Both quinoa and amaranth are highly nutritious pseudocereal grains that do not contain gluten, making them suitable alternatives for those with celiac disease. While some *in vitro* studies suggested that certain quinoa cultivars might trigger celiac-toxic epitopes in susceptible individuals, recent studies indicate that quinoa meets the Codex Alimentarius gluten-free standards (gluten < 20 mg/kg), making it safe for most celiac patients (Zevallos *et al.*, 2012; Bergamo *et al.*, 2011; Ballabio *et al.*, 2011)^[5, 8, 95].

An *in vivo* study on celiac patients also confirmed that quinoa can be safely incorporated into a gluten-free diet (GFD), as it did not exacerbate the condition (Zevallos *et al.*, 2014)^[97]. Therefore, quinoa and amaranth can be valuable dietary options for individuals with celiac disease, offering both nutritional benefits and gluten-free alternatives.

6. Utilization of Quinoa and Amaranth in Food

Due to their rich nutritional profiles, quinoa and amaranth seeds have attracted significant attention for use in various food products. These seeds can also serve as valuable supplements to other cereals, enhancing the overall nutritional value of food. In particular, quinoa and amaranth are gluten-free, making them ideal for individuals with celiac disease, wheat allergies, or gluten intolerance (Taylor *et al.*, 2002)^[81].

6.1 Gluten-Free and Bakery Products

Currently, gluten-free products are often considered low quality with limited nutritional benefits (Alvarez *et al.*, 2009; Alvarez *et al.*, 2010)^[1, 2, 3]. However, quinoa and amaranth offer a potential solution. Studies have explored replacing wheat flour with amaranth flour in baking. Sanz-Penella *et al.* (2013)^[67] evaluated the effects of substituting up to 40% of wheat flour with whole amaranth flour. The results showed a significant increase in proteins, dietary fibers, lipids, minerals, and phytates, though the ideal supplementation level for sensory acceptability was found to be 20 g/100 g flour. Despite challenges with gluten-free bakery products' technological quality, a study found that bread made entirely from amaranth, incorporating 60-70%

popped amaranth flour and 30-40% raw amaranth flour, was rated highly in terms of technological quality.

6.2 Indian Savory Dishes

Puffed amaranth grains and flour are integral components of various traditional Indian savory dishes. According to Spurthi *et al.* (2021) ^[73], amaranth flour was used in the preparation of murukulu, namkpara, khakra, and chuduwa, four classic Indian snacks. Among these, namkpara received the highest acceptance score, followed by chuduwa, murukulu, and khakra. These dishes highlight the versatility of amaranth in savory applications.

6.3 Amaranth in Cookies

Amaranth flour has also been incorporated into cookie recipes. A study by Sindhuja *et al.* (2005) ^[72] found that adding amaranth flour to cookie dough at levels ranging from 20% to 100% improved the cookies' spread and diameter while reducing hardness. Sensory evaluations indicated that 60% amaranth flour was the upper limit for achieving acceptable cookies in terms of texture and overall acceptability.

6.4 Quinoa in Various Food Forms

Quinoa can be used in numerous ways in the kitchen. It can be boiled in water to make infant cereals or used as a hot breakfast cereal or rice substitute. Additionally, quinoa seeds can be popped like popcorn or sprouted for use in salads after turning green (Valencia-Chamorro, 2003) ^[85]. Quinoa flour can be mixed with wheat or maize flour for a variety of baked goods. For instance, quinoa flour has been substituted in bread (10-13%), pasta (30-40%), and sweet biscuits (60%) with successful outcomes, producing high-quality products. Quinoa flour can also be extruded and drum-dried, which results in products with favorable sensory, nutritional, and physical qualities.

6.5 Tempeh Production from Quinoa

Quinoa can even be fermented into high-quality tempeh using *Rhizopus oligosporus* Saito in solid-state fermentation (Valencia-Chamorro, 2003) ^[85]. This opens the door for quinoa to be used as a plant-based protein source in fermented food products.

6.6 Plant-Based Meat Alternatives

Quinoa and amaranth are also being explored as sources of plant-based protein for vegan meat substitutes. Many current plant-based meat alternatives rely on wheat and soybean gluten, which may cause allergies in certain individuals. Felix *et al.* (2015) ^[33] demonstrated the creation of quinoa flour gels, which possess a texture similar to that of sausage, offering an innovative way to use quinoa in meat alternatives. The strength of the quinoa gel was influenced by both the concentration of quinoa flour and the gelation temperature.

6.7 Quinoa Milk

In addition to its use in food products, quinoa is also being developed as an alternative to dairy milk. Pineli *et al.* (2015) ^[59] investigated quinoa milk, finding that it contained half the protein of cow's milk and 5.66 times more protein than rice milk. Specifically, quinoa milk had a protein content of 1.7%, compared to 3.2% in cow's milk and 0.3% in rice

milk. This positions quinoa as a potential source of plant-based milk for individuals seeking dairy alternatives.

7 Conclusion

Amaranth and quinoa are not only highly nutritious but also versatile ingredients with significant potential for use in various food products. Their gluten-free nature makes them particularly beneficial for individuals with celiac disease or gluten intolerance. Both seeds can be incorporated into bakery products, snacks, breakfast cereals, and even plant-based meat alternatives, offering a wide range of culinary possibilities. Furthermore, the addition of quinoa and amaranth to food formulations enhances their nutritional value, providing a rich source of proteins, dietary fibers, essential fatty acids, vitamins, and minerals. Beyond their nutritional advantages, quinoa and amaranth also possess health-promoting properties, including anti-inflammatory, antioxidant, and anti-obesity activities. As research continues, these grains hold promise as functional foods that can contribute to better health outcomes while meeting the growing demand for gluten-free and plant-based alternatives in the food industry.

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