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Quinoa (*Chenopodium Quinoa* Willd.) is a highly nutritious source of grains

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Abstract

The main objective of this paper is the chemical evaluation of quinoa seeds (Chenopodium quinoa wild). The chemical composition, mineral content, active compounds (polyphenols, flavonoids, and tocopherols), vitamins, amino acids, and fatty acids of quinoa seeds were estimated. The results indicate that quinoa seeds are rich in minerals, the most important of which are Ca and K. They are also rich in biologically active compounds that play an effective role as antioxidants, the most important of which are phenolic compounds (455 ppm), flavonoids (245 ppm), tocopherols (505 ppm), and finally vitamins (A, C, and D), which are effective in preventing many diseases. The results also showed that quinoa seeds contain essential amino acids, which amount to 35.78 g/100 g, respectively, so it contains high-quality protein.Also, the main essential fatty acid in quinoa seeds is Linoleic (55.00%), which is known as Omega 6, then alpha-linolenic acid (9.49%).Therefore, quinoa seeds have a distinct composition of important nutritional elements and are considered a high-nutrition alternative to grains. Finally, more studies should be conducted on these high nutritional value seeds and they should be included in many products as an alternative to grains.

Keywords: Amino acids, Bioactive components, Fatty acids, Flavonoids, Phenolic compounds, Quinoa seeds.

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Contents

Contribution of this paper to the literature

The study of quinoa seeds and their composition is distinctive due to its comprehensive nutritional profile, including complete protein, fiber, and essential minerals. Understanding quinoa's composition can inform sustainable agriculture, improve crop yields, and enhance its potential health benefits, making it a valuable research area.

1. Introduction

Modern healthy lifestyles have changed dramatically as a result of the substantial influence that food and food additives have had on human health over the past few decades. Consumers are increasingly coming to believe that food has a direct impact on their health by preventing illness and enhancing their physical and emotional well-being [1]. By choosing foods that are high in bioactive compounds with beneficial health effects, in addition to being an excellent source of nutrients, the consumer has chosen to alter their eating patterns [2, 3].

Cereals continue to be the world's most important food source, both directly for human consumption and indirectly through the production of animals. Nonetheless, more and more cereals are being used to produce bioethanol [4, 5]. About 50% of the market is made up of cereals for feed, 40% is made up of food and human consumption, 19% is made up of seeds and other purposes, and 3% is made up of bioethanol [6].

Among the many issues facing global agriculture are food shortages and population increase. The demand for food will increase as there is a possibility of more than 10 billion people on the planet by 2050 [7]. Agriculture yields and growth are affected by the warming temperatures and effects of global climate change [8]. Thus, one of the crops that has garnered increased interest recently is quinoa (Chenopodium quinoa Willd) [9]. It is also regarded as a multipurpose crop that produces seeds. Since seeds and flour have a high nutritional value, they are used as food ingredients in bakery items [10]. Quinoa belongs to the Chenopodiaceae family, a class of Dicotyledonae that also contains beets and spinach. It is also a species of quinoa, whose Latin name is Chenopodium quinoa Willd [11, 12]. Consequently, it is commonly used as a nutrient-dense diet. It's called "the Singh" or a "superfood" [13]. Superfoods are foods with demonstrated physiological advantages that resemble conventional diets. People can reduce their risk of sickness and enhance their health by consuming superfoods [14]. Consequently, there has been a recent surge in the demand for these products [15].

The ancient crop quinoa (*Chenopodium quinoa Willd.*) has the potential to significantly contribute to global food security. Quinoa's great nutritional content and genetic diversity make it a hopeful plant for humanity, according to the Food and Agriculture Organization (FAO). Quinoa has been dubbed "the grain of the twenty-first century" because of its role in ensuring food security" [16].

To raise awareness of this plant and acknowledge its enormous potential, the UN designated 2013 as the "International Quinoa Year" [16-18]. Quinoa is rich in sulfur-rich amino acids and has a balanced essential amino acid composition. It also contains high-quality proteins. Along with carbohydrates, fats, and a low glycemic index, it is a rich source of vitamins, fibers, and minerals like calcium, iron, and zinc [19, 20]. Additionally, because Quinoa is adaptable to human demands during space missions, the National Aeronautics and Space Administration (NASA) has used it [21, 22].

To verify the high nutritional content of quinoa seeds and assess them from a nutritional standpoint, the current study aims to examine a thorough chemical analysis of these seeds.

2. Materials and Methods

- *Source ofquinoa seeds*:Quinoa seeds used in this study were purchased from Desert Research Center, Cairo, Egypt.
- *Solvents and reagents:* All solvents used throughout the whole work were analytical grade and distilled before use. Caffeic acid (98%) and Folin-Ciocalteau reagent were purchased from Sigma-Aldrich (St. Louis, MO, USA) and Gerbsaure Chemical Co., Ltd., Germany, respectively.
- Nutritional Value. Moisture, protein, carbohydrates, lipids, fibers, and ash contents of quinoa seeds were expressed on a dry weight basis, and the results were presented in g/100g. Analyses were carried out in three replicates and were determined by following the methods as described in AOAC. Association of Official Analytical Chemists [23]. Carbohydrate was calculated by difference.
- Fatty acids composition: Capillary gas chromatograph (HP 6890) was used for the qualitative and quantitative determinations of fatty acids of the quinoa seed oil and reported in relative area percentages. Fatty acids were trans esterified into their corresponding carboxylic acid methyl esters by shaking an amount of oil (0.1g) in heptane (2 ml) with a solution of methanolic potash (0.2 ml, 2N). The carboxylic acid methyl esters were identified employing a gas chromatograph equipped with DB-23 (5%–cyanopropyl–methyl poly siloxane) capillary column (60 m x 0.32mm X0.25µm film thickness) and flame ionization detector. Nitrogen flow was 0.6ml/min, hydrogen and air flow rates were 45 and 450ml/min, respectively. The oven temperature was isothermally heated to 195˚C. The injector and therefore the detector temperatures were 230˚C and 250˚C, respectively. Carboxylic acid methyl esters were identified by comparing their retention times with a known carboxylic acid standard mixture. Peak areas were automatically computed by an integrator. All GC measurements for every oil sample were made in triplicate, and therefore, the averages were reported.
- Determination of total polyphenolic: The levels of total polyphenols of quinoa seeds were determined according to the method of Zilić, et al. [24].Caffeic acid was used as a standard compound for the preparation of the calibration curve.

Determination of the total flavonoids: The total flavonoid content of the quinoa seeds was determined by the aluminum chloride test Kim, et al. [25] using quercetin as a standard, and the results were calculated as mg quercetin equivalent/Kg of extract (mg QE/Kg).

Determination of Tocopherols: Tocopherols were determined in quinoa seed powder according to Annunziata, et al. [25].

Determination of Vitamins: Ten grams of quinoa seeds powder was weighed, homogenized in the mortar with a pestle, transferred into a conical flask and 25 mL of the extraction solution (made by mixing 50 mL of acetonitrile with 10 mL of glacial acetic acid and the volume was finally made up to 1000 mL) was added. The prepared solution of quinoa seed powder was injected into the HPLC using an autosampler to determine water-soluble vitamins [26].

- Mineral content: Mineral content by using atomic absorption (NC.9423-400-30042), England of the spirulina algae was determined according to the method techniques described by AOAC. Association of Official Analytical Chemists [23].
- Amino acid analysis: The protein quantification was done with the micro-Kjeldahl method. Amino acid analysis procedure involves acid/alkaline hydrolysis, separation by cation exchange column, post-column derivatization with Ninhydrin, and detection using UV/V is detector at 570 nm as described in the AOAC. Association of Official Analytical Chemists [23]. The data from three independent samples were expressed as the mean value ± standard deviation.

2. Results and Discussion

The chemical composition and Total Energy of Quinoa Seeds (QS) were determined (dry weight), and the obtained results are presented in Figure 1. The moisture, ash, protein, fat, fiber, and total carbohydrate(mg/100mg) were 11.91, 13.01.01, 6.00, 6.11, and 71.67%, respectively (Figure 1). Also, the total energy of Quinoa seeds recorded 402.545 K.cal/100g.

Quinoa is recognized as a superior source of vegetal protein (12–23%); its protein content is similar to milk protein content and higher than that of real cereals like wheat, maize, and rice [27].

According to Martínez-Villaluenga, et al. [28] the proximate analysis of quinoa seeds. The water, protein, lipids, and total carbohydrate were 8.2-13.1,9.1-16.7,4-7.6 and 48.5-77.0, respectively are in the same range as our results.

The above-mentioned data could be compared with those of Abdelshafy, et al. [29] who found higher contents of protein (14.40) and fat (6.88). In contrast, moisture (8.90), fiber (5.12), ash (2.63), and carbohydrates (62.07) were lower than our results.

Thus, the chemicaland nutritional composition of the quinoa seeds is directly impacted by the lack of adaptation to regions that are very different from those where the cultivar originated [30].

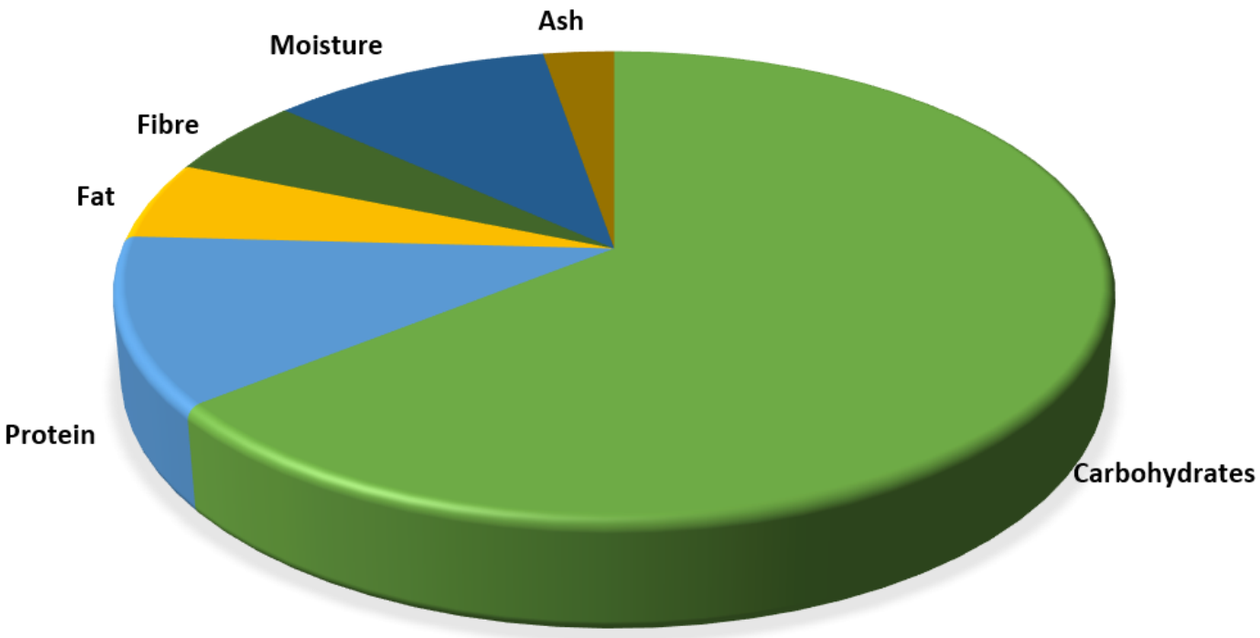

Figure 1. Chemical composition (%) of quinoa seeds.

Quinoa contains more ash than other common grains, including rice, corn, and wheat. The bioavailable forms of minerals like calcium, magnesium, and potassium justify their high concentration [31, 32]. Quinoa's seeds are high in calcium, magnesium, iron, manganese, copper, potassium, sodium, zinc, and other minerals, and its overall mineral content is 3.4% [33].

Minerals are thought to be necessary components for maintaining a normal physiological response. Minerals like magnesium, potassium, and phosphorus are present in the quinoa embryo. whereas the pericarp's Ca and P are linked to the cell wall's pectic substances. Konishi, et al. [34] Konishi et al. Quinoa seeds were found to contain a variety of minerals, including macro (Ca, K, Mg, and P) and microelements (Fe, Zn, and Mn) Figure 2. The mineral content (mg/100 g) of quinoa whole was reported by Dev and Gupta [35] as follows: Ca (232), P (189), K (414), Mg (115), and Fe (6.9). Quinoa seeds are high in calcium, iron, potassium, and magnesium, according to the current study. low in phosphorus as well.This demonstrates how the current research on quinoa seeds can preserve their nutritional value while acting as a beneficial source of important minerals. Bolaños, et al. [36] observed that quinoa seeds contained microelements like Mn and Zn at levels of 24.07 ± 0.23 mg/kg and 28.08 ± 0.35 mg/kg, respectively. As a result, our findings indicate average concentrations that are higher than those of other articles.

The use of different cultivars and environmental growth conditions can be blamed for the variations in mineral content between this study and earlier ones. The presented datain Figure 2 illustrate the mineral contents and daily values of quinoa seeds. quinoa seeds have a higher content of minerals such as (K:834, Ca:653, Mg:330, Na:170, P:119 mg/100g). These contents represent (119.14,124.38,78.57,48.57,17%) ofthe recommended daily intake of these minerals, respectively. The opposite situation was observed for both Zinc, iron, and Manganese (43.0,15.50,4.06), respectively. These contents represent (614.29,140.90,176.52%) ofthe recommended daily intake of these minerals.

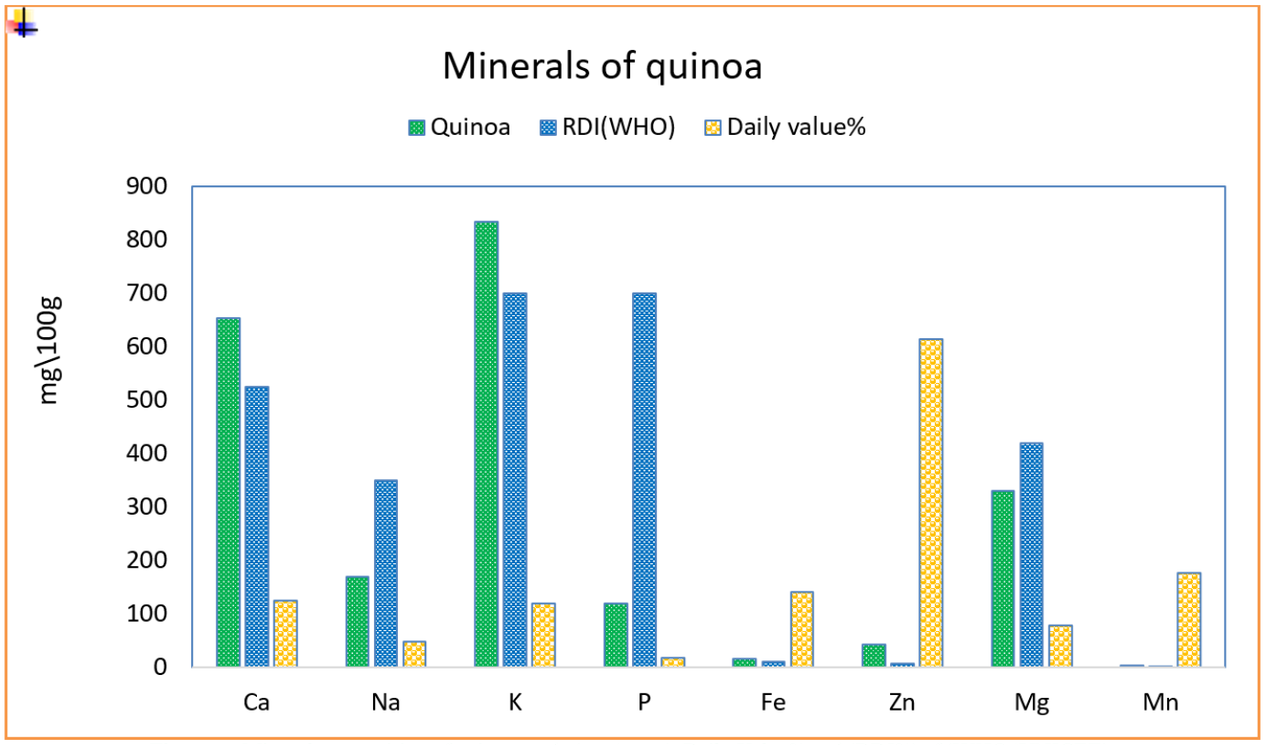

Figure 2. Mineral composition of quinoa seeds (mg/100g), Daily Value% and (RDI%) of (WHO/UNICEF).

Bioactive compounds are secondary plant metabolites with therapeutic potential[37, 38].

Quinoa seeds have a fine quality of nutrition, such as bioactive substances, with high antioxidants, which include polyphenols, tocopherols, and flavonoid compounds that are superior to those found in common grains for their health benefits, such as preventing chronic diseases. Interestingly, quinoa seed coat color appears to contribute to antioxidant activity due to the content of flavonoids [39].

The data in Figure 3shows the most essential phytochemicals in quinoa seeds (ppm),and the total polyphenols present in quinoa seeds were455.00 ppm.Most secondary plant metabolites that result in various functional characteristics are composed of phenolic compounds, mostly in the seed coat of quinoa seeds [40].

It is believed that the seeds of Quinoa contain the highest concentration of ferulic acid and quercetin, and it has more phenolic compounds than whole grains [21]. Because of their connection to fibers, the biological effects of phenolic materials have been of recent interest to scientists. The highest rates of a-glucosidase and a-amylase inhibition of bound phenols during digestion have been shown to lower blood sugar [40, 41]. Total flavonoids and polyphenols in quinoa were measured by Repo-Carrasco-Valencia, et al. [10] who discovered that the polyphenols were 131.8 ± 10.3 mg 100 g^{-1} and flavonoids were 62.07 ± 5.1 mg 100 g^{-1}.A high concentration of total tocopherol (vitamin E) (505 ppm) is a characteristic of quinoa. The most prevalent tocopherol in quinoa seeds was γ-tocopherol (330 ppm), followed by α-tocopherol (49 ppm) and β-tocopherol (20 ppm). The fatty acids in the cell membrane are protected from oxidative stress by the tocopherol content of quinoa, which acts as an antioxidant at the membrane layer. According to quinoa seed phytochemical content values, the use of quinoa as a natural antioxidant is crucial for preventing degenerative and chronic illnesses [40].

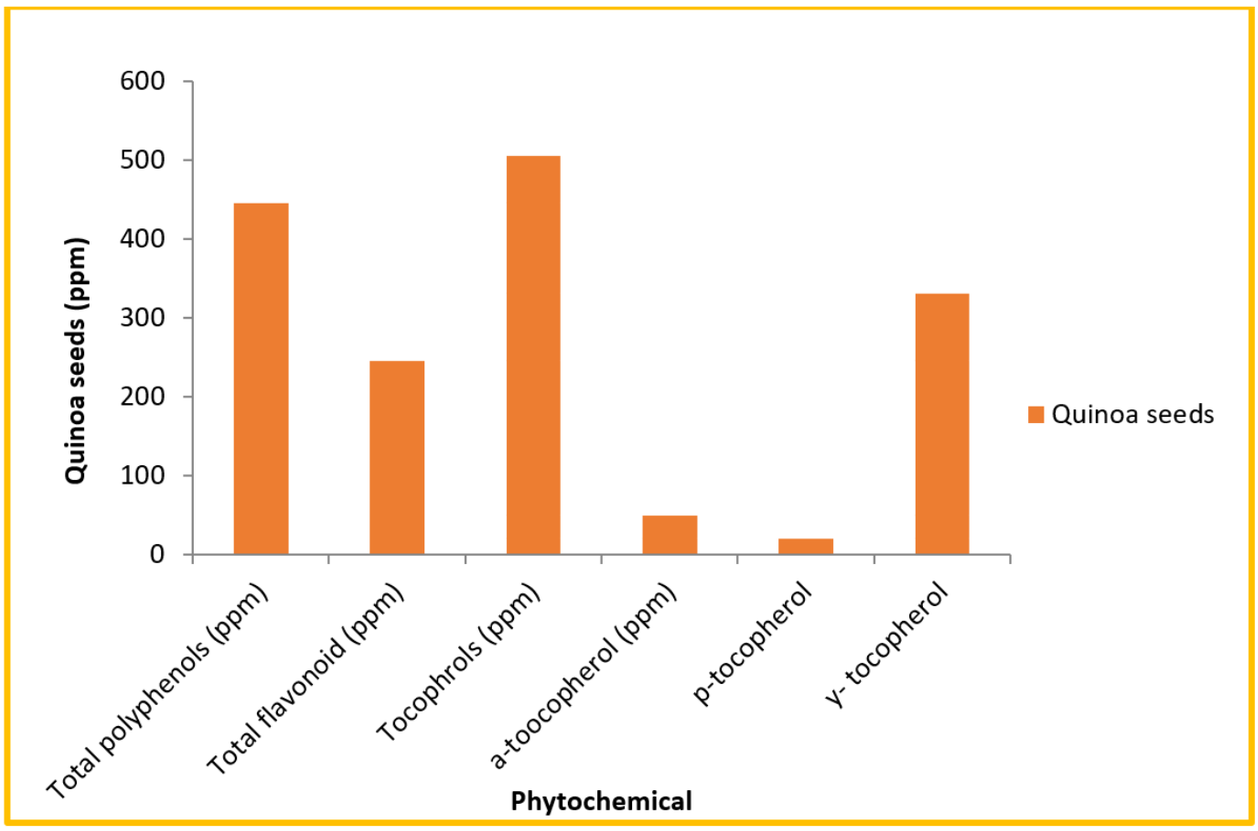

Figure 3. Phytochemical composition of quinoa seeds (ppm).

Vitamins are trace organic substances that humans need to obtain from food to maintain normal physiological functions. It plays an important role in the process of human growth, metabolism, and development. Figure 4 shows the number of certain vitamins. Vitamin B1 (VB1), also known as thiamine, is involved in carbohydrate metabolism. Quinoa seeds are rich in vitamins, which are essential compounds for human health. Compared to common cereals like wheat, barley, and rice, quinoa seeds have a significantly higher vitamin content [11].

According to Figure 4, each 100 g of quinoa seeds has 9.90 mg of vitamin C, 14.99 mg of ergocalciferol, and 60.00 mg of vitamin A in the form of carotenoids. Niacin, essential for physical well-being, was present at (0.95 mg/100 g), vitamin B1 was (1.10 mg/100 g), and vitamin B2 was (2.50 mg/100 g). Additionally, each 100 g of quinoa seeds includes (0.43 mg) of vitamin B12, absent from cereals, (6.10 mg) of vitamin B5, (0.42 mg) of pyridoxine, and (6.25 mg) of folic acid. The basic minerals needed for the metabolism of the majority of known living things, are vitamin C (1.93 mg/kg), vitamin B3 (0.15 mg/kg), vitamin B6 (11.22 mg/kg), and vitamin B12 (0.09 mg/kg), are all abundant in quinoa flour, according to Sohaimy, et al. [42]. So, eating quinoa helps avoid viruses and diseases.

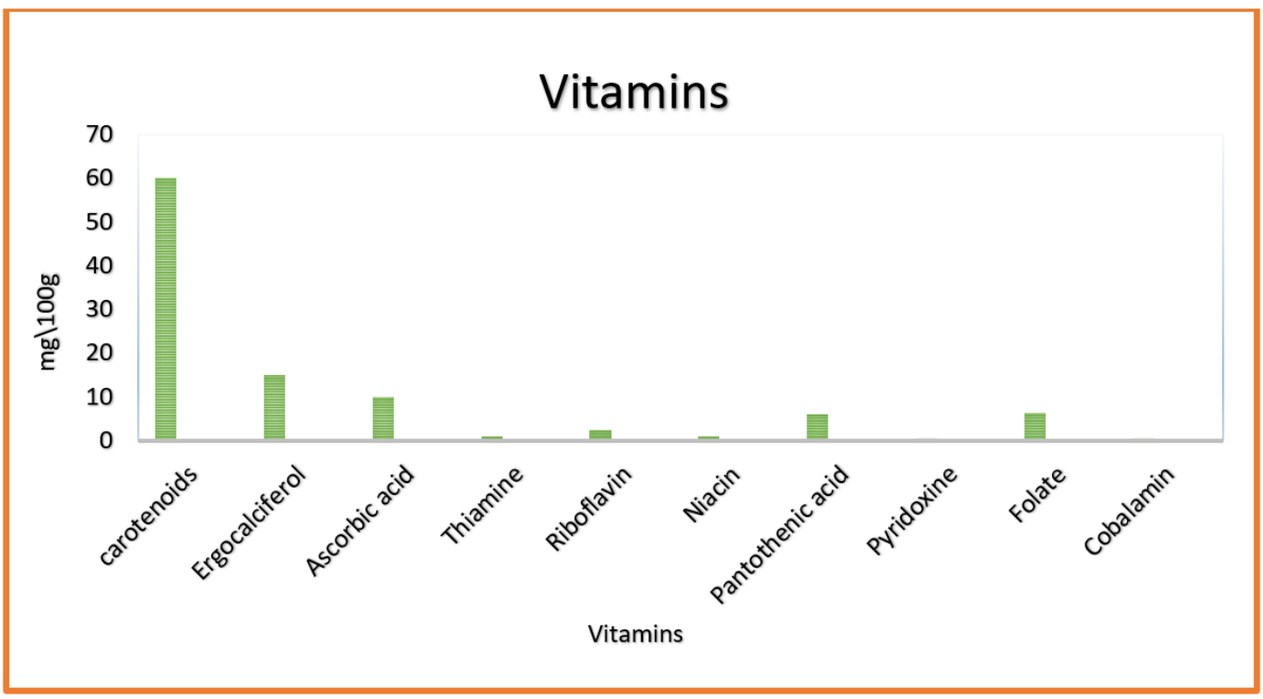

Figure 4. Vitamins in quinoa seeds (mg/100g).

Table 1. Amino acid composition of quinoa seeds (g/100g quinoa).

Amino acids	Quinoa seeds
Essential amino acids (EAA)	
Tyrosine	2.89
Phenylalanine	1.02
Total aromatic amino acids	3.90
Threonine	2.35
Cystine	9.27
Methionine	4.35
Total sulfur amino acids	15.97
Leucine (LEU)	4.29
Isoleucine (ILE)	2.01
Lysine (LYS)	5.78
Valine (VAL)	2.70
Tryptophan	1.12
Total essential	35.78
Non-essential amino acids(NEAA)	
Aspartic	8.28
Glutamic	20.07
Proline	ND
Serine	5.33
Glycine	15.33
Alanine	6.56
Arginine	5.12
Histidine	3.65
Total non-essential	64.22

Quinoa contains high amounts of amino acids, which are usually limited to wheat and corn; these include lysine, methionine, and threonine [31].

Pseudocereals are a safe substitute for gluten-free cereals, which are beneficial for patients with celiac disease. In contrast to quinoa, the Chenopodiaceae family has amino acid amounts and kinds that can satisfy dietary requirements for adult humans without the need for food supplements [43, 44]. The amino acid composition of quinoa seeds is shown by the data in Table 1. According to the statistics, there were 35.77 g of essential amino acids and 64.22 g of non-essential amino acids in 100 g of quinoa seeds.

All necessary amino acids, including methionine, valine, lysine, isoleucine, histidine, threonine, phenylalanine, tryptophan, and leucine, are found in greater amounts in quinoa seeds, according to Pathan and Siddiqui [45]. Additionally, non-essential amino acids (glutamic acid, aspartic acid, arginine, glycine, alanine, tyrosine, and cysteine) are contrasted with other commonly consumed primary grains, including rice, corn, and wheat. According to Table 1's findings, quinoa seeds are a good source of the non-essential amino acids glutamic acid (20.07%), glycine (15.33%), and aspartic acid (8.28%). Moreover, it has significant levels of leucine, methionine, cysteine, and lysine (9.27,5.78,4.35,4.29, respectively). whereas the lowest levels of tryptophan and phenylalanine (1.02 and 1.12) were found in quinoa seeds.

Table 2. Fatty acid composition of quinoa seeds.

Name of fatty acids	Quinoa seeds%
Myristic (C14:0)	0.35
Palmitic (C16:0)	8.41
Palmitoleic (C16:1)	0.21
Stearic (C18:0)	0.85
Oleic (C18:1)	22.1
Linoleic (C18:2)	55.00
Gamma Linolenic (γ-C18:3n6)	0.11
Linolenic (α-C18:3n3)	9.49
Arachidic (C20:0)	0.25
Gadoleic (C20:1)	0.83
Erucic (C22:1)	1.40
Σ Saturated fatty acids	9.86
Σ Monounsaturated fatty acids	24.54
Σ Polyunsaturated fatty acids	64.60
Oleic/Linoleic ratio	0.40
Sat./Unsat ratio	0.11
ω-6/ω-3	5.79

Table 2 displays the results of the current study on fatty acids. The fat content revealed a diverse range of fatty acids, with linoleic acid (omega-6 polyunsaturated fatty acids) making up most of them. Quinoa seeds had the highest fatty acid content (55.00%), followed by oleic acid (22.1%) and a-linolenic acid (9.49%). On the whole, quinoa seeds have a low percentage of total saturated fatty acids (9.86%), a high percentage of polyunsaturated fatty acids (64.60%), and a low percentage of monounsaturated fatty acids (25.54%).

Lipids are essential for human health and nutrition, as they affect a range of physical processes and disease outcomes, serve as a primary energy source, and play important roles in diverse biological functions. They are crucial for the structure and function of cell membranes. In contrast, polyunsaturated fatty acids (PUFAs),

including omega-3 fatty acids, have been associated with anti-inflammatory effects and a reduced risk of cardiovascular disease [46, 47].

Essential fatty acids can be grouped into two families called omega-3 (alpha-linolenic acid) and omega-6(linoleic acid), which are known to be essential to human health and are known as polyunsaturated fatty acids that make up the majority of quinoa oil in this study. In quinoa, unsaturated fatty acids account for 88% of the total fatty acids and consist primarily of oleic (19.97%–22.2%), linoleic (59.35%–71.87%), and linolenic acids (3.54%–6.21%), similar to those in soybean oil [48]. Essential fatty acids can be found in quinoa seeds, making them a viable alternative to oilseeds [33].

Table 2 displays the composition of unsaturated fatty acids, which are the main fatty acids obtained from whole quinoa. Quinoa whole contains Myristic, Palmitic, Palmitoleic, Stearic, Oleic, Linoleic, γ-Linolenic, α-Linolenic, Arachidonic, and Eicosenoic acids (0.35,8.41,0.21,0.85,22.10,55.00,0.11,9.49,0.25,0.83, and 1.40) g/100 g, respectively. Linoleic acid was the main fatty acid detected, followed by oleic acid, α-Linolenic, and palmitic acid. Wu, et al. [49] observed that quinoa has the highest linoleic acid content.This distinctive fatty acid profile benefits human health by lowering cardiovascular disease risk factors [50].

To determine the fatty acid composition of any oil, it's important to know the ratio of total saturated fatty acid to total unsaturated fatty acid, which is associated with the oil's oxidation stability, and the oleic/linoleic ratio, which has a positive effect on the oil's taste [51].

Based on the previous results, we recommend using quinoa seeds as a high-nutritional alternative and expanding their cultivation to compensate for the shortage of wheat.

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