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Chemical Composition and Health Effects of Quinoa: A Review

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ABSTRACT

Many herbs in traditional and modern medicine comprise saponins, which are generally responsible for the therapeutic properties they possess. Many saponins are known to show biological activities such as antiviral, antidiabetic, and cytotoxic properties. These substances and plants containing them are becoming more and more attractive for pharmacological research purposes. Quinoa seed, which contains various phytochemicals and antioxidant substances, is one of the grain groups on which research has been conducted and the mechanisms of its effects are intended for clarification. This study aims to explain the effects of its consumption on health by giving information about the chemical composition of quinoa seeds and by showing scientific data as an example. The results obtained in the literature studies have determined that quinoa has an important potential to be used as a food supplement, in pharmacology, and in the production of new food products, thanks to the positive effects of its consumption on health.

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is an Andean pseudocereal that has been used in South America for centuries (Vega-Gálvez et al., 2010) and its grains are grown in Canada, Europe, North Africa, and India (Multari et al., 2018). It has been recognized for its phytochemical content and its unique nutrient values; therefore, quinoa consumption has increased significantly in recent years (Jancurova et al., 2009).

Quinoa seeds are the primarily edible parts of the plant and are rich in amino acids including carbohydrates (77.6%), protein (12.9%), lipids (6.5%), high lysine, and methionine (Ando et al., 2002). Its carbohydrate content is higher than cereals such as oats, wheat, corn, and rice (Lindeboon, 2005). In addition, its seeds contain more Fe, Ca, K, Cu, Mg, and Mn than wheat and rice (Konishi et al., 2004).

Quinoa seeds are rich in a wide variety of antioxidants such as carotenoids, ascorbic acid, and phenolics (Mohyuddin et al., 2019). These antioxidant compounds are primarily responsible for antioxidant capacity, which plays an important role in the prevention of cancer and inflammatory (Gawlik-Dziki et al., 2013). In addition to its many beneficial effects on health, the use of quinoa in foods produced for celiac patients, thanks to its gluten-free property, is another factor that explains the increasing interest in quinoa (Deželak et al., 2014). The maximum prolamine content detected (<2.56 mg/kg) is significantly lower than the level required for gluten-free products (<20 mg/kg) (Anonymous, 2014).

Pearling process are the abrasion process applied to separate the outer layers of the grains. Despite its nutritional content, the saponins found in the seed's pericarp leads to bitter taste (Brady et al., 2007). The pearling process applied to grains may also affect the phenolic compound content of quinoa due to the higher concentrations of antioxidants in the outer layers of the seeds (Liyana-Pathirana et al., 2006). In this review, the results of studies investigating the chemical composition, nutritional value, and effects of consumption of quinoa on health are included. In this way, it was aimed to increase awareness about the use and consumption of quinoa in the medical, pharmacology, and food industries with the results of the current study.

2. Chemical Composition and Nutritional Value

In recent years, there has been a great increase in studies on the determination of the nutritional value and chemical composition of quinoa (Kaspchak et al., 2017; Multari et al., 2018). The major carbohydrate component of quinoa is starch which constitutes 52%-69% of the grain weight (Filho et al.,

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2017). Quinoa exhibits a low glycemic index (GI) and it provides better control of glucose absorption thanks to enzyme inhibitors that inhibit α-amylase and α-glucosidase (Hemalatha et al., 2016). Total dietary fiber is close to that of cereal products (7% - 9.7% dry basis), but soluble fiber content is in the range of 1.3% - 6.1% (dry basis). Moreover, the sugar content of quinoa is about 3% dry basis. In addition to low glucose and fructose levels, it mostly includes D-galactose, D-ribose, and maltose (James, 2009).

Quinoa is rich in Mg, Cu, Fe, Mn, and Mo, which are elements that are incomplete in almost all gluten-free cereals. In addition, compared to corn (720 mg), wheat (390 mg), and rice (60 mg), the phytic acid content in quinoa (ranges from 10.5 mg to 13.5 mg) is lower (Kozioł, 1992). However, the presence of phytic acid and saponins in the seeds may affect bioavailability (Gupta et al., 2015).

The major protein fractions (44%–77% of total protein) in quinoa are albumins and globulins, but it has low prolamin content (0.5%–7.0%). Its histidine and methionine+cystine content is particularly high level in comparison with rice, maize and wheat (Galwey, 1992). Also, it possesses higher protein content and better-balanced protein composition than other grains (Dini et al., 2005).

Quinoa is rich in phenolic compounds, carotenoids, phytosterols, phytoecdysteroids, saponins, betalains, squalene and phagopyritols (Lutz & Bascuñán, 2017). Phenolic acids and flavonoids contained in quinoa are in the main phenolic group. According to recent studies, these seeds have 23 phenolic compounds, which are in either free or conjugated forms. Moreover, the main detected compounds are phenolic acids consisting of vanillic acid, ferulic acid, and their derivatives as well as syringaldehyde, quercetin, and kaempferol (Tang et al., 2016; Multari et al., 2018). Seeds with high phenolic content show stronger antioxidant activity, pancreatic lipase, and α-glucosidase enzyme inhibitory activity (Tang et al., 2016). According to Nowak et al. (2016), quinoa seeds contained flavanols (130–193 mg/100 g fresh weight), quercetin (12–56 mg/100 g fresh weight), and kaempferol (0.5–54 mg/100 g fresh weight). The total carotenoid content of quinoa leaves is 496–738 μg/g dry weight (Tang et al., 2014). In addition, the β-carotene content of quinoa leaves has been reported to be in the ranges from 4.3 μg to 19.5 μg per 1 g (Sharma et al., 2012). The total phytosterols content in quinoa varies from 38.8 to 41.2 mg/100 g (Islam et al., 2017), with campesterol, β-sitosterol, stigmasterol, and brassicasterol being the main components (Villacr'es et al., 2013). In addition to their cholesterol-reducing properties, phytosterols have antioxidant, anti-inflammatory, and anticancer effects (Islam et al., 2017; Tang & Tsao, 2017). The presence of phytochemicals may contribute to protection against a number of oxidative stress-related diseases (Forni et al., 2019). In addition, quinoa contains high amounts of phytoecdysteroids, and the most widely available phytoecdysteroid is 20-hydroxyecdysteroid (20HE) (Graf et al., 2014).

The content of ascorbic acid, α-tocopherol, β-carotene, and riboflavin in quinoa is higher than in wheat, barley, and rice (Filho et al., 2017). 100 grams of quinoa contains 0.20 mg of pyridoxine (vitamin B6), 0.61 mg of pantothenic acid, 23.5 μg of folic acid, and 7.1 μg of biotin (Bhargava, 2006). β-carotene concentration (0.39 mg/100 g dry weight) in quinoa is higher as compared to cereals like wheat (0.02 mg/100 g dry weight) and barley (0.01 mg/100 g dry weight) (Koziol, 1992).

Palmitic acid (16:0) (9.9%-11.0%) constitutes a large part of the saturated fatty acid content of quinoa (Valencia-Chamorro, 2003). Linoleic acid (C18:2) is one of the most abundant polyunsaturated fatty acids (PUFA) identified in quinoa seeds (James, 2009). The total lipid content of quinoa is 14.5%, with approximately 70%-89.4% being unsaturated. The unsaturated fat content of quinoa is 38.9%-57% linoleic acid, 24.0%-27.7% oleic acid, and 4% α-linolenic acid (Vega-Gálvez et al., 2010; Tang et al., 2015; Filho et al., 2017). Linoleic (C18:2), oleic (C18:1), and α-linolenic (C18:3) fatty acids of quinoa seeds were found to be at similar levels when compared to soybean oil composition (Filho et al., 2017).

Although it is reported that the health benefits of quinoa are largely due to the macro and micronutrient elements it contains, secondary metabolites also contribute to human health and the protection of health (Graf et al., 2015a). The main secondary metabolite groups found in quinoa are triterpenoids (saponins, phytosterols, and phytoecdysteroids), phenolics, betaines, and glycine betaine (Graf et al., 2015a). Saponins are glycosides of sapogenins. Saponins are health-promoting compounds thanks to their hypocholesterolemic, analgesic, antiallergic, and antioxidant activities (Güçlü-Ustundag et al., 2007). Saponins are bitter and depending on the structure, some may have an adverse impact on animals and humans (Ruales & Nair, 1993). The main disadvantage associated with the consumption of foods with high saponin content is the decrease in mineral and vitamin bioavailability (Cheeke et al., 2000). Therefore, they are eliminated or significantly reduced before cooking or industrial processing (Simmonds, 1965).

3. Health Effects of Quinoa Consumption

Quinoa's high nutritional content, therapeutic and gluten-free properties have been indicated to be beneficial for high-performance athletes, elderly people, vegetarians, and celiac disease (Agza et al., 2018). These properties are thought to be related to the presence of fiber, fatty acids, minerals, antioxidants, vitamins and especially phytochemicals, and it has been stated that quinoa provides a great advantage compared to other foods in terms of human health and nutrition (Vega-Gálvez et al., 2010).

In a study in which administration of 20HE isolated from quinoa seeds to rats fed a high-fat diet at 25-50 mg/kg doses for 12 weeks, insulin sensitivity increased, and positive improvements were reported in diabetic rats (Wang et al., 2011). Hemalatha et al. (2016) tested the α-glucosidase and α-amylase enzyme inhibitory activities of phenolic extracts of whole grain, peel, groats, ground grain, and bran of quinoa. Extracts of bran and hull fractions displayed strong inhibition towards α-amylase (IC_{50}, 108.68 lg/ml for bran and 148.23 lg/ml for hulls) and a-glucosidase (IC_{50}, 62.1 lg/ml for bran and 68.14 lg/ml for hulls) activities. At the end of the study, it was reported that quinoa phenolics may have the ability to prevent hyperglycemia and related complications.

Gawlik-Dziki et al. (2013) reported that compounds in quinoa leaves exert a chemopreventive and anticarcinogenic effect on oxidative stress and reactive oxygen species induced intracellular signaling. Pasko et al. (2010) concluded that a diet containing quinoa resulted in a decrease in plasma malondialdehyde level, antioxidant enzyme activity, and lipid peroxidation in rats under oxidative stress. In the same study, it was determined that quinoa can reduce oxidative stress in the plasma, heart, pancreas, kidney, testis, and lungs. Similarly, the hydrophilic and lipophilic fractions of quinoa seed significantly inhibited catalase, glutathione, and tyrosinase activities and intracellular ROS (reactive oxygen species) production in cells and were reported to preventing skin aging, an oxidation process (Graf et al., 2015b).

In an experimental group consisting of 22 students (18-45 years age group), daily consumption of quinoa in cereal bar form (19.5 g quinoa/day) for 30 days resulted in a significant decrease in plasma LDL-C, total cholesterol and triglyceride concentrations (Farinazzi-Machado et al., 2012). In a study by Jenkins et al. (2008) in which they tested quinoa as a low GI diet, 210 people divided into two groups (high grain fiber diet or low GI diet) for 6 months were examined. They observed a greater decrease in Hemoglobin A_{1c} (HbA_{1c}) and a statistically significant increase in high-density lipoprotein (HDL) (1.7 mg/dL) in patients with type 2 diabetes on the low GI diet (-0.50%). Noratto et al. (2019) aimed to investigate quinoa phytochemicals that can modulate risk disease biomarkers on obese-diabetic mice. In this study, the mice fed quinoa-supplemented or AIN-93G diet (obese) were compared to lean control fed AIN-93G diet. As a result, quinoa intake significantly reduced plasma total cholesterol, LDL-C, and oxidized-LDL to levels similar to lean and results showed that quinoa intake can improve/reduce conditions associated with type 2 diabetes and obesity in db/db mice. Obaroakpo et al. (2020) determined that quinoa yogurt protects liver tissue structure, increases body weight, hepatic glycogen content, HDL-C level, catalase, superoxide dismutase, and glutathione peroxidase activities, and decreases fasting blood sugar and total cholesterol, triglyceride, lipid peroxidation and LDL in mice with type 2 diabetes.

Gullón et al. (2016) assessed the prebiotic potential of quinoa through human fecal microbiota. The results showed that quinoa contains certain components with potential prebiotic effects, which is revealed by the increase of selected groups in the gut microbiota. Liu et al. (2018) reported that the consumption of quinoa suppressed the dysbiosis of gut microbiota and alleviated clinical symptoms induced by dextran sodium sulfate. In addition, similar to Gullón et al. (2016), they concluded that quinoa has demonstrated its potential to be used as a dietary approach to improve gut health. Cao et al. (2020) demonstrated that quinoa polysaccharide supplementation could ameliorate the hyperlipidemia induced by high-fat diet in association with modulating gut microbiota in a positive way. Ballegaard et al. (2021), in their study investigating the effect of quinoa on intestinal barrier function and inflammation, the results showed the ability of quinoa to increase intestinal permeability and promote protein intake.

Quinoa extracts were found to increase the liver's superoxide dismutase and glutathione peroxidase activities and to enhance the production of 12-hydroxy-eicosatetraenoic acid in the lung of treated rats. As a result, it was concluded that fermented quinoa is an active superoxide scavenger and peroxide reducer (Matsuo et al., 2005). Meneguetti et al. (2011) studied the effects of an extract from quinoa for 30 days in male rats. On the basis of the obtained results, it was concluded that hydrolyzed quinoa showed no liver or renal toxicity, thus, it can provide a potential use in human nutrition.

Iron-deficiency anemia is the most common form of nutritional anemia in both developed and developing countries. The antianemic effect of a quinoa-enhanced phytogenic diet in the treatment of rats induced by iron deficiency anemia was evaluated by Darwish et al. (2021). The results showed that fortification with 10% quinoa sprouts can be recommended as the best treatment to restore organs weights, body weight, serum profile (ferritin, zinc, protein, and iron), and blood cell counts (Hb, WBCs, RBCs, and platelets) (Darwish et al., 2021).

Hu et al. (2017) reported that polysaccharides from quinoa demonstrated significant proliferation inhibition against cancer cells. Similarly, Stikić et al. (2020) determined that quinoa extract showed potent anticancer activity against colorectal cancer cells. Konishi et al. (2004) determined that a 3% quinoa pericarp added diet significantly decreased liver and serum cholesterol levels in mice. Similarly, protein isolates from quinoa (> 10% grains) significantly reduced plasma and liver total cholesterol levels in mice fed fat-enriched diets (Takao et al., 2005). Alghamdi (2018) reported that dieting fortified with 35% and 45% quinoa seed powder improved weight gain, reduced lipid profiles, and reduced organ risk.

Navarro-Perez et al. (2017) concluded that the consumption of 50 g quinoa/day for 12 weeks lowers serum triglyceride in overweight and obese humans and reduces the prevalence of metabolic syndrome. Pourshahidi et al. (2020) conducted a study to investigate the effect of consuming 15 g quinoa biscuits (60 g quinoa flour/100 g) on markers of cardiovascular disease risk over 4 weeks in older adults (50-75 years). End of the study, it was concluded that consumption of quinoa biscuits showed positive effects on body weight, body mass index, and cholesterol concentrations, all of which may contribute to a reduced risk of cardiovascular disease in older adults. Similarly, Farinazzi-Machado et al. (2012) reported that the cereal bar produced with quinoa grains may be effective in the prevention and treatment of risk factors related to cardiovascular diseases.

In the study by Wahba et al. (2019) rats that consumed quinoa seed powder at different levels showed a significant increase in the concentration of serum testosterone, estrogen, follicle-stimulating hormone, and luteinizing hormone, compared to the positive control group. Also, the administration of quinoa seed powder at different levels improved lipid profile and antioxidant parameters in female rats. The results of the study revealed that quinoa seed powder is a potent polyphenol, mineral, and vitamin-rich source with great anti-inflammatory and antioxidant power, which can be used to prepare a functional food that, can counteract the symptoms of cisplatin toxicity and prevent its complications. Bahnasy & Ragheb (2020) investigated the effectiveness of quinoa powder as nutraceuticals on lipids profile for rats exposed to the administration of synthetic food colors (azo dyes), chocolate brown, or sunset yellow. After 56 days of treatment, it was concluded that quinoa was effective in dysfunction caused by azo dyes.

Guo et al. (2020) reported that quinoa protein hydrolyzate reduced systolic blood pressure and diastolic blood pressure in spontaneously hypertensive model rats. The results showed that quinoa protein hydrolyzate may be a good candidate for inclusion in functional foods in the management of hypertension. In another study that analyzed the effect of quinoa seed extract on scopolamine-induced memory deficits in the object recognition task in mice were evaluated. The administration of seed extract prevented memory deficit, changes of acetylcholinesterase activity and oxidative stress indicators (ROS, catalase, thiobarbituric acid-reactive substances and SOD) induced by scopolamine, partially in the cerebral cortex and in the hippocampus (Souza et al., 2020).

Saxena et al. (2017) studied the effect of quinoa seed on liver toxicity in male mice induced with carbon tetrachloride (CCL_4). The results indicated that the treatment with quinoa seed powder significantly reduced the elevated serum hepatic enzyme level in CCl_4-induced mice and restored the level of liver antioxidant enzymes to normal levels. In a study in which extracts of red quinoa sprouts (RQS) and yellow quinoa sprouts (YQS) were biochemically investigated in rats against CCl_4-induced oxidative stress, both extracts distinctly attenuated liver hypertrophy in treated rats and they again attained a normal weight. Also, it was founded that RQS and YQS significantly decreased liver relative weight and reduced inflammation (Al-Qabba et al., 2020).

Ali (2019) investigated the protective effect of quinoa seeds on 30 male rats' health that were injected nicotine. The results showed that liver and kidney functions were significantly improved in the rat groups treated with quinoa seeds. Therefore, this study revealed the health benefits of quinoa seeds in functional foods for patients with liver disease, hypercholesterolemia, and heart disease. El-Kewawy & Morsy (2019) reported that quinoa seeds can improve kidney function and reduce oxidative stress. Moreover, a diet supplemented with a quinoa seed mixture may be beneficial for hyperuricemia patients.

Saponins show bacteriostatic, anti-obesity, antioxidant, antidiabetic, and anti-inflammatory properties (Verza et al., 2012; Yao et al., 2015; Escribano et al., 2017; Tang & Tsao, 2017). It was stated that saponin stimulates insulin release from the β cell, activates glycogen synthesis, and inhibits mRNA expression of glycogen phosphorylase and glucose 6-phosphatase in addition to lowering blood glucose levels by increasing GLUT4 expression (El Barky et al., 2017). A study showed that oral pathogenic bacteria can be inhibited by saponins extracted from quinoa husks (Sun et al., 2019). It has been reported that saponins obtained from quinoa exhibit antibacterial activities against *Botrytis cinerea* (Stuardo & Martín, 2008) and *Pomacea canaliculate* (Ricardo et al., 2008), and thus the quinoa peel has antibiotic properties.

4. Conclusions

Quinoa seed is food that shows unique properties compared to many cereal groups with its nutritional elements, phenolic components, antioxidant activity, and phytochemical groups. Although the structural composition of quinoa and its use in traditional medicine have been known for many years, scientific studies on the effects of its consumption on health are still very new and insufficient in number. In this review, scientific studies on the properties of quinoa seeds and the effects of consumption on humans and experimental animals were included. By evaluating the results of the study, the effect of quinoa use/consumption was tried to be explained. As stated in the literature, thanks to the positive effects of quinoa on health, it has the potential to be used as a functional food, food supplement, in health applications, in the pharmacology sector and in the production of new food products (especially celiac patients). In this review, current studies and results related to quinoa were brought together and it is thought that it will contribute to researchers/producers for future studies.

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