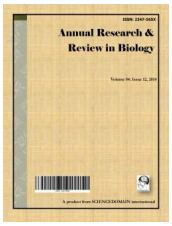

Annual Research & Review in Biology

22(1): 1-11, 2018; Article no.ARRB.38435
ISSN: 2347-565X, NLM ID: 101632869

Compositional Analysis and Functional Characteristics of Quinoa Flour

S. A. El Sohaimy[1*], S. E. Mohamed[1], M. G. Shehata[1], Taha Mehany[1] and M. A. Zaitoun[2]

[1]Department of Food Technology, Arid Lands Cultivation Research Institute, City of Scientific Research and Technological Applications, 21934 Alexandria, Egypt.
[2]Department of Food Science, Faculty of Agriculture (Saba Basha), Alexandria University, Alexandria, Egypt.

Authors' contributions

This work was carried out in collaboration between all authors. Author SAES designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SEM, MGS and TM managed the analyses of the study and contributed in the write of the first draft of the manuscript. Author MAZ managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARRB/2018/38435
Editor(s):
(1) Msafiri Yusuph Mkonda, Lecturer, Sokoine University of Agriculture, Tanzania.
(2) George Perry, Dean and Professor of Biology, University of Texas at San Antonio, USA.
Reviewers:
(1) Müzeyyen Berkel Kaşikci, Manisa Celal Bayar University, Turkey.
(2) Yongchun Zhu, Shenyang Normal University, China.
(3) Nilgün Ertaş, Necmettin Erbakan University, Turkey.
Complete Peer review History: http://www.sciencedomain.org/review-history/22648

Original Research Article

Received 27th November 2017
Accepted 28th December 2017
Published 9th January 2018

ABSTRACT

Aim: The current study was intended to evaluate the nutritional and functional properties of quinoa flour for the potent of its use in food manufacturing.
Materials: Quinoa seeds were obtained from the Egyptian Company for Natural Oils, Cairo, Egypt. The collected seeds were cleaned of foreign materials and stored at room temperature (25 ± 2℃) for further analysis.
Methodology: Minerals, vitamins, phenolic contents and flavonoids, antioxidant activity and functional properties of quinoa flour were carried out in the department of food technology, Arid Lands cultivation research institute, City of Scientific research and Technological Applications.
Results: Quinoa flour has the most balanced and perfect minerals content such as potassium (443

**Corresponding author: E-mail: selsohaimy@srtacity.sci.eg;*

mg/ Kg), sodium (858 mg/ Kg), magnesium (174 mg/ Kg), calcium (127 mg/ Kg) and iron (63 mg/ Kg). Quinoa flour is a good source of vitamins such as Vitamin C (1.93 mg/ Kg), B3 (0.15 mg/ Kg), B6 (11.22 mg/ Kg), and B12 (0.09 mg/ Kg). The total phenolic content of quinoa flour was 17.86± 0.49 µg GAE/g dry weight, while the total flavonoids was 14.82 ± 0.75 µg/g dry weight. Quinoa flour was presented a reasonable antioxidant activity with IC_{50}= 21.76 µg/ml. The water absorption of quinoa flour was 141.5±0.54%, whereas its oil absorption was 110±0.18%. Quinoa flour foaming capacity and stability were 14.33±0.76% and reached 9.63±1.72% after 60 min. while emulsion capacity and stability were 100.4± 0.25% and reached 45.83± 0.18% after 60 min. The protein digestibility of quinoa flour was 86.85±0.83%.

Conclusion: Quinoa flour is a likely nutritive source and can be used as a functional food supplement to be used in food manufacturing.

Keywords: Quinoa flour; vitamin content; phenolic compounds; antioxidant activity; protein digestibility; emulsion properties; foaming properties.

1. INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd) is a pseudocereal grain crop, which is grown mainly for its edible seeds. It has been domesticated in the Peruvian Andes from wild populations of the same species around 5000 years ago [1]. Quinoa seeds have become increasingly popular in the United States, Canada, Europe, Australia, China, Japan and the Middle East region. Although such regions are far from its original habitat, the crop has successfully grown because it has a broad genetic diversity, which allows it to adapt to various severe environments [2]. Quinoa is a dicotyledonous annual plant and its height about 1-2 m. It has pubescent powdery lobed leaves normally arranged alternately. The woody central stem could be branched or unbranched depending on the variety, and its color may be green, red or purple. The seeds are small, round and flat about 2 mm in diameter and of various colors from white to red or black depending on the cultivar after 5-6 months of maturation. Quinoa is significantly known as a high protein source (more than 15%), and balanced amino acid composition compared to the major cereals [3], with higher content of lysine (5.1-6.4%) and methionine (0.4-1.0%) [4]. It contains a considerable amount of fiber and minerals [5]. Quinoa is also rich in antioxidants such as polyphenols [6]. It has the highest content of bioactive compounds compared to other cereal and pseudocereal crops [7]. Furthermore, it has been found that quinoa is considered gluten-free and subsequently it is suitable for celiac as well as wheat allergy patients [8]. Quinoa seeds have bitter tasting components (mainly saponins) that are located in the seed's outer layer known as the hull; which can be removed by dehulling/polishing seeds and washing them in cold water [9]. The seeds are the perfect example of functional food especially for lowering the risk of different diseases and exerting health-promoting effects [10]. Due to such previously mentioned features that distinguish quinoa from other conventional major cereals, it is classified by FAO as one of the humanity's promising crops, which can contribute to food security in the 21st century, because quinoa plants are tolerant to salinity and drought stress. Quinoa plants can grow in marginal regions [11]. Moreover, the United Nations has declared 2013 the International Year of Quinoa, which aims at focusing global attention on the plant's contribution to food security, nutrition and poverty eradication and policies [12]. In our previous study, quinoa seeds proximate analysis was performed, and the moisture content of quinoa seed was 9.68 ± 0.33, ash content was 2.97 ± 0.021, fiber content was 4.06 ± 0.34, protein content was 14.03 ± 0.25, fat content was 6.79 ± 0.19 and carbohydrate content (NFE) was 72.15 ± 0.28 [13] (Table 1). A proximate analysis in this study was evident the potentiality of quinoa seeds as a super functional food due to their content of essential nutritional elements (protein, carbohydrate, fat, and fiber). Our research is continued to evaluate the nutritional and functional characteristics of quinoa flour to proof its quality and its capability to be utilized as a promising food supplement.

Table 1. Proximate analysis of quinoa seeds

Constituents	% Dry weight basis
Moisture	9.68±0.33
Ash	2.97±0.021
Crude fiber	4.06±0.34
Crude protein (N x 6.25)	14.03±0.0.25
Crude fat	6.79±0.19
Carbohydrates (NFE)	72.15±0.28

Values presented in mean of triplicates ± SD, P≤0.05 [13]

2. MATERIALS AND METHODS

2.1 Materials

Quinoa seeds (Chenopodium quinoa Willd, var. NAT OIL1) were obtained from the Egyptian Company for Natural Oils, Cairo, Egypt. The plant was cultivated in Egypt for over seven years till now on Cairo-Ismailia desert road. The collected seeds were cleaned of foreign materials and stored at room temperature (25 ± 2℃) for further analysis.

2.1.1 Flour preparation

Quinoa flour was prepared according to [14] with some modifications to remove saponins. Whole seeds were washed twice with cold water then seeds were soaked in the alkaline solution for 10- 20 min, and then rinsed with 1% citric acid solution for 10 min. The cleaned seeds were washed with water until there was no foam as an indication of saponins removal from the seeds hull. Later saponins-free seeds were overnight oven-dried at 45±1℃. During drying treatment, the seeds were spread in a thin layer to avoid germination process and any further contamination. Finally, treated whole seeds were ground into flour using Miller (KARIZMA- JX-1000A) and kept at 5℃ for further analyses.

2.2 Methods

2.2.1 Determination of minerals content

The ash was digested using advanced microwave digestion system, and the concentration of elements (mg/ Kg) in the samples was determined using Inductively Coupled Plasma- Mass Spectrometer (ICP/MS), NEXION 300X series. Argon gas was used for excitation of the element atom [15].

2.2.2 Determination of vitamin content

Determination of vitamins content in quinoa flour was carried out according to the protocol of Agilent Application Note, publication number 5989-931EN [16] using Agilent 1260 infinity HPLC Series (Agilent, USA) equipped with the quaternary pump and a Kinetex-XB-C18 column 100×4.6 mm (Phenomenex, USA) operated at 35℃. The separation was achieved using a binary linear elution gradient with (A) 25 mM NaH_2PO_4 (pH 2.5, v/v), (B) Methanol. About 20 µL was injected, and VWD detector was used at 254 nm for ascorbic acid and 220 nm for vitamins B3, B6, and B12.

2.2.3 Preparation of quinoa extract

The methanol extract was prepared according to [17]. 50 g of quinoa flour was mixed with 1000 ml methanol (1:20 w/v) in 2 L-glass beaker, covered with aluminum foil to prevent the evaporation of the solvent and stirred for 60 min at room temperature. The extract was filtered through filter paper (Wattman No.1) and evaporated to dryness under vacuum. The same procedure was carried out for aqueous extraction. The dried extract was stored at (-80℃) for further analyses.

2.2.4 Total phenolic content

Determination of total phenolics was carried out using the Folin-Ciocalteu reagent, following the method of [17] and based on the reduction of a phosphorwolframate-phospho molybdate complex by phenolic compounds to blue reaction products. 1 mg extract was dissolved in 1 ml absolute methanol and 500 µL of dissolved sample was taken and added to 0.5 ml of distilled water and 0.125 ml of Folin-Ciocalteu reagent. The mixture was shaken and allowed to stand for 6 minutes before addition of 1.25 ml of 7% Na_2CO_3. The solution was adjusted to 3 ml with distilled water and mixed thoroughly. After incubation in the dark for 30 min, the absorbance was read at 650 nm against blank. A standard curve was made using different concentrations of Gallic acid (standard, 0-1000 µg/ml). Total phenolic content was estimated as µg Gallic acid equivalents (GAE/g) of dry weight sample.

2.2.5 Total flavonoids

Total flavonoid content was measured using colorimetric assay developed by [18]. 1 ml extract was mixed with 4 ml of distilled water. Then, 300 µl of $NaNO_2$ (5%, w/v) was added to the mixture. After 5 min, 300 µl of $AlCl_3$ (10% w/v) was added, followed by the addition of 2 ml of NaOH (1 M) after 6 min. Then the volume was increased to 10 ml by ddH_2O. The mixture was stirred to ensure adequate mixing and the absorbance was read at 510 nm. A calibration curve was created using a standard solution of catechol (5, 10, 20, 40, 60, 80 and 100 µg/ml; Abs = 0.0113 C - 0.0668 R2 = 0.997). The results were expressed as µg per g of dry weight of the extract.

2.2.6 Phenolic compounds (HPLC)

Determination of polyphenols in quinoa extract was carried out according to the protocol of Agilent Application Note, publication number 5991-3801EN [19]. A 0.1 g sample was soaked in 25 ml methanol 80% overnight then centrifuged for 20 min at 4000 rpm. The supernatant was evaporated till dryness then dissolved in 5 ml methanol HPLC grade filtered through 0.45 µm PTFE syringe filter. HPLC was performed using Agilent 1260 infinity HPLC Series (Agilent Technologies, USA), equipped with a quaternary pump, a Zorbax Eclipse Plus C18 column (100×4.6 mm id) operated at 25℃. The separation was achieved using a ternary linear elution gradient with (a) HPLC grade water with 0.2% H_3PO_4 (v/v), (b) Methanol and (c) Acetonitrile. About 20 µl was injected, and VWD detector was used at 284 nm.

2.2.7 Antioxidant activity

The free radical scavenging activity of the extract was evaluated by 1, 1-diphenyl-2-picryl-hydrazyl (DPPH) according to the previously reported by [20] with some modifications. Briefly, a 0.1 mM solution of DPPH (39.432 g / l methanol) was prepared and 2 ml of this solution was added to 1 ml of the solution of the extracts in methanol at different concentrations (10, 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200 µg/ml). The solutions were stirred and stand at room temperature for 30 min. Then, the absorbance was measured at 517 nm using a UV-VIS spectrophotometer (T 80 UV/Vis spectrometer PG instrument Ltd). Ascorbic acid was used as the reference. Total antioxidant capacity (TAC) was expressed as the percentage inhibition of the DPPH radical and was determined by the following Equation:

% DPPH scavenging effect = {(A0– A1)/ A0} X 100

Where, *A0* is the absorbance of the control, and *A1* is the absorbance of the extract and standard.

2.2.8 Functional properties of quinoa flour

2.2.8.1 Oil and water absorption

For determination of oil and water of quinoa flour, the method of Sathe and Salunkhe [21] was followed. One gram of quinoa flour was mixed with 10 ml deionized distilled water for 30 s in the Blender (Waring model HGBTWTS3, USA). The sample was then stood at room temperature (25℃± 2℃) for 30 min, centrifuged at 7000 g for 30 min and the volume of supernatant was noted in a 10 mL graduated cylinder. The same procedure was carried out to determine the oil absorption of quinoa flour. Water or oil absorption capacity was expressed as percent water or oil absorbed by 1 g flour.

2.2.8.2 Foaming capacity and stability

The foaming properties of quinoa flour were determined according to the method described by [22]. 20 ml of (1%; w/v quinoa flour) were whipped by the blender (Waring model HGBTWTS3, USA) at high speed of (16,000 rpm) to incorporate the air for 1 min. After that, the whipped mixture was transferred to 50 ml-cylinder; the total volume was measured at zero time after whipping to determine foam capacity. The total volume remaining at an interval of 0.5, 5, 10, 20, 40 and 60 min was noted for the study of foaming stability. Foaming capacity was calculated according to the following equation:

Foaming capacity (%) = A – B / B X 100

Where A = volume after whipping (mL) and B = volume before whipping

% Foam stability = foam volume after time (t) / Initial foam volume X 100

2.2.8.3 Emulsion capacity and stability

The emulsion capacity and stability were determined according to [23]. The emulsion (1 g sample, 10 ml distilled water, and 10 ml soybean oil) was prepared in calibrated centrifuged tube. The emulsion mixture was centrifuged at 2000 g for 5 min. The ratio of the height of emulsion layer to the total height of the mixture was calculated as emulsion activity in percentage. The stability of the emulsion of the sample was estimated after heating the emulsion contained in calibrated centrifuged tube at 80℃ for 30 min in a water bath followed by cooling with tap water for 15 min and then centrifuged at 2000 g for 15 min. The emulsion stability (%) was calculated as the ratio of the height of emulsified layer to the total height of the mixture.

2.2.8.4 In vitro protein digestibility of quinoa flour

In vitro protein digestibility of quinoa flour was carried out by multi-enzymes according to the method previously described by [13]. Porcine pancreatic trypsin (type IX, 15 310 units/mg protein), bovine pancreatic chymotrypsin (type II,

48 units/mg of solid), porcine intestinal peptidase (P-7500, 115 units/g of solid) and bacterial protease (type XIV, 4.4 units/mg of solid) were used for the enzymatic digestion of protein. 63.8 mg sample in was dissolved in 10 ml distilled water at 37℃ and the pH of the mixture was adjusted to 8.0. One ml of three enzyme solution previously dissolved in water (1.58 mg of trypsin, 3.65 mg of chymotrypsin and 0.45 mg of peptidase) was added to the flour sample and stood for 10 min at 37℃ for digestion. After that 1 ml (1.48 mg) of protease solution was added and the solution was incubated for additional 9 min at 55℃. The pH value was noticed after a further 1 min at 37℃ and used to estimate the *in vitro* protein digestibility of the quinoa flour according to the following equation:

$$Y=234.84-22.56X$$

Where; *Y* is the *in vitro* digestibility of protein (%), and *X* is the pH of the suspension after 20 min digestion.

2.2.9 Statistical analysis

Results were given as mean ± standard deviation of three independent determinations. Significant differences between results were calculated by one-way analysis of variance (ANOVA), Duncan test. Differences were considered to be significant at $P < 0.05$ (95% confidence level). All statistical analyses were performed with SPSS 16.

3. RESULTS AND DISCUSSION

3.1 Mineral Content

That quinoa minerals were found in the outer bran layers in levels greater than that reported for most grain crops [24]. The minerals analysis of quinoa flour is presented (Table 2). The presented data demonstrated that quinoa flour showed a high content of sodium (858 mg/kg), potassium (443 mg/kg) and magnesium (174 mg/kg) and calcium (127 mg/kg) while showed a low concentration of copper (2 mg/kg) and moderate level of Iron (63 mg/kg), zinc (25 mg/kg) and manganese (18 mg/kg). Our data revealed that the quinoa flour contained 6.5 times of iron more than wheat which emphasize the benefit of quinoa flour for malnutrition. Our findings are in agreement with the previous studies that reported iron (81 mg/ Kg) and calcium (874 mg/ Kg) levels are higher in quinoa than those recorded for maize and barley [25]. Moreover, quinoa iron is in a highly soluble form and subsequently could be readily available to anemic populations [26]. Potassium was recorded the most abundant mineral (after sodium; 858 mg/ Kg) with a value of 443 mg/ Kg. It is well documented that potassium and sodium content in quinoa seeds flour are predominant if that grain crop was germinated in arid or saline areas. Potassium, sodium, and magnesium are essential minerals for the human body because they are neurotransmitters, while calcium is inadequate content for infants to develop their bones and teeth. It was significantly close to the data recorded by [27]. Since sodium and potassium were the highest predominant minerals discovered in Nigerian agricultural products. Such previous data proof that quinoa seeds flour has the most balanced and perfect essential minerals content comparing to the other main grain cereals.

3.2 Vitamin Content

Vitamins are vital nutrients that are required in trace amounts to be involved in almost all known metabolisms that organize the life of all organisms. Table 3 presented that; quinoa flour contained ascorbic acid (vitamin C) in concentration of (1.93 mg/Kg) which cover 2.2% of human daily requirements. It is emphasized the potency of quinoa flour to treat and prevent scurvy and cold infection. The concentration of niacin was (0.15 mg/Kg) which cover 10% of daily requirements. Niacin in the body is important for general good health and can improve cholesterol levels and lower cardiovascular risks. Pyridoxine (B6) registered (11.22 mg/Kg) which cover 800% of daily requirements. Pyridoxine is used for preventing and treating anemia. It is also used for heart disease; high cholesterol; reducing blood levels of homocysteine. Cobalamin (B12) concentration was (0.09 mg/Kg) which not found in wheat cereals. Cobalamin is a water-soluble vitamin that has a key role in the normal functioning of the brain and nervous system, and the formation of red blood cells. The obtained results evident quinoa flour has significantly higher vitamins content compared to major conventional grains (wheat, barley and rice) [30]. Quinoa flour supplies 0.2 mg pyridoxine (B6), 0.61 mg pantothenate (B5), 23.5 g folic acid (B9) and 7.1 g biotin (B7) in terms of a 100 g flour [31]. Furthermore, quinoa flour has an abundant level of α-tocopherols (vitamin E) that improves its antioxidant properties by protecting the fatty acids of the cell membranes against damage

Table 2. Quinoa flour minerals compared with wheat flour minerals and the human daily intake

Minerals	Quinoa flour minerals *(mg/ Kg)*	Wheat flour minerals *(mg/ Kg)* [28]	Human daily intake *(mg/ day)* [29]	(%) of Quinoa flour coverage of human intake	(%) of Wheat flour coverage of human intake
Calcium	127	202.7	1000	12.7	20.3
Iron	63	9.6	27.4	229.9	35.0
Magnesium	174	235.1	323.8	53.7	72.6
Potassium	443	930.7	3510	12.6	26.5
Sodium	858	207.6	2000	42.9	10.4
Zinc	25	6.5	7.0	357.1	92.9
Manganese	18	4.5	3.5	415.3	128.6
Copper	2	3.8	2	100	190

Values of wheat and quinoa flour minerals are presented in mean of triplicates, p ≤ 0.05

Table 3. Quinoa flour vitamins compared with wheat flour vitamins and the human daily intake

Vitamins	Quinoa flour vitamins *(mg/ Kg)*	Wheat flour vitamins *(mg/ Kg)* [29]	Human daily intake *(mg/ day)* [29]	Quinoa flour coverage of human intake (%)	Wheat flour coverage of human intake (%)
Niacin (B_3)	0.15	63.3	1.5	10	4220
Pyridoxine (B_6)	11.22	3.3	1.4	801.4	235.7
Cobalamin (B_{12})	0.09	0.0	0.002	4500	0.0
Ascorbic acid (C)	1.93	0.0	87	2.2	0.0

Values of wheat and quinoa flour are presented in mean of triplicates, p ≤ 0.05

caused by free radicals [10]. β-carotene concentrations in quinoa flour (0.39 mg/ 100 g dry weight) has been found to be higher as compared to major cereals such as wheat (0.02 gm/ 100 g dry weight) and barley (0.01 mg/ 100 g dry weight) [30]. Quinoa flour folate content (132.7 mg/ 100 g dry weight) was ten times more that of wheat [32]. Rules and Nair [33] have reported appreciable amounts of thiamin (B1; 0.4 mg/ 100 g), folic acid (B9; 78.1 mg/ 100 g) and vitamin C (16.4 mg/ 100 g). It was noticed that such vitamins content is significantly vary from a study to another and this may be referred to the difference in quinoa cultivars and their wide biodiversity. Again, quinoa flour appears to have the best-balanced formula of vitamins content comparing to major conventional cereals.

3.3 Total Phenolic Content and Flavonoids

All plant-derived foods contain phytochemicals such as phenolic compounds that affected of their organoleptic as well as nutritional properties. In the present study, the total phenolic content in the quinoa flour was 17.86± 0.49 µg GAE/g dry weight (Table 4). For human nutrition, polyphenols play an important role because of their potential beneficial effects on human health due to their role as antioxidant, anti-inflammatory, anti-microbial and as cardioprotective. Polyphenols also playing a crucial role in the prevention of neurodegenerative diseases and diabetes mellitus [34]. Moreover, they have been found to have antiviral, anti-allergic, anti-platelet, anti-inflammatory, anti-tumor and antioxidant activities [35,36].

Flavonoids are phenolic compounds (flovonols, flavones, flavanones, isoflavones, catechins, anthocyanidins and chalcones) occurring in fruits, vegetables and some cereal crops that are involved in the color of most fruits and vegetables. In our investigation, the total flavonoids content of quinoa flour was 14.82± 0.75 µg/g dry weight (Table 4). In other study, quinoa has exceptionally high flavonoid content varying from 36.2 to 144.3 mg/ 100 g [6].

Table 4. Total phenolic content and flavonoids of quinoa flour

Quinoa flour extract	Concentration *(µg/g)*
Total Phenolic Content	17.86± 0.49
Total Flavonoid compounds	14.82± 0.75

Values presented in mean of triplicates, p ≤ 0.05

3.4 Phenolic Compounds

Table 5 indicates quinoa flour phenolic compounds using both water and methanol extraction by HPLC. An aqueous extract of quinoa flour showed high significant concentrations of benzoic acid (74.29 mg/100 g) showed the highest concentration followed by rutin (29.10 mg/100 g) and gallic acid (11.03 mg/100 g) while caffeic acid (4.18 mg/100 g) and p-hydroxy benzoic (4.10 mg/100 g) showed the lowest concentrations respectively. While the methanol extract showed a high content of ellagic acid (93.64 mg/100 g) followed by benzoic acid (37.85 mg/100 g), ferulic acid (33.05 mg/100 g), rutin (26.85 mg/100 g) and salicylic acid (19.62 mg/100 g) respectively. Several phenolic acids, including derivatives of hydroxycinnamic acid and hydrobenzoic acid, have been identified in quinoa seeds and leaves [37]. Individual phenolic acids have been reported in quinoa seeds at concentrations as high as 251.5 µg/g dry weight [38]. Quercetin and kaempferol derivatives, were found in quinoa with concentrations of individual compounds occurring at levels as high as 839 µg/g dry weight [39,7]. The obtained results emphasized that the quinoa flour considered a good source of phenolic compounds that have a crucial role in the improvement of human health.

3.5 Antioxidant Activity

The antioxidant activity of quinoa flour determined by DPPH and the results was presented in (Fig. 1). Quinoa flour showed an increasing in a scavenging activity with increasing of the extract concentrations since quinoa extract with concentration of 200 mg/ml posed 98% inhibition. Quinoa extract showed IC_{50} (21.76 µg/mL) while of ascorbic acid showed IC_{50} (9.58 µg/ mL). Quinoa (310 g/ Kg fodder) was found to act as moderate protective agent against changes caused by fructose induction such as increase in plasma monodialdehyde (MDA) through reducing lipid peroxidation and enhancing the antioxidant capacity of the blood, heart, kidney, testis, lung and pancreas [40]. The low values of correlation between total phenolic content and antioxidant activity suggest that the high antioxidant activity in the quinoa flour extract may be from other non-phenolic compounds beside phenolics. Despite the proportion of total phenols, other nonphenolic compounds, such as ascorbic acid, phytic acid, tocopherols, sterols, carotenoids, saponins, ecdysteroids, may be contributes to the antioxidant activity of the tested samples. [41].

Table 5. Quinoa flour phenolic compounds

Phenolic compounds	Water extract *(mg/100 gm)*	Methanol extract *(mg/100 gm)*
Gallic acid	11.03	ND*
Catechol	ND*	ND*
p- Hydroxy benzoic acid	4.10	10.07
Caffeine	3.38	ND*
Vanillic acid	ND*	1.33
Caffeic acid	4.18	9.23
Syringic acid	2.68	8.18
Vanillin	2.52	6.88
p- Coumaric acid	3.07	9.51
Ferulic acid	0.95	33.05
Rutin	29.10	26.85
Ellagic	5.65	93.64
Benzoic acid	74.29	37.85
O-Coumaric acid	ND*	1.11
Salicylic acid	ND*	19.62
Cinnamic acid	1.80	1.55

ND= Not detected*

3.6 Functional Properties

3.6.1 Water and oil absorption

Water and oil absorption capacity of food materials are important functional properties due to improving mouthfeel and flavor retention. In the present study, quinoa flour showed water absorption of 141.5± 0.54% that is significantly higher than that of wheat flour (76.3%) [42] and quinoa flour oil absorption was 110± 0.18%. Latter oil absorption percent was two-fold higher than that reported by [43], and this may be explained by the difference in quinoa cultivars and the areas where quinoa germinated in. The water absorption capacity of quinoa flour (147%) was higher than that of fluted pumpkin seeds (85%) [44], soy flour (130%) [45], and pigeon pea flour (138%) [46]. Water absorption is a function of protein in viscous foods such as soups, dough and baked products; hence, quinoa flour may be good in these food formulations. Oil absorption capacity of quinoa flour (46%) [43] was lower than those of soy flour (84.4%) and wheat flour (84.2%) [45] and African yam bean (110.25-132.82%) [47]. Oil absorption is paramount since oil serves as a flavor retainer and increases the mouth feel of foods [48]. This

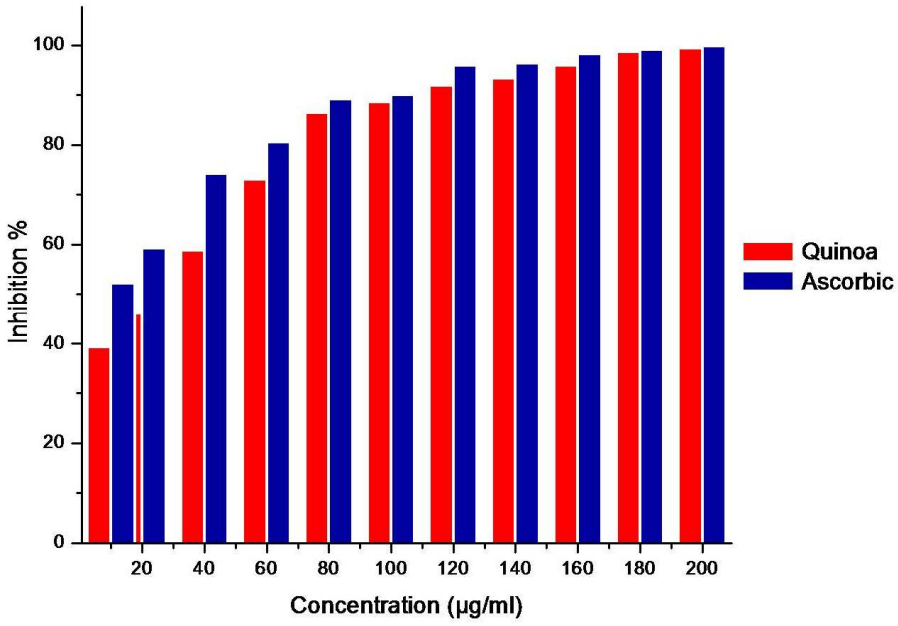

Fig. 1. Antioxidant activity of quinoa flour, values presented in mean of triplicates, $p \leq 0.05$

indicates that quinoa flour may have a lower flavor retainer that wheat, yam bean and soy flour.

3.6.2 Foaming capacity and stability

Foaming capacity and stability are limiting factors involved in the characterization of the functional properties of food products. Table 6 indicated that foaming capacity of quinoa flour was 14.33± 0.76% and its stability was 9.63± 1.72% after 60 min. The foaming capacity and stability of quinoa seeds flour were 9% and 2%, respectively [43]. Such indicated records were lower than that of soy flour (160%, 14.6%) and pigeon pea flour (68%, 20%) reported by [46], but compared favorably with those of full-fat fluted pumpkin seeds (10.8%, 5%) reported by [48] and of *Zonocerus variegatus* (12%) reported by [49].

3.6.3 Emulsion capacity and stability

Emulsion properties are the vital functional properties that affect the behavior of food products. Quinoa flour emulsion capacity was averaged to be 100.4± 0.25% while the emulsion stability was averaged to be 45.83± 0.18% after 60 min. Ogungbenle [43] reported that the emulsion capacity of quinoa seeds flour was 104% that completely agreed with our results. Latter percent is higher than those of yam bean dehulled seed flours (10- 20%) [47], soy flour (18%) [45], pigeon pea (49.9%) [46], benniseed (63%) and pearl millet (89%) [3], and *Z. variegatus* (25.6%) [49]. This indicated that quinoa seeds flour may be an excellent substitute for yam bean, pigeon pea, pearl millet, benniseed and soy flours as a food additive for binder formulation and for stabilization of colloidal foods.

Table 6. Foaming capacity and stability of quinoa seeds flour

Property	Quinoa flour	Time interval (min)
Foaming capacity (%)	14.33 ±0.76	0
	71.36±0.70	0.5
	66.66 ±1.75	5
	61.16 ±2.46	10
Foaming stability (%)	35.56±2.69	20
	16.0 ± 2.17	40
	9.63 ±1.72	60

Values presented in mean of triplicates, p ≤ 0.05

3.6.4 *In vitro* protein digestibility of flour

The protein digestibility of the quinoa flour is a crucial parameter to evaluate its quality and availability for human body. The obtained result revealed that the *in vitro* digestibility of protein in quinoa flour was 86.85± 0.83% (untabulated data). The digestibility of protein in quinoa flour was higher than the digestibility of isolated

protein (78.37±1.08%) that reported in our pervious study [13]. Several earlier studies showed the *in vitro* digestibility of protein of quinoa varieties was between 75.3% and 84% [6]. The in vitro protein digestibility of wheat grains in the previous studies was 47% [50], 54.87% [51]. The high digestibility of quinoa flour protein (86.85 ± 083%) is supporting its high availability and digestibility in the human stomach and consequently its benefits for human health.

4. CONCLUSION

Quinoa is an ancient Andean grain noted by FAO as has an exceptional nutritional profile that implemented in different health benefits. Quinoa is tolerable and acceptable to celiac patients due to the absence of gluten, since that cereal crop resists adverse climatic conditions, has a potential to diversify shrinking food basket, fights hunger and malnutrition world over and possible health benefits the grain proves itself to be a wonder grain. Quinoa flour has perfect-balanced ingredients such as minerals (potassium, sodium, magnesium and calcium and even soluble iron). It has different kinds of vitamins such as B_3, B_6, B_9, and C that are vital for human metabolism and prevention of several diseases. Its natural antioxidants such as phenolic compounds and flavonoids are helpful in treatment of degenerative diseases. The water and oil absorptions of quinoa flour were favorably sound, which enhances its potentiality in human food and drinks formulations. Foaming as well as emulsion capacities and stabilities prove the importance of quinoa seeds flour to be used as a food additive/ingredient in food processing for its manufacturing quality. The high digestibility of quinoa flour protein was (86.85 ± 0.83%) which is supporting its high availability and digestibility in the human stomach and consequently its benefits for human health. Thus, it can be used in daily dietary forms such as breads, cookies, pasta, and salads for adopting a healthy lifestyle.

ACKNOWLEDGEMENT

This work is the part of the project was supported financially by the Science and Technology Development Fund (STDF), Egypt, Grant No. 15030.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bhargava A, Shukla S, Rajan S, Ohri D. Genetic diversity for morphological and quality traits in quinoa (*Chenopodium quinoa* Willd.) germplasm. Genetic Resources and Crop Evolution. 2007;54: 167–173.
2. Jacobsen SE. The worldwide potential for quinoa (*Chenopodium quinoa* Willd.). Food Reviews International. 2003;19:167-177.
3. Oshodi AA, Ogungbenle HN, Oladimeji MO. Chemical composition, nutritionally valuable minerals and functional properties of benniseed, pearl millet and quinoa flours. International Journal of Food Science and Nutrition. 1999;50:325-331.
4. Bhargava A, Shukla S, Ohri D. Genetic variability and heritability of selected traits during different cuttings of vegetable *Chenopodium*. Indian Journal of Genetics and Plant Breeding. 2003;63:359-360.
5. Ando H, Chen YC, Tang H, Shimizu M, Watanabe K, Mitsunaga T. Food components in fractions of quinoa seed. Food Science and Technology Research. 2002;8:80-84.
6. Repo-Carroso-Valencia RAM, Serna LA. Quinoa (*Chenopodium quinoa*, Willd.) as a source of dietary fiber and other functional components. Ciencia E Tecnologia de Alimentos. 2011;31:225-230.
7. Hirose Y, Fujita T, Ishii T, Ueno N. Antioxidative properties and flavonoid composition of *Chenopodium quinoa* seeds cultivated in Japan. Food Chemistry. 2010;119:1300-1306.
8. Abugoch James LE. Quinoa (*Chenopodium quinoa* Willd.) composition, chemistry, nutritional, and functional properties. In Taylor, S., Advances in Food and Nutrition Research. 2009;58(1):1-31.
9. Lopez-Garcia R. Quinoa: A traditional Andean crop with new horizons. Cereal Foods World. 2007;52:88-90.
10. Vega-Galvez A, Miranda M, Vergana J, Uribe E, Puente L, Martinez EA. Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.) an ancient Andean grain: A review. Journal of the Science of Food and Agriculture. 2010;90: 2541-2547.
11. FAO. Regional Office for Latin America and the Caribbean, and PROINPA. Quinoa: An ancient crop to contribute to world food security, FAO Regional Office

for Latin American and the Caribbean, Santiago, 2011.
Available:http://www.fao.org/file/media/pubs/2011/cultivo_quinoa_en.pdf
12. FAO. Home-international year of quinoa; 2013.
(Retrieved 21 February 2014)
Available:http://www.fao.org/quinoa-2013/en/
13. El Sohaimy SA, Refaay TM, Zaytoun MAM. Physicochemical and functional properties of quinoa protein isolate. Annals of Agricultural Science. 2015;60:297–305.
14. Abugoch LE, Romero N, Tapia CA, Silva J, Rivera M. Study of some physicochemical and functional properties of quinoa (*Chenopodium quinoa* Willd.) protein isolates. Journal of Agriculture and Food Chemistry. 2008;56:4745-4750.
15. Nardi EP, Evangelista FS, Tormen L, Saintpierre TD, Curtius AJ, De Souza SS, Barbosa F. The use of inductively coupled plasma mass spectrometry (ICP-MS) for the determination of toxic and essential elements in different types of food samples. Food Chemistry. 2009;112:727-732.
16. Agilent Application Note. Publication number 5989-931 EN, USA; 2008.
17. El Sohaimy SA. Chemical composition, antioxidant and antimicrobial potential of artichoke. The Open Nutraceuticals Journal. 2014;7:15-20.
18. Zhishen J, Mengcheng T, Jianming W. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. Food Chemistry. 1999;64:555-559.
19. Agilent Application Note. Publication Number 5991- 3801 EN; 2014.
20. Turkmen N, Sari F, Velioglu YS. The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. Food Chemistry. 2005;93:713–718.
21. Sathe SK, Salunkhe DK. Functional properties of great northern bean (*Phaseolus vulgaris*) proteins: Emulsion, foaming, viscosity and gelation properties. Journal of Food Science. 1981;46:71–75.
22. Tsutsui T. Functional properties of heat treated egg yolk low density lipoprotein. Journal of Food Science. 1988;53:1103-1106.
23. Yasumatsu K, Sawada K, Maritaka S, Toda J, Wada T, Ishi K. Whipping and emulsifying properties of soy bean products. Agricultural and Biological Chemistry. 1972;36:719-727.
24. Prego I, Maldonado S, Otegu MII. Seed structure and localization of reserves in *Chenopodium quinoa*. Annals of Botany. 1998;82:481-488.
25. Ahamed T, Singhal R, Klukarni P, Pal M. A lesser-known grain, *Chenopodium quinoa*: Review of the chemical composition of its edible parts. The United Nations University, Food Nutrition Bulletin. 1998; 19:61-70.
26. Valencia S, Svanberg U, Sandberg S, Ruales J. Processing of quinoa (*Chenopodium quinoa* Willd.): Effects on *in vitro* iron availability and phytate hydrolysis. International Journal of Food Science and Nutrition. 1999;50:203-211.
27. Olaofe O, Sanni CO. Mineral contents of agricultural products. Food Chemistry. 1988;30:73-77.
28. Tejera RL, Luis G, Gonzalez-Weller D, Caballero JM, Gutierrez AJ, Rubio C, Hardisson A. Metals in wheat flour; comparative study and safety control. Nutrition Hospital Journal. 2013;28:506-513.
29. FAO. Vitamin and mineral requirements in human nutrition (second edition), Sun Fung, China; 2012.
30. Koziol M. Chemical composition and nutritional evaluation of quinoa (*Chenopodium quinoa* Willd.). Journal of Food Composition and Analysis. 1992;5: 35-68.
31. Bhargava A, Shukla S, Ohri D. *Chenopodium quinoa*- An Indian perspective. Indian Crops Production. 2006;23:73-87.
32. Schoenlechner RS, Seibenhand I, Berghofer E. Pseudocereals, Gluten-free cereal products and beverages. In Arendt, E.K. and Dal Bello, F. (Eds.), London: Academic Press. 2008;149-176.
33. Rules J, Nair BM. Effect of processing on *in vitro* digestibility of protein and starch in quinoa seeds. International Journal of Food Science and Technology. 1994;29: 449-456.
34. Scalbert A, Johnson IT, Saltmarsh M. Polyphenols: Antioxidants and beyond. Am J Clin Nutr. 2005;81(suppl):215S–217S.
35. Yao LH, Jiang YM, Shi J, Tomas-Barberan FA, Datta N, Singanusong R, Chen SS. Flavonoids in food and their health benefits. Plant Foods for Human Nutrition Journal. 2004;59:113-122.

36. Stevenson DE, Hurst RD. Polyphenolic phytochemicals – just antioxidants or much more? Cell Molecular Life Sciences CMLS Journal. 2007;64:2900-2916.
37. Brittany LG, Patricio R, Leonel ER, Jose D, Manuel EB, Ilya R. Innovations in health value and functional food development of Quinoa (*Chenopodium quinoa* Willd.). Comprehensive Reviews in Food Science and Food Safety. 2015;14:431– 445.
38. Gorinstein S, Lojek A, Ciz M, Pawelzik E, Delgado-Licon E, Medina OJ, Moreno M, Salas IA, Goshev I. Comparison of composition and antioxidant capacity of some cereals and pseudocereals. International Journal of Food Science and Technology. 2008;43:629–37.
39. Dini I, Tenore GC, Dini A. Phenolic constituents of Kancolla seeds. Food Chemistry. 2004;84:163–8.
40. Pasko P, Sajewicz M, Gorinstein S, Zachwieja Z. Analysis of selected phenolic acids and flavonoids in *Amaranthus cruentus* and *Chenopodium quinoa* seeds and sprouts by HPLC. Acta Chromatographica. 2008;20:661-672. DOI: 10.1556/AChrom.22008.4.11
41. Nsimba RY, Kikuzaki H, Konishi Y. Antioxidant activity of various extracts and fractions of *Chenopodium quinoa* and *Amaranthus* spp. seeds. Food Chemistry. 2008;06:760 -766.
42. Sudha ML, Vetrimani R, Leelavathi K. Influence of fiber from different cereals on the rheological characteristics of wheat flour dough and on biscuit quality. Food Chemistry. 2007;100:1365-1370.
43. Ogungbenle HN. Nutritional evaluation and functional properties of quinoa (*Chenopodium quinoa*) flour. Intentional Journal of Food Science and Nutrition. 2003;54:153-158.
44. Fagbemi TN, Oshodi AA. Chemical composition and functional properties of full fat fluted pumpkin seed flour. Nigerian Food Journal. 1991;9:26-32.
45. Linn MJY, Humbert ES, Susulski FW. Certain functional properties of sunflower meal products. Journal of Food Science. 1974;39:368-370.
46. Oshodi AA, Ekperigin MM. Functional properties of pigeon pea (*Cajanus cajan*) flour. Food Chemistry. 1989;34:187-191.
47. Oshodi AA, Ipinmoroti KO, Adeyeye EI. Functional properties of some varieties of African Yam bean (AYB) flour. International Journal of Food Science. 1997;48:243-250.
48. Kinsella JE. Functional properties of protein foods. Critical Reviews in Food Science and Nutrition. 1976;1:219-229.
49. Olaofe O, Arogundade LA, Adeyeye EI, Falusi OM. Composition and food properties of the variegated frasshopper (*Zonocerus variegatus*). Tropical Science. 1998;38:233-237.
50. Booth RG, Moran T. Digestibility of high extraction wheat in flours. Lancet. 1946;251:119.
51. Capritca R, Caprita A, Cretescu I, Nicu V. In vitro determination of wheat dry matter solubility and protein iuliana digestibility. Journal of Animal Science and Biotechnology. 2012;45:113–116.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/22648