E-ISSN: 2663-1067
P-ISSN: 2663-1075
NAAS Rating: 4.74
www.hortijournal.com
IJHFS 2025; 7(5): 26-37
Received: 18-01-2025
Accepted: 22-02-2025

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Quinoa: A comprehensive review of its nutritional composition, health benefits and applications

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DOI: https://www.doi.org/10.33545/26631067.2025.v7.i5a.293

Abstract
Quinoa *(Chenopodium quinoa Willd.)* is a gluten-free, nutrient-dense crop indigenous to the Andes, known for thriving in diverse climates and soil types. It is frequently referred to as a "superfood" because of its antioxidant and anti-inflammatory qualities. Since it is rich in protein, amino acids, vitamins & minerals quinoa is excellent for celiac patients. This versatile grain is used to make variety of dishes such as soups, cereals, baked goods, and fermented drinks. Beyond basic nutrition, quinoa contains bioactive compounds such as phytosterols, carotenoids, phenolics, and polyphenols, offering additional health benefits. It has antioxidant and anti-inflammatory effects, helping prevent persistent diseases like cancer and heart disorders. It also aids in managing diabetes, regulating blood sugar levels, and improving cholesterol, which lowers cardiovascular risks. This review highlights quinoa's nutritional qualities and health advantages, along with its role as a partial or complete substitution for traditional grains in the food industry.

Keywords: Quinoa, Nutritional value, Anti- nutritional factors, Bioactive compounds, Health benefits

1. Introduction
Quinoa *(Chenopodium quinoa Willd.)* belongs to Chenopodiaceae family, is a plant indigenous to the Andes and can adapt to a variety of soil types and climates [1]. It is a food crop that resembles grains and has been used for subsistence and nourishment [2]. Quinoa is a member of the Chenopodiaceae family, which also includes beets and spinach. There are over 250 species in the genus Chenopodium, which is found all over the world [3]. This plant is notable for its greater food value, more importantly, for its significant tolerance to soil and climate conditions. Quinoa's protein concentration is greater than that of cereals, and its more uniform arrangement of dietary essential amino acids is comparable to the milk's protein biological value. Additionally, it is distinguished by its gluten-free status, which allows for a wider range of more nutrient-dense and appropriate food items for Celiac disease sufferers [3].

The major edible part is quinoa grains, and gluten-free grains are abundant in protein, vital dietary essential amino acids, vitamins & minerals. Quinoa is regarded as a unique, healthful food and is sometimes called a "superfood" owing to its nutritive value and wholesomeness advantages. In recognition of its significance 2013 is designated as the "International Year of Quinoa" by United Nations General Assembly to advertise it as one of the crops that reduces poverty and hunger worldwide [4].

Quinoa's exceptional ability to tolerate other harsh environments, like cold and salinity in soils and irrigation water, is another factor supporting its promotion [5]. In addition to being a staple food like potatoes and corn, it is eaten for breakfast. Cheaper imported foods like rice and pasta are increasingly replacing quinoa, which was once a staple in the Andes [6]. It is remarkable for its greater nutritional value, but more significantly, quinoa is extremely resilient to soil, weather, and climate. Quinoa grains are eaten in soups, puffed to make morning meals or floured to make baked goods including tortillas, cookies, bread, biscuits, spaghetti and pancakes [7]. Furthermore, the fermentation of quinoa grains can produce beer or chicha, a type of traditional alcoholic drink prevalent in South American religious ceremonies [7].

Another argument made by the FAO to support quinoa's global production and use is its

nutritional value. Quinoa grain has high nutritional and functional value because of its 20 amino acids, twice as many proteins as many cereals, minerals, vitamins, antioxidants and high-grade starch [5]. According to Miranda *et al*. (2013), additional flavonoids that are likely derived from the saponins in its seed coat appear to have antibacterial properties [8].

Quinoa, a once-obscure Andean staple, has made a spectacular resurgence in recent years and is now served on the tables of foodies and health-conscious people everywhere. The Andean indigenous people have long held quinoa in high regard, referring to it as "the mother of all grains." These days, quinoa is praised for its extraordinary nutritional content, which includes a full protein profile and a variety of vital vitamins and minerals, in addition to its nutty flavor and delicious finish. It is a favourite in the kitchen because of its versatility in a range of recipes, including salads and grain bowls. Quinoa's rising demand worldwide has sparked questions about sustainability and how it may affect the indigenous populations in South America, where it first appeared [9].

Quinoa is regarded as a unique individual crop similar to maize because of several unique characteristics. Although quinoa has several indigenous names, quinoa is the most widely used [10]. Quinoa grain is a starchy raw material that contains a lot of carbs. It is mostly made up of starch with a tiny amount of sugar [3]. The quality and nutritional significance of the proteins in this seed have drawn interest as a potential new source of food. In particular, its amino acid makeup is close to milk and nearly at the optimal protein balance advised by the FAO, making quinoa a high protein diet than numerous vegetables due to high lysine content [3]. The lack of gliadins, which are gluten-forming proteins found in wheat, and gliadin corresponding protein fragments, which are available in rye, malt, barley and oats makes it suitable for making food items that are commonly referred to as "gluten free." This is significant because it makes more nutrient-dense foods suitable for celiac disease sufferers more readily available [3].

Quinoa is another great idea of a "functional food" which may lower the chances of a number of illnesses. Its functional qualities could be linked to the fibres, minerals, vitamins, fatty acids, antioxidants and phytonutrients which are available. These nutrients support human nourishment, particularly in the area of cell membrane protection, which has been shown to enhance brain functioning. For human nutrition and health wellbeing, these qualities provide the grain a significant edge over other plant diets [1]. Quinoa has drawn interest from the public as a great source of phytochemicals and minerals when consumed raw. It has also been shown to have certain health advantages, including preventing cardiovascular diseases, reducing blood pressure and having antiphlogistic & antioxidant properties [11,12].

1.1 Origin & History

German botanist and chemist Carl Ludwig Willdenow was the first to describe quinoa, a tetraploid agricultural plant, in 1797. For the last 8,000 years, it has been grown in the Andes of South America [5]. Native American communities in South America, including the Incas, have been growing quinoa for thousands of years. Quinoa was valued for its cultural importance in addition to its nutritional value. Quinoa was venerated by the Incas as a sacred crop, along with staples like potatoes and maize. Its cultivation was closely associated with religious rituals and celebrations. An Incas credited divine intervention for quinoa's resilience and adaptability, considering it a gift from the gods. This respect is mirrored in the Quechuan term for quinoa, "chisaya mama," which translates to "mother of all grains" [9]. Quinoa has always been considered a low-status food since the the conquest of South America by the Spanish when the colonists denigrated it as a food of the Indians or peasants. Additionally, after learning that Quinoa was used in indigenous religious ceremonies as a holy beverage (Mudai) the Catholic Church actively opposed its development. As a result, Europeans were unable to access quinoa and had to substitute other grains [13].

1.2 Plant description

Chenopodium quinoa Willd is the botanical name for quinoa, which is a dicot plant that may reach heights of 1 to 3 meters and is classified as a “pseudo-cereal” rather than a complete grain. Quinoa belongs to a member of Goosefoot family, or "Chenopodiaceae." The flat, spherical seeds vary in shade from white to gray and black, with tints of violet, purple, rose and yellow. They weigh around one gram and have a diameter of 1.5 to 4.0 mm [14]. Quinoa can withstand low temperatures (down to -5°C) and hot temperatures (up to 35°C) on soils which are alkaline, acidic, or salty. Quinoa is available in 250 variants all over the world. It is categorized according to the shape of the plant or the color of the fruits and plants [13].

Quinoa can withstand a broad spectrum of soil acidity, ranging from pH 6.0 to 8.5. Around -1°C has little effect on the plant. Quinoa can withstand drought. It may thrive even in regions with 200-400 mm of annual precipitation. Quinoa is grown using mechanized agricultural techniques in rows with a 40-80 cm gap between each row [14]. Upon reaching physiological maturity, quinoa is harvested. It gets harder to shatter the grains with a fingernail because they get hard and dry. About 70 to 90 days after flowering, physiological maturity may be attained. The maturity period of plants varies from 5 to 8 months, depending on the variety. The variety and growth conditions can affect the quinoa production, which can range from 45 to 500 g/m2 [14].

Quinoa's fruit is called achenes, which are composed of a one seed covered in an external pericarp [15]. The quinoa seed is spherical, seed coat, endosperm, and embryo that are high in protein and oil surround the perisperm, which contains the seed's carbohydrate reserves. Because it contains a lot of bitterness, The quinoa fruit's pericarp has to be washed or mechanically removed before the seeds are eaten. We call this process as desaponification.

Quinoa belongs to the group of "whole grains" in terms of nutrition [2]. This plant has evolved tolerance to a number of stressors, including drought, salt, and cold, and it can be grown at high elevations. Quinoa is a food high in nutrients that is cultivated in arid soils that are now unsuitable for other typical crops [11]. It is regarded as the "golden grain" due to its long history of cultivation & well acknowledged excellent nutritional content [13,16].

1.3 Cultivation &Production

Quinoa is said to have spread over the Andes at the same time as the Incan civilization and believed to have been domesticated close to the Peruvian-Bolivian border in the Lake Titicaca area. These days, quinoa is farmed at

elevations between sea level to 4,500 meters in Ecuador, Peru, Colombia, Chile, Argentina, and Bolivia [2]. Due to its halophytic qualities, high genetic diversity, and effective water use, the crop can withstand a variety of of conditions, including snow, inadequate rainfall, soils low in nutrients with pH values between 6.0 and 8.5, high salt levels (40 mS/cm), frost & extremely hot temperatures (−4 to 38 °C) [2,15].

This paper highlights the quinoa nutritive value and its benefits for health. Further, focuses on its culinary uses and their applications in various industries.

2. Nutritional Composition

Quinoa has a low glycemic index, is heavy in carbohydrates, dietary fibre, unsaturated fatty acids, and proteins with significant biological value. It contains a lot of vitamins, minerals, and phytochemicals [11]. Quinoa is regarded as one of the finest source of vegetable protein since its protein concentration is higher compared to the cereal grains and is equivalent to that of milk [13]. Quinoa is a desirable plant for the production system because of its properties and grain composition [3]. Its nutritional value can be attributed to the fibre, minerals, vitamins, fatty acids, antioxidants, and plant hormones that support human nutrition, particularly in the defense of cell membranes, which has been shown to enhance neural function. These characteristics give the grain a substantial benefit over supplementary diets comprised of plants to sustain human nourishment and wellbeing [3]. Secondary metabolites may potentially help maintain human well-being and health, even though the majority of research on health benefits of quinoa have focused on its macro- and micronutrient profiles. Quinoa primarily contains three types of secondary metabolites: phenols, beta-lains, Triterpenoids, which include phytoecdysteroids, saponins and phytosterols, as well as glycine betaine [2].

2.1 Protein

Proteins in quinoa are regarded as excellent quality because to their great in vitro digestibility, gluten-free status, and equivalent composition of amino acids. Tryptophan, valine, phenylalanine, histidine, isoleucine, leucine, lysine, methionine, and threonine are among the proteins found in quinoa [11]. Quinoa provides an excellent protein source consist a protein value of 14-20 g/100g because to its greater lysine and methionine amino acid content [10,17].

Quinoa is richer in number of amino acids than other cereals, but it is especially high in lysine, which is absent from other vegetable plants. The embryo had the majority of the quinoa's protein [10,18]. Albumin and globulins are two important proteins found in quinoa [10]. Quinoa mostly includes globulin and albumin, prolamins, is the primary storage proteins found in many cereals, are either scarce or absent in it. Prolamins, sometimes referred to as "glutens," trigger immunological responses in celiac disease patients [2]. The body uses proteins and amino acids as key biological macromolecules for protein synthesis, energy production, and enzymatic reactions in addition to acting as structural components [13,19 , 20].

Proteins are essential for tissue formation and maintenance, hormone, enzyme, and antibody creation, energy generation, and metabolic process regulation. Amino acids supply sulfur molecules to the body in addition to nitrogen [3]. By FAO/WHO standards, protein in quinoa may supply beyond 180% of an adult's daily required amino acid intake. According to the FAO (2011), quinoa is similar to casein and dry whole milk in terms of the necessary amino acid content.

2.2 Carbohydrates

Carbohydrates are the known as chemical compounds composed of carbon, hydrogen, and oxygen. Carbohydrates serve as structural elements, signalling molecules, and energy sources [13,20]. Together with proteins, Carbohydrates are the most abundant and reasonably priced supplier of calories for humans and comprise one of the primary types of organic molecules present in nature [3]. Carbohydrates make up the majority of quinoa, accounting for 67% to 74% of its dry content. Quinoa's main source of carbohydrates is starch. Quinoa contains 50 - 60% starch by dry matter, with amylose accounting for 11 percent of this proportion. The starch component is found in the seeds' perisperm; it can exist as spherical clusters or as single units [14]. The primary biopolymer component of plants (beans, seeds, roots, and tubers), starch, usually takes the form of granules in a range of sizes and forms.

The polygonal quinoa starch granules are smaller than the starch present in the majority of cereal grains, with a diameter of 0.6 to 2.2 mm. They can be found alone or in clusters of spherical or elliptical composite frameworks [3]. Amylopectin makes up 77.5% of quinoa starch. Quinoa has a higher percentage of amylopectin than other types of rice [3]. Rich in amylopectin, they exhibit exceptional freeze-thaw consistency, which enhances their usefulness as a thickening in frozen foods [10]. Additional carbohydrates, such as crude fibre, pentosans & monosaccharides are present in trace levels [14]. Additionally, quinoa contains a low amount of glucose and fructose and a large amount of D-xylose and maltose [13].

2.3 Dietary fibre

Dietary fibre is known as the indigestible component of plant-based food made up of two primary parts: soluble and insoluble. In addition to having prebiotic qualities, soluble fibre easily ferments in the colon to produce gasses and physiologically active byproducts. Insoluble fibre that dissolves in water can either be prebiotic and go through metabolic large intestinal fermentation or physiologically inactive fermentation that adds volume. Bulking fibres absorb water, which facilitates defecation [13,21].

Quinoa is the great source of dietary consisting of 2.6% - 10% of the total grain of which 78% comprises the insoluble fibre and 22% comprises the soluble fibre [13]. The primary components of insoluble quinoa galacturonic acid, arabinose, galactose, xylose, and glucose. Soluble fibre is mostly composed of arabinose, galacturonic acid, and glucose subunits [2]. Dietary fibre from quinoa is mostly made up of cellulose, hemicellulose, and pectin; it has less lignin than other fibres and may be more effective in binding heavy metals [11,22]. Dietary fibre is thought to be necessary for the best possible digestive health in addition to providing a number of functional advantages. Dietary fibre can enhance intestinal microbiota, reduce inflammation and the risk of gastrointestinal infections enhance satiety, decrease the absorption of fat and cholesterol [2].

2.4 Lipids

Lipids are both structural elements of cell membranes and concentrated sources of energy that the body uses for a

number of regular processes [13,23]. Quinoa's lipid percentage, both in terms of quality and quantity, has made it an alternative oilseed crop [3]. Quinoa has a greater oil content than maize (3% to 4%), ranging from 2% to 10% (average 5% to 7%). PUFAs (polyunsaturated fatty acids) make up 54.2% - 58.3% of quinoa seed oil, whereas unsaturated fatty acids make up 89.4%. Quinoa's two primary fatty acids are linoleic and linoleneic acids [2]. α and γ-tocopherol are the antioxidants abundant in it. Quinoa oil consists 721.4 and 797.2 ppm of α and γ-tocopherol, respectively [3]. According to de Lima Brito *et al*. (2022), the primary saturated and monounsaturated fatty acids found in quinoa cholesterol are palmitic and oleic acid [11].

Quinoa seeds contain free fatty acids as well, making up 18.9 and 15.4% of total lipids.

There are also a lot of triglycerides [10,25]. Triglycerides make up 20% of the seed's neutral lipid content and are found throughout the seed [10]. Essential fatty acids are crucial for brain development, immunity, cardiovascular health, insulin sensitivity and membrane function. Essential fatty acids may have advantageous physiological and logical impacts on people via disturbing lipid rafts, changing the amount of phospholipid fatty acids in cell membranes, preventing transcription factors that promotes inflammation from being activated and attaching itself to the G protein-coupled receptor GPR120 [2].

Table 1: Nutritional value of quinoa (100g)

Nutrient	References		
	(USDA,2013)	(Nowak *et al*., 2015)	(Hussain *et al*., 2021)
Protein (g)	14.12	9.1- 15.7	16.1
Total Lipids/ fat (g)	6.07	4.0- 7.6	6.1
Ash (g)	2.38	2.0-7.7	2.6
Carbohydrates (g)	64.16	48.5- 69.8	64.2
Dietary Fibre (g)	7.0	7.0- 14.1	7.0
Energy (kcal)	368	331- 381	368

2.5 Minerals and Vitamins

Vitamins and Minerals often referred as micronutrients are abundant in quinoa. Vitamins are the components that are significant for the both humans as well as animal health [3]. Vitamins are abundant in quinoa seeds, which the body needs to support many physiological processes, regulate cell development and division, prevent oxidative damage, improve eyesight, and act as enzyme cofactors in metabolism [2].

Quinoa contains the water-soluble vitamins such as B vitamins (Thiamin, Riboflavin, Niacin, Panthothenic acid, Pyridoxine & Folic acid) and vitamin C/ ascorbic acid. and fat-soluble vitamins such as tocopherols/vitamin E [2]. The gamma-tocopherol content (5.3 mg/100g) is double that of the alpha-tocopherol (2.6 mg/100g) [10]. Additionally, quinoa has a range of carotenoids, mainly luteins and zeaxanthins, with whole amounts 1.2 - 1.8 mg/100 g. Quinoa contains greater levels of some of these vitamins than other cereal grains [2].

Unlike proteins, lipids, and carbohydrates, minerals are inorganic micronutrients that biological organisms cannot produce. Among their many essential functions in the body are the control of electrolyte balance, glucose homeostasis, nerve impulse transmission, and enzyme cofactors [13]. Vital functions may be impaired and health imbalances may result from low intake or decreased bioavailability [3].

Quinoa is a grain that includes calcium, iron, magnesium, and zinc; its iron concentration is particularly noteworthy. Its ash level (3.4%) is greater than most of the cereal grains like rice and wheat [10]. While it contains more calcium, phosphorus, magnesium, iron, zinc, potassium, and copper than cereal grains, it will have lower levels of cadmium, lead, and mercury. The proportion of minerals such as iron, zinc, and potassium, copper and magnesium are reduced as a result of quinoa seed polishing and washing [10]. Quinoa has adequate amounts of calcium, magnesium, and potassium in accessible forms required to support a healthy human diet [13].

3. Bioactive Compounds

A variety of chemicals known as bioactive compounds are found in trace amounts in plants and foods derived from plants and offer health advantages over and above their nutritional worth.

It is hypothesized that eating foods high in bioactive chemicals can lower oxidative stress and prevent heart disease, cancer, and other illnesses. The important bioactive substances are Tocols, phytoecdysteroids, phytosterols, polyphenols, carotenoids, bioactive proteins, and peptides [4].

3.1 Phytosterols

Phytosterols are lipophilic substances that resemble cholesterol structure. Quinoa seeds contain four main phytosterols: stigmasterol, brassicasterol, campesterol, and βsitosterol with amounts as high as 118 mg/100 g. Additionally, it has greater levels of stigmasterol (3.2 mg/100 g), campesterol (15.6 mg/100 g), and β-sitosterol (63.7 mg/100 g) than other cereals. By interfering with lipid for intestinal uptake and preventing the liver and intestines from producing atherogenic lipoproteins, phytosterols lower blood cholesterol levels. Additionally, studies have demonstrated the properties of anti- inflammation, antioxidation and anticancer of phytosterols [2].

3.2 Carotenoids

The majority of the pigments called carotenoids are produced by plants and algae. Due to their antioxidant properties and role as precursors to vitamin A, carotenoids are vital for human nutrition. The most important three carotenoids are: beta-carotene, lutein, and lycopene [4]. In plants, carotenoids serve to shield chlorophyll from photodamage. The amounts of carotenoid in white, red, and black quinoa seeds are 11.87, 14.97, and 17.61 µg/g, respectively [13].

3.3 Betalains

The various colours such as yellow, red and black of quinoa

seeds and vegetable edible parts are caused by betalains. Pigments of betalain which include yellow-orange betaxanthins and red violet betacyanins, are aromatic indole derivatives that include nitrogen and are produced from tyrosine [2,27]. They belong to the order Caryophylales, which includes Amaranthaceae crops, and are neither physically or biosynthetically related to phenolics [2].

The two most prevalent betalains in quinoa seeds, bethanin and isobetanin, provide several health advantages with phenolic substances, such as anti-inflammatory and antioxidant effects [2,27]. Betalains can be utilized as a natural dye since they are stable within the pH range of 3 to 7. The European Union and the U.S. FDA now permit betalains as colorants for use in medicines, dairy goods, sauces, soups, cosmetics, and cosmetics (E-162) [2,28].

3.4 Glycine betaine

Betaine, also known N, N, N as trimethylglycine, is an N-trimethylated amino acid. Choline, a precursor to betaine, is crucial for the control of homocysteine and has been linked to the management and prevention of obesity, diabetes, and cardiovascular disease. Quinoa contains a greater content of betaine (3930 to 6000 µg/g) than other cereals) [2].

3.5 Phenolics

Phenolics are a broad and varied family of chemicals that have a well-known antioxidant action due to their very stable chemical structure, which consists of a hydroxyl group or groups joined to a minimum of one ring of aromatic hydrocarbon. Additionally, phenolics serve a variety of biological purposes, such as anti-carcinogenic, cardioprotective, antidiabetic, anti-inflammatory and anti-obesity properties, because of their impact on cell signaling and metabolism.

Phenolics come in two forms: polyphenols, which are multi ringed compounds, and phenolic acids, which are simple single-ringed compounds [2]. Quinoa grains and leaves contain a variety of phenolic acids, namely hydroxycinnamic acid and hydrobenzoic acid derivatives. It has been demonstrated that quinoa seeds contain up to 251.5 µg/g dry weight of phenolic acids [2].

3.6 Polyphenols

Polyphenols are natural organic compounds contain many different phenol structural units. They are the most common antioxidants in the human diet and are usually found in plant-based foods [13]. Polyphenols, which are important byproducts of physiologically active plant secondary metabolism, are abundant in quinoa. These substances include hydroxyl groups and one or more aromatic rings. Both the functional qualities and taste of quinoa are influenced by the amount of these phenolic chemicals present [29]. Quinoa has minimum 23 distinct types of phenolic chemicals. Ferrulic acid and quercetin are the most prevalent phenols. Compared to entire grains like rice, millet, wheat, barley and buckwheat, quinoa has a higher phenol content [13].

There are several subgroups of polyphenols, but the flavonoids—which include isoflavones and flavonol glycosides—have been studied the most [2]. Through intracellular enzymes, protein synthesis, growth factor activities, angiogenesis, differentiation, and malignant cell proliferations, isoflavones are chemical compounds that influence biological activity and sex hormone metabolism. Daidzein and genistein, two isoflavones found in quinoa, are hormones that can be identified by human estrogen receptors. They also lower vascular resistance and function as antagonists of artery contraction [13].

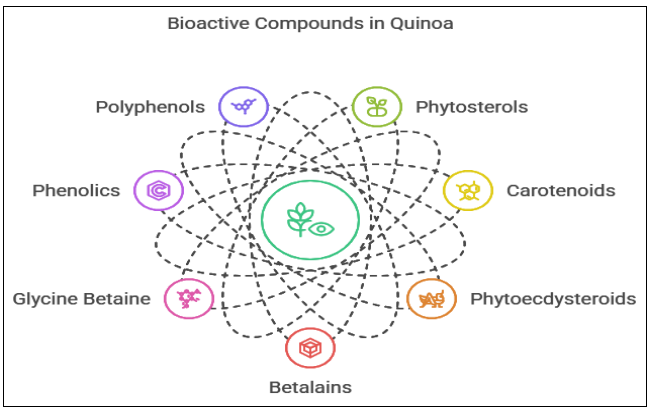

Fig 1: Bioactive compounds in quinoa

4. Anti - Nutritional Factors

Antinutrients are molecules that interact with nutrients and prevent them from being absorbed [4,30]. Quinoa's primary antinutritional components are tannins, oxalates, phytic acids, saponins, and trypsin inhibitors [4].

Saponins are secondary metabolites that give grains their bitter flavor and are mostly located on their outer layer. About 0.00-4.4% of quinoa grains are saponins [4,31,32]. These compounds are triterpenoid glycosides with an unclear chemical formula that are present in plants, especially those in the Leguminosae family: $C_nH_{2n-8}O_{10}$ ($n \geq 5$). They have the poisonous ability to hemolyze red blood cells and are soluble in both water and methanol [4].

Attributed to its large negative charge, phytic acid is categorized as an anti-nutritional item. It may reduce the bioavailability of proteins, enzymes, carbohydrates, and minerals including calcium, iron, magnesium, zinc, and copper by chelating them [3]. Quinoa grains consist 200 - 880 mg of phytic acid/ 100g [4,33].

Antinutrient compounds called oxalates have the ability to attach to calcium, iron, and magnesium ions and block the availability of nutrients. High dietary soluble oxalate intakes can result in kidney calcium oxalate stones as well as reduce the Minerals and trace elements' bioavailability. The total oxalate concentration of quinoa varied from 874 - 1959 mg/100 g in the leaves and stems and from 143 - 232 mg /100 g in the roots and grains [4].

Tannins are antinutritional, polyphenolic substances that can interact with proteins and macromolecules to reduce food's nutritional value [4,30]. Small quantities of them, between 23.00 and 31.00 mg/100 g, are found in quinoa grains [4]. The negative consequences of tannins include gastrointestinal mucosal injury, disruption of iron, glucose, and vitamin B12 absorption, food discoloration from enzymatic browning reactions, and reduced palatability from astringency. Results suggest that using the right washing and cooking techniques for quinoa grain may improve digestibility by reducing the harmful effects of tannins [3].

Protease inhibitors, also known as trypsin inhibitors, are naturally occurring proteins that unite with the proteolytic enzymes to create very stable complexes. Trypsin, is the enzyme that breaks down proteins, is less active when

trypsin inhibitors are present in the digestive system. This results in increased enzyme production by the pancreas, which reduces the organ's swelling and expansion [3]. TI becomes inactive when heated since it is a thermolabile material. Quinoa grains have far lower TI values than soybeans, ranging from 1.36 to 5.04 TIU/mg [4].

Naturally occurring in all plants, nitrates (NO3) are an important source of nitrogen for regular growth. While mesophyll in particular has high quantities in leaves, petioles and stems have the highest concentrations [3]. Nitrates affect the thyroid gland's ability to operate and the metabolism of vitamin A. Their conversion to nitrites can result in the formation of metmyoglobin, which causes cyanosis when ingested. On the other hand, they can form an N-nitrous molecule, which can cause cancer, by combining with secondary and tertiary amines. The nitrate content in quinoa is 63.26 mg /100 g, which was double as low as those in fresh vegetables such as spinach, lettuce, radish, and beets, where the levels are greater than 100 mg/100 g [3].

Quinoa contains low-content elements such minerals, fatty acids, and anthocyanins. Beyond to the active compounds mentioned above these components are equally crucial for supporting human health. Prior research had shown that the anthocyanin concentration of quinoa is correlated with its colour, and dark quinoa has been found to have stronger antioxidant activity than other hues [29,34].

5. Processing Techniques

After harvesting, grains are processed in an industrial setting before being marketed [35]. The goal of industrial quinoa seed processing is to increase the nutritional content and improve digestibility by elimination of anti-nutritional constituents such tannins, saponins and phytic acid [36]. Mechanical dehulling is one of the main processes, which eliminates the seed outer layer, that contains the majority of the bitter-tasting saponins [36,37]. This procedure is necessary because, although not harmful, saponins imparts bitter taste to food and may aggravate the digestive tract if consumed in excess [36]. After dehulling, all leftover saponin residues are removed by carefully washing and rinsing [36,38]. Ensuring the taste and texture of quinoa is essential for increasing its commercial appeal [36]. Roasting or heat-treating of quinoa grains at specific temperatures may reduce some phytic acid, increasing the accessibility of essential minerals including calcium, iron, and zinc [36,38]. Another method used commercially to deal with the phytic acid problem is sprouting. The process of sprouting involves steeping and germination of the seeds which releases enzymes that naturally lower the amount of phytic acid. Through increased vitamin and mineral availability, this procedure improves the quinoa's nutritional profile [36].

Furthermore, fermentation is occasionally used in the preparation of quinoa [36]. The microorganisms found in the seeds carried out the fermentation process naturally [35,39]. This process breaks down phytic acid and other antinutrients by controlled or natural fermentation. Additionally, fermentation enhances the taste profile of quinoa-based goods and aids in the development of advantageous probiotics [36,40].

A crucial technique for lowering antinutritional elements, especially phytic acid, is heat treatment [36]. The full digestion of dietary proteins needs heat processing. These procedures have a major impact on protein structures and, as a result, their ability to withstand digestion [35]. The method of malting quinoa grains with a modest heat treatment is thought to be an efficient way to enhance their antioxidant content for future usage as a functional component in the creation of meals and drinks that are gluten-free [35,39].

A common food preparation method is extrusion cooking method that includes briefly treating food at high temperatures. By applying high pressure and temperature simultaneously, this process can alter starch's molecular composition and promote molecular interactions [41,42]. Extruded ready-to-eat (RTE) products are made from quinoa using extrusion processing. The extrudates have higher phenolic content, that could be because higher barrel temperatures cause maillard products to form and at 140 ˚C, the anthocyanin content is 9.63 mg/kg [35,43]. Extrusion increases the digestibility of fibre, destroys aflatoxins, and inactivates antinutrients. In addition to converting insoluble dietary fibre into soluble dietary form through the process of extrusion, transglycosidation produces resistant starch and enzyme-resistant glucans [35].

6. Health Benefits of Quinoa

Quinoa have numerous advantageous on health which includes benefit high risk consumers, such as children, the elderly individuals, athletes, lactose intolerance individuals, women susceptible for osteoporosis, individuals with celiac disease, diabetes, dyslipidemia, anemia, and obesity due to its high nutritional value, medicinal qualities, and gluten-free nature. Regarding human nourishment and health these characteristics—which are thought to be connected to quinoa's fibre, minerals, vitamins, fatty acids, antioxidants, and particularly phytochemicals give it a notable advantage over other crops [7]. Quinoa is an outstanding source of nutrients since it is free of gluten, have low glycemic index, and has high quantities of nutrients that frequently exceed those found in popular cereals. This could help maintain the welfare of the customer [11]. This section reviews the functions of quinoa and its fractions in human health and goes over the possible health advantages of quinoa grains.

6.1 Antioxidant activity of quinoa

Antioxidant activity is a measurement of how much a material lowers the adverse effects of ROS. Human metabolism produces free radicals, but too much of them can lead to oxidative stress. The radicals that produce oxygen are called as Reactive oxygen species [11]. Carotenoids, flavonoids, polyphenolic chemicals, and tocopherols are examples of common natural antioxidants that may provide defence hostile to oxidatively-linked chronic diseases including heart disease, cancer and cerebrovascular disorders [11,44]. Because of its high phenolic component levels, quinoa is a renowned as natural antioxidant source with a high perceived action of antioxidants. By inhibiting the actions of α-amylase and α-glucosidase and preventing oxidative damage to the several organs required in the breakdown of carbs, quinoa phenolics can help manage hyperglycaemia and its associated consequences. Quinoa has a remarkable antioxidant potency due to its greater protein concentrations and quantity of phenolic components, which suggests that it might be used in the therapeutic food sector as a nutraceutical component [11].

6.2 Anti-inflammatory activity of quinoa

The immune system relies on inflammation to protect against infections and dangerous chemicals [11]. It was discovered that the grains of quinoa and their fractions have potent anti-inflammatory qualities. One study reported that, extracts from quinoa seeds that are rich in saponin concentration prevented lipopolysaccharide-stimulated RAW264.7 macrophage cells from producing inflammatory cytokines, such as tumour necrosis factor-α (TNF-α) and interleukin-6 (IL-6). Additionally, they reduce the synthesis of inflammatory mediators, including nitric oxide. Quinoa saponins were suggested as a potential treatment and prevention for inflammation. One of the primary proteins in quinoa seeds, chenopodin, has anti-inflammation qualities that lower the synthesis of nuclear factor κ, light chain enhancer of activated B cells (NF-κB) and interleukin-8 (IL-8) in Caco-2 cells [11,45]. According to Capraro *et al*. (2021), quinoa seeds' albumin and very low-charge globulins were superior to the low-charge and high-charge globulin fractions in terms of lowering inflammation [11,46].

6.3 Antidiabetic activity

Type 2 diabetes, which is more common worldwide, is a significant problem that affects the way that people absorb carbs, fats, and proteins. Quinoa is one of the whole-grain foods that is crucial for both preventing and managing diabetes. The primary mechanism by which quinoa reduces blood sugar is via inhibiting the activity of dipeptidyl peptidase IV, α-amylase, and α-glucosidase. DPP-IV is in charge of cleaving insulins, such as glucose-dependent insulinotropic polypeptide (GIP) and glucagon-like peptide-1 (GLP-1), which lowers insulin release during the postprandial period [11].

It has been demonstrated that anti-diabetic medications which focus on the present targets of type 2 diabetes treatment are successful in lowering levels of glycosylated hemoglobin and glucose in blood. The scientific community is looking at alternate interventional techniques to glycemic management because of the possible adverse effects of these medications [11,49]. Additionally, in vivo tests have shown that quinoa grain has anti-diabetic qualities. In 2022, Díaz-Rizzolo *et al*. assessed the impact of substituting quinoa for complex carbohydrate-rich meals on blood glucose variations in pre-diabetic older individuals. According to the results, quinoa may help decrease postprandial glycemia and prevent type 2 diabetes since it is high in protein & unsaturated fats and low in carbohydrates [11].

6.4 Quinoa effects on cardiovascular diseases

Globally, CVDs are the major cause of deaths. Diets high in whole grains are linked to a decreased risk and death from CVD, according to several epidemiological studies. The levels of triglycerides, low-density lipoprotein cholesterol (LDL-c), and total cholesterol are hazards for cardiovascular disease. A short dietary intervention experiment revealed that consuming quinoa-enriched bread on a daily basis changed people's glycemic responses but had no appreciable impact on risk factors for CVD [11,47]. Another in vivo investigation examined the effects of eating biscuits high in quinoa on potential risk factors for cardiovascular disease in healthy older persons [11]. The findings demonstrated that there were positive improvements in body mass index, body weight & blood cholesterol levels, all of which lower the chance of CVD [11,48].

6.5 Anticancer activity

Quinoa leaves include a range of phenolic substances that work in concert to reduce the effects of oxidative stress and ROS-dependent intracellular signal transduction, both of which support chemoprevention and anticancer actions. It has been demonstrated that amaranthin and apigenin II, which are abundant in quinoa hypocotyls, marginally suppress the activity of cancerous cells [29]. According to Stikic *et al*., 2020 quinoa seed extract exhibited strong anticancer properties antagonistic towards the human colorectal cancer cell line HCT-116 and included 13 phenolic components present in the quinoa cultivars Puno and Titicaca [51].

The majority of research on quinoa's anticancer properties to date has been conducted using experiments on cells in vitro. In 2017, Hu *et al*. made use of quinoa extract on human hepatoma cancer cell lines SMMC 7721 and MCF-7 breast cancer cell lines to show that the polysaccharide constituent inhibited cancer cells while leaving healthy cells unaffected. The above discovery suggests the possibility of using quinoa extracts to make anticancer medications [29,52].

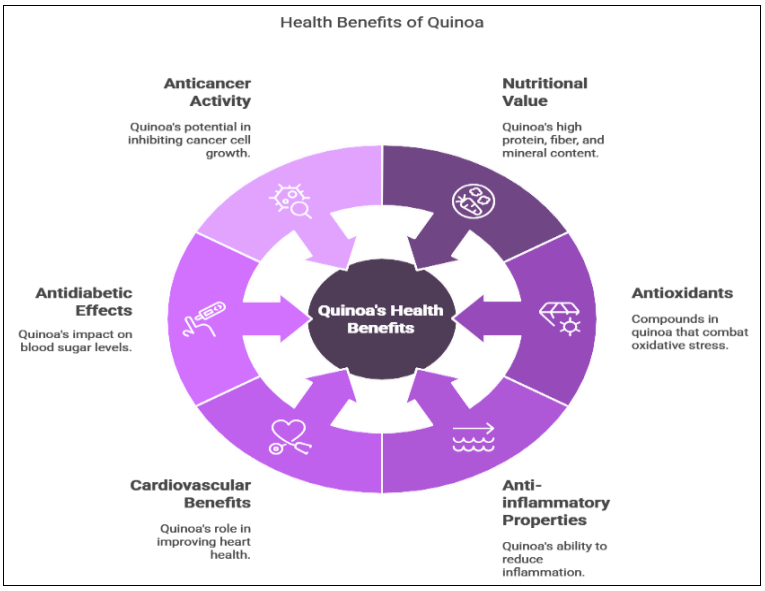

Fig 1: Health benefits of quinoa

7. Quinoa based Food Products

Food products with nutritional value are becoming more and more popular among customers who are concerned about their diet. Quinoa has gained widespread recognition and use worldwide due to its distinct nutritional qualities. There are several ways to prepare and eat quinoa grains. They can be used in place of rice in baby food and morning porridge, or they can be fermented to create drinks like beer. Numerous investigations have been carried out to analyse how quinoa affects the sensory qualities and quality of items including bread, cake, and biscuits [11]. The many quinoa-based product types along with their nutritional characteristics are described in Table 1.

Table 2: Quinoa based food products

Product	Properties	References
Bread	•Abundant in dietary fibre and PUFAs (linoleic and linolenic acids) • Lower Gi & anticipated glycemic load • Free of gluten	[53], [54]
Biscuit	• High levels of antioxidants	[55]
Crackers	• Good consumer acceptability • High antioxidant activity • Notable protein, fiber, and ash content	[56]
Beverages	•A rise in the quantity of Lactobacillus species found in the feces •Variations in several asvs' log2Fold change in samples of feces and saliva	[57]
Noodles	• Increased antioxidant activity and overall polyphenol content; • Better consistency & look	[58]
Sprouted yoghurt quinoa	• Against hypertension and diabetes • Effects of α-glucosidase and aCe inhibition	[59]

8. Allergencity

According to Asao and colleagues, quinoa consumption did not produce a favorable response to wheat protein immunoglobulins suggesting that quinoa may be consumed by those who are allergic to wheat proteins. On the other hand, Astier and others documented a quinoa allergy case in France involving a 52-year-old male had urticaria, angioedema, dysphagia, and dysphonia after consuming quinoa with bread and fish. Analysing samples of the patient's meal, they found that quinoa had reactivity to immunoglobulin E (IgE) in their blood [13].

It was discovered that a 38-year-old woman with wheat-induced eosinophilic esophagitis developed buckwheat and quinoa cross-reactivity. The quinoa seed and buckwheat flour extracts were used to make samples for the skin prick test, and both extracts produced positive findings. Consequently, the patient was recommended to refrain from ingesting quinoa and buckwheat. Therefore, before recommending buckwheat and quinoa as a product substitution for individuals who are extremely sensitive to flour in the future, a cross-sensitivity investigation should be conducted [7,60].

A 29-year-old lady was discovered to have angioedema in her lips, urticaria, a rash on her arms and chest, and itching on her palms and soles of her feet just five minutes after eating quinoa salad. Skin prick testing, which was employed to ascertain food allergies, quinoa came up positive" Hong *et al*. (2013) claim that this was the first instance of quinoa allergy in the US [7].

9. Uses

Quinoa is a excellent source for protein and offers several vitamins and minerals. It may be consumed hot in the form of cereal for breakfast or cooked in water to create baby cereal meal or as an alternative to rice. This cereal gives you energy, helps you lose weight, and may be eaten for breakfast as well [10]. Flour of quinoa can also be combined with wheat or maize flour due to its greater nutrient value. The seeds may be used to prepare porridge, thicken soups, or boil them like rice. Noodles were produced using quinoa flour [14].

Quinoa may be popped to produce popcorn since it has a high fibre content. Popcorn aids with digestion and is a simple way to lose weight. These seeds are used as flour, and their sprouts must be green before they can be used in a salad. The high fibre and protein content of quinoa flour makes it suitable for baking. Since barley and wheat contain the protein gluten, it works well for gluten-free baking [10].

Furthermore, buckwheat increases protein, iron, calcium, and fibre, making it a highly beneficial addition to any gluten-free meal or snack [10,62]. Compared to other cereals, quinoa is thought to be higher in nutrients and offers nutrients that are absent from goods produced from animals [10].

It is used to make noodles, porridge, dosa, breakfast, dark chocolate, soup, bread, and alcohol. It is nutritious. Furthermore, quinoa-based bread has the potential to inspire the creation of several new bakery goods with improved nutritional content. Quinoa was used to make a few foods, including salad, payasam, and porridge [63]. According to Urquizo *et al*., (2017) it may also be fermented to make beer, a beverage, or fodder for farm animals [64]. Quinoa, a gluten-free grain, has anti-diabetic, antihypertensive, and antioxidant qualities. It can be utilized as an element in functional foods and [63,65].

10. Industrial Applications

Quinoa has made a variety of dietary applications easier due to its unique nutritional makeup and functional qualities. According to Agarwal *et al*., (2023), these uses demonstrate the adaptability and increasing significance of quinoa in a variety of domains, including food, health, agriculture, and industry [36,37].

Numerous academics have carried out extensive study in recent years on the nutritional concentration of quinoa and the development of goods made from it. Baked goods including cakes, pies, muffins, and biscuits can be made using quinoa. It is believed that coloured quinoa seed flour has antioxidant properties and is utilized as prime ingredient for the preparation of bread [29].

Fernández-López *et al*. (2020) state that quinoa products may be utilized as natural nitrates and antioxidants in

bologna sausage with good microbiological safety [66]. Additionally, quinoa paste may partially substitute fat when cooking meat items, which improves the product's fiber content and reduces fat level to some amount [11,69]. Prior investigations have examined the function of quinoa in dairy beverages and indicated its potential for use. The yogurt made from quinoa that has germinated has substantial antioxidant properties, making it a beneficial functional dietary ingredient for human well-being [11,70].

One important area of study for novel quinoa products is the production of gluten-free drinks. In the beverage industry, quinoa might be effectively utilized to create malted drink recipes. It may be fermented to produce beer or fed to animals [42]. In fact, malted quinoa drinks may have antihypertensive and antidiabetic properties. Quinoa has recently been used to make baby food due to its high nutritional content, making it the best component for feeding babies [36].

Quinoa has bioactive compounds that may find application as cosmetic ingredients. Saponin-rich quinoa seed extract might be utilized in cosmetics to increase skin suppleness and penetration [36]. As it is the best option for leaf protein concentrate, it might serve as a protein replacement in food, fodder, and medicinal products. Additionally, the whole plant can be fed to cattle, horses, pigs, lambs, and poultry as green fodder [41,69]. Moreover, quinoa is said to have therapeutic uses. The herb is said to have analgesic, anti-inflammatory, and urinary tract-cleaning properties. It is also used to treat internal bleeding, fractures, and as an insect [41,70].

In order to lessen its influence on the environment and provide an alternative to plastic. Quinoa starch is being researched as a potential ingredient in biodegradable, eco-friendly packaging materials. As it is greater source of protein and carbohydrates, quinoa can be utilized to make environmentally friendly and biodegradable coatings and films [36].

Furthermore, quinoa's bioactive components make it easier to include into nutraceutical products that provide health benefits for overall wellbeing [36]. Because of its unique composition, quinoa is employed in nutraceuticals as a helpful element to promote general health and prevent chronic illnesses. Quinoa is therefore a viable option for plant-based nutraceuticals [36]. Quinoa might be helpful in the managing diabetes and heart disorders, according to Nowak *et al*., 2015b, who evaluated the quinoa's impact on blood glucose control and found that regular ingestion promotes metabolism of lipid and glucose. Quinoa's nutritional advantages and adaptability make it a suitable component for the production of nutraceuticals [36,71].

11. Conclusion and Future Prospects

In conclusion, quinoa is a very nutrient-dense, gluten-free crop that has numerous health advantages which include anti-inflammatory, and antioxidant qualities. Due to its environmental flexibility, it is an important crop that provides a sustainable food source for a variety of places. But it's crucial to acknowledge the possible effects on native Andean people and encourage ethical farming methods. Its high protein, fiber and vital minerals make advantageous for hig- risk populations. Beyond its culinary uses, quinoa has industrial uses in animal feed, dairy products, baked goods, and cosmetics. Given its many applications and potential health advantages, quinoa offers a plant-based, nutrient-dense food source for people all over the world and offers a useful way to solve future food security issues.

More research on quinoa's potential applications is required given its rising popularity worldwide. As new technology appears in the domains of pharmacology, molecular biology, and chemical research, quinoa's use as a nutraceutical component gains popularity. To completely understand the pharmacological potential of these phytochemicals, however, further study is needed to thoroughly comprehend their toxicity, metabolic profile, pharmacokinetic and pharmacodynamic activity, and interactions with other substances, formulation, and dose that may affect therapeutic efficacy.

Declaration of competing Interest

The authors reports that there are no competing interests to declare.

Acknowledgement

The authors are grateful to Prof. Neetu Singh, Head of the department, Food and Nutrition, Babasaheb Bhimrao Ambedkar University, Lucknow, for providing valuable suggestions, assistance and encouragement.

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