Chapter 12
Quinoa

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12.1 Introduction

Quinoa (*Chenopodium quinoa Willd*) is an annual self-pollinated dicotyledonous plant and belongs to the Chenopodiaceae family, also known as *Chenopodium album*, Indian wheat, and quinoa. It is originally from the Andean region of South America, mainly distributed in Bolivia, Ecuador, and Peru, with cold-resistant, drought-tolerant, barren-resistant, and salt-tolerant characteristics. It is a cool, high-altitude crop and is the main traditional food of indigenous Incan peoples. It has a planting history of 5000–7000 years. It is a kind of cereal that is used for both medicine and food. It has both rich nutritional value and medicinal value. As understandings of the nutritional value and health functions of quinoa have grown, its consumption demand has also increased.

Quinoa has a high nutritional value. It is the only food that the United Nations Food and Agriculture Organization (FAO) recognizes as a single plant to meet the basic nutritional needs of the humans and is called "the mother of grain" by the ancient Incan peoples [1]. Quinoa is listed as one of the ten most nutritious foods in the world and is one of the ideal space food choices of the US space agency (NASA). Quinoa, as a "whole grain," is not only rich in protein and calcium, iron, and zinc but also rich in many bioactive substances, such as saponins, flavonoids, polyphenols, and anthocyanins. It has good adjuvant therapy for the prevention of obesity, cardiovascular disease, diabetes, and cancer but also has anti-inflammatory, antioxidizing, and immune system-enhancing effects [2]. Because of its rich and comprehensive nutritional value and medicinal value, quinoa has received extensive attention both by food scientists and consumers in recent years. However, as a new crop to the world stage and public consciousness, there are few reports on its nutri-

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tional active ingredients. To this end, combined with the latest research trends at home and abroad, and based on previous studies, this reivew explained the nutrients and active ingredients of quinoa which could provide theoretical basis for quinoa in nutrition, healthcare, and medicinal purposes.

12.2 Bioactive Ingredients

Quinoa is the only monomer plant identified by FAO as meeting the basic nutritional needs of the human [3] and listed as the ten most healthy and nutritious foods in the world. Quinoa is not only rich in protein, fatty acids, and minerals but also rich in bioactive ingredients such as polyphenols, saponins, and flavonoids. It plays a very important role in both preventing and treating diseases and maintaining human health. With a deeper understanding of the nutritional value and health functions of quinoa, scientists have paid increasingly close attention and studied the active ingredients.

12.2.1 Polyphenols

Plant polyphenol is a kind of secondary metabolite with polyphenol structures that are widely found in plants. It mainly exists in the skin, roots, leaves, and fruits of plants and is biologically active in scavenging free radicals and antioxidants [4]. Plant polyphenols include a variety of natural phenols such as tannins, catechins, quercetin, gallic acid, ellagic acid, and arbutin [1], which are natural antioxidants. Nowadays, quinoa is attracting increased attention due to the high content of polyphenols in its tissues and organs.

Repo-Carrasco-Valencia et al. [5] have measured the content of total phenol and soluble phenolic acid in quinoa, amaranth, and pallidicaule. They found that phenol content varied from 16.8 to 59.7 mg/100 g, the proportion of soluble phenolic acids ranged from 7% to 61%, and polyphenols showed strong antioxidant activity in vitro. Paweł et al. [6] determined the content of anthocyanin and polyphenol in quinoa and leek. Through the comparative analysis of DPPH free radical scavenging ability, ferric reducing ability of plasma (FRAP), and ABTS radical scavenging ability, they determined that the total phenol content in quinoa and leek was (3.75 ± 0.05) mg/g and (2.95 ± 0.07) mg/g, respectivley. The total polyphenol content of quinoa is higher than that of leeks. Both have good antioxidant capacity.

12.2.2 Saponins

Saponin, also known as alkali soap, is a compound composed of one or more sugar chains and one triterpene aglycone or steroidal glycoside and is an anti-nutrient material. The main saponins of quinoa are oleanolic acid, ivy saponin, phytolaccagenic acid, and serjanic acid. Its carbohydrates include glucose, arabinose, and galactose [7]. Saponins are mainly distributed in plants grown at high elevations, and trace amounts also exist in marine life such as starfish and sea cucumbers. The saponin content in quinoa is very high and it has highly biologically active. It has analgesic, anti-inflammatory, anti-microbial, antioxidation, anti-virus, and anti-cytotoxicity functions. Quinoa can be divided into sweet quinoa (<0.11%) and bitter quinoa (≥0.11%) based on saponin content. The saponin of quinoa is mainly located in the seed coat. Sweet quinoa contains 0.02%–0.04% of saponin and bitter one contians 0.47%–1.13%. Both varieties contain higher levels than soybeans or oats [8].

Estrada et al. [9] studied the effect of saponin extracted from quinoa on the gastric and nasal mucosa of mouse antigen model. When quinoa saponins were combined with cholera toxin or ovalbumin and carried in the stomach or nose, specific immunoglobulin G (Ig G) and Ig A antibodies in the blood, small intestine, and lung triggered antigen responses, suggesting that saponins have a positive effect on human immune regulation. Although saponins have a variety of positive effects on the human body, it is also an anti-nutrient material and affects the taste of quinoa. Therefore, before consuming quinoa, water is needed to remove saponin from the seed surface [10].

12.2.3 Flavonoids

Flavonoids are compounds that exist in nature and have a 2-phenyl flavonone structure. Its hydroxyl derivatives are mostly yellow. Flavonoids usually bind to sugars in the plant body as glycosides, and small fractions exist in free form. Most plants contain flavonoids, which play an important role in plant growth, development, flowering, production, and antibacterial and disease prevention. Quinoa has high flavonoid content ranging from 36.2 to 144.3 mg/100 g [11]. According to reports [12], flavonoids are often present in the form of flavonoid glycosides in the plant family. Quinoa is rich in flavonoid glycosides, including quercetin, isorhamnetin, kaempferol, aglycones, and disaccharides and trisaccharides, whose sugar groups are attached at the C-3 position. According to reports, the scavenging capacities of quinoa flavone extracts for DPPH and ·OH were 89.3% and 86.6%, respectively, and the inhibition rate for amylase was 41.38%. It has been proved that flavonoids effectively scavenge free radicals and have antioxidative functions [4].

12.2.4 Anthocyanins

Anthocyanins are water-soluble natural pigments widely found in plants. They are colored elements derived from the hydrolysis of anthocyanins. Most of the major coloring matter in fruits, vegetables, and flowers is related to it. Anthocyanin content in quinoa is very high, in the form of glycosides. Paweł et al. [6] found that the content of anthocyanin in the grain of quinoa was 120.4 ± 7.2 mg cyanidine-3-glucoside equivalent (CGE)/100 g DW, higher than that of many grains and legumes. Furthermore anthocyanin content was increased with the germination process. Studies have shown that anthocyanins have certain antioxidant and therapeutic effects, such as antitumor, anticancer, anti-inflammatory, and cardiovascular disease prevention [7].

12.2.5 Phytic Acid

Phytic acid is also known as creatine, cyclohexanol hexahol-dihydrogen phosphate, which is found mainly in the seeds, roots, and stems of plants. The content in bran and germ of quinoa is the highest, which can produce insoluble compounds with metal ions such as calcium, iron, magnesium, and zinc and reduce the effectiveness of metal ions. Phytic acid can also form complexes with proteins, making metal ions even more unusable and affecting the availability of mineral elements. It is an anti-nutritional component.

12.2.6 Lipids

Quinoa is rich in fat, the content of which is much higher than common grains. The fat content of quinoa was twice that of corn, but fatty acid composition was similar to corn. Therefore, quinoa has great potential in vegetable oil extraction and utilization. There are many essential fatty acids in quinoa, which are mainly polyunsaturated fatty acids omega-6 and omega-3 [14]. Omega-6 content was significantly higher than wheat and rice, and the content of omega-3 was about three times that of wheat. According to the study, the proportion of unsaturated fatty acids in quinoa accounts for more than 83% of total fatty acids, which can reduce low-density lipoprotein and increase high-density lipoprotein. The ratio of high unsaturated fatty acids can also maintain lipid membrane fluidity. Most of the omega-3 and omega-6 unsaturated fatty acids contain carbon-carbon double bonds, including linoleic acid, linolenic acid, and arachidonic acid, all of which are essential for the human body [13]. Linoleic acid can be metabolized to arachidonic acid, which can be further metabolized to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). EPA and DHA play an important role in the prevention and treatment of prostaglandins, thrombosis, atherosclerosis, immunity, anti-inflammatory, and membrane function [14].

12.2.7 Carbohydrates

Quinoa is rich in soluble and insoluble cellulose, and some of them have a very important role in regulating blood glucose levels and reducing cholesterol. The most common carbohydrate in quinoa is starch, which accounts for 58%–64.2% of the total dry matter [15]. In addition, the physical properties of starch in quinoa are different from other crops. For example, quinoa starch has similar expansion capacity to wheat, but its freeze-thaw stability is much higher than that of wheat, and the onset temperature and the maximum temperature of starch gelatinization are lower than that of barley [16]. Studies have shown that soluble sugar content in quinoa is very high, up to 15.8%, and glucose, fructose, and sucrose contents were 4.55%, 2.41%, and 2.39%, respectively [17]. Quinoa is low glycemic index (GI) food that can play a beneficial role in the metabolism of glucose and lipids [18]. There are many studies on the extraction methods of quinoa polysaccharides, in which YIF93 (YIF91) and YGF93 (YGF91) have significant antioxidant and immunomodulatory activity, which can be used as potential antioxidants and immunomodulators [19].

12.3 Nutrition and Functions

12.3.1 Gluten-Free

Gluten is a group of proteins in grains, especially in wheat. For most people, gluten is an unremarkable protein that is easily digested in the gastrointestinal tract. However, there is a small group of people who cannot digest gluten protein as most people do. These people have trouble with gluten protein digestion and commonly suffer from celiac disease (a type of intestinal disorder that is not resistant to gluten) [20].

The protein content of different quinoa varieties is different and it is mainly present in the endosperm. Quinoa has much more protein than rice, wheat, barley, and many other common grains. The protein of quinoa is mainly composed of albumin and globulin (account for 44%–77% of the total protein), both of which have good stability due to their disulfide bonds. Alcohol-soluble glutenin and gliadin content in quinoa is comparatively much lower and is commonly called gluten-free [21], so it has better solubility and absorption effects than others [22]. It is an excellent source of nutrition for patients with celiac disease [23–27].

12.3.2 Antioxidant Activity

Many of the bioactive ingredients in quinoa are antioxidant, such as phenols and carotenoids, making quinoa an excellent source of antioxidants [28]. The antioxidant components in quinoa were determined by DPPH, FRAP and ORAC, and

unsaturated fatty acid (UFAs), total carotenoid index (TCI) and total tocopherol index (TTI) were found to have a positive correlation with the antioxidant capacity [29].

Polyphenols play the most important role among all the antioxidants. Polyphenols are the secondary metabolites of plants related to their antioxidative property and are widely present in plant roots, stems, skins, leaves, and fruits. They exhibit certain biological activities such as free radicals scavenging ability and antioxidative function [30]. Paweł et al. [6] found that the polyphenol content in quinoa kernel and bud seedling was positively correlated with its antioxidant capacity. Phenolic compounds in most foods exist in the form of esters, glycosides, or polymers that cannot be edible. These polyphenols must be hydrolyzed first in the intestine by intestinal enzymes or bacterial degradation and then they can be absorbed by human body. Nearly 80% of the total polyphenol compounds in quinoa remain biologically active in vitro [31].

Among the evaluation methods for antioxidant capacity, a cell-based antioxidant assay (CAA) was selected which could highlight the bioavailability, absorption properties, and antioxidant metabolic compounds of the antioxidant active substances [32, 33].

Another method for assessing antioxidant capacity is to determine antioxidant enzymes activities, such as glutathione (GSH), superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase (CAT) in vitro [32, 34]. At present, although many studies have shown phytochemicals such as saponins and flavonoids exhibit strong antioxidant activity, the mechanisms of these compounds are not fully understood, and further studies on the regulation of bioactive components of quinoa in vivo are needed [35].

12.3.3 Anti-inflammatory Activity

There are many bioactive ingredients in quinoa that have anti-inflammatory and antifungal functions. Noratto et al. [36] found that polyphenols extracted from quinoa had the effect of lowering inflammatory cytokines expression such as IL-1β, IL-8, and TNF-α, and protecting against inflammation caused by obesity and maintaining a healthy environment in the cecum of mice.

Flavonoid compounds that exist in quinoa possess anti-inflammatory functions. Formica and Regelson [37] found that flavonoids had many biological activities, including inducing apoptosis; resisting mutagenesis; inhibiting protein kinase C, superoxide dismutase, and lipoxygenase activity; and inhibiting histamine release through vitro experiments.

Quinoa is also an important and active anti-inflammatory substance, which can inhibit macrophages from producing harmful metabolites NO, tumor necrosis factor-alpha, and interleukin-6 [19].

Woldemichael and Wink [12] have isolated and identified 16 saponins from quinoa seeds and detected the hemolytic activities and antifungal activities of these compounds through NMR, mass spectrometry, and chemical methods. Alkaline treatment could destroy cells member which helps to enhance the antifungal activities of quinoa saponins.

12.3.4 Skin Care Activity

Quinoa's proteins exist in its endosperm, which is generally 8%–22% higher than common grain, such as rice, wheat, and barley. It does not contain glutenin. The protein of quinoa is a kind of acid protein, mainly composed of albumin and globulin (they account for 44%–77% of the total protein). The two proteins have good stability because of the two sulfur bonds it contains. The content of gliadin and glutenin is lower than other grains, and it is easy to be absorbed in and utilized by the human body.

On skin care and beauty products, plant's protein mainly has the effect of horniness removing, firming, antiaging, whitening, antioxidant, moisturizing, and anti-inflammatory functions. In recent years, due to plant protein's active ingredients and mild side effects, natural beauty products based on it have becoming more and more popular. Thus quinoa protein is a kind of excellent cosmetic raw material. Hydrolyzed quinoa protein can be used as a natural skin nutrition and hair conditioner. Quinoa saponins are natural and mild plant surfactants. Quinoa seed oil is edible, and it has potential medicinal beauty uses. The rich mineral elements in quinoa are also the nutritional ingredients of human skin [38].

Quinoa is also rich in vitamins and amino acids [6], which can be used for skin care products, cosmetics, and other raw materials.

12.3.5 Anti-obesity and Diabetes Treatment

Quinoa contains low fat, low sugar, and low starch. The regular consumption of quinoa not only reduces the occurrence of type II diabetes mellitus but also has the function of reducing weight. The rich mineral elements of quinoa that regulate glucose levels in the human body act as an inhibitor or activator of key enzymes in glucose metabolism. The rich contents of quinoa's isoflavones and VE contribute to blood circulation, softening blood vessels, promoting sugar and lipid metabolism and insulin secretion, and reducing blood glucose levels [5]. Ruales and Nair [39] reported that quinoa contains 11% of insoluble fiber and 2.4% of soluble fiber. These two kinds of cellulose have a very important role in regulating blood glucose levels, lowering cholesterol levels, and protecting the heart. Furthermore, cooked quinoa's volume is 3–4 times larger than raw, which makes the absorbing capacity of dietary fiber stronger and produces a strong feeling of satiety after eating. Thus, it is helpful for weight control. Quinoa is a kind of low sugar and low calorie food. Experiments with mice found that blood glucose and blood lipids were significantly decreased after feeding with quinoa [32]. Quinoa is also a healthy food for hypertensive patients, hyperlipidemia patients, hyperglycemia patients, obese people, and diabetics.

12.3.6 Cardio-cerebrovascular Diseases and Other Diseases

Many active ingredients in quinoa can regulate human diseases. The consumption of quinoa can regulate fructose metabolism in the human body, which plays an important role in oxidative stress reactions. Thus it has a protective effect on the heart, kidney, liver, and other important organs. Gawlikdziki et al. [40] found that ferulic acid, mustard acid, gallic acid, kaempferol, isorhamnetin, and rutin extracted from quinoa could inhibit the activity of fatty acid enzymes, hinder intercellular communication, and inhibit the proliferation of cancer cells.

12.4 Summary and Outlook

In the recent years, with the rapid development of functional foods, the international market of quinoa is expanding gradually, from its origins in South America to the United States and later to Europe, Asia, and beyond. The annual production of quinoa is rising steadily. The planting areas of quinoa are growing in the United States, Britain, France, Italy, Germany, and other countries. Quinoa, just one single plant, could meet the basic nutritional needs of the human body and is officially recommended by the United Nations Food and Agriculture Organization (FAO) as the most suitable food for human consumption because of its "full nutrition." Therefore it was listed as one of the world's ten healthiest nutritional foods. The year of 2013 was marked as the "International Quinoa Year" [41]. Although quinoa contains some anti-nutritional factors, it can be removed during processing or applied better through appropriate treatments.

The cultivation of quinoa has also developed rapidly in China. It has been introduced and researched since the beginning of the 1990s, and its cultivation has been expanded rapidly. However, since its introduction to China is in a relatively short time, research on it is still at initial stages.

There are few studies on the breeding of new varieties, the nutritional components, and the bioactivities of quinoa. Thus, there is still a long way to go in the research and development of quinoa production.

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