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Review

Agro-nutritionnel Characterisation of Quinoa (*Chenopodium quinoa*, Willd.)

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Abstract: Quinoa (*Chenopodium quinoa* Willd.) originated in the Andean region of South America; is a dicotyledonous species for seeds and, therefore, is not known as a cereal grain and is a pseudograin, which is introduced nowadays as a new crop in the world. Quinoa is an annual herbaceous plant belongs to Amaranthaceae family, but formerly placed in Chenopodiaceae family. It's well adapted to a wide range of climatic conditions and has significant potential for increased production as a new crop in the Mediterranean region and in other parts of the world, including northern Europe, North America, Asia, and Africa. Quinoa is associated with exceptional grain nutritional quality and is highly valued for its ability to tolerate abiotic stresses. The protein content of quinoa grains is higher than other cereals while it has better distribution of essential amino acids. It can be used as an alternative to milk proteins. Additionally, quinoa contains a high amount of essential fatty acids, minerals, vitamins, dietary fibers, and carbohydrates with beneficial hypoglycemic effects while being gluten-free. e. In addition, it is found to contain a number of bioactive chemical compounds whose various therapeutic properties are actively studied in the scientific field. Quinoa is sought in several industries whether it is the food industry, pharmacology, cosmetics, etc., as a plant (use of leaves, seeds, or stem) or these extracts (saponins, vegetable oil and essential).

Keywords: Quinoa; agro-nutritionnel; abiotic stress; antidiabetic; anti-inflammatory.

1. Introduction

Quinoa (*Chenopodium quinoa*, Willd.) is one of the seeds considered as pseudocereals; it is a broadleaf plant that has been used like the cereals. It's a dicotyledonous annual species belonging to the family Amaranthaceae (formerly Chenopodiaceae), which includes other economically important species such as spinach (Spinacia olereaceae L.) and sugar beet (Beta vulgaris L.). The genus Chenopodium comprises about 250 species [1], which include herbaceous, suffrutescent and arborescent perennials, although most species are colonizing annuals [2]. Chenopodium spp. have been cultivated for centuries as a leafy vegetable, as well as an important subsidiary grain crop for human and animal foodstuff due to high-protein and a balanced amino-acid spectrum with high lysine (5.1–6.4%) and methionine (0.4–1.0%) contents [3]. Diverse studies have revealed that quinoa possesses a plethora of bioactive compounds, such as proteins, polysaccharides, saponins and flavonoids [4]. Therefore, these bioactive compounds have been identified as playing important roles in promoting health by serving as antioxidant [5], hypolipidemic [6], antidiabetic [7], anti-inflammatory [8], and anticancer [9,10]. In addition, quinoa can be regarded as an important raw material for development as a functional ingredient and food to improve human health. In recent years, more in-depth research has been carried out on the nutritional value of quinoa and the development of quinoa products, with different processing methods resulting in a great impact on their nutritional quality and health benefits. Several challenges remain in optimizing the role of quinoa in promoting global human health and nutrition. Considering the development and innovation in the quinoa industry, this review focuses on Agro-nutritional characterization, their related biological activities and benefits to health.

2. Origin of quinoa

The oldest archeological remains of domesticated quinoa date to 5000 BC [11]. Quinoa (*Chenopodium quinoa* Willd.) is a domesticated staple food in Andean South America (Figure 1A), was domesticated by ancient Andean civilizations in the region surrounding the Bolivian and Peruvian Altiplano (high plain). [12] examined genetic diversity in quinoa landraces and found that the greatest diversity is native to an area between Cuzco, Peru and Potosí, Bolivia, with the largest number of landraces located in the area of the Altiplano surrounding Lake Titicaca in Bolivia and Peru. According to [13] there is a consensus that quinoa's center of origin is in the Andean Altiplano and that the area of ancient cultivation extends from Andean Altiplano to regions of Bolivia, Peru, Ecuador, Northern Chile, and Colombia. Figure 1B, indicates the geographical location of the 26 genebanks in South America that store quinoa. Twenty-four of these banks belong to countries in the Andean region.

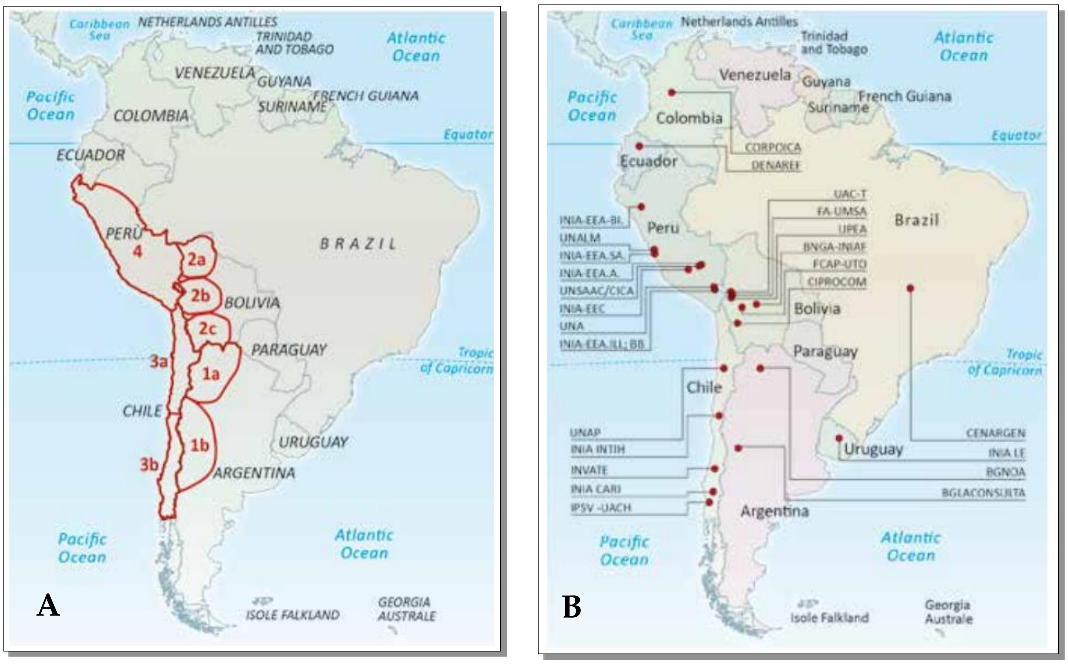

Figure 1. A) Andean region and geographic areas with archaeological finds of C. quinoa. 1a NWA (Argentina); 1b Cuyo (Argentina); 2a Northern Altiplano (Bolivia); 2b Central Altiplano (Bolivia); 2c Southern Altiplano (Bolivia); 3a North (Chile); 3b Coastal Centre and the Andes (Chile); 4 Peru. B) Geographical location of the 26 genebanks in South America that store quinoa. Twenty-four of these banks belong to countries in the Andean region [14].

3. Classification and genetics

Quinoa is a dicotyledonous annual species belonging to the family Amaranthaceae (formerly Chenopodiaceae), [2] described in detail the botanical classification of cultivated Chenopodium species. The domesticated Chenopodium species are classified in two subsections: Cellulata and Leiosperma. Leiosperma includes the South American species cañihua (*C. pallidculale*) and the Eurasian species group *C. album*. Quinoa (*C. quinoa*) and huazontle (*C. berlandieri* subsp. nuttalliae) are members of the subsection Cellulata. Cytological evidence has shown that quinoa is an allotetraploid species (2n = 4x = 36, with basic chromosome number of x = 9) (Figure 2), mainly possessing a diploid type of chromosomal segregation, but some tetrasomic inheritance occurs as well [15,16], confirmed that the chromosome number of Chenopodium quinoa is 2n = 4X = 36 with a diploid genome of 967 Mbp, but the chromosome sizes are very small and basically without distinguishing parameters to be able to enable traditional karyotyping or develop biomarker libraries. An evidence points to *C. standleyanum* and *C. ficifolium* as the putative progenitor-diploids that donated to the tetraploid complex that includes *C. quinoa*.

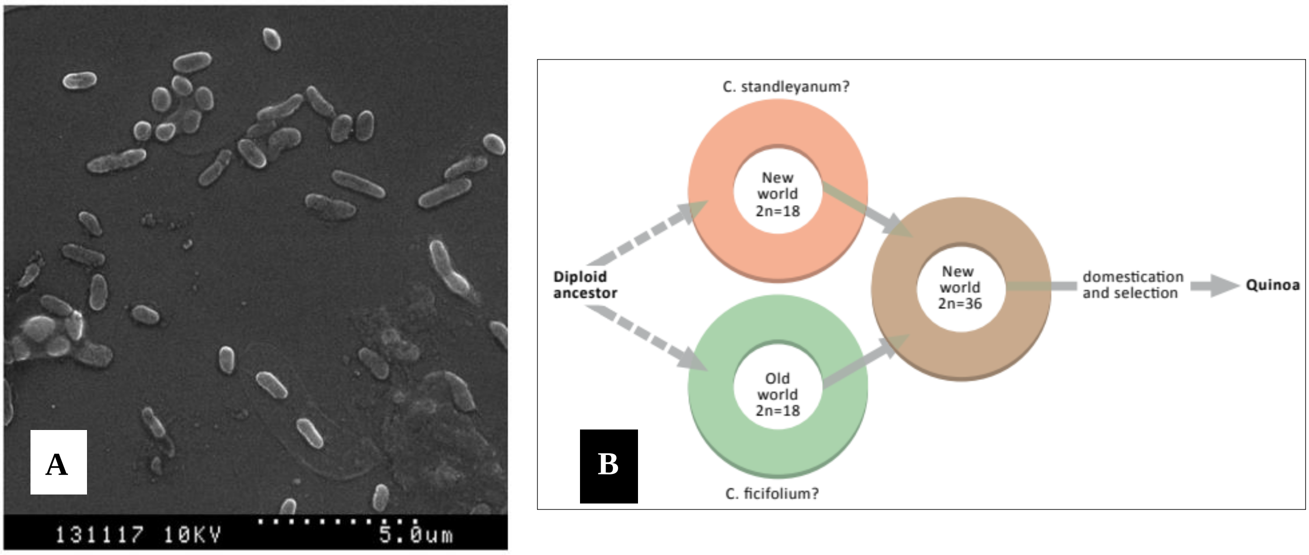

Figure 2. A) Air-dried processed scanning electron microscopy image of quinoa chromosomes [16]. B) Schematic representation of the allopolyploidization event in the evolution of quinoa [14].

4. Morphological description

Quinoa, is an annual spring crop, which reaches a plant height ranging between 0.5-3.0 m, with an average of 1.0-1.5 m. It exhibits a degree of branching which is controlled by genetic and environmental factors.

4.1. Root system

Quinoa has a vigorous, deep-rooting tap root. Due to a lack of seed dormancy in any of the known quinoa cultivars, seedling emergence, including root elongation, occurs quickly in the presence of adequate soil moisture. Just below the root neck the tap root divides to give rise to secondary and tertiary roots (Figure 3A). The deep, branching root system of quinoa may be one of the reasons for the high degree of drought resistance of the crop, and it also may explain why lodging is rarely seen [17].

4.2. Stems and Branches

Below the root neck the stem is cylindrical, while above it becomes angular with alternating leaf positions (Figure 3B), originating from the four sides in turn. Inside the stem there is a fibreless, white to cream-coloured marrow, which in the early stages of growth is massive and soft, but which becomes hollow and spongy as maturity approaches. In contrast, the cortex is firm and compact. The outer stem can be green, green with coloured (mostly red) axils, green with purple or red stripes, or red [17]. The branches originate from the axils of each leaf on the stem. Their length may vary from just a few cm to the same length as the main stem, according to cultivar and environmental conditions (Figure 3C).

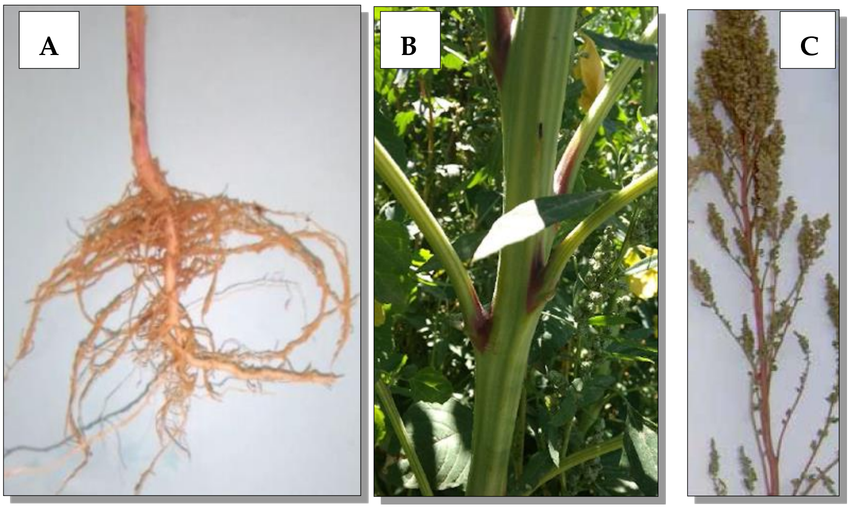

Figure 3. Morphological characteristics in Chenopodium quinoa. A) Root system, B) Stem and C) Branches.

4.3. Leaves and inflorescence

Petioles are long, fine and furrowed. The lower leaf laminae are rhomboidal or triangular, while the upper leaves are triangular or lanceolate. According to [18], who evaluated a large number of accessions, the triangular lower leaves are more frequent than the rhomboidal ones, and the lanceolate upper leaves are totally dominant. Most often the laminae are plane, but in certain types they may be undulating (Figure 4A). The inflorescence of quinoa consists of a number of racemes, which originate from the axils of the whole plant starting from the top. When the branches in the upper part in relation to the lower part of the plant are vigorous and closely spaced, the inflorescences can be easily differentiated from the rest of the plant, and thus give the impression of being terminal, two types of inflorescences exist: glomerulate, where small groups of flowers (glomeruli) originate from tertiary axes, and amaranthiform, which has glomeruli originating mainly from secondary axes (Figure 4B).

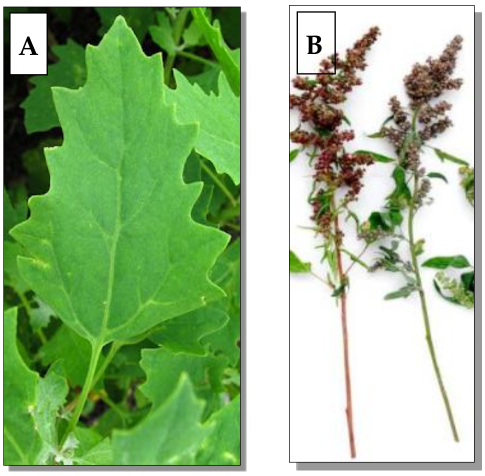

Figure 4. Characteristic of Chenopodium quinoa. A) Leaves and B) Inflorescence.

5. Quinoa growing requirements

Quinoa can be grown on various types of soils, including marginal soils with a wide pH range [11]. In addition, it's a crop that demonstrates a range of requirements for humidity and temperature, with different ecotypes adapted to different conditions. Some genotypes of quinoa are grown under conditions of severe drought, suggesting resistance to this adverse factor [11]. Although, sowing can be done in rows, groups, mixed, broadcast or by transplanting, row spacing of 25–50 cm is preferable since it allows easy hoeing. A level, well-drained seedbed is most suited for quinoa cultivation. Seeds should be sown 1–2 cm deep in a fine structured, moist seed bed [19]. Water management is very important for quinoa cultivation in the initial 20-30 days of crop, if irrigation is not provided the crop will show wilting symptom and results in lower yields. Quinoa responds well to nitrogenous fertilizers, but high levels of available nitrogen are reported to decrease yield due to slow maturity and intense lodging. However, recent studies [20] suggest that quinoa responds strongly to nitrogen fertilization, and grain yield did not show decrease with increasing N rates. Nitrogen application is known to increase seed yield as well as the protein content of the seeds [21].

6. Abiotic stress tolerance in quinoa

6.1. Soil salinity

Salinity tolerance allows plants to continue growing and producing photo-assimilates under saline conditions; this is governed by a polygenic mechanism [22]. Quinoa has been successfully grown in NaCl concentrations equivalent to that of seawater, up to 40 dS m^{-1}, or 400 mM NaCl, making it the most salt-tolerant crop [23],[24]. As detailed by [25], there is wide-ranging variability in the tolerance of quinoa ecotypes to salinity stress. For example, seeds of the Peruvian cultivar, Kancolla, could germinate at salinity levels of up to 57 dS m^{-1}. By contrast, [26] studied 182 Peruvian accessions, and only the 15 most tolerant accessions had a germination rate above 60% at salinity levels of 25 dS m^{-1}.

6.2. Drought

Drought can be defined as a lack of precipitation over an extended period of time, affecting specific sectors and activities. Quinoa is naturally tolerant to drought as it has low water requirements. Some of the key physiological factors are a low osmotic potential, growth plasticity and tissue elasticity, low turgid weight/dry weight ratio, low elasticity and maintenance of positive turgor at low water potentials [27],[28]. Quinoa's high WUE is thought to balance its decreased leaf stomatal conductance and optimise carbon gain. The results indicated that photosynthesis was maintained even after stomatal closure and ABA was produced in response to mild water deficit [29].

6.3. Temperature

Temperature stress has a strong effect on the growth and development of quinoa. Temperature can be broadly split into the following categories: low temperature, associated with cold stress responses; optimum temperature range for plant growth and development and high-temperature, associated with heat stress responses. Quinoa has been grown in the mountainous Andes for thousands of years, at an altitude in excess of 4000 m. In these areas, frosts are common and quinoa in these regions has been noted for its relatively high level of tolerance to frost and cold stress, although this is dependent on the developmental stage [19]. Quinoa can grow at −5 °C and it can survive in a vegetative state at −16 °C [27]. However, at the anthesis stage, even a mild frost (−2 °C), can cause serious damage. Hot climates and deserts can pose very significant challenges to the cultivation of quinoa, causing abortion of flowers and death of pollen [19]. [30] studied the growth and physiological responses of quinoa to temperature stress, the results proved that quinoa displayed optimal growth at higher temperatures (25/20 °C vs. 18/8 °C).

7. Quinoa seed composition

Quinoa seeds (QS) are compact, digestible, and also a rich source of protein, lipids, iron, magnesium, fibers and vitamins.

7.1. Protein content

Quinoa seeds (QS) in comparison with standard grains, it has higher protein content and more favorable amino acids [31]. In addition, QS are a complete food with high-nutritional value due mainly to their high content of good quality protein [32]. Many studies proved that the protein content in Quinoa seeds ranged between 12–23% [32][33]. Compared to cereal grains, the total protein content of QS (16.3% dry basis (db)) is higher than that of barley (11% db), and is comparable to that of wheat (15.4% db) [32] [34]. The amino acid composition of QS has been studied [35][36]. Relative to cereal grains, quinoa proteins are particularly high in lysine, the limiting amino acid in most cereal grains (Table 1).

Table 1. Amino acids composition of quinoa seed, barley, soybeans, and wheat [34].

Amino acid	Quinoa seed	Barley pearled	Soybean raw	Wheat durum
	mg/g protein			
Arginine	77.3	50.1	69.5	83.4
Aspartic acid	80.3	62.5	136.3	94
Cystine	14.4	22.1	12.1	20.5
Glycine	49.2	36.2	38.6	45.5
Glutamic acid	132.1	261.2	151	195.1
Histidine	28.8	22.5	26.7	23.5
Isoleucine	35.7	36.5	44.5	43.2
Leucine	59.5	98.2	72	82.8
Lysine	54.2	37.2	57.8	36.2
Methyonine	21.8	19.2	10.6	23.5
Phenylalanine	42	56.1	49.2	53.5
Serine	40.2	42.2	50	52.6
Threonine	29.8	34	38.6	35.8
Tryphtophan	11.8	16.6	12.2	11.5
Tyrosine	18.9	28.7	36.2	33.4
Valine	42.1	49	47.6	61.1
Alanine	41.6	39	42.2	58

7.2. Carbohydrate content

The carbohydrate content of QS is comparable to that of barley and rice (73-74%) [37]. Starch is the major component of quinoa carbohydrates, and it is present between 52–69 % (Table 2), due to its high starch content it can be used in the same way as cereals for flour production [38]. Carbohydrates from quinoa can be considered a nutraceutical food because they have beneficial hypoglycemic effects and induce lowering of free fatty acids. Studies made in individuals with celiac disease showed that the glycemic index of quinoa was slightly lower than that of gluten-free pasta and bread [39].

Table 2. Carbohydrate composition of quinoa seed, rice, and barley (% dry basis) [34].

	Quinoa	Rice	Barley
Carbohydrate by difference	73-74	79.2	77.7
Starch	52-69	80-90	60-75
Fiber total dietary	7-9.7	2.8	15.6
Sugar	2.9	0.1	0.8

7.3. Lipid and fatty acid

Quinoa seed has high content and good biological quality of their proteins, has an interesting lipid composition of about 5.5-7.4 % (Table 3), higher than wheat (1.7 %) and rice (0.7 %), making quinoa be accepted as an alternative oilseed seed [40]. Quinoa seed lipids contained the largest amount of neutral lipids among all the seed fractions analyzed. A very high content of free fatty acids was detected in the whole quinoa seed and hulls, accounting for 18.9 % and 15.4 % of total lipids, respectively. Some researchers have characterized the fatty acid composition of quinoa lipids as follows: total saturated 12.3–19 %, mainly palmitic acid; total monounsaturated 25–28.7%, mainly oleic acid, and total polyunsaturated 58.3%, chiefly linoleic acid (about 90%) [34,41].

Table 3. Fatty acid composition of crude fat from quinoa seed, corn, and soy oil [34,42].

Fatty acid (%)	Quinoa	Soy	Corn
Saturated			
Myristic C14:0	0.1–2.4		
Palmitic C16:0	9.2–11.1	10.7	10.7
Stearic C18:0	0.6–1.1	3.6	2.8
Monounsaturated			
Myristoleic C14:1	1		
Palmitoleic C16:1	0.2–1.2	0.2	
Oleic C18:1	22.8–29.5	22	26.1
Polyunsaturated (PUFA)			
Linoleic C18:2 (n - 6)	48.1–52.3	56	57.7
Linolenic C18:3 (n - 3)	4.6–8	7	2.2

7.4. Vitamins and minerals

Quinoa has recently been considered as a food source due to its resistance to drought, salinity, and high nutritive value in terms of protein, essential amino acids, vitamins, minerals and essential elements [43]. The vitamin content (Table 4) is also interesting, because Quinoa seed have high levels of vitamin B6 and total folate, whose amounts in 100 g can cover the requirements of children and adults. The riboflavin content in 100 g contributes 80% of the daily needs of children and 40% of those of adults [44]. In addition, high vitamin C levels have been also determined in quinoa seeds ranged from 4.0 to 16.4 mg/100 g dry matter (Table 4). However, the thiamin content is lower than that of oat and barley [40]. The niacin content does not cover the daily needs, but is beneficial in the diet. Thiamin values in quinoa are lower than those in oat or barley, but those of niacin, riboflavin and total folate are higher [45][34]. The mineral content of quinoa is also of great importance. The seeds have high content of calcium, magnesium, iron, copper, and zinc. Many of these minerals are present in higher concentrations to those found in common grains. Moreover, calcium, magnesium, and potassium are found in quinoa in bioavailable forms, thus their contents are considered to be adequate for a balanced diet [35].

Table 4. Mineral and vitamin content of quinoa and selected grains [46].

Mineral (mg/100g)	**Quinoa**	**Rice**	**Wheat**
Calcium	148.7	17.1	50.3
Iron	13.2	2.1	3.8
magnesium	249.6	137.1	169.4
Phosphorus	383.7	292.6	467.7
Potassium	926.7	377.1	578.3
Zinc	4.4	2.9	4.7
Vitamin (mg/100g)			
Thiamine (B1)	0.2-0.4	0.42	0.45-0.49
Riboflavin (B2)	0.2-0.3	0.1	0.17
Folic acid (B9)	0.0781	0.026	0.078
Niacin (B3)	0.5-0.7	1.8	5.5
Ascorbic acid (C)	4-16.4	0	0

8. Potential of quinoa for human health

An important aspect to consider for promoting quinoa consumption is to inform consumers of the good properties of quinoa and let them incorporate it in their daily diet as a healthy, nutritious, good tasting, and versatile food. Quinoa has been reported to exert beneficial effects on high-risk group consumers, such as children, the elderly, lactose intolerant, and people with anemia, diabetes, obesity, dyslipidemia, and celiac disease [40].These benefits have been linked with the content of protein, fiber, vitamins and minerals, fatty acids, and especially with the presence of a plethora of phytochemicals that provide quinoa a remarkable advantage over other grains in terms of human nutrition and health [40]. In addition, squalene is an intermediary in cholesterol biosynthesis, and 33.9–58.4 mg/100 g of it was found in the lipid fraction of quinoa [41]; squalene is the biochemical precursor of the whole family of steroids, and besides their effective antioxidant activity, tocotrienols have other important functions, in particular in maintaining a healthy cardiovascular system and a possible role in protection against cancer [47]. Moreover, supplementation of diet with quinoa has been demonstrated to prevent cardiovascular disorders in healthy people [48] as well as to modulate metabolic parameters in postmenopausal overweight women [49].

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