

REVIEW

A COMPREHENSIVE REVIEW OF QUINOA (CHENOPODIUM QUINOA): ITS NUTRITIONAL VALUE, PHYTOCHEMICAL COMPOSITION, FOOD APPLICATIONS AND HEALTH ADVANTAGES

Manish^{1,*}, Shiv Kumar¹, Namrata¹, Ravi Kumar²

¹Institute of Food Technology, Bundelkhand University, Jhansi (U.P.) India

²Institute of Engineering and Technology (Department of Food Technology), B.U. Jhansi (U.P.) India

ABSTRACT

Quinoa (*Chenopodium quinoa*) is a pseudo-cereal crop native to the Andean regions of Bolivia and Peru in South America known as the "Golden Grain." It is a highly nutritious and gluten-free cereal, containing essential fatty acids, minerals, vitamins and dietary fiber. Despite the fact being gluten-free and low glycemic index, it also have an excellent distribution of essential amino acids. Among cereals, quinoa is unique because it has an enormous quantity of lysine, an amino acid that is absent in most of the other grains. As a member of the Amaranthaceae family and the genus *Chenopodium*, quinoa exhibits various therapeutic properties, including anticancer, antiviral, antifungal, hypocholesterolemic, anti-inflammatory, hypoglycemic and antithrombotic activities. It has also demonstrated antioxidant, antihypertensive and antidiabetic effects, making it a valuable component for nutraceuticals and therapeutic foods. Quinoa can help alleviate conditions such as osteoporosis in women, anemia, obesity and celiac disease. This gluten-free grain is easy to cook, versatile in preparation and can be cultivated in different environments. It is enriched with various phytochemicals, including polyphenols, flavonoids, phytic acid, oxalates and tannins. Quinoa can be incorporated into daily diets in the form of bread, cookies, pasta and salads for a healthy lifestyle.

KEYWORDS:

Gluten-free, Health benefits, Healthy food, Mother grain, Pseudo cereal, Quinoa, Phytochemical

INTRODUCTION

Archaeological evidence suggests that Quinoa (*Chenopodium quinoa*) originated between 5,000 and 7,000 years before in the Andean region of Bolivia and Peru. Quinoa is an ancient pseudocereal that was domesticated in the Andean region several

millennium ago. It is referred to by various local names in different regions. In Quechua (one of the indigenous languages spoken in the Andean regions of Bolivia and Peru), it is simply called "quinoa" [1]. The National Academy of Sciences of the United States has classified quinoa as one of the "golden grains" due to its exceptional nutritional value. Recognizing its potential benefits, NASA has incorporated quinoa into the diet of astronauts [2]. Grains of the *Chenopodium quinoa* plant is famed as "Mother Grain" and is considered a gift from the Gods, utilized to cure health problems [1]. Quinoa is considered as a superfood because of its out of the common nutritive quality. But in reality, it is not a true grain or cereal. Rather, it is categorized as a pseudo-grain or pseudo-cereal, which means that although it is a member of a different plant family, it shares many of the same characteristics and applications as grains. Quinoa's high-quality protein content makes it an incredibly salubriousness food. Because of its remarkable nutritional profile, it is recognized as a "complete food" [3]. With the increasing global population and need of sustainable and nutritious food sources, quinoa has gained attention as a potential solution of food insecurity due to its bizarre alimentary value and adaptability to grow in marginal environments [1].

Additionally, quinoa holds cultural significance as it has been cultivated for thousands of years in the Andean region of South America by indigenous communities, and its revival and promotion as a global food crop can help preserve traditional agricultural practices and support rural economies [4]. Quinoa is a very healthy food and it has been promoted as such in the past few years because of its high nutritional value and Food Security potential [5]. As the only plant that satisfies all nine requirements for essential amino acids, quinoa has gained superfood status because of its impressive protein levels.. [2]. It is filled with dietary fibre, minerals like iron, magnesium, and zinc; vitamins such as B & E along with a powerful antioxidant. Being gluten-free itself, Quinoa aids those with Celiac Disease or gluten intolerance [6]. Quinoa is a versatile crop

that thrives in diverse environmental conditions, including poor soils, drought-prone areas, and high altitudes, making it valuable for regions facing climate change challenges [7]. With its mild, nutty flavor and rich nutritional profile, quinoa serves as both a popular gluten-free ingredient in global cuisines and a sustainable food source that can be prepared in various ways to support good health [8].

The main objective of this review is to summarize the latest literature to achieve a clear view of quinoa regarding its nutritional values and plant-derived physio pharmaceutical bioactive molecules to deal with different health problems. The article will also review the presence of anti-nutritional factors in quinoa as well as explore the various quinoa-based food products available. This review highlights quinoa's exceptional qualities as a highly nutritious, gluten-free pseudocereal with numerous health-promoting attributes. Additionally, it aims to showcase quinoa's versatility in diverse food preparations and its potential as a valuable component for nutraceuticals and therapeutic foods, ultimately advocating for its wider adoption as a functional and healthful food ingredient.

BIOLOGICAL CHARACTERISTICS

A pseudocereal grain with significant nutritional value and biological properties, quinoa (*Chenopodium quinoa*) stands out among other grains. It is a complete protein, defining it as having all nine essential amino acids making this grain an excellent source of high-quality nutrition [5]. Quinoa is gluten-free by nature, which means it can be eaten comfortably by people with celiac disease or their own gluten sensitivity [5]. Bioactive compounds such as phenolic constituents, phytosterols, flavonoids, and saponins have been implicated in the antioxidant and anti-inflammatory activities of quinoa [2,9,10,11]. Quinoa also has some health-related benefits as well like better glycemic control, chances lowered of getting cardiovascular diseases but more research is still in the way for support [2,5,12]. With its low glycaemic index, quinoa is a suitable option for people with diabetes or those who may develop the disease because it can assist in stabilizing blood sugar levels [8,14]. Quinoa has cholesterol-lowering potential because it contains a high fiber, antioxidants, and

plant sterols content that can be useful for cardiovascular health and prevent heart diseases by lowering the levels of serum lipids [5,15]. Saponins and phytosterols play an important role in the quinoa's biochemical properties, such as antimicrobial activity (against bacteria and fungus) [5,16].

PLANT TRAITS

Quinoa (*Chenopodium quinoa*) belongs to the pseudocereal group of herbaceous flowering plants, belonging in Amaranthaceae family or other species like amaranth as well some ornamental plant weeds [17]. From plant is 1-3 meters with an erect stem. Plants are woody Perennial and taproot system is well developed alternate, flat and lobed leaves with a powdery coating are present [7]. The inflorescence is a terminal panicle with small, green or red flowers, Fruit) a little, dried indehiscent achene with no dissections and containing one seed [5,7].

NUTRITIONAL VALUE OF QUINOA

Quinoa (*Chenopodium quinoa*) is highly praised for its exceptional nutritional value, making it a nutrient-dense superfood. In terms of macronutrients, quinoa is a complete protein source containing all nine essential amino acids, with a high protein content ranging from 13% to 21%, higher than many cereals and grains [2,5]. It contains moderate carbohydrates (64% to 72%), primarily starch and dietary fiber. Quinoa is a good source of dietary fiber with 7% to 14% total fiber content. It has a relatively low fat content (4% to 8%) but a favourable fatty acid profile rich in unsaturated fats like linoleic and alpha-linolenic acids [5,8]. Regarding micronutrient composition, quinoa represents a propitious source of vitamins, encompassing vitamin E, the B-vitamin and vitamin C, as well as an array of minerals, including iron, magnesium, zinc, calcium, potassium, and phosphorus, exhibiting higher concentrations than numerous cereal grains [2,5]. Moreover, quinoa harbors bioactive phytochemicals, such as flavonoids, phenolic acids, and phytosterols, which contribute antioxidant, anti-inflammatory, and putative health-promoting properties [2,5]. This exceptional nutrient profile makes quinoa a valuable addition to a healthy and balanced diet [10,11,13,15,20].

Kingdom	Plantae	 Quinoa Plant	 Quinoa Seed
Order	Caryophyllales		
Family	Amaranthaceae		
Genus	Chenopodium		
Species	<i>C. quinoa</i>		
Binomial name	Chenopodium quinoa		

FIGURE 1
Chenopodium quinoa

NUTRITIONAL ASSESSMENT ABOUT PSEUDO-GRAINS AND OTHER GRAINS

Within grains and pseudocereals, quinoa (*Chenopodium quinoa*) excels because of its superior nutritional profile. It has a higher protein content (13-21%) compared to traditional cereals like wheat (10-15%), rice (7-8%), and corn (9-10%), and the protein in quinoa is of high quality, containing all nine essential amino acids, making it a complete protein source unlike many other plant proteins [2,5].

NUTRITIONAL PROFILE OF QUINOA SEEDS

Analyses of quinoa seeds have revealed a chemical composition comprising 62.07% carbohydrates, 14.40% protein, 6.88% fat, 5.12% crude fiber, 2.63% ash, and 8.90% moisture [22]. Quinoa is recognized as a superior source of plant-based protein (12–23%), with protein content comparable to that of milk and exceeding that of conventional cereals such as wheat, maize, and rice [23]. Moreover, quinoa exhibits substantial starch content (52–60%) with low

TABLE 1
Nutritional Composition Of Quinoa Grains

	Nutrients	Amount
Chemical Composition of Quinoa	Protein	14.1g 100g ⁻¹ dry weight
	Carbohydrate	64.2g 100g ⁻¹ dry weight
	Fibre	7.0g 100g ⁻¹ dry weight
	Fat	6.1g 100g ⁻¹ dry weight
	Ash	2.4g 100g ⁻¹ dry weight
	Energy	353 kcal 100g ⁻¹
Vitamin Concentration of Quinoa	Thiamine (B1)	0.36mg 100g ⁻¹ dry weight
	Riboflavin (B2)	0.32mg 100g ⁻¹ dry weight
	Niacin (B3)	1.52mg 100g ⁻¹ dry weight
	Ascorbic acid (C)	n.r.
Essential Amino Acids	Phenylalanine	0.59g 100g ⁻¹
	Methionine	0.31g 100g ⁻¹
	Histidine	0.41g 100g ⁻¹
	Isoleucine	0.50g 100g ⁻¹
	Valine	0.59g 100g ⁻¹
	Leucine	0.84g 100g ⁻¹
	Lysine	0.77g 100g ⁻¹
	Threonine	0.42g 100g ⁻¹
	Tryptophan	0.17g 100g ⁻¹
	Arginine	0.03g 100g ⁻¹
Non-Essential Amino Acids	Cystine	0.19g 100g ⁻¹
	Tyrosine	0.52g 100g ⁻¹
	Aspartic acid	1.45g 100g ⁻¹
	Glutamic acid	12.8g 100g ⁻¹
	Alanine	0.64g 100g ⁻¹
	Glycine	0.30g 100g ⁻¹
	Proline	0.86g 100g ⁻¹
	Serine	0.47g 100g ⁻¹
Mineral Composition of Quinoa	Phosphorus (P)	457mg 100g ⁻¹ dry weight
	Potassium (K)	563mg 100g ⁻¹ dry weight
	Calcium (Ca)	47mg 100g ⁻¹ dry weight
	Magnesium (Mg)	197mg 100g ⁻¹ dry weight
	Copper (Cu)	0.59mg 100g ⁻¹ dry weight
	Iron (Fe)	4.57mg 100g ⁻¹ dry weight
	Zinc (Zn)	3.10mg 100g ⁻¹ dry weight
Nutritional Components	β-carotene	8.00μg 100g ⁻¹ dry weight
	β-cryptoxanthin	1.00μg 100g ⁻¹ dry weight
	Lutein + Zeaxanthin	163μg 100g ⁻¹ dry weight
	α-tocopherol	2.44mg 100g ⁻¹ dry weight
	β-tocopherol	0.08mg 100g ⁻¹ dry weight
	γ-tocopherol	4.55mg 100g ⁻¹ dry weight
	δ-tocopherol	0.35mg 100g ⁻¹ dry weight

(Schmidt et al., 2021, Agarwal et al., 2023)

n.r. = not reported

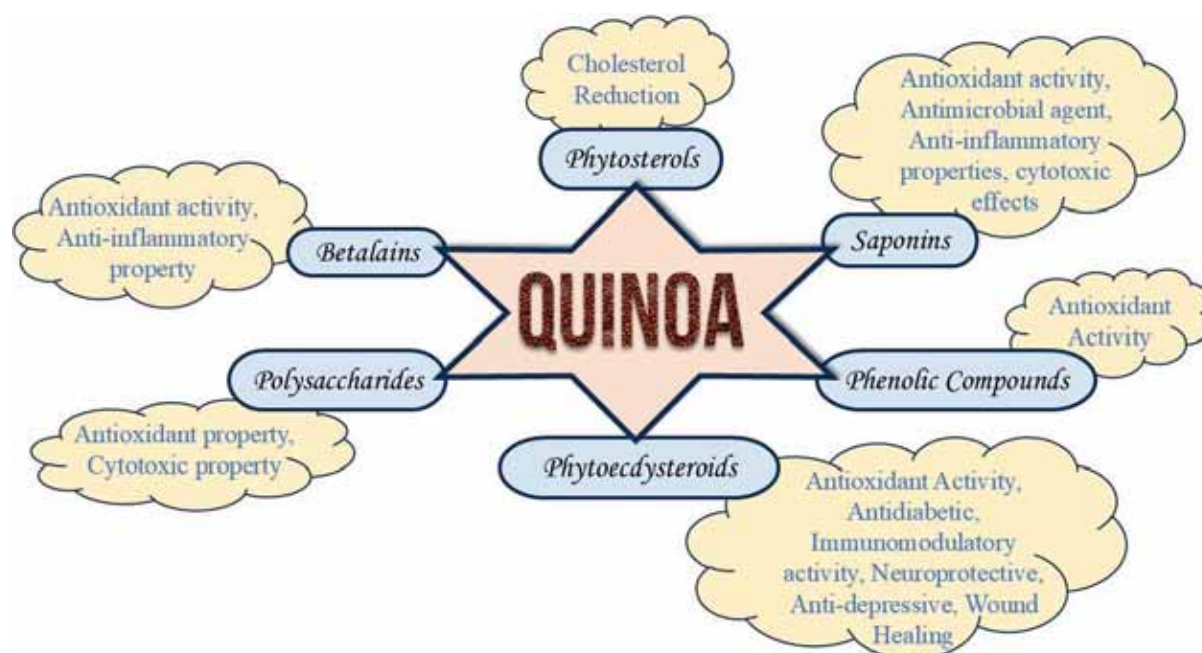


FIGURE 2
Functional properties of quinoa (*Chenopodium quinoa*)

amylose levels (7-11%). The dietary fiber content in quinoa surpasses that of other grains [1]. Quinoa seeds are rich in bioactive components, including phenolic compounds, flavonoids, bioactive polysaccharides, and bioactive peptides, as well as minerals (phosphorus, potassium, iron, zinc, and magnesium) and vitamins (C, E, and B groups) [24,25]. The nutritional profile, phytochemical content, and experimental evidence of quinoa's bioactivity have established it as a significant functional food with diverse biological activities, such as antioxidant, anticancer, antidiabetic, anti-obesity, antihyperlipidemic, anti-hypertensive, antimicrobial, anti-inflammatory, and prebiotic properties, as well as liver protection, immunomodulatory, and hormone-regulating effects [24,26]. These attractive characteristics have led to increased interest in quinoa seeds within the field of functional foods, particularly as a potential symbiotic food [58].

PHYTOCHEMICAL PROFILE

Quinoa (*Chenopodium quinoa*) is a protein-rich pseudocereal that contains diverse phytochemicals with multiple potential health benefits. It is a source of phenolic compounds: esters and derivatives, with the predominance of acids such as ferulic, vanillic, and p-coumaric acid, flavonoids type quercetin or kaempferol glycoside e tannins [11,13]. Phenolic compounds in quinoa have antioxidative, anti-inflammatory, and possibly anticancer activities [10,20]. It is also the best food source of phytosterols, compounds that have been shown to lower cholesterol and may reduce the risk for cardiovascular disease due to β -sitosterone but are in 10 less

amounts than in quinoa [5,15]. Moreover, seeds of quinoa are covered with saponins and triterpenoid glycosides conferring a bitter taste in those structures, being mentioned that they presented antimicrobial (against *Bacillus*), and antioxidant properties, besides potential antitumoral effects but on the other hand compounds can affect negatively palatability and digestibility when present without proper processing [5,16,20]. Some types of quinoas are rich in betalains, water-soluble pigments that give both red-purple and yellow colours with potential for use as antioxidants with possible anti-inflammatory effects [21]. Moreover, quinoa contains large amounts of vitamin E and B vitamins as well as minerals such as iron, calcium, zinc, or magnesium which increases its nutritional value [5].

BIOACTIVE COMPONENTS AND THEIR HEALTH IMPLICATIONS

Quinoa (*Chenopodium quinoa*) contains numerous bioactive components with potential health-promoting effects. The seeds, wrapped in a natural coating of saponins and triterpenoids glycoside have been linked to potential beneficial outcomes against broad range antimicrobial, ameliorating oxidative stress effects by its antioxidant capability and being reported as an anticancer agent including mechanisms and effectors; nevertheless, overconsumption may impose major side outcomes [5,16,20]. Additionally, quinoa is a rich source of dietary fiber, which has been linked to improved gut health and blood sugar control in addition to decreased risk for chronic disease [8]. Moreover, quinoa garners a unique distinction of being a balanced protein source

TABLE 2
Bioactive Compounds And Antioxidant Activity Of Quinoa

Bioactive Compounds	Unit	Availability (Per 100 g)
Phytosterols	mg	38.0–118
Saponins	mg	20–3400
Phenolics	mg	46.0–202
Phytoecdysteroids	mg	13.8–57.0
Betalains	µg	150–610
Flavonoids	mg	25.9–289
Carotenoids	µg	0.65–1.81
Squalene	µg	148–256
Tocopherols	mg	0.4–52.0
Oil	%	2.00–10.0
Linolenic acid (omega 3)	%	6.5–6.7
Linoleic acid (omega 6)	%	56.4–60.1
Antioxidant activity (DPPH)	mg TE/g	1.3–6.0
Antioxidant activity (FRAP)	mg TE/g	0.7–9.0

(Agarwal et al., 2023)

containing all nine essential amino acids (making it therefore an important supplement to vegetarian and vegan diets) [5]. In addition, this pseudocereal is rich in a range of vitamins including vitamin E and the B-vitamin family as well as several minerals like iron, magnesium zinc, and calcium which all together promote health [5].

Flavonoids. Quinoa is considered a good source of flavonoid glycosides such as quercetin and kaempferol; also, can be acylated in higher class that is derived from both de-glyconation or arabinose polyphenolic compounds [13,20]. The flavonoid glycosides identified are quercetin-3-O-sophoroside, quercetin-3-O-robinobioside and kaempferol-3-O-robinobioside [20]. These varied compounds of the flavonoids present in quinoa are linked to its antioxidant, anti-inflammatory, and potential anticancer properties respectively, and thus makes it a rich source of health-promoting phytochemicals.

Phenolic Compounds. Quinoa is an important source of phenolics, including the major antioxidants in quinoa being detailed as ferulic acid, vanillic acid, p-coumaric and gallic acids [2,11]. Quinoa contains a very high concentration of Ferulic acid and its derivatives are connected to some extent in Quinoa aid form or the other quartered across organisms [11,13]. Quinoa is additionally rich in a group of antioxidants called proanthocyanidins, or condensed tannins. Phenolic compounds of hydroxycinnamic acids (e.g., caffeic acid) were also detected in quinoa [2,11]. The phytochemical profile and all amounts of phenolic compounds depend on the quinoa variety, growing conditions, as well processing methods [2,11]. This wide range of phenolic compounds may produce antioxidant and possible health-promoting effects in quinoa [11,15].

PROSPECTIVE BIOACTIVE PROPERTIES OF FERMENTED QUINOA

New insights from the field of nutritional science have shed light on how food choices may affect maturation and health in general. Clinical trials and epidemiological investigations have consistently revealed an inverse relationship between the consumption of plant-based foods and the incidence of various human diseases. Among these plant-based foods, fermented quinoa has garnered particular attention due to its diverse array of biological activities. These activities encompass antioxidant, antidiabetic, anti-hypertensive, anticancer, anti-hypercholesterolemic, and antimicrobial properties, suggesting its potential as a functional food with multifaceted health benefits [27].

APPLICATIONS OF QUINOA AS FERMENTED FOOD

The resurgence of traditional food sources, particularly quinoa (*Chenopodium quinoa*), has been driven by the contemporary demand for nutritionally enhanced and functional dietary options. This pseudocereal, which held significant cultural and nutritional importance in various ancient civilizations, exhibits superior nutritional composition compared to conventional cereals prevalent in modern dietary patterns. Recent investigations have demonstrated quinoa's notable concentrations of essential nutrients, including ascorbic acid, protein, and mineral elements, specifically phosphorus and potassium [28,29,30]. The functional properties of quinoa seeds have facilitated their incorporation into diverse food applications, encompassing synbiotic formulations, gluten-free and lactose-free fermented products, and bioactive peptide derivatives. Additionally, quinoa has demonstrated utility as a functional ingredient in

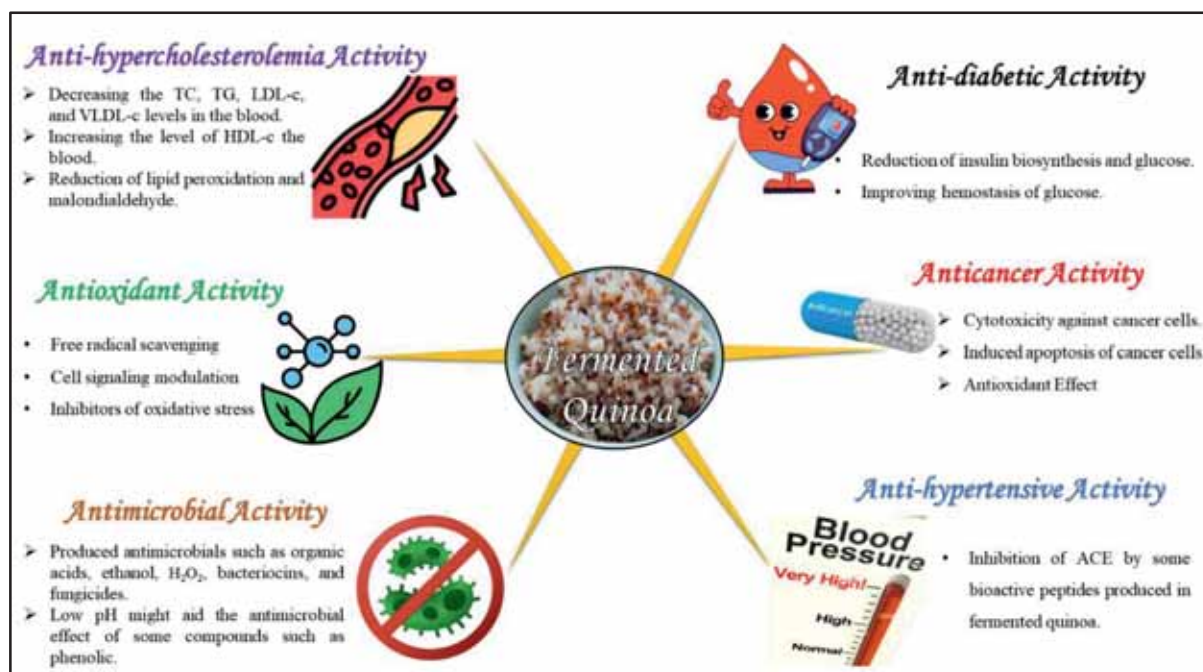


FIGURE 3

Visual representation of the prospective bioactive properties of quinoa post-fermentation

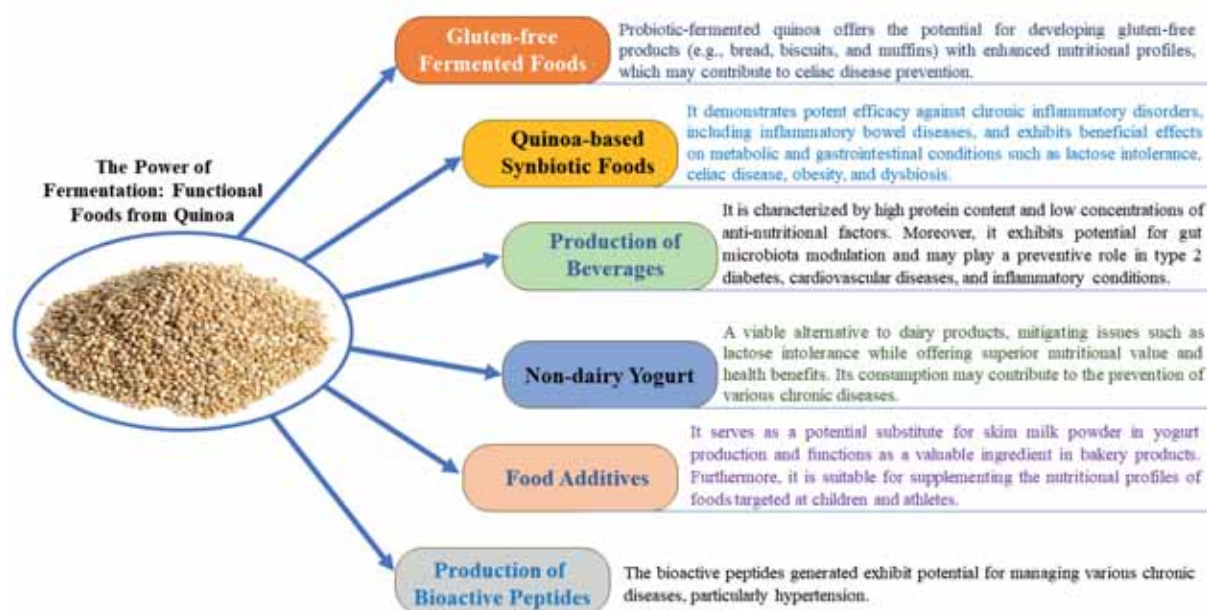


FIGURE 4

Fermented quinoa-derived functional food products

both fermented dairy and non-dairy food systems [31,32,27].

POTENTIAL FOR INCLUSION IN FUNCTIONAL FOODS

Quinoa (*Chenopodium quinoa*) is a nutritious pseudocereal, its unique profile has made it an appealing option for the growth of functional meal foods that go beyond basic nutritional value to offer health benefits. The gluten-free and hypoallergenic nature of quinoa qualifies

it as an important element for the development of functional foods aimed at serving people with celiac disease, gluten intolerance or food allergies due to its incorporation into non-traditional applications in various processed products (bread, pastry snacks), offering possible nutritious replacements for a variety of wheat-based traditional products [9,35]. The high protein level and lysine content of quinoa, which is one the most important amino acid in nutrition, have been reported to be advantageous for application of following processes protein concentrates & isolates on an assortment of type meat analogs, ready-to-eat cereals snack/potato chips/analogues, extruded cereal breadstick. etc.,

food coatings/de-brining agents like flour bakery products) or palatable bakeries-confectionary foods such as biscuits-cakes-bar-cookies-for-overall unique/tasty flavours by consumption quality [36,44]. Moreover, dietary fibre (soluble and insoluble) in quinoa also makes them appealing for the production of fiber enriched functional foods known to enhance gut health. Given that high-fibre diet has been linked with improved digestion activity, weight management and reducing lifestyle related disorders including non-communicable diseases help us proudly position our novel variety among potential food formulations designed by developing world population focusing on quality nutrition [2,5]. Its antioxidant and anti-inflammatory potential, quinoa has been recognized as a suitable food ingredient for the development of antioxidant-rich functional foods [11,21]. This beneficial nutrient profile, especially the high levels of fiber and plant protein, along with antioxidants like phytosterols presents quinoa as a more attractive pseudocereal for incorporation in functional food formulations aimed at promoting cardiovascular health [33,37]. The presence of a high biological value protein with essential amino acids and several vitamins (especially B-class) as well as minerals and excellent nutritional quality makes this pseudocereal suitable for use in functional foods aimed at populations such as infants children pregnant women elderly due to nutrient requirements [37,38].

FOOD APPLICATION OF QUINOA

The ancient grain quinoa (*Chenopodium quinoa*) has become extremely popular nowadays because of its impressive nutrient-rich profile and versatility in a wide range of culinary preparations. Quinoa hails from the Andes in South America, and for thousands of years, native communities have relied on it as a main source of nourishment. Today, it is celebrated globally as a nutrient-dense and gluten-free alternative to traditional grains [33,34]. Its high protein content, comprising all essential amino acids, and its impressive amount of dietary fiber contribute to its popularity as a healthier alternative to traditional grains [33]. It has that nutty flavor and is light and fluffy so when combined with vegetables like broccoli or cauliflower you have a solid grain bowl [34]. Being naturally force-fed with flavor courtesy and high at thickeners, quinoa becomes a go-to grain to use as an accompaniment in soups & stews (or anything that you prefer lending it the texture of milk), be part of them for protein and fiber loving [2]. The mild taste of quinoa does help; making it a perfect breakfast cereal to replace oatmeal or use in granola, muffins, and pancakes [57]. Quinoa flour is now a popular gluten-free baking ingredient; it gives rise to yeasted breads, pastries, and other baked goods with the addition of good nutrition [35].

Quinoa is a great plant-based meat substitute because like lentils it has the capacity to prevent crumbling but also contains significantly more protein than legumes, allowing for better binding [36]. Quinoa cooked provides an excellent base for pilafs, or side dishes which are often a more nutrient-dense alternative to rice or another grains and can be flavoured with other vegetables, herbs & spices [37]. Its soft texture and neutral taste make quinoa a good addition to homemade baby food recipes, especially when looking for an organic source of plant protein, fiber and essential vitamins [38]. The versatility of quinoa not only for traditional dishes but can also create new snacks and foods such as puffed ex-quinoa crackers (cooked flaked chips) instead mix with cereal grains even produces a drink from whole grains that is Quinoa Milk [39].

Quinoa in all fermentation state or storage products such as quinoa beer, beer bread making with Quinoa and pasta can be manipulated by selecting the varieties on taste blending all together nutritive and gluten free alternative to traditional wheat-based product bumps [40]. Quinoa nowadays becoming more popular throughout different ethnicities worldwide. Peruvian quinoa soups, Bolivian quinoa stews, and Mexican Walnut Kefir Quinoas are all excellent examples of centuries old recipes to where the dish gets an added flavor or a nutritional bonus from incorporating some form of ground up seeds [2,5,17,41,42,43].

INDUSTRIAL APPLICATION OF QUINOA

Quinoas are one of the seeds that has received a lot more attention lately, and for several reasons. Quinoa has been utilised not merely as a food but also in the production of numerous industrial goods, particularly those related to food processing and the creation of new products. Considering its unique composition and functional qualities, quinoa flour has found use in the baking and food manufacturing industries to develop low-gluten or GFT foods by replacing wheat flour in breads, pastries, and other baked goods, in response to the growing global demand for gluten-free products [9,35,40]. Quinoa is a promising option for creating plant-based proteins and meat substitutes because of its high protein content and excellent amino acid composition. goods like veggie burgers and hot dogs created with quinoa protein isolates or concentrates are examples of these goods. [36,44]. Quinoa has a high protein content and nutritional value, but it also contains a variety of bioactive compounds, including flavonoids, phytosterols, and polyphenols, which have been linked to a number of health benefits. These compounds can be used as natural sources to create new functional ingredients or even nutraceuticals, which are used in the food and pharmaceutical industries [2,21,33].

Quinoa's advantageous nutritional qualities, such as its high protein content and easy digestion, make it a good addition to baby and infant meal formulas, giving them the necessary protein in addition to other vital elements in a form that is easy to absorb [37,38]. Extrusion has also been used to produce ready-to-eat and snack quinoa products, providing them with a variety of textures and shapes and enhancing their bioavailability and digestibility in the process [45,46]. The fermentation process can enhance the sensory qualities of fermented and processed quinoa goods such beverages made from quinoa, and bread made with a large amount of quinoa. Nutrient availability may also extend the shelf life of these items [40,47]. Additionally, processing quinoa seeds produces additional byproducts (quinoa bran and quinoa stalk residues), which include dietary fibre and bioactive ingredients that may be considered as potential functional ingredients in feed formulation, nutraceuticals, biomass residue sources in the liquid or solid phases of bioreactors, and composite materials [2,5].

HEALTH BENEFITS OF QUINOA

Its biological and therapeutic qualities include anti-inflammatory and anti-cancer, antiviral, anti-fungal, and cholesterol-lowering effects, it is also high in antioxidants and anti-inflammatory agents, hypoglycemic (lower blood sugar), anti-thrombotic (avoids plate narrowing caused by fat deposits on the inner lumen wall), and choleric. It's a pseudocereal and one of the few plant-based foods that has all nine crucial amino acids required for human health. This makes it a great source of protein, especially for those who follow vegan or vegetarian diets. Quinoa is an excellent choice for anyone trying to increase

the amount of nutritious nutrients in their diet because it is a fantastic source of high-quality, plant-based protein, which means that it has far higher concentrations and quality than almost all other grains on the market today. [5,33,36]. Quinoa is also a good source of various bioactive compounds like polyphenols, flavonoids and phytosterols which are known to exhibit anti-inflammatory or antioxidant properties that might reduce the risk factors to combat oxidative stress-induced chronic diseases [11,13,21]. The high fiber content, plant-based protein and presence of bioactive compounds such as phytosterols in quinoa provide the opportunity to reduce risk factors associated with cardiovascular diseases by modulating blood pressure, lipid profile among other parameters [10,33,37]. In addition, since it is naturally gluten free and hypoallergenic food quinoa can serve as a viable grain alternative for people with celiac disease, or those that are intolerant of gluten or have allergies to grains [9,35]. Quinoa's low glycemic index and relatively high fiber content make this an excellent dietary option, especially for individuals with diabetes who are looking to control their blood sugar levels as the slow-release of glucose from quinoa will help keep insulin levels steady and avoid significant spikes in your insulin level [5,12,14]. Quinoa has many more benefits including magnesium, present in minerals that are proven to be best for strong bones so adding this to your diet can help. It contains phytic acid which may improve bone mineralization and is known as a likely contributor towards the prevention of osteoporosis [9,33,48]. Quinoa is packed full of vitamins, minerals and other beneficial molecules that makes it a valuable food to help meet the daily requirements for nutrients in some populations - like pregnant women, growing children or elderly [33,37]. In fact, quinoa may help with weight control because of its fiber content, high protein quality and low glycemic index which helps to keep you full as well as stabilizing your blood sugar levels in order



FIGURE 5
Health Benefits of Quinoa

not having sudden during hunger or cravings [5,9,14,33].

FUTURE PERSPECTIVES

The demand for a pseudocereal, rich in vital nutrients, Quinoa has increased exponentially. Its popularity has increased due not only to its amazing nutritional profile but also the recognition that amaranth could contribute to tackling food security challenges internationally. Quinoa is an attractive option to improve food availability and diet diversity in malnutrition contexts and face environmental constraints because it has a great ability to adapt to different environments [49]. With global overpopulation and sustainability, the healthy food market is set on that trajectory as well; thus, it would very much appear in quinoa's favor [5]. A major reason why pioneering quinoa will gain an important place in the world is its high adaptability to various environmental factors such as drought and salinity which enable it to be cultivated even on low soil fertility [59]. Furthermore, quinoa is extremely nutritional boasting all 9 essential amino acids which gives it a full range of protein. The consumer shift towards a healthier food and beverage lifestyle has directly benefitted quinoa-based products, as they are known to offer several health benefits in comparison with alternate grains/superfoods [50]. Hence the global Quinoa market is projected to witness significant revenue traction at a compound annual growth rate (CAGR) of about 5.8% from year 2022 till the past forecast year i.e., up to the end of fiscal years through sales generations, attributing surge seen almost all over regions such as North America, Latin American and Western Europe quarter on various parameters that have been edited by Market Insights for an effective % CAGR during this period across the globe so far works under Progression [51]. The rise happened due emerging popularity of enough renowned miracles done by low calorie/fat weight loss community efforts against those processed sugary items clubbed alongside hand-made Quinoa! Current research is even working on developing new varieties of quinoa and methods to increase its productivity and improve nutrition content as well as durability under harsh environmental conditions which will help contribute for a sustainable crop in order the accomplishing global food security. Yet the future health of quinoa will depend on meeting challenges such as fair-trade issues and equitable sharing of benefits to small-holder farmers in its traditional Andean home, plus environmental degradation through water use and soil erosion from large-scale planting [52].

RESEARCH GAPS AND AREAS FOR FURTHER INVESTIGATION

Even though there has been much research attention towards the nutritional quality of quinoa and its potential as a new alternative crop, many aspects needs to be explored before this species reaches full development. Low yield and resistance against several biotic or abiotic stresses deserving an special mention; even with its exceptional fit to marginal environments, quinoa yields just remain a tenth of major cereals that possess breeding schemes seeking for solutions concerning the improvement in productivity due without great lost nutritional value keep tolerance to different conditions (drought, saline soil) including on pest attack intending commercial purposes pursuing food security [50]. Finally, more studies must be performed the optimization of quinoa agronomy under each agro-ecological zone; examining plant growth regulators in order to achieve characteristic values are output given specific properties developing with soil type, water supply regime and crop management practices on productivity which could help promoting its introduction into new areas [53]. Moreover, its functional food properties or as a nutraceutical source since quinoa is rich in bioactive compounds having potential benefits for health will offer new possibilities to R&D on nature-suitable characteristics of this ancient grain appeared 12 thousand years ago into these regions [54]. Therefore, developing proper post-harvest practices to maintain the quality of quinoa during storage will help both in saving yields and marketing acceptance after processing [2,36]. In summary, on-country research is required to inform the social and environmental trade-offs of expanded quinoa production within many landscapes scenarios with respect to making use of rights applicable for traditional quinoa growing communities but accompanied by locally agreed market rules with benefit-sharing mechanisms [52].

OPPORTUNITY FOR EXPANDING QUINOA CONSUMPTION GLOBALLY

Quinoa is a very healthy and versatile pseudocereal that offers opportunities for increased worldwide consumption since the world population demands more healthy food from sustainable sources. One important market is the promotion of quinoa for celiac patients, since more than 1% of the global population suffers from Celiac disease or gluten intolerance and a great number of demand shows that this free product segment continues to grow [55]. Utilizing its capacity as a functional food ingredient, quinoa is a rich source of bioactive compounds known for their health benefits against different chronic diseases such as antioxidant, anti-inflammatory and antidiabetic properties [2]. Quinoa could

also be poised for public interest based on the growing popularity of plant-based diets and flexitarian lifestyles, as it boasts a high protein content with all nine essential amino acids which makes quinoa an appealing choice in place of animal proteins [56]. The high nutritional profile of quinoa may help to alleviate micronutrient deficiencies, and increased consumption especially in areas with high malnutrition or food insecurity rates would be a step towards improved food security and nutrition. In addition, the development of new quinoa products and culinary uses has created opportunities to expand the market as its versatility is well suited for product innovation in a multitude of food applications [2]. Marketing needs to be more effective and consumer education is key to raise awareness of the nutritional benefits, sustainability value proposition and versatility across cuisines that quinoa brings as a crop; this will bring interest & drive demand from consumers on a global basis.

CONCLUSION

Sprouting into the modern age as a bona fide superfood capable of furnishing incredible nutritional support and an outlet for immense culinary creativity, quinoa (*Chenopodium quinoa*) is one food you don't want to miss out on. One of the most nutrient-rich pseudocereal, Quinoa, is a very good source of high-quality protein, dietary fiber, and vitamins/minerals, also rich in bioactive compounds such as flavonoids and phenolic acids, which should provide antioxidant properties responsible for its beneficial healthy effects. Quinoa offers a sustainable and inclusive dietary option for people of varying food preferences or with selective eating behaviours who require alternate choices because it is versatile in the face of geographical differences, easily Vietnam's most naturally gluten-free crop. But there are a number of challenges to be overcome regarding fair-trade issues, the environment, and how quinoa needs to be grown & processed. Therefore, future work would be devoted to breeding high-yielding and stress-resistant quinoa lines through modern genetics/genomic-aided focus on agronomy improvements for better expression of the functional traits linked with climate-smart agriculture in societies affected by malnutrition. As such, the preliminary results suggest that quinoa could be an important solution in new food systems to address global demand for healthier and more sustainable sources of food.

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CORRESPONDING AUTHOR

Manish

Institute of Food Technology

Bundelkhand University

Jhansi (U.P.) – India

e-mail: manishuboriya@gmail.com