Chenopodium Quinoa: Nutritional Benefits, Disease Remedies, and Product Development Applications with Emphasis on Protein Supplementation

Muhammad Irfan[1], Sana Aslam[2], Syed Ashiq Hussain[3], Muhammad Mubashir Ramzan[1], Muhammad Muzamil[1], Eshrat Fatima[4], Muhammad Bilal Haider[5], Bisma Khaliq[1], Ghulam Murtaza[2], Madeeha Saeed[2]

[1]Faculty of Food Science and Nutrition, Bahauddin Zakariya University, Multan 60800, Pakistan.
[2]National Institute of Food Science and Technology, University of Agriculture Faisalabad, Pakistan.
[3]College of Food Science and Engineering, South China University of Technology, China.
[4]College of Horticulture, University of Poonch Rawalkot, AJK, Pakistan.
[5]Department of Food Science and Technology, Texas A&M University, Texas, United States.

Abstract: Chenopodium quinoa, widely known as quinoa, has gained global acclaim due to its remarkable nutritional profile and diverse health benefits. As a pseudocereal, quinoa stands out for its gluten-free, high-quality protein content and its starch-rich endosperm, making it an excellent food choice for individuals with various dietary restrictions. Quinoa seeds are loaded with essential macro and micronutrients, including vital amino acids, dietary fiber, minerals, and antioxidants. This review highlights quinoa's nutritional profile and its comparison with other protein rich foods and demonstrates its health benefits particularly its contributions to cardiovascular and gastrointestinal health, its role in reducing inflammation, and its potential anticancer properties. Moreover, quinoa's low glycemic index renders it particularly suitable for individuals with diabetes, further enhancing its appeal as a healthful food option. The review also examines quinoa's versatile applications in food product development, including its use in bakedgoods, snack bars, beverages, and dairy alternatives for lactose-intolerant consumers. This makes quinoa as a valuable ingredient within the food industry, appealing to health-conscious consumers seeking nutritious and functional foods. In conclusion, this review underscores quinoa's multifaceted benefits and its potential as a staple in modern diets, advocating for its broader inclusion in health-oriented food products.

Graphical Abstract

Keywords: Quinoa, Nutritional Profile, Health benefits, Gluten free, Food Product Development

1. Introduction

Quinoa (Chenopodium quinoa Willd.), native to the Andes of Bolivia, Chile, and Peru, has been a staple for ancient Andean civilizations for thousands of years and is often called "the Golden Grain" for its high nutritional value (Chaudhary et al., 2023). Quinoa is known for its high nutrition as it is full of protein and is often referred to as "the mother grain" (Nisar et al., 2017). Quinoa has higher protein content than most cereals and offers a more balanced profile of essential amino acids, making it a potential substitute for milk proteins. It is also rich in essential fatty acids, minerals, vitamins, dietary fiber, and carbohydrates with hypoglycemic properties, all while being gluten-free (Angeli, 2020). Furthermore, recent research shows that quinoa leaves are rich in protein and essential amino acids, while being low in carbohydrates. They also contain high amounts of manganese, potassium, copper, and moderate levels of calcium, sodium, phosphorus, and zinc (Adamczewska-Sowińska et al., 2021). Quinoa seeds contain high amounts of gluten-free protein of high-quality and contain a starch-rich endosperm, giving them characteristics similar to cereals. This is why quinoa is often classified as a pseudocereal. Its protein boasts substantial amounts of essential amino acids, and the seeds also provide a significant amount of antioxidants, minerals, and fiber (Vidueiros et al., 2015).

Quinoa is a multifunctional plant, prized for its edible and medicinal uses, and rich in a variety of functional components such as polysaccharides, saponins, proteins, flavonoids, polyphenols, and other bioactive substances (Ren et al., 2023). Quinoa, a nutrient-dense grain of South America, is globally recognized as a superfood for its medicinal benefits, including antidiabetic, antioxidant, antiobesity, and cardiovascular characteristics (Chaudhary et al., 2023; Pathan and Siddiqui, 2022).

Additionally, Quinoa is a rapidly gaining global crop, renowned for its superb-quality plant-based protein, containing around 16% protein on a dry weight basis. This resilient species, known for its ability to withstand various environmental stresses, boasts significant biodiversity and is being cultivated in regions far beyond its native Andean roots (Scanlin et al., 2017). Moreover, Quinoa, recognized as a phytoecdysteroid, provides numerous health benefits, including supporting protein synthesis and muscle growth. Its high content of essential amino acids and proteins offers it as a valuable natural supplement in bodybuilding. With these properties, quinoa is often included in fitness supplements to aid in muscle repair, development, and overall physical performance (Bastidas et al., 2016).

Research on quinoa has advanced its use in nutrition, cosmetics, and animal feed due to its bioactive compounds. Technological developments, including genetic improvements and post-harvest processing, make quinoa a valuable ingredient for enhancing food products with essential amino acids, particularly lysine (Flórez-Martínez et al., 2023). Quinoa can be good option to develop a diverse range of functional foods, offering additional health benefits due to its rich nutrient profile. It fits well within plant-based diets, catering to the increasing demand for dairy-free and gluten-free options while supporting a reduction in meat consumption. Quinoa-based products can also serve as energy-boosting foods, providing long-lasting energy from its high-quality carbohydrate and protein content. Additionally, quinoa aligns with the growing preference for natural, unprocessed foods, making it an ideal ingredient for health-conscious consumers (Angeli et al., 2020).

The goals of this review article are to explore the nutritional benefits of Chenopodium quinoa, focusing on its role as a valuable source of protein supplementation. It aims to explore the potential of quinoa in disease remedies and its applications in product development, highlighting its versatility in enhancing dietary quality. Additionally, the review seeks to examine current research on quinoa's functional properties and its implications for health and wellness in various culinary contexts.

2. Chemical Composition of Chenopodium Quinoa

Quinoa possesses a distinctive profile of amino acids, carbohydrates, lipids, and micronutrients, with many nutrient levels exceeding those found in traditional cereals. While much attention has been given to its macro- and micronutrient composition, the potential health benefits of quinoa's secondary metabolites may also a key contributor in supporting well-being of humans (Graf et al., 2015). Quinoa seeds are naturally gluten-free and packed with protein, vital amino acids, essential minerals, and key vitamins. Quinoa has experienced resurgence in the whole world due to its exceptional nutritional profile, medicinal properties, and abundance of bioactive compounds, earning it the title of "superfood." Its hardiness and superior nutrient profile position quinoa as a key contributor crop for ensuring food and nutritional security (Pathan et al., 2024).

Quantitative analysis revealed that quinoa's primary nutritional components include fat (4.4–8.8%). protein (10–18%) and starch. (32–60%). Fiber content ranges from 1 to 14%, while ash, primarily consisting of potassium and phosphorus, makes up 2 to 4% of the grain (Romano et al., 2020). Another study evaluated the proximate composition, antioxidant properties, and impacts of quinoa seed powder on diabetes affected rats. Quinoa seeds were rich in minerals like potassium (3441.95 mg/kg) and magnesium (1147.32 mg/kg), as well as vitamins such as B2, B6, B9, B12, E, and beta carotene. Total phenolic and flavonoid content measured 2.63 mg GAE/g and 0.53 mg CE/g, respectively. Antioxidant scavenging property was notable, and quinoa consumption reduced blood glucose levels in diabetic rats significantly. Histopathological analysis showed no pancreas damage in rats fed with QSP (AL-Sayed et al., 2019). The nutritional profile of quinoa varieties cultivated in Southern Europe was evaluated, focusing on protein content (15.6–18.7%) with a broad amino acid profile, with high amounts of lysine and arginine, and fatty acids especially unsaturated fatty acids like linoleic (58–61%), oleic (18–20%), and α-linolenic acid (6–8%). Mineral analysis revealed high levels of magnesium, phosphorus, potassium and, while sucrose was the main sugar. Saponin content remained low at ≤0.9%. Findings suggest these varieties align with known quinoa nutritional standards under Southern European conditions (Gómez et al., 2021).

Quinoa boasts higher protein, essential minerals, and fiber like calcium, potassium, and zinc, making it nutritionally superior, its lower carbohydrates and fat content also support weight management and balanced energy intake as presented in Table 1.

Table 1: Comparison between Nutritional Profiles of Cereals

Cereals	Quinoa	Barley	Oat	Rice	Maize	Wheat
Moisture (%)	8.20-10.13	10.34	13.3	12-14	12.8-29.0	7.1-12.5
Carbohydrates (%)	58.1-64.2	76.84	66.3	42	63-69	83-85
Fat (%)	2-10	2.67	7.5	3.5	4.5	2.15-2.55
Protein (%)	12.9-16.5	10.8-11.0	11.6	7.5-9.1	10.2-13.4	14.3-15.4
Minerals (%)	3.4	2.36	3.1	0.5	1.5	1.8
Fiber (%)	1.0-9.0	5.65	10.3	13	2.81	13
Thiamine mg/100 g	0.2-0.4	5.1	0.763	0.06	0.42	0.45
Riboflavin mg/100 g	0.2-0.3	1.8	0.139	0.06	0.1	0.49
Niacin mg/100 g	0.5-0.7	63.2	0.961	5.3	3.63	2.2
Potassium (mg/100g)	2.6	530	350	1.9	1.8	5.5
Calcium (mg/100g)	874	31.2-36.8	60	1.2	30	80
Zinc (mg/100g)	36	2.25- 2.66	3.8	5.0	2.049	2.93
Iron (mg/100g)	81	4.33-6.56	13.76	2.9	6.03	6.03
(Graf et al., 2015; Shewry and Hey, 2015; Kechkin et al., 2020; Ikhtiar and Alam. 2007; Castillo et al., 2019; Pathan et al., 2024; Butt et al., 2008; Angeli, et al 2020; Hussain et al., 2021; Lukinac and Jukić, 2022; Maboodurrahman and Birari, 2015; Lardy et al., 2018; Barnwal et al., 2012)						

3. Chenopodium Quinoa as a Remedy for Various Diseases

Quinoa is known for its exceptional nutritional profile, gluten-free nature, and therapeutic properties, offering potential nutraceutical advantages. Various research studies have emphasized the health-boosting effects of quinoa, which are primarily due to its bioactive peptides (BAPs), polysaccharides, unsaturated fatty acids, and particularly its rich content of phytochemicals (Xi et al., 2024). Quinoa has demonstrated antioxidant, antimicrobial, and anti-inflammatory effects, which are linked to promoting overall health. These properties offer potential protective benefits against various conditions, including diabetes, obesity, cardiovascular diseases, and even cancer (Brito et al., 2022) as presented in Figure. 1.

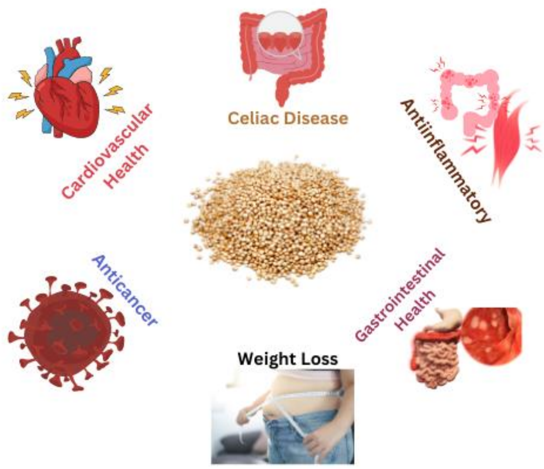

Figure 1: Therapeutic Potential of Quinoa

3.1. Antioxidant properties and their role in disease prevention:

Quinoa varieties show differences in their antioxidant potential. Among 25 yellow-seeded quinoa types, Temuco and Rainbow stood out as the best at neutralizing free radicals, while Baer and Temuco exhibited the strongest reducing power, highlighting their ability to give electrons to reactive oxygen species (ROS) (Sobota et al., 2020). A detailed comparative analysis of total sapogenins, saponins, flavonoids, polyphenols, and antioxidant activity in various quinoa plant parts revealed that the sprouts and roots contain the highest levels of phenolic acids and flavonoids. These bioactive compounds are primarily responsible for the stronger antioxidant activity observed in these parts compared to others (Lim et al., 2020).

3.2. Anti-inflammatory Properties:

Quinoa, renowned for its anti-inflammatory properties, is especially good for the people with celiac disorder and digestive issues because of its excellent gluten-free nature. This anti-inflammatory effect is largely contributed by its rich composition of bioactive compounds, including bioactive peptides (BAPs), polyphenols, polysaccharides, and saponins. Saponins, in particular, are recognized as the main anti-nutritional compounds in quinoa but also possess potent anti-inflammatory activity (Tang et al., 2017). Studies have shown that four different saponin ingredients separated from quinoa significantly decreased the production of nitric oxide (NO), a key inflammatory marker, and avoided the flow of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6) in lipopolysaccharide (LPS)-stimulated RAW264.7 cells. This dual action of saponins underpins quinoa's strong potential as an anti-inflammatory food source (Yao et al., 2014).

In a systematic review, studies on the effects of quinoa on inflammatory markers such as interleukin-6 (IL-6), interleukin-1β (IL-1β), and tumor necrosis factor-alpha (TNF-α) were analyzed using databases like PubMed and Scopus. Out of 20 eligible animal and in vitro studies, most reported significant reductions in these inflammatory factors following quinoa administration. Although quinoa shows potential in reducing inflammation, its effectiveness in treating systemic inflammatory diseases requires further confirmation (Mahdavi et al., 2023).

Another study investigated the effects of quinoa and corn flakes consumption on inflammatory markers and urinary enterolignans in overweight, postmenopausal women. In a double-blind trial, 34 women used 25 grams of quinoa and corn flakes alternatively for 4 weeks. Results indicated that quinoa intake significantly reduced interleukin-6 (IL-6) levels, a key marker of inflammation, suggesting quinoa's potential role in mitigating inflammation in postmenopausal women. The findings highlight quinoa's possible therapeutic value for addressing postmenopausal inflammatory conditions (Carvalho et al., 2015).

Another study focused on developing an anti-inflammatory diet (ITIS diet) tailored for rheumatoid arthritis (RA) patients to potentially alleviate symptoms like pain and joint swelling. Patients were surveyed on their dietary habits, supplement use, cooking methods, and ingredient intake. Based on their feedback, a diet rich in anti-inflammatory ingredients were designed, ensuring ease of adoption based on individual lifestyles (Bustamante et al., 2020).

3.3. Cardiovascular Health:

Excess weight, hypertension, and dyslipidemia are major CVD risk factors. Quinoa, rich in amino acids, unsaturated fats, fiber, and phytochemicals, shows potential for supporting heart health and reducing CVD risk, though its full effectiveness and underlying mechanisms need further exploration (Li et al., 2024).

In a study with six-week-old C57BL/6 male mice fed a 60% diet with high fat for thirteen (13) weeks, the group treated with 10 mg 20HE per kg daily showed 18% less weight gain and a 38% lower adipose to lean mass ratio compared to the control group. 20HE increased adiponectin expression 7.9-fold in visceral fat, improved insulin sensitivity, and reduced plasma insulin by 4.5-fold. It also lowered blood glucose levels within 60 minutes during a glucose tolerance test. Hepatocyte cultures revealed that 20HE reduced PEPCK and G6Pase expression via PI3K and increased AMPK expression (Kizelsztein et al., 2009).

The impact of quinoa bread on glycemic index, lipid profile, and biochemical parameters was examined in human subjects aged 20–50. Over a 3-month period, participants consumed quinoa bread daily, with TQ13 (20% quinoa flour and 3% wheat bran) chosen for examination. Results showed a significant reduction in blood glucose, triglycerides, total cholesterol, LDL, and VLDL levels, while the bread exhibited a low glycemic index (GI 42.00) compared to control (GI 69.20). Long-term quinoa bread consumption demonstrated functional benefits, particularly in improving lipid profiles (Marak et al., 2024).

3.4. Anticancer Properties:

Cancer, marked by uncontrolled cell growth, is a serious disease. Quinoa, rich in functional bioactive compounds, has shown promising potential as an adjunct in cancer management. Studies reveal that quinoa extracts can inhibit cancer cell viability, with earlier research demonstrating their ability to suppress the in vitro growth of human acute leukemia lymphocytes (Bhaduri, 2016).

A study investigating the effects of quinoa protein and its hydrolysate on an AOM/DSS-induced colorectal cancer (CRC) mouse model demonstrated that quinoa protein mitigated CRC symptoms and increased short-chain fatty acid (SCFA) production in colon tissues. Additionally, it partially alleviated gut microbiota dysbiosis by reducing pathogenic bacteria and enhancing probiotics. Functional analysis of the gut microbiota showed that the quinoa protein-treated group had a microbial profile closer to the control group. These results suggest that quinoa protein may ameliorate CRC through gut microbiota modulation (Fan et al., 2023).

Thirteen phenolic compounds were identified and quantified in both quinoa varieties (Puno and Titicaca quinoa), revealing differences in their profiles and concentrations. Both cultivars demonstrated cytotoxic effects on colorectal cancer cells, with Puno extracts showing a more significant concentration-dependent response. Overall, Puno and Titicaca quinoa extracts are rich in beneficial phenolic and flavonoid compounds, exhibiting strong antioxidant activity and notable anticancer effects against the HCT-116 human colorectal cancer cell line. This study highlights the health-promoting potential of these quinoa varieties cultivated in Serbia, marking the first documentation of their anticancer properties and the discovery of seven novel phenolic and flavonoid compounds (Stikić et al., 2023).

In an in vitro study, quinoa and safflower were assessed for their phytic acid level, fatty acid content and phenolic acid profile, along with their anticancer activities against liver cancer. The preventive effects of both seeds on non-alcoholic fatty liver disease were evaluated using 24 male rats. The study demonstrated that quinoa and safflower seed powders effectively improved liver function and lipid profiles in rats with non-alcoholic fatty liver disease induced by a high fructose diet. Both powders reduced lipid peroxidation, dyslipidemia, and liver damage, while quinoa also showed cytotoxic activity against the HepG2 cancer cell line. These results suggest the potential use of quinoa and safflower as protective dietary interventions for liver health (Mohamed et al., 2019).

3.5. Gastrointestinal Health:

Quinoa's potential in reducing dysbiosis and colitis caused by dextran sodium sulfate (DSS) was explored in mice. Quinoa consumption significantly alleviated clinical symptoms and reduced histological damage ($P < 0.05$), while also mitigating DSS-induced gut microbiota dysbiosis by increasing species diversity and controlling harmful bacterial overgrowth. Compared to the AIN-93M diet, quinoa preserved a healthier balance of Firmicutes and Bacteroidetes. Overall, quinoa shows promise as a dietary strategy for improving gut health and managing colitis (Liu et al., 2018).

In an in vivo study, effects of quinoa consumption in patients facing celiac disease were evaluated, as quinoa was suggested for a gluten-free diet (GFD) despite concerns about immune activation. Nineteen adult celiac patients incorporated 50g of quinoa daily into their GFD for six weeks, with no adverse gastrointestinal effects observed. Moreover, histological improvements were noted in villus-to-crypt ratio and intraepithelial lymphocyte counts, along with a mild reduction in cholesterol levels. Quinoa was well tolerated, but further studies are necessary to explore long-term safety (Zevallos et al., 2014).

This study examined quinoa's effects on intestinal permeability and inflammation compared to cholera toxin (CT) and capsaicin. Using Caco-2 cells and Brown Norway rats, quinoa increased intestinal permeability but showed different protein absorption patterns in various intestinal areas. Unlike CT and capsaicin, quinoa had a distinct impact on intestinal barrier function and protein uptake (Ballegaard et al., 2021).

Duodenal 16rDNA analysis revealed that treating with 1% quinoa quercetin promoted the growth of beneficial probiotic bacteria, decreased harmful E. coli, and increased the prevalence of the dominant bacterial phylum, Firmicutes, when compared to the control group. Moreover, the combination of 1% quinoa quercetin with 5% quinoa cellulose further enhanced intestinal health by increasing goblet cell production, which in turn raised mucin levels and strengthened the gut's protective barrier (Kim et al., 2010).

Various researches indicated that quinoa saponin, when hydrolyzed by intestinal flora, releases sapogenin, a process influenced by the initial composition of gut microbes. This initial microbial setup affects the sapogenin conversion. Additionally, quinoa saponins have been found to positively regulate intestinal flora in rats (Huang et al., 2024).

4. Vital Constituents of Quinoa

4.1. Protein content and amino acid profile:

Quinoa's protein content ranges from 12% to 22%, higher than rice corn (13.4%), barley (11%), and (7.5%). Protein quality depends on essential amino acids, which must come from the diet. Quinoa's protein composition differs from other cereals, as it contains glutelins (18%) and minimal prolamins (0.5–7%). Instead, its primary storage proteins are albumins (35%) and globulins (37%) which are balaced by S-S bonds (Dakhili et al., 2019).

Quinoa offers a highly favorable amino acid profile, providing essential amino acids (EAAs) necessary for increase in size and metabolism with their good availability. Notably, quinoa protein is abundant in histidine, lysine, and methionine, which are typically deficient in many other cereals. Additionally, it contains elevated levels of aspartic acid and glutamic acid, while proline and arginine are present in lower concentrations compared to common grains (Dakhili et al., 2019). One of previous researches on quinoa protein confirmed globulins as the primary proteins in quinoa seeds, making up 37%, followed by albumins at 35%, while prolamins are present in much smaller amounts, ranging from 0.5% to 7% (Abugoch et al., 2008).

The nutritional quality of Washington-grown quinoa was assessed, analyzing 100 samples for 23 amino acids and other key components. Results revealed that most samples met essential amino acid requirements set by WHO for all age groups, except for leucine in infants, with only 9 genotypes meeting the leucine requirement across all ages. While lysine and tryptophan requirements were met by 52 and 94 samples respectively, the study highlights leucine as a limiting amino acid in quinoa, underscoring the need for further research on genotype, environment, and management influences on its nutritional profile (Craine et al., 2020). Quinoa is a highly nutritious plant, famous for its high-quality protein, particularly rich in lysine. Its seeds contain 11S-type globulin (chenopodin) and 2S albumin, which together make up over 70% of the total protein, stabilized by disulfide bonds. With low prolamin content, quinoa is suitable for celiac patients. Its protein's nutritional and functional properties can be further enhanced through enzymatic, chemical, or physical modifications, making quinoa a valuable ingredient for human food products (Dakhili et al., 2019).

Table 2: Comparison of Amino Acid Composition with other Protein Sources:

Amino Acids	Phenylalanine	Isoleucine	Leucine	Lysine	Methionine	Threonine	Tryptophan	Valine
Quinoa	4.0	4.9	6.6	4.0	2.3	3.7	0.9	4.5
Rice	5.0	4.1	8.2	5.0	2.2	3.8	1.1	6.1
Wheat	4.7	4.0	12.5	4.7	2.0	3.8	0.7	5.0
Bean	4.8	4.2	6.8	4.8	1.4	2.8	1.2	4.4
Meat	5.4	4.5	8.1	5.4	1.2	3.9	1.1	5.0
Milk	4.1	5.2	8.2	4.1	2.5	4.4	1.2	5.5
FAO standard	1.4	10.0	6.5	1.4	2.5	4.7	1.4	7.0
(Filho et al., 2017)								

4.2.

Phytochemicals in Quinoa:

The two techniques employed to measure saponin content in the five quinoa genotypes revealed varying results. The spectrophotometry method based on the values from the physical extraction process, indicated saponin levels ranging from 0.4% to 4.9%. In contrast, the afrosimetric method showed much lower saponin levels, between 0% and 0.18% (Mora-Ocació et al., 2022).

20 phenolic compounds, including 13 phenolic acids and 7 flavonoids were identified in a study, with crimson and yellow quinoa seeds showing the raising levels. Crimson seeds were also richest in betalains, while yellow had the most saponins. Black quinoa exhibited the strongest iron-reducing and free radical scavenging abilities. The findings suggested that colored quinoa varieties are a rich source of phenolic compounds and antioxidants, making them valuable as antioxidant foods (Yang et al., 2024).

The total phenolic acid content in seeds was similar across samples, with quinoa seeds having the highest concentration at 490.2 mg/kg dry weight, predominantly gallic acid. Quinoa also contained significant flavonoids, including orientin (1076 mg/kg), vitexin (709 mg/kg), and rutin (360 mg/kg), along with smaller amounts of morin (88.9 mg/kg) and trace levels of hesperidin (1.86 mg/kg) and neohesperidin (1.93 mg/kg) (Paśko et al., 2008).

Research has shown that quinoa offers significant benefits for human metabolic, gastrointestinal and cardiovascular health (Navruz-Varli and Sanlier, 2016), as quinoa is an excellent source of numerous health-promoting phytochemicals such as phytosterols, saponins and phytoecdysteroids as presented in Figure. 2:

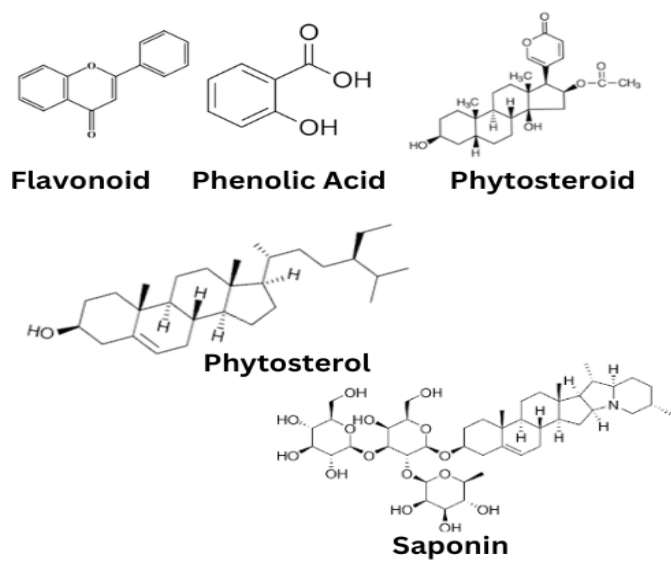

Figure 2: Phytochemicals in Quinoa

5. Impact of Quinoa Proteins on Health

Quinoa's low prolamin content makes it a valuable selection for people with celiac disorder, offering a valuable gluten-free alternative. The predominant protein in quinoa is 11S globulin, also called globular globulin, which has a hexameric configuration. It consists of six sets of small, basic polypeptides (22–23 kDa) paired with larger, acidic polypeptides (32–39 kDa). This unique structure adds to its functional benefits in gluten-free applications (Xi et al., 2024).

Due to allergies and intolerances related to common protein sources like milk and eggs, researchers have turned to plant-based alternatives such as quinoa protein (QP) and legumes. However, certain legumes contain gliadins and glutenins, which are linked to celiac disease. Quinoa, a pseudo-cereal with high protein content and minimal gluten, presents a promising alternative. Its protein can be extracted through methods like solubilization and precipitation, offering a viable substitute for animal-based proteins (Föste et al., 2015).

Bioactive peptides are known for their beneficial impact on various biological functions. While microorganisms are capable of breaking down bioactive peptides, protein peptides, in return, have been found to influence and regulate the chemistry and structure of number of microbes in the gut (Guo et al., 2021).

Quinoa proteins have emerged as a valuable source of peptides (bioactive). In a study on spontaneously hypertensive rats (SHR), quinoa protein treatment released bioactive peptide precursors, reduced blood pressure, and improved gut microbiota composition, making it more similar to non-hypertensive rats. The treatment also increased bacterial diversity and acted as a natural source of ACE-inhibitory peptides, helping to regulate hypertension and intestinal dysbiosis. These findings highlight quinoa's potential as a therapeutic agent for blood pressure management and gut health improvement (Guo et al., 2021).

Additionally, quinoa proteins and their hydrolysates were studied in an azoxymethane/dextran sulfate sodium (AOM/DSS) mouse model of colorectal cancer (CRC). The results indicated that quinoa proteins alleviated CRC symptoms by modifying intestinal flora and increasing short-chain fatty acids (SCFAs) in colonic tissues. Moreover, quinoa proteins were found to mitigate intestinal microbiota imbalances by reducing pathogenic bacteria and promoting the growth of probiotic strains. PICRUSt analysis showed that the functional traits of intestinal flora in the quinoa protein-treated group were comparable to the control group, highlighting quinoa's therapeutic potential in improving CRC-induced intestinal dysbiosis (Fan et al., 2023).

Quinoa protein-enriched flour significantly enhanced cecal microbial activity, along with the activities of enzymes such as α-glucosidase, β-glucosidase, and α-galactosidase, and boosted SCFA production in rats. This was accompanied by a reduction in the pH of digesta, indicating a positive influence on the growth and metabolic activity of intestinal microbiota (Fotschki et al., 2020). Moreover, another study examined the impact of quinoa seeds supplemented with protease and phytase, either separately or together, on microbial activity and gut health in broilers. Results showed that these enzyme supplements enhanced growth, improved gut morphology, and positively influenced gut flora. Specifically, the addition of protease and phytase increased Lactobacillus populations while decreasing E. coli levels. This effect was attributed to better protein digestion, improved amino acid availability, and the antimicrobial properties of protease supplement (Amiri et al., 2021).

6. Applications in Product Development

6.1. Use of quinoa in gluten-free products:

The prevalence of celiac disease and gluten sensitivity has been increasing significantly around the world. Additionally, the consumption of gluten-free products has surged even among individuals without intolerances, often driven by psychosocial influences. Biscuits, which are affordable and widely enjoyed baked goods, are consumed globally by a diverse range of people. However, the absence of gluten in these baked items can lead to undesirable qualities, including altered textures and flavors. The primary objective is to develop gluten-free food products that replicate the taste and texture of their gluten-containing counterparts. Furthermore, many gluten-free baked goods tend to be low in protein quality and dietary fiber. Quinoa stands out as a nutritious option, being rich in both total dietary fiber and high-quality protein (Bravi et al., 2024).

Gluten-free bread was developed using varying quinoa flour substitutions (0%, 15%, and 25%) and examined the impact of lipase and protease enzymes on its quality. The analysis included physicochemical and rheological properties, as well as microstructure and sensory evaluation. Findings indicated that incorporating quinoa flour enhanced the bread's overall quality, with lipase and protease improving volume, particularly in the 15% quinoa sample. Additionally, staling was delayed in the 25% quinoa substitution, which received the highest consumer acceptance scores (Azizi et al., 2020).

In another study, a gluten-free bread batter was developed using a blend of quinoa, lupin, and rice flours, with proportions of 41% quinoa flour, 29% rice flour, and 18% lupin flour. This formulation aimed to lower carbohydrate and lipid content while enhancing protein quality, particularly focusing on sulfur-rich amino acids like histidine and serine. Various flour mixtures and minor ingredients, such as gums and starches, were statistically analyzed. The results indicated that quinoa flour's water absorption and particle size played a key role in determining the bread's firmness and volume, while leavening agents and hydrocolloids, except HPMC, had minimal impact on loaf quality (Villa et al., 2020).

Various formulations using extruded and non-extruded quinoa flour, potato starch, tara gum, and protein isolates were tested. Results showed that quinoa flour, potato starch, and tara gum negatively impacted pasta firmness and cooking quality. Lupine flour alone could not fully replace egg white, but increasing its content to 12% improved the texture, particularly without tara gum. The final recipe, with 30% lupine flour, pea protein, and POx enzyme, resulted in gluten-free noodles with good quality, high protein, and fiber content (Linares-García et al., 2019).

Gluten-free pasta was produced by incorporating quinoa flour with different concentrations of chia seed flour (7.5%, 10%, 12.5%, 15%, and 17.5%), and the resulting quality traits were assessed to determine the ideal combination. The best-performing pasta's nutritional, color, and texture characteristics were then compared to those of standard durum wheat pasta. Results showed that pasta with 15% chia seed flour offered the best cooking performance and sensory appeal. Additionally, this optimized gluten-free pasta contained significantly higher ($p < 0.05$) levels of protein, fiber, minerals, phenolic compounds, and polyunsaturated fats than the control sample (Khatri et al., 2023).

The effect of quinoa white flour on gluten-free bread quality, particularly volume was assessed. Replacing 40-100% of rice and corn flour with quinoa white flour increased the bread's specific volume by 33%, due to higher α-glucosidase activity and glucose content. The enhanced dough aeration resulted in a finer crumb structure without affecting taste. Quinoa flour's properties make it a promising ingredient for improving gluten-free bread, benefiting individuals with celiac disease (Elgeti et al., 2014).

Quinoa flour was dissolved in water, rich in essential nutrients like proteins, starch, fiber, lipids, antioxidants, and minerals. The spray-drying process was optimized by adjusting inlet temperatures (150-180 °C) and feed flow rates (4.5-10.5 mL/min). Analyzing the powders for composition and properties, the best results were obtained at 180 °C and a 7.5 mL/min flow rate, yielding 85% powder with low water activity (0.047 ± 0.005) and high solids content (0.956 ± 0.005). The findings show that spray-drying preserves quinoa's nutritional qualities and enhances its functionality for use in food products (Romano et al., 2020).

Wheat bread enriched with quinoa flour (QF) of varying particle sizes and their effects on baking properties, texture, nutrition, and sensory qualities were assessed. Breads made with small QF particles improved water absorption, dough stability, and reduced firmness, while medium and large particles decreased protein weakening, dough extensibility, and Falling Number index. Nutritionally, quinoa-enriched breads saw up to 19% more protein, 15% more lipids, and significant increases in key minerals and amino acids. Sensory analysis favored medium QF, achieving the highest consumer score (8.70). These findings suggest quinoa flour can enhance both nutrition and sensory appeal in bread formulations (Coţovanu et al., 2023).

6.2.Fortification in food products:

Plant-based beverages, like quinoa-based drinks, face the challenge of high microbial contamination. Lactic acid fermentation using probiotic strains can enhance safety and probiotic content. In this study, white quinoa was pasteurized and fermented with Lactobacillus plantarum DSM 9843 at 30°C for 2 days, then stored for 28 days at 4°C. Post-fermentation, the pH dropped below 4, Enterobacteriaceae counts were undetectable, and Lactobacillus counts were high. Over storage, lactic acid levels remained stable, though Lactobacillus counts decreased. Enterococci growth, originating from quinoa, was a noted safety concern, suggesting the need for more active or antagonistic starter cultures (Paz et al., 2016).

To explore new and healthier applications for quinoa, a fermented beverage was created using two varieties: Rosada de Huancayo and Pasankalla. The study monitored fermentation, viscosity, acidity, and metabolic activity during production and storage, along with the drink's preliminary sensory acceptance. The beverage maintained a viable and stable microbiota throughout storage, with homolactic fermentation as the dominant process. While both quinoa types were suitable for fermentation, Pasankalla stood out for its higher protein content, lower saponin levels, and reduced viscosity loss, making it a more favorable choice for product development. These variety-based differences highlight their significant impact on food processing and final product quality, essential considerations for creating novel quinoa-based items (Urquizo et al., 2016).

In recent years, the demand for healthy foods has risen, particularly functional foods and beverages that offer health benefits. This study focuses on developing a probiotic quinoa beverage through enzymatic hydrolysis and lactic acid fermentation. Fermentation was conducted with varying concentrations of probiotic cultures and fermentation times, with optimal results achieved at 10% inoculum and 10 hours of fermentation. The final product contained 108 CFU/mL of probiotic microorganisms and was composed of 84.6 Kcal, 19.3 g of carbohydrates, and 1.4 g of protein per 100 g. This beverage promotes gut health and may help prevent chronic diseases (Castillo et al., 2023).

The study developed an instant-mix beverage using fermented quinoa with reduced phytate content and viable lactic bacteria. Two fermentation methods were tested: F1 involved fermenting roasted quinoa for 9 hours, while F2 used raw quinoa fermented for 6 hours, followed by drying, roasting, and an additional 3-hour fermentation. Both processes significantly reduced phytate levels (61.8% in F1 and 64.4% in F2), improving mineral absorption. Freeze-dried samples showed high microbial viability, and the pineapple-orange flavor with 5% fermented quinoa flour had the highest sensory acceptability. Overall, fermentation enhanced the nutritional and sensory qualities of the product (Ayub et al., 2021).

Three fermented plant-based beverages were prepared using varying quinoa-to-chickpea ratios and stored for 50 days to evaluate physicochemical and microbiological stability. A 50% quinoa-chickpea blend exhibited higher viscosity (18 Pa.s) and water-holding capacity (65%) during short-term storage, likely due to the amylose and amylopectin content in chickpea starch. However, after 50 days, this blend showed higher acidity, reduced viscosity (0.78 Pa.s), and lower LAB counts (~1×10^8 CFU/mL), indicating a negative long-term effect. These findings suggest that optimal plant flour ratios are crucial for maintaining stability over time, as starch and protein interactions influence both short- and long-term storage quality (Hurtado-Murillo et al., 2024).

6.3.Development of Quinoa Bars:

A cereal bar was formulated using organic quinoa, amaranth, chia seeds, nuts, and dried fruits, with seven prototypes tested for consumer preferences in flavor, sweetness, texture, and appearance. The most popular recipe included 9.1% puffed quinoa, 12.1% quinoa flakes, 6.1% puffed amaranth, 5.2% chia seeds, 12.1% dried cranberries, 15.2% macadamia nuts, 12.1% sunflower oil, 18.2% honey, 9.1% panela, and 0.8% agar-agar. Stability testing over 48 days at different temperatures revealed shelf life estimates of 35 days at 18 °C, 29 days at 25 °C, and 25 days at 37 °C, with peroxide value as the primary measure of quality retention. This product highlights the potential of quinoa-based snacks to boost organic food consumption in Colombia (Iuliano et al., 2019).

A novel quinoa-based probiotic snack was developed by incorporating spore-forming Bacillus coagulans at 0.3% and 0.35%, applied post-extrusion along with salt and oil. The probiotic snack's bacterial viability, resistance to gastric conditions, and quality were evaluated over 120 days at room temperature (20°C). Results showed the probiotic maintained viability above 10^7 CFU/g with a 70% survival rate in gastric simulations. No significant differences in sensory or physicochemical properties were noted compared to the control. Molecular analysis confirmed 98% identity with Bacillus coagulans, demonstrating its effectiveness and stability throughout storage (Huang et al., 2024).

Development of quinoa bars by combining different proportions of quinoa and defatted soy flour was performed. To address the bitter and beany flavors from anti-nutritional factors in quinoa and soybeans, the seeds were treated with sodium bicarbonate and citric acid, followed by drying and roasting. Various formulations were prepared with defatted soy flour levels ranging from 0% to 40%. The quinoa bar containing 20% defatted soy flour achieved the highest sensory score of 8.3 and provided a nutritional profile of 18.1% moisture, 14.5% protein, 2.14% fat, 62.1% carbohydrates, 1.5% ash, and 2.2% crude fiber, offering 325.6 kcal per 100g. The findings suggest that defatted soy flour can enhance the nutritional value of quinoa bars (Bawachkar et al., 2021).

6.4. Trends in the food industry and consumer demand for quinoa products:

The growing demand for nutritious foods and alternatives to dairy proteins is fueling interest in quinoa, a crop known for its high protein content, essential amino acids, fatty acids, vitamins, minerals, dietary fibers, and bioactive compounds. However, the nutrient content and bioavailability of quinoa are affected by various factors, including genotype, environmental conditions, and postharvest processing. Using bibliometric and scientometric methods, the study identifies key trends, scopes, and main topics within each area. The findings indicate a strong link between breeding efforts to create stress-tolerant quinoa varieties and the pursuit of functional compounds that enhance food safety and product value (Flórez-Martínez et al., 2023). The market is seeing a surge in dairy alternatives, particularly plant-based and hybrid products, with soy as the dominant ingredient. However, consumer demand for healthier, tastier, and more innovative options is expected to shift focus toward other plant sources. In this regard, the growing importance of allergy-friendly and gluten-free options positions quinoa as a strong contender to meet these criteria (Fernández-López et al., 2024).

7. Role of Quinoa as an Alternative Plant-based Protein Source

Quinoa is an emerging global crop recognized for its high-quality plant protein content, which is about 16% on a dry weight basis. This stress-tolerant species possesses significant biodiversity and is being cultivated in various regions beyond its native Andes. The main commercial product is polished whole quinoa seeds, while the outer hull, rich in saponins, is considered a waste by-product. Quinoa proteins are nutritionally superior to typical cereal proteins, which often lack lysine. While existing research focuses on quinoa protein, it primarily occurs in laboratory settings rather than in food-grade applications. Effective processing methods are necessary to create suitable protein concentrates or isolates for food use, but current high costs and processing challenges hinder progress. To successfully integrate quinoa protein concentrates and isolates into commercial food products, it is essential to have competitively priced seeds, acceptable yields, and marketable co-ingredients (Scanlin et al., 2024). Quinoa is a nutrient-dense pseudocereal known for its high bioavailable protein, micronutrients, and beneficial bioactive compounds. This study aimed to create a healthy, crispy, ready-to-eat snack bar using puffed quinoa and to evaluate its sensory properties. Quinoa seeds were treated with moisture and salt before being puffed in a hot air oven, resulting in three types of bars: sweet, spicy, and chocolate-coated. Sensory analysis, conducted by 30 semi-trained panelists using a 9-point hedonic scale, revealed that the spicy quinoa bar had a significantly higher texture rating ($p < 0.05$). However, the chocolate-coated bar excelled in overall acceptability, scoring an average of 7.83 for attributes like appearance, taste, odor, and flavor. This strong consumer preference indicates significant commercial viability for the chocolate-coated puffed quinoa bar (Subramani et al., 2020).

Emulsion gels are structured systems that function as soft solid-like materials and are widely utilized in food product development as fat replacers and carriers for bioactive compounds. Various plant-based proteins, such as those from soy, chia, and oats, have been incorporated into emulsion gels to replace fat in meat products and to deliver vegetable dyes or extracts. Although quinoa protein isolates have received limited attention in emulsion gel formulations, they present a promising option due to their high protein content, balanced amino acid profile, and excellent emulsifying and gelling properties. Notably, unlike quinoa starch, quinoa protein isolates do not require chemical modification for use (Lingiardi et al., 2022).

8. Conclusion

Quinoa stands out as a versatile crop with an impressive nutritional composition, rich in high-quality protein, essential amino acids, dietary fiber, minerals, and antioxidants. The established health benefits of quinoa—including improved cardiovascular health, anti-inflammatory properties, and support for gastrointestinal function—highlight its significance in a balanced diet. Furthermore, its gluten-free status and low glycemic index render it an ideal option for individuals with celiac disease and those managing diabetes, reinforcing its position as a valuable ingredient in a wide array of food products.

However, despite these benefits, there are still significant gaps in research concerning quinoa's bioactive compounds and their specific biological effects. Future investigations should prioritize comprehensive clinical trials to substantiate its health benefits and assess its potential in disease prevention. Moreover, improving cultivation practices and advancing innovative food processing techniques will be vital to enhance the availability of quinoa and facilitate its incorporation into various dietary patterns. As the market for functional foods continues to grow, addressing these research shortcomings will be essential for unlocking quinoa's full potential as a key player in health-oriented dietary solutions.

Conflict of Interest: Authors declare no conflict of interest.

Funding Source: None

Data Availability: Not Applicable

Authors Contributions: Muhammad Irfan: Conceptualization, Original Draft Writing, Review and Editing, Supervision; **Sana Aslam:** Writing, Review and Editing; **Syed Ashiq Hussain:** Writing, Review and Editing; **Muhammad Mubashir Ramzan:** Writing, Review and Editing; **Muhammad Muzamil:** Original Draft writing, Data Curation and Supervision, **Eshrat Fatima:** Writing, Review and Editing; **Muhammad Bilal Haider:** Writing, Review and Editing; **Bisma Khaliq:** Writing, Review and Editing; **Ghulam Murtaza:** Writing, Review and Editing; **Madeeha Saeed:** Writing, Review and Editing.

References

Abugoch, L. E., Romero, N., Tapia, C. A., Silva, J., & Rivera, M. (2008). *Journal of Agricultural and Food Chemistry*, 56(12), 4745–4750. https://doi.org/10.1021/jf703689u

Adamczewska-Sowińska, K., Sowiński, J., & Jama-Rodzeńska, A. (2021). The effect of sowing date and harvest time on leafy greens of quinoa (Chenopodium quinoa Willd.) yield and selected nutritional parameters. *Agriculture*, 11(5), 405. https://doi.org/10.3390/agriculture11050405

AL-Sayed, H. M., Zidan, N. S., & Abdelaleem, M. A. (2019). Nutritional applications of quinoa seeds (Chenopodium quinoa W.) and their effect on diabetic rats. *International Journal of Pharmaceutical Research and Allied Sciences*, *8*(4-2019), 23-36. Available online www.ijpras.com

Amiri, M. Y. A., Jafari, M. A., & Irani, M. (2021). Growth performance, internal organ traits, intestinal morphology, and microbial population of broiler chickens fed quinoa seed-based diets with phytase or protease supplements and their combination. *Tropical Animal Health and Production*, 53, 535. https://doi.org/10.1007/s11250-021-02980-0

Angeli, V., Miguel Silva, P., Crispim Massuela, D., Khan, M. W., Hamar, A., Khajehei, F., Graeff-Hönninger, S., & Piatti, C. (2020). Quinoa (*Chenopodium quinoa* Willd.): An Overview of the Potentials of the "Golden Grain" and Socio-Economic and Environmental Aspects of Its Cultivation and Marketization. *Foods (Basel, Switzerland)*, *9*(2), 216. https://doi.org/10.3390/foods9020216

Anwar, H., Habib, A., Taj, M. U., & et al. (2024). Phytochemical screening and antimicrobial potential of Chenopodium quinoa extract against pathogenic bacterial strains. Vegetos, 37(2), 585–595. https://doi.org/10.1007/s42535-023-00784-1

Ayub, M., Castro-Alba, V., & Lazarte, C. E. (2021). Development of an instant-mix probiotic beverage based on fermented quinoa with reduced phytate content. *Journal of Functional Foods*, 87, 104831. https://doi.org/10.1016/j.jff.2021.104831

Azizi, S., Azizi, M. H., Moogouei, R., & Rajaei, P. (2020). The effect of Quinoa flour and enzymes on the quality of gluten-free bread. *Food Science & Nutrition*, 8(5), 2373–2382. https://doi.org/10.1002/fsn3.1527

Ballegaard, A. S. R., Larsen, J. M., Rasmussen, P. H., Untersmayr, E., Pilegaard, K., & Bøgh, K. L. (2021). Quinoa (Chenopodium quinoa Willd.) seeds increase intestinal protein uptake. *Molecular Nutrition & Food Research*, 65(13), 2100102. http://dx.doi.org/10.1002/mnfr.202100102

Barnwal, P., Kadam, D. M., & Singh, K. K. (2012). Influence of moisture content on physical properties of maize. *International Agrophysics*, *26*(3). http://dx.doi.org/10.2478/v10247-012-0046-2

Bastidas, E. G., Roura, R., Rizzolo, D. A. D., Massanés, T., & Gomis, R. (2016). Quinoa (Chenopodium quinoa Willd), from nutritional value to potential health benefits: an integrative review. *Journal of Nutrition & Food Sciences, 2016, vol. 6, num. 3*. http://dx.doi.org/10.4172/2155-9600.1000497

Bawachkar, R. R., More, D. R., Alane, S. T., Praveen, B. R., & Swami, A. M. (2021). Studies on development, sensory evaluation and nutritional composition of quinoa bar. *Biological Forum – An International Journal*, 13 (2), 314-319. Retrieved from http://www.researchtrend.net

Bhaduri, S. (2016). An assessment of antioxidant and antiproliferative activities of super grain quinoa. *Food Processing & Technology*. http://dx.doi.org/10.4172/2157-7110.1000549

Bravi, E., Sileoni, V., & Marconi, O. (2024). Quinoa (Chenopodium quinoa Willd.) as functional ingredient for the formulation of gluten-free shortbreads. *Foods*, 13(3), 377. https://doi.org/10.3390/foods13030377

Brito, I. D. L., Chantelle, L., Magnani, M., & Cordeiro, A. M. T. D. M. (2022). Nutritional, therapeutic, and technological perspectives of quinoa (Chenopodium quinoa Willd.): A review. *Journal of Food Processing and Preservation*, 46(5), e16601. https://doi.org/10.1111/jfpp.16601

Bustamante, M. F., Agustín-Perez, M., Cedola, F., Coras, R., Narasimhan, R., Golshan, S., & Guma, M. (2020). Design of an anti-inflammatory diet (ITIS diet) for patients with rheumatoid arthritis. *Contemporary clinical trials communications*, *17*, 100524. https://doi.org/10.1016/j.conctc.2020.100524

Butt, M. S., Tahir-Nadeem, M., Khan, M. K. I., Shabir, R., & Butt, M. S. (2008). Oat: unique among the cereals. *European Journal of Nutrition*, 47, 68-79. http://dx.doi.org/10.1007/s00394-008-0698-7

Carvalho, A., Marchini, J., & Navarro, A. (2015). Quinoa or corn flakes to prevent peripheral inflammation after menopause?. *Journal of Obesity*, *1*(1), 8. This article is available in : http://obesity.imedpub.com/

Castillo, C. S. H., & Morales, J. G. J. (2023). Preparation of a probiotic quinoa beverage by enzymatic hydrolysis of its starches and subsequent lactic acid fermentation. *Vitae*, 30(2). https://doi.org/10.17533/udea.vitae.v30n2a352397

Castillo, C., García, G., Hernández, A., & Zamora, M. (2019). Proximate composition and energy value analysis of five varieties of malting barley. *International Journal of Food Sci and Biotechnology*, 4(2), 35. https://doi.org/10.11648/j.ijfsb.20190402.11

Chaudhary, N., Walia, S., & Kumar, R. (2023). Functional composition, physiological effect and agronomy of future food quinoa (Chenopodium quinoa Willd.): A review. *Journal of Food Composition and Analysis*, *118*, 105192. https://doi.org/10.1016/j.jfca.2023.105192

Coţovanu, I., Mironeasa, C., & Mironeasa, S. (2023). Nutritionally improved wheat bread supplemented with quinoa flour of large, medium, and small particle sizes at typical doses. *Plants*, 12 (4), 698. https://doi.org/10.3390/plants12040698

Craine, E. B., & Murphy, K. M. (2020). Seed Composition and Amino Acid Profiles for Quinoa Grown in Washington State. *Frontiers in Nutrition*, 7, 126. https://doi.org/10.3389/fnut.2020.00126

Dakhili, S., Abdolalizadeh, L., Hosseini, S. M., Shojaee-Aliabadi, S., & Mirmoghtadaie, L. (2019). Quinoa protein: Composition, structure and functional properties. *Food chemistry*, *299*, 125161. https://doi.org/10.1016/j.foodchem.2019.125161

Elgeti, D., Nordlohne, S. D., Föste, M., Besl, M., Linden, M. H., Heinz, V., ... & Becker, T. (2014). Volume and texture improvement of gluten-free bread using quinoa white flour. *Journal of Cereal Science*, 59(1), 41-47. https://doi.org/10.1016/j.jcs.2013.10.010

Fan, X., Guo, H., Teng, C., Yang, X., Qin, P., Richel, A., ... & Ren, G. (2023). Supplementation of quinoa peptides alleviates colorectal cancer and restores gut microbiota in AOM/DSS-treated mice. *Food Chemistry*, 408, 135196. https://doi.org/10.1016/j.foodchem.2022.135196

Fernández-López, J., Ponce-Martínez, A. J., Rodríguez-Párraga, J., & others. (2024). Quinoa and its co-products as ingredients for the development of dairy analogs and hybrid dairy products. *Current Food Science and Technology Reports*, 2 (319-331). https://doi.org/10.1007/s43555-024-00035-7

Filho, A. M. M., Pirozi, M. R., Borges, J. T. D. S., Pinheiro Sant'Ana, H. M., Chaves, J. B. P., & Coimbra, J. S. D. R. (2017). Quinoa: Nutritional, functional, and antinutritional aspects. *Critical reviews in food science and nutrition*, *57*(8), 1618-1630. http://dx.doi.org/10.1080/10408398.2014.1001811

Flórez-Martínez, D. H., Rodríguez-Cortina, J., Chavez-Oliveros, L. F., Aguilera-Arango, G. A., & Morales-

Castañeda, A. (2023). Current trends and prospects in quinoa research: An approach for strategic knowledge areas. *Food Science & Nutrition*, *12*(3), 1479–1501. https://doi.org/10.1002/fsn3.3891

Föste, M., Elgeti, D., Brunner, A. K., Jekle, M., & Becker, T. (2015). Isolation of quinoa protein by milling fractionation and solvent extraction. *Food and Bioproducts Processing*, *96*, 20-26. https://doi.org/10.1016/j.fbp.2015.06.003

Fotschki, B., Juśkiewicz, J., Jurgoński, A., Amarowicz, R., Opyd, P., Bez, J., et al. (2020). Protein-rich flours from quinoa and buckwheat favourably affect the growth parameters, intestinal microbial activity and plasma lipid profile of rats. *Nutrients*, 12(2781). https://doi.org/10.3390/nu12092781

Gómez, M. J. R., Prieto, J. M., Sobrado, V. C., & Magro, P. C. (2021). Nutritional characterization of six quinoa (Chenopodium quinoa Willd) varieties cultivated in Southern Europe. *Journal of Food Composition and Analysis*, *99*, 103876. https://doi.org/10.1016/j.jfca.2021.103876

Graf, B. L., Rojas-Silva, P., Rojo, L. E., Delatorre-Herrera, J., Baldeón, M. E., & Raskin, I. (2015). Innovations in Health Value and Functional Food Development of Quinoa (*Chenopodium quinoa* Willd.). *Comprehensive Reviews in Food Science and Food Safety*, *14*(4), 431–445. https://doi.org/10.1111/1541-4337.12135

Guo, H., Hao, Y., Fan, X., Richel, A., Everaert, N., Yang, X., et al. (2021). Administration with quinoa protein reduces the blood pressure in spontaneously hypertensive rats and modifies the fecal microbiota. *Nutrients*, 13(2446). https://doi.org/10.3390/nu13072446

Huang, H., Jia, C., Chen, X., Zhang, L., Jiang, Y., Meng, X., & Liu, X. (2024). Progress in research on the effects of quinoa (Chenopodium quinoa) bioactive compounds and products on intestinal flora. *Frontiers in Nutrition*, 11. https://doi.org/10.3389/fnut.2024.1308384

Hurtado-Murillo, J., Franco, W., & Contardo, I. (2024). Role of quinoa (Chenopodium quinoa Willd.) and chickpea (Cicer arietinum L.) ratio in physicochemical stability and microbiological quality of fermented plant-based beverages during storage. *Foods*, 13(15), 2462. https://doi.org/10.3390/foods13152462

Hussain, A., Ali, S., Hussain, A., Hussain, Z., Manzoor, M. F., Hussain, A., Ali, A., Mahmood, T., Abbasi, K. S., Karrar, E., Hussain, M., & Tajudin (2021). Compositional profile of barley landlines grown in different regions of Gilgit-Baltistan. *Food science & nutrition*, *9*(5), 2605–

2611. https://doi.org/10.1002/fsn3.2215

Ikhtiar, K., & Alam, Z. (2007). Nutritional composition of Pakistani wheat varieties. *Journal of Zhejiang University. Science. B*, *8*(8), 555–559. https://doi.org/10.1631/jzus.2007.B0555

Iuliano, L., Gonzalez, G., Casas, N., Moncayo, D., & Cote, S. (2019). Development of an organic quinoa bar with amaranth and chia. *Food Science and Technology*, 39(Suppl. 1), 218-224. http://dx.doi.org/10.1590/fst.25517

Kechkin, I. A., Ermolaev, V. A., Ivanov, M. V., Romanenko, A. I., & Gurkovskaya, E. A. (2020). Dependence of fat acidity value on wheat grain storage conditions. In BIO Web of Conferences (Vol. 17, p. 00107). *EDP Sciences*. http://dx.doi.org/10.1051/bioconf/20201700107

Khatri, M., Singh, A., Singh, R., Kamble, D. B., Dar, A. H., & Sharma, A. (2023). Optimization and evaluation of quinoa and chia based gluten free pasta formulation. *Food and Humanity*, *1*, 174-179.

Kim, Y. S., & Ho, S. B. (2010). Intestinal goblet cells and mucins in health and disease: Recent insights and progress. *Current Gastroenterology Reports*, 12(5), 319–330. https://doi.org/10.1007/s11894-010-0131-2

Kizelsztein, P., Govorko, D., Komarnytsky, S., Evans, A., Wang, Z., Cefalu, W. T., & Raskin, I. (2009). 20-Hydroxyecdysone decreases weight and hyperglycemia in a diet-induced obesity mice model. *American Journal of Physiology-Endocrinology and Metabolism*, 296(3), E433-E439. https://doi.org/10.1152/ajpendo.90772.2008

Lardy, G. P., Bauer, M. L., Swanson, K. C., & Zwinger, S. F. (2018). Barley grain and forage for beef cattle (AS 1609). *North Dakota State University*. https://www.researchgate.net/publication/325654077

Li, L., Lietz, G., & Seal, C. J. (2024). Effects of Quinoa Intake on Markers of Cardiovascular Risk: A Systematic Literature Review and Meta-Analysis. *Food Reviews International*, *40*(1), 1-19. https://doi.org/10.1080/87559129.2022.2148689

Lim, J. G., Park, H. M., & Yoon, K. S. (2020). Analysis of saponin composition and comparison of the antioxidant activity of various parts of the quinoa plant (Chenopodium quinoa Willd.). *Food Science & Nutrition*, *8*(1), 694-702. https://doi.org/10.1002/fsn3.1358

Linares-García, L., Repo-Carrasco-Valencia, R., Glorio Paulet, P. et al. Development of gluten-free and egg-free pasta based on quinoa (Chenopdium quinoa Willd) with addition of lupine flour, vegetable proteins and the oxidizing enzyme POx. *European Food Research*

Technology, 245, 2147–2156 (2019). https://doi.org/10.1007/s00217-019-03320-1

Lingiardi, N., Galante, M., de Sanctis, M., & Spelzini, D. (2022). Are quinoa proteins a promising alternative to be applied in plant-based emulsion gel formulation?. *Food Chemistry*, 394, 133485. https://doi.org/10.1016/j.foodchem.2022.133485

Liu, W., Zhang, Y., Qiu, B., Fan, S., Ding, H., & Liu, Z. (2018). Quinoa whole grain diet compromises the changes of gut microbiota and colonic colitis induced by dextran Sulfate sodium in C57BL/6 mice. *Scientific Reports*, *8*(1), 14916. https://doi.org/10.1038/s41598-018-33092-9

Ludena Urquizo, F. E., García Torres, S. M., Tolonen, T., Jaakkola, M., Pena-Niebuhr, M. G., von Wright, A., Repo-Carrasco-Valencia, R., Korhonen, H., & Plumed-Ferrer, C. (2016). Development of a fermented quinoa-based beverage. *Food Science & Nutrition*, 5(3), 602–608. https://doi.org/10.1002/fsn3.436

Lukinac, J., & Jukić, M. (2022). Barley in the production of cereal-based products. *Plants*, *11*(24), 3519. http://dx.doi.org/10.3390/plants11243519

Maboodurrahman, & Birari, S.S. (2015). Sensory and Analytical Study of Oats Chocolate Chips.

Malek Mahdavi, A., Javadivala, Z., Khalili, Y., & Khalili, M. (2023). Effects of Quinoa (Chenopodium quinoa) on inflammatory mediators: a systematic review of preclinical studies. *Inflammopharmacology*, *31*(1), 241-251. http://dx.doi.org/10.1007/s10787-022-01091-y

Mohamed, D. A., Fouda, K. A., & Mohamed, R. S. (2019). In vitro Anticancer Activity of Quinoa and Safflower Seeds and Their Preventive Effects on Non-alcoholic Fatty Liver. *Pakistan Journal of Biological Sciences*: PJBS, 22(8), 383-392. http://dx.doi.org/10.3923/pjbs.2019.383.392

Mora-Ocación, M. S., Morillo-Coronado, A. C., & Manjarres-Hernández, E. H. (2022). Extraction and quantification of saponins in quinoa (Chenopodium quinoa Willd.) genotypes from Colombia. International Journal of Food Science, 2022(1), 7287487. https://doi.org/10.1155/2022/7287487

Navruz-Varli, S., & Sanlier, N. (2016). Nutritional and health benefits of quinoa (Chenopodium quinoa Willd.). *Journal of Cereal Science*, *69*, 371-376.https://doi.org/10.1016/j.jcs.2016.05.004

Nisar, M., More, D. R., Zubair, S., & Hashmi, S. I. (2017). Physico-chemical and nutritional properties of quinoa seed: A review. *Journal of Pharmacognosy and Phytochemistry*, 6(5), 2067-2069. Availabe online at https://www.phytojournal.com

Paśko, P., Sajewicz, M., Gorinstein, S., & Zachwieja, Z. (2008). Analysis of selected phenolic acids and flavonoids in Amaranthus cruentus and Chenopodium quinoa seeds and sprouts by HPLC. *Acta chromatographica*, 20(4), 661-672. http://dx.doi.org/10.1556/AChrom.20.2008.4.11

Pathan, S., & Siddiqui, R. A. (2022). Nutritional composition and bioactive components in quinoa (Chenopodium quinoa Willd.) greens: A review. *Nutrients*, 14 (3), 558. https://doi.org/10.3390/nu14030558

Pathan, S., Ndunguru, G., & Ayele, A. G. (2024). Comparison of the nutritional composition of quinoa (Chenopodium quinoa Willd.) inflorescences, green leaves, and grains. *Crops, 4*(1), 72-81. https://doi.org/10.3390/crops4010006

Paz, P. C., Janny, R. J., & Håkansson, Å. (2020). Safeguarding of quinoa beverage production by fermentation with Lactobacillus plantarum DSM 9843. *International Journal of Food Microbiology*, *324*, 108630. https://doi.org/10.1016/j.ijfoodmicro.2020.108630

Ren, G., Teng, C., Fan, X., Guo, S., Zhao, G., Zhang, L., ... & Qin, P. (2023). Nutrient composition, functional activity and industrial applications of quinoa (Chenopodium quinoa Willd.). *Food Chemistry*, 410, 135290. https://doi.org/10.1016/j.foodchem.2022.135290

Romano, N., Ureta, M. M., Guerrero-Sánchez, M., & Gómez-Zavaglia, A. (2020). Nutritional and technological properties of a quinoa (Chenopodium quinoa Willd.) spray-dried powdered extract. *Food Research International*, 129, 108884. https://doi.org/10.1016/j.foodres.2019.108884

Scanlin, L., Lewis, K. A., & Dugger, P. (2024). Quinoa as a sustainable protein source: Production, nutrition, and processing. In Sustainable protein sources (pp. 381-398). *Academic Press.* http://dx.doi.org/10.1016/B978-0-12-802778-3.00014-7

Shewry, P. R., & Hey, S. J. (2015). The contribution of wheat to human diet and health. *Food and energy security*, *4*(3), 178–202. https://doi.org/10.1002/fes3.64

Sobota, A., Świeca, M., Gęsiński, K., Wirkijowska, A., & Bochnak, J. (2020). Yellow-coated quinoa (Chenopodium quinoa Willd)–physicochemical, nutritional, and antioxidant properties. *Journal of the Science of Food and Agriculture*, *100*(5), 2035-2042. https://doi.org/10.1002/jsfa.10222

Stikić, R. I., Milinčić, D. D., Kostić, A. Ž., Jovanović, Z. B., Gašić, U. M., Tešić, Ž. L., ... & Pešić, M. B. (2020). Polyphenolic profiles, antioxidant, and in vitro anticancer activities of the seeds of Puno and Titicaca quinoa cultivars. *Cereal*

Chemistry, 97(3), 626-633. https://doi.org/10.1002/cche.10278

Subramani, D., Tamilselvan, S., Murugesan, M., & Shivaswamy, M. S. (2020). Development of snack bars from puffed quinoa and its sensory evaluation. *International Journal of Food Sciences and Nutrition*, 5, 30-33. http://dx.doi.org/10.1002/mnfr.202100102

Tang, Y., & Tsao, R. (2017). Phytochemicals in quinoa and amaranth grains and their antioxidant, anti-inflammatory, and potential health beneficial effects: a review. *Molecular Nutrition & Food Research*, *61*(7), 1600767. https://doi.org/10.1002/mnfr.201600767

Vidueiros, S. M., Curti, R. N., Dyner, L. M., Binaghi, M. J., Peterson, G., Bertero, H. D., & Pallaro, A. N. (2015). Diversity and interrelationships in nutritional traits in cultivated quinoa (Chenopodium quinoa Willd.) from Northwest Argentina. *Journal of Cereal Science*, *62*, 87-93. https://doi.org/10.1016/j.jcs.2015.01.001

Villa, P. M., Cervilla, N., Mufari, R., Bergesse, A., & Calandri, E. (2020). Making nutritious gluten-free foods from quinoa seeds and its flours. Proceedings, 53(1), 5. https://doi.org/10.3390/proceedings2020053005

Xi, X., Fan, G., Xue, H., Peng, S., Huang, W., & Zhan, J. (2024). Harnessing the potential of quinoa: Nutritional profiling, bioactive components, and implications for health promotion. Antioxidants, 13(7), 829. https://doi.org/10.3390/antiox13070829

Yang, C., Zhu, X., Liu, W., Huang, J., Xie, Z., Yang, F., ... & Wei, Y. (2024). Quantitative analysis of the phenolic compounds and antioxidant activities of six quinoa seed grains with different colors. *LWT*, 203, 116384. https://doi.org/10.1016/j.lwt.2024.116384

Yao, Y., Yang, X., Shi, Z., & Ren, G. (2014). Anti-inflammatory activity of saponins from quinoa (Chenopodium quinoa Willd.) seeds in lipopolysaccharide-stimulated RAW 264.7 macrophages cells. *Journal of Food Science*, *79*(5), H1018-H1023.

Youssef, Nassar, A., Fishawy, F.A., & Mostafa, M.A. (2017). Assessment of Proximate Chemical Composition and Nutritional Status of Wheat Biscuits Fortified with Oat Powder.

Zevallos, V. F., Herencia, L. I., Chang, F., Donnelly, S., Ellis, H. J., & Ciclitira, P. J. (2014). Gastrointestinal effects of eating quinoa (Chenopodium quinoa Willd.) in celiac patients. *The American Journal of Gastroenterology*, 109(2), 270–278. https://doi.org/10.1038/ajg.2013.431

Authors

First Author – Muhammad Irfan, M.Phil., Bahauddin Zakariya University, Multan, Pakistan

2nd Author – Sana Aslam, B.Sc. (Hons.), University of Agriculture, Faisalabad, Pakistan

3rd Author– Syed Ashiq Hussain, M.Phil., South China University of Technology, China

4th Author– Muhammad Mubashir Ramzan, M.Phil., Bahauddin Zakariya University, Multan, Pakistan

5th Author– Muhammad Muzamil, M.Phil., Bahauddin Zakariya University, Multan, Pakistan

6th Author– Eshrat Fatima, M.Phil., University of Poonch Rawalakot, AJK

7th Author– Muhammad Bilal Haider, PhD, Texas A&M University, Texas, United States

8th Author– Bisma Khaliq, M.Phil., Bahauddin Zakariya University Multan, Pakistan

9th Author– Ghulam Murtaza, B.Sc. (Hons.), University of Agriculture Faisalabad, Pakistan

10th Author– Madeeha Saeed, M.Phil., University of Agriculture Faisalabad, Pakistan

Correspondence Author – Muhammad Irfan, M.Phil., Bahauddin Zakariya University, Multan, Pakistan