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A review on the function and application of polyphenol compound of quinoa

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Abstract Quinoa is pseudo cereal and considered as full nutritional food for its functional ingredients such as peptides, polysaccharides, saponins and polyphenols. Up to now, over 20 phenolic compounds have been reported in quinoa, and these polyphenols are related to anti-cancer, anti-inflammatory, anti-obesity, anti-diabetic and cardioprotective activities. Recently, more and more attentions are focused on quinoa in the food and pharmaceutical fields. Many new products such as bakery, beverage and meat product made from quinoa are popular in the market. This article presents a review of the literature on the function and application of polyphenols in quinoa. The review will benefit the researchers working with nutrition, functional diets of quinoa.

Keywords: quinoa; polyphenols; function; application

1 Introduction

Quinoa originated in the Andes Mountains of South America, where it has been cultivated for centuries. It belongs to the quinoa family and is a versatile herb that is nutritious and widely adapted to its environment [1]. For this reason, it was honored by ancient civilizations as the "mother of grains" or the "golden grain". It has gained popularity worldwide as a new alternative crop. Peru is the largest producer and exporter of quinoa, followed by Bolivia. These two countries account for a significant portion of global quinoa production and are showing a clear trend of growth. In recent years, quinoa has expanded to North America, Asia and Europe [2]. In China, quinoa is mainly grown in Inner Mongolia, Gansu, Shanxi, Qinghai and Yunnan Province, with a total growing area of 21 100 acres in 2022. According to the color of the seeds, quinoa is divided into three main types of white, red and black. In addition, different color of quinoa shows different sensory and nutritional characteristics [3]. Moreover, quinoa is a popular addition in salads, chocolate chip cookies, bread, pasta, pancakes, cookies, pasta, cakes and cookies in everyday life due to its compatibility with a wide range of foods. Therefore, quinoa is a promising resource for the future of the food industry [4].

Polyphenols are mainly composed of phenolic acids and phenol alcohols and can be further categorized according to the structure of the phenolic rings including flavonoids and phenolic acids. Flavonoids contains anthocyanins, flavanols and isoflavones. Phenolic acids are usually categorized as hydroxybenzoic acid and hydroxycinnamic acid. Phenolic compounds

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play a crucial role in the antioxidant properties of quinoa, contributing to its potential health benefits. In quinoa, phenolic compounds are important secondary metabolites and exist in both free and bound forms [5]. It has been shown that phenolic compounds are widely distributed in quinoa seeds, with free phenol contents ranging from 167.2 to 308.3 mg gallic acid equivalents per 100 g dry weight. It is noteworthy that the percentage of total free phenol content varied from 53% to 78% in different quinoa varieties. An overview of the specific effects of these polyphenols on human health may provide valuable insights for the nutritional value of quinoa products [6].

2 Polyphenolic composition of quinoa

Many researches have shown that quinoa is rich in phenolic compounds, especially flavonoids and phenolic acids [3]. One study identified a total of 26 polyphenolic compounds in quinoa and determined the content of 23 free phenols in tricolor quinoa, highlighting their potential health benefits. Table 1 shows the 23 phenolic compounds both free and conjugated (released by alkaline or acidic hydrolysis); most of them were phenolic acids, mainly vanillic acid, ferulic acid and their derivatives, and the main flavonoids quercetin, kaempferol and their glycosides. In addition, the darker colored quinoa seeds possessed higher phenolic concentrations and antioxidant activity [5]. The total polyphenol content and phenolic acid composition of quinoa are influenced by several factors, such as quinoa variety, growing region, cultivation techniques and measurement methods. Among the different colors of quinoa seeds, black quinoa seeds had the highest total polyphenol content, followed by red and then white.

Table 1 Concentration of individual phenolic compounds in white, red and black quinoa species measured by HPLC-DAD-MS [3] (mg·kg^{-1})

Code	Phenolic compounds	White quinoa	Red quinoa	Black quinoa
1	3,4-dihydroxybenzoic acid	Not detected	29.82 ± 0.67	47.38 ± 1.39
2	P-coumaric acid 4-glucoside	Not detected	19.34 ± 1.21	31.31 ± 1.88
3	P-hydroxybenzoic acid	15.84 ± 0.72	17.24 ± 0.49	16.97 ± 0.31
4	Vanillic acid 4-glucoside	23.09 ± 1.75	24.62 ± 1.12	27.39 ± 1.09
5	2,5-dihydroxybenzoic acid	0.59 ± 0.06	0.73 ± 0.13	0.28 ± 0.04
6	Caffeic acid	4.39 ± 0.02	4.94 ± 0.03	19.61 ± 0.02
7	Vanillic acid	63.45 ± 2.22	70.02 ± 1.71	39.03 ± 2.04
8	Epigallocatechin	1.55 ± 0.03	2.71 ± 0.04	3.21 ± 0.04
9	Epicatechin	4.62 ± 0.12	3.89 ± 0.11	4.23 ± 0.18
10	Vanillin	4.19 ± 0.09	6.65 ± 0.24	8.39 ± 0.39
11	Acacetin/questin/apigenin-7-methylethe	10.08 ± 0.73	13.33 ± 0.48	16.56 ± 0.55
12	P-coumaric acid	13.01 ± 0.58	22.73 ± 0.54	29.52 ± 1.06
13	Ferulic acid	37.52 ± 2.61	58.41 ± 1.82	47.21 ± 1.77
14	Ferulic acid 4-glucoside	131.97 ± 2.26	51.65 ± 3.17	161.39 ± 0.64
15	Isoferulic acid	8.21 ± 0.26	19.44 ± 0.62	12.35 ± 0.49
16	Kaempferol-3,7-dirhamnoside	20.61 ± 0.94	27.00 ± 1.14	29.41 ± 0.52
17	Kaempferol-3-galactoside	24.01 ± 1.42	28.78 ± 1.77	23.32 ± 0.81
18	Quercetin-3-rutinoside	57.10 ± 2.76	71.04 ± 1.99	57.63 ± 1.47

(to be continued)

Continued Table 1

Code	Phenolic compounds	White quinoa	Red quinoa	Black quinoa
19	Kaempferol-3-glucoside	13.29 ± 1.33	16.42 ± 1.58	24.08 ± 1.69
20	Quercetin-3-arabinoside	24.97 ± 1.19	26.46 ± 1.28	65.79 ± 0.71
21	Quercetin	5.27 ± 0.82	11.82 ± 0.41	12.99 ± 0.11
22	Kaempferol	2.56 ± 0.88	1.18 ± 0.08	1.58 ± 0.07
23	Biochanin A	0.67 ± 0.27	6.44 ± 0.45	2.42 ± 0.79
	Total phenols index (TPI)	466.99 ± 3.27	634.66 ± 5.87	682.05 ± 4.73

2.1 Flavonoids

Quinoa is rich in flavonoids, mainly glycosides such as quercetin, isorhamnetin and kaempferol. In addition, some quinoa varieties contain small amounts of populin and isorhamnetin. Among them, quercetin and kaempferol are the most abundant [7]. Flavonoids are synthesized from phenylalanine via the tricarboxylic acid and acyl polymalonic acid pathways. Structurally, flavonoids consist of 15 carbon atoms, of which two aromatic rings (A and B rings) are connected by three carbon bridges to form a third 6-carbon ring (C ring), which is bound to an oxygen and two carbons of the A ring [8]. The differences between the subclasses arise from the different substituents on the A and B rings (Fig. 1). In one article, quinoa was undergone to gastrointestinal enzyme treatment and found that most of the flavonoids in quinoa remained largely intact and in significantly higher concentrations. The total flavonoid content of black quinoa was found to be higher than that of white, and red quinoa. The quercetin content of Japanese quinoa varieties was significantly higher compared to South American quinoa. The quercetin content of Japanese quinoa varieties ranged between 150 and 225 μmol/100 g fresh weight, which is about three times higher than that of other quinoa varieties (52.3−71.0 μmol/100 g fresh weight) [9]. The seeds of three Andean amaranths, including quinoa, pale-stemmed quinoa, and tailed amaranth, contained between 7% and 61% of the total soluble phenolic acids, and the total phenolic acid content varied considerably, ranging from 16.8 mg/100 g to 59.7 mg/100 g [10].

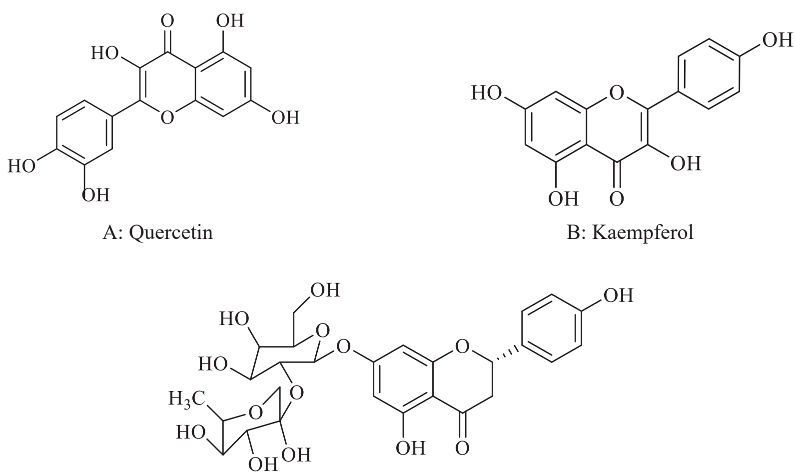
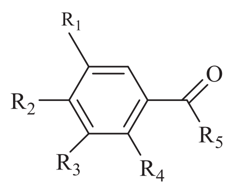


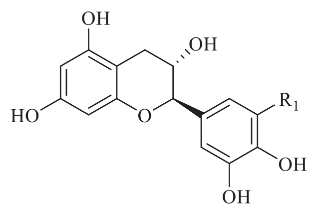
Fig. 1 Common flavonoids found in quinoa

2.2 Phenolic acids

The content of glycosylated phenolic acids in quinoa seeds contributes to its antioxidant properties. Quinoa grains contain 97 different levels of phenolic acids. Phenolic acids associated with quinoa grains are also present in the form of glycosides and glycosylated derivatives [11, 12]. Currently, ferulic acid, caffeic acid and p-coumaric acid are the major phenolic acids found in quinoa. And most of the phenolic acids in quinoa exist in conjugated form. In addition, 4-hydroxybenzoic acid and protocatechuic acid were identified as primary phenolic acids; the content of 4-hydroxybenzoic acid was highest in red and white quinoa grains, while the content of protocatechuic acid was highest in black quinoa grains [13]. Protocatechuic acid is a precursor for the synthesis of several complex substances, such as vanillin and anthocyanin 3-O-*β*-*d*-glucoside, and possesses antimicrobial, anti-inflammatory and antioxidant activities Phenolic acids are derivatives of benzoic acid [14] and cinnamic acid. Hydroxybenzoic acid has a C6−C1 structure and members of this subclass include protocatechuic acid and gallic acid, which are the most common phenolic acids (Fig. 2). The differences in the molecular structure of different types of phenolic acids are mainly due to the differences in the substituent groups on the benzene ring. Quinoa varieties contain benzoic acid phenolic acids (p-hydroxybenzoic acid and vanillic acid) as well as cinnamic acid phenolic acids (ferulic acid, caffeic acid, and p-coumaric acid). The types of phenolic acids in quinoa are influenced by different quinoa varieties, growing conditions and cultivation techniques.



A: Benzoic acid



B: Kaempferol

Fig. 2 Phenolic acid compounds in quinoa

3 Function activity of quinoa

Phenolics in quinoa promote gut health by maintaining a healthy microbial balance in the digestive system [15]. Many studies have emphasized the health-promoting effects of quinoa and its bioactive components. Polyphenols are important by-products of biologically active plant secondary metabolism and contain one or more aromatic rings and hydroxyl groups in their structure [16]. Specific phenolic acids promote metabolism and cell signaling, resulting in potent anticancer, anti-inflammatory, anti-obesity, antidiabetic and cardioprotective effects. Quinoa is rich in these compounds and they influence the flavor and functional properties of the grain The different bioactive components of quinoa and their respective mechanisms of activity *in vivo* and *in vitro* (Fig. 3, Fig. 4).

3.1 Antioxidant activity

Quinoa seeds, young shoots and seedlings are rich in phenolics and polyphenols, which are positively correlated with their antioxidant capacity [18, 19]. The powerful free radical scavenging and antioxidant capacity of quinoa polyphenols stems from its phenolic hydroxyl structure and low redox potential. Phenolic hydroxyl groups provide hydrogen, which reduces free radicals to more stable compounds (Fig. 3). The content of secondary metabolites, antioxidant activity and antioxidant enzymes in quinoa can be affected by biotic and abiotic factors, and their content increases in response to salt stress or environmental conditions.

Different processing methods have different effects on the antioxidant activity of quinoa. For example, germination treatment increases the phenolic content and antioxidant capacity of quinoa. On the contrary, processes such as steaming disrupt the tissue structure of quinoa, leading to a significant decrease in phenolic and antioxidant capacity. A comprehensive study on the antioxidant activity of different parts of quinoa showed that roots and shoots had higher antioxidant capacity, which may be due to the fact

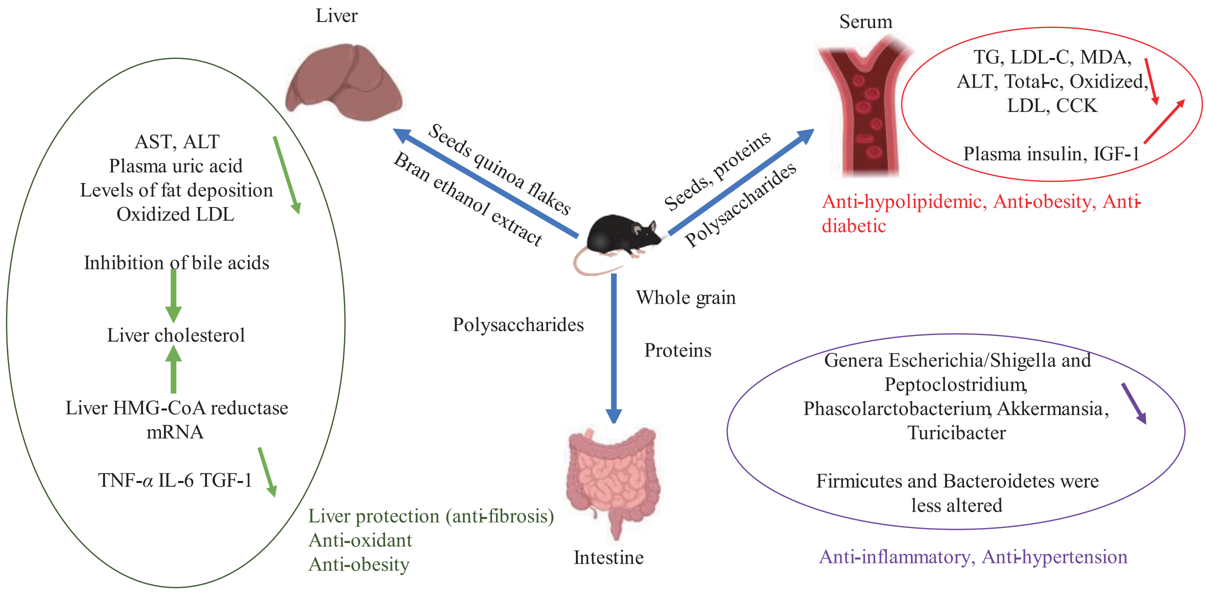


Fig. 3 Different bioactive components in quinoa and theirs *in vivo* activity mechanisms [17]

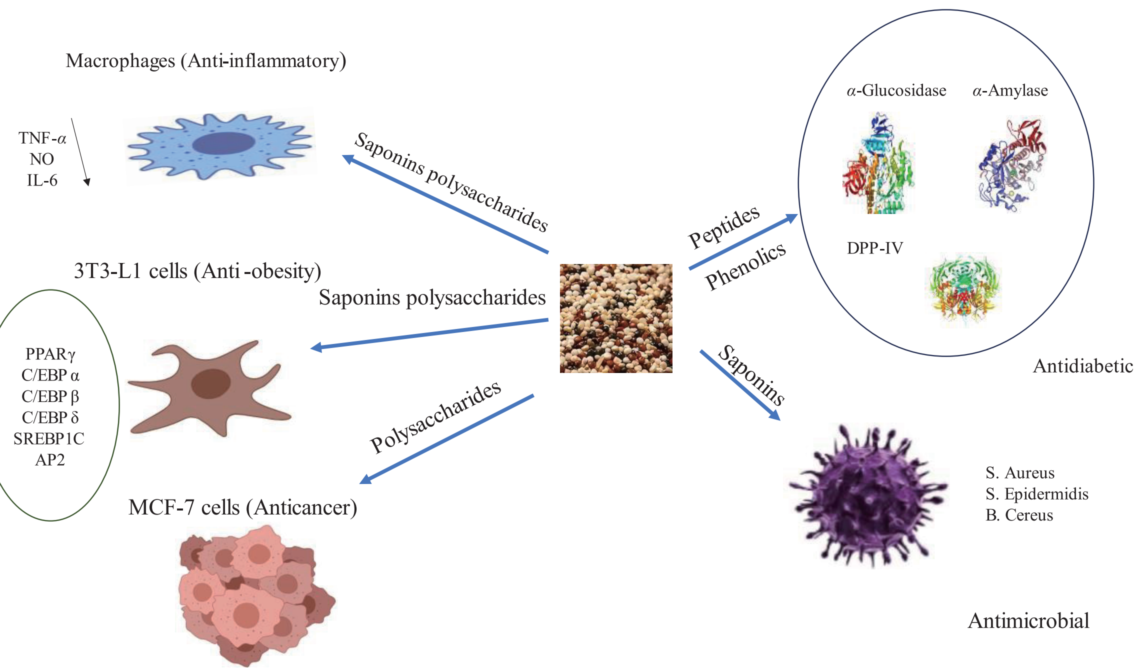


Fig. 4 Different bioactive components in quinoa and theirs *in vitro* activity mechanisms [17]

that they contain different phenolic compounds. Diet supplemented with quinoa seeds reduced oxidative stress in plasma, kidney, liver and lungs of rats fed fructose (Fig. 3). Plasma lipid peroxidation was also inhibited [20], which is reflected in the fact that the hydroalcoholic extract of quinoa seed coat may contain thiol compounds that inhibit microsomal lipid peroxidation and reduce microsomal thiol content. According to DPPH, FRAP and β-carotene bleaching tests, ethyl acetate extract showed the highest antioxidant activity. Non-alcoholic beer produced by co-fermentation of quinoa with Picher yeast showed strong antioxidant activity, which was mainly attributed to phenols and flavonoids in quinoa [21, 22]. A study showed that the removal of saponins from quinoa reduced the total polyphenol, total flavonoid, and γ tocopherol content and antioxidant activity of quinoa ethanol extract. Quinoa extracts have demonstrated antioxidant capacity in real food systems, resulting in improved food quality and extended shelf life [23].

3.2 Anti-inflammatory activity

Quinoa flavonoids, particularly quercetin and its glycosides, possess anti-inflammatory properties and are known for their thirst-quenching and expectorant effects [24]. These flavonoids also exhibit apoptosis-inducing, anti-mutagenic, enzyme-inhibiting (such as protein kinase C and lipoxygenase), and histamine release-blocking properties. Polyphenols derived from quinoa have been found to down-regulate IL-1β, IL-8, and TNF cytokines in cultured colonic epithelial CACO-2 cells (Fig. 4), as well as to prevent inflammation induced by obesity and promote gastrointestinal health in mice [25]. Two purified quinoids (low/highly charged) have demonstrated potential anti-inflammatory activity in an enterocyte CACO-2 model by modulating the NF-κB signaling pathway and inhibiting IL-1β expression [26]. Furthermore, *in vitro* enzymatic techniques have been utilized in food protein processing to generate peptides with various beneficial effects. Both total proteins and protein hydrolysates from quinoa possess anti-inflammatory properties by inhibiting NO release [27]. Quinoa leaf extract and quinoa phenols have shown concentration-dependent inhibition of LPS-stimulated NO production, with free phenols exhibiting higher inhibitory activity compared to bound polyphenols. Notably, red quinoa phenolics have demonstrated superior anti-inflammatory activity compared to white quinoa [28].

3.3 Anti-cancer and anti-tumor

Polyphenols exhibit strong reducing activity, effectively neutralizing free radicals, inhibiting oxidase activity, and preventing the formation of DNA adducts [29]. This process helps eliminate carcinogens and promote overall health. This process helps eliminate carcinogens and promotes overall health. The quinoa leaf polyphenol extract can hinder the growth of prostate cancer cells in animal models by reducing the expression of gap junction protein-43, inhibiting lipoxygenase and blocking fat oxidation (Fig. 3). Several articles have also emphasized the cytotoxic activity of quinoa against human cervical cancer cell lines [30] (Fig. 4). Additionally, the hypocotyl of quinoa contains compounds like am Aran thin and apigenin II, which have shown mild inhibitory effects on cancer cell activity. Potent anticancer activity in quinoa seed extract against a human colorectal cancer cell line, attributed to the presence of 13 phenolic compounds [31]. Quinoa leaves are also a valuable source of active constituents, including various phenolic acids that not only inhibit the proliferation of prostate cancer cells in laboratory settings but also contribute to chemoprevention by modulating oxidative stress and ROS-dependent intracellular signaling.

3.4 Hypoglycemia and hypolipidemia

The *omeg*a-3 fatty acids in quinoa have vasodilatory and hypolipidemic effects, while its phytosterols help regulate serum cholesterol levels [32]. Rutin in quinoa can improve vascular health by reducing permeability and brittleness, dilating coronary arteries, and preventing blood cell coagulation, ultimately lowering the risk of cardiovascular disease (Fig. 4). Quinoa soluble dietary fiber demonstrates higher α-amylase and α-glucosidase inhibition compared to wheat soluble dietary fiber, attributed to differences in network structure, fiber composition, and polyphenol content. Polysaccharides extracted from quinoa using ultrasound techniques showed a glucose and arabinose molar ratio of 1.17:1, leading to reduced levels of TG, LDL-C, MDA, ALT, and AST, along with improvements in dyslipidemia induced by a high-fat diet in rats [33]. Additionally, it positively affected the intestinal microbial community and mitigated HFD-induced hyperlipidemia (Fig. 3). *Quinoa* seed ethanolic extract normalized leptin and lipocalin hormone levels, enhanced growth performance in hyperlipidemic rats, and exhibited antioxidant properties by reducing lipid peroxidation and increasing catalase and glutathione peroxidase activities.

3.5 Hepatoprotective activity

Quinoa is a rich source of phenols, polyunsaturated fatty acids, and phytic acid, displaying anticancer activity and protective effects against non-alcoholic fatty liver disease in HepG2 cancer cell lines [34]. Numerous animal studies have demonstrated the positive impact of dietary quinoa and quinoa extracts on liver function (Fig. 4). These studies have shown that quinoa reduces hepatic lipid peroxidation, promotes a balanced distribution of tocopherols, and prevents hepatic steatosis in obese mice. The other articles have shown that red quinoa bran ethanol extract attenuates hepatic fibrosis in mice by activating antioxidant enzyme system and blocking TGF-1 pathway (Fig. 3). In addition, quinoa ethanol extract increased the levels of GSH, SOD, GPX, and catalase in the liver of male rats, thereby attenuating cyclophosphamide-induced hepatotoxicity [35, 36].

3.6 Antimicrobial activity

Polyphenols are commonly utilized as bacteriostatic agents due to their ability to coagulate microbial protoplasm and inhibit microbial enzyme activity (Fig. 4). Phenols found in quinoa act as antibiotics, synergistic antibiotics, and inhibit bacterial activity [37]. Flavonoids, in particular, have a strong inhibitory effect on a variety of bacteria and some fungi. Some research demonstrated significant inhibitory effects of quinoa flavonoids on *Staphylococcus aureus, Escherichia coli, Bacillus subtilis,* as well as certain fungi. Other researchers further investigated the antibacterial properties of flavonoid extracts from quinoa bran, revealing substantial inhibition rates against various bacteria, with the most notable effect observed on *Bacillus subtilis*. Yang, et al. [38] conducted studies on the inhibitory effects of quinoa bran flavonoids on fungi using disc diffusion and optical density methods. Their findings highlighted the strong antibacterial activity of quinoa extract, particularly against foodborne pathogens such as *Staphylococcus aureus, Listeria monocytogenes, Bacillus cereus, Salmonella typhimurium, and Campylobacter jejune.* In addition to their enhanced antibacterial activity, quinoa flavonoids are deemed safe and environmentally friendly. They can be combined with proteins and polysaccharides to create a film for food preservation through methods such as spraying, encapsulation, or coating.

4 Applications

In recent years, numerous researchers have conducted comprehensive studies on the nutritional value of quinoa and the development of quinoa products. It has been observed that processing can alter the texture, nutritional properties, and digestive characteristics of quinoa. As a result, various processing methods can greatly influence the nutritional quality and health benefits of quinoa products (Fig. 5).

4.1 Bakery products

Quinoa is a versatile ingredient that can be incorporated into a variety of baked goods, such as cookies, cakes, muffins, and pies. Flour made from colored quinoa seeds is known for its antioxidant properties and is often used as a functional ingredient in bread production. Research has shown that quinoa-based cookies have higher lysine content and antioxidant activity compared to traditional wheat cookies [39]. Quinoa products can also serve as antioxidants and natural nitrates in dishes like Bolognese sausages, ensuring high levels of microbiological safety [40]. Furthermore, quinoa sauces can be utilized as a partial substitute for fat in meat cooking, thereby enhancing the overall health profile of the dish by reducing fat content and increasing fiber content. The optimal consumption level of red quinoa was found to be 5%. Adding quinoa to pasta improved various characteristics such as expansion

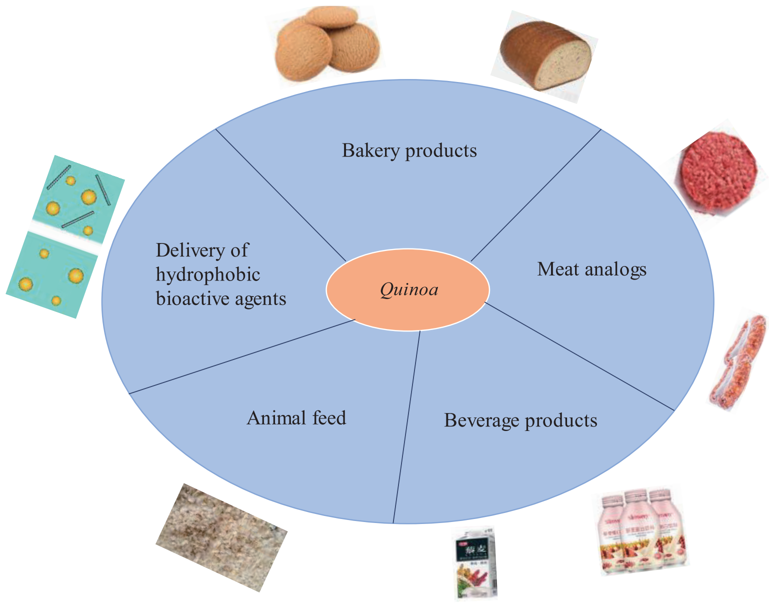


Fig. 5 Classification of quinoa application

index, cooking loss, water absorption, and protein retention, while enriching the protein content with essential amino acids like lysine and methionine. This enhancement in nutritional and functional properties has led to a growing interest in the development of fermented quinoa products [41]. Additionally, rats fed with quinoa tempeh showed higher activity of hepatic glutathione peroxidase, indicating superior antioxidant activity compared to rats fed with regular quinoa seeds [42].

4.2 Beverage products

Yogurt derived from sprouted quinoa is considered a functional food with health benefits due to its strong antioxidant activity. Incorporating quinoa extract into goat's milk has been shown to reduce fermentation time, enhance the viability of lactic acid bacteria, and improve the viscosity of yogurt [43]. Furthermore, combining camel's milk and quinoa seeds has resulted in mixed fermented milks with high nutritional value and excellent safety profile, as no harmful microorganisms were detected. Gluten-free beverages made from malted quinoa have demonstrated higher protein and total phenolic content compared to un-malted varieties, showing promise for potential antidiabetic and antihypertensive effects [44]. A study by Hussein, Fouda, Mehaya, Mohamed, and Mohamed utilized almonds, quinoa seeds, and carrot juice to create a beverage rich in γ tocopherol, suitable for promoting liver and heart health by reducing cholesterol, triglycerides, oxidative stress, and inflammation [45]. Moreover, the choice of quinoa variety can impact processing and product quality, as evidenced by a comparison of two varieties in fermented beverages, where Pataskala exhibited higher protein content, lower saponin content, and less viscosity loss than Rosada's Huancayo variety [46].

4.3 Meat analogs

Quinoa sauces have the potential to replace fat in meat products, enhancing their health profile by reducing fat content and increasing fiber content. The nutritional richness and bioactive properties of quinoa seeds make them a valuable ingredient or fat substitute in meat products [47]. Incorporating quinoa seed flour and quinoa seed starch in meat formulations can enhance the overall quality of the products from a health perspective. Typically, quinoa seed flour is used in concentrations of less than 15%. Research has shown that the addition of quinoa seed flour does not compromise the physicochemical, textural, or organoleptic characteristics of meat products; Moreover, it can improve oxidative stability [48]. Felix, et al. [49] explored the impact of concentration and temperature on the rheological properties of quinoa seed flour-based gels, revealing that concentrations exceeding 200 g/kg lead to the formation of gels with a texture reminiscent of sausages, offering potential for the development of meat-free products suitable for vegan diets. Quinoa seeds and starch have also been utilized in the production of chicken meatballs [50]. Quinoa seed starch is particularly effective in preventing water loss during steaming and repeated freezing and thawing, and its incorporation into products ensures optimal acceptability. Furthermore, the lower cooking yield observed in meat patties with added quinoa seeds, compared to those with quinoa seed flour, is attributed to the challenge of the quinoa seed component in interacting with the meat matrix [51].

4.4 Animal feed

Quinoa can serve as a dual-purpose crop for both food production and livestock feed. Shah, et al. [52] evaluated 15 quinoa germplasm for forage yield, morphological, and quality traits during flowering and seed filling. They observed that genotypes with more branching and moderate plant height produced higher quinoa forage. Quinoa seed meal has been utilized as a protein source in chicken feed to enhance renal (ALT and AST) and hepatic (urea and creatinine) function, indicating its potential in improving poultry health [53]. That quinoa offers superior nutritional value compared to wheat and corn in chicken diets. While the inclusion of whole quinoa seeds hindered chicken growth, hulled quinoa improved weight gain in the short term. The growth inhibition is primarily due to bitter compounds in the bran, but poultry can adapt to the saponins' bitter taste and effectively utilize quinoa nutrients after an adjustment period. Beyond seeds, the nutritional value of quinoa hay and straw is significant, with quinoa hay and straw containing 19.9% and 10.6% crude protein, respectively, and dry matter digestibility of 75.8% and 54.2%, respectively [54].

4.5 Delivery of hydrophobic bioactive agents

Quinoa seed starch can be fashioned into microspheres with high adsorption capacities, showing promise as a material for drug delivery [55]. The development of biopolymer systems for delivering functional ingredients is a current focus of research, with the goal of improving solubility, stability, bioaccessibility, and bioavailability. Proteins and polysaccharides have been identified as key components due to their biodegradability and compatibility with biological systems. Quercetin seed proteins have been utilized as carriers for hydrophobic compounds, forming amorphous complexes that create nano-micelles. The encapsulation efficiency for quercetin was found to be 81.3%, with a loading capacity of 33.9% [56]. Similarly, quinoa seed starch, characterized by its small particle size and high amylose branching, has been shown to stabilize emulsion droplets effectively. Quinoa seed starch nanoparticles demonstrated superior quercetin loading compared to corn starch nanoparticles, attributed to the higher branched starch content in quinoa seeds resulting in lower crystallinity and increased quercetin adsorption. The stability of quercetin was notably improved, and the presence of quercetin slowed the enzymatic hydrolysis of starch nanoparticles [57]. Rutin-loaded starch nanoparticles also exhibited higher encapsulation efficiency and loading capacity compared to corn starch nanoparticles. Moreover, octenyl succinic anhydride modified quinoa seed starch displayed enhanced trapping ability. Amphiphilic quinoa starch-stabilized rutin-loaded Pickering emulsions achieved exceptional encapsulation efficiencies of up to 99.3% and demonstrated slow release *in vitro* [58].

5 Conclusion

This review summarizes the functional properties of quinoa polyphenols and their applications. Quinoa polyphenols exhibit anti-inflammatory, antibacterial, antiviral, anticancer and hepatoprotective properties with benefit human health, being widely distributed in quinoa plants. Despite the development and consumption of various quinoa products, such as health drinks and functional fermented foods, limited research has been conducted on the impact of different food processing methods on important bioactive compounds. It is necessary to optimize the use of quinoa in the functional food industry. Reliable scientific tools must be employed to assess the quality of quinoa and its functional ingredients to ensure the efficacy and safety of these products.

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