Journal of King Saud University – Science 35 (2023) 102427

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Journal of King Saud University – Science

journal homepage: www.sciencedirect.com

Original article

Quinoa seeds (Chenopodium Quinoa): Nutritional value and potential biological effects on hyperglycemic rats

Eman Alamri [a,*], Basuny Amany [b], Hala Bayomy [a,c]

[a] Department of Nutrition and Food Science, University of Tabuk , Saudi Arabia
[b] Department of Biochemistry, Beni-Suef University, Egypt
[c] Department of Food Science and Technology, Damanhour University, Egypt

ARTICLE INFO

Article history:
Received 1 February 2022
Revised 30 October 2022
Accepted 31 October 2022
Available online 4 November 2022

Keywords:
Quinoa seeds
Active components
Hyperglycemia
Fat profile

ABSTRACT

Quinoa seeds have an excellent nutrient characterization and contains many phytochemicals which play an important health role. The current study pointed to the chemical composition, minerals content, active compounds (polyphenols, flavonoids and tocopherols), vitamins, amino acids, and fatty acids of quinoa seeds (*Chinopodium quinoa*). Also, evaluation of quinoa seeds on plasma glucose and lipid profiles in streptozotocin-induced diabetes in male rats. Rats were split into three groups, the first group was the normal control, the second group was the diabetic control, and the third group was diabetic rats treated with quinoa seeds. Chemical composition revealed that the percent of moisture, protein, fat, fiber, ash and calculated carbohydrates were 11.20 %, 13.64 %, 5.89 %, 6.7 %, 3.1 % and 70.67 % respectively. The total essential amino acid of quinoa seed was 4.88 g/100 g sample. The results indicate that serum alanine amino transferase (ALT), aspartate amino transferase (AST), alkaline phosphatase (ALP), creatinine and urea were significantly unchanged in diabetic rats whereas, statistically decreased in diabetic rats treated with quinoa seeds compared with control rats. Total serum lipids, total cholesterol, and low density lipoproteins (LDL) cholesterol levels were significantly increased in diabetic rats, while high density lipoproteins (HDL) cholesterol levels were decreased, compared to control rats. Otherwise, no significant effect was observed in these parameters between the rats in group 3 and the control group. Eating quinoa seeds among diabetic rats had a hypoglycemic effect and caused the best changes regarding cholesterol, HDL and LDL levels. The results obtained suggest that quinoa may become important as an inexpensive and unique natural source of anti-diabetes, and thus quinoa seed is a promising complementary therapeutic agent against diabetes.

1. Introduction

Diabetes is a chronic metabolic condition marked by elevated blood glucose levels, which leads to irreversible damage to the cardiovascular, kidneys, eyes, and nerves. According to the WHO, type 2 diabetes is the most prevalent, mainly affecting adults, and arises when the body develops insulin resistance or fails to produce enough insulin. The expansion of type 2 diabetes has grown rapidly in nations of all economic levels during the last three decades. High sugar blood can lead to serious health problems. Studies have confirmed the negative impact of diabetes on the liver, an organ that plays a key role in regulating metabolism and maintaining blood sugar levels. Metabolism is usually disturbed, and diabetes may affect the function of liver cells, such as the amino acid alanine transferase (ALT), alkaline phosphatase (ALP), preparing them for various liver disorders as well as causing disturbance in renal function such as urea and creatinine (Zhao et al. 2018; Abdel-Wahhab et al., 2021). Blood glucose can be controlled and regulated by diet specifically high fiber diet which can manage both types of diabetes. Quinoa seeds have recently become very popular as a result of their nutritional benefits. Quinoa seeds contain approximately 10–16 g of fiber, high concentration of bioactive compounds and contain all essential amino acids, high amounts of antioxidants as well as minerals and vitamins compared to other cereals (Okon, 2021**).** Quinoa is a complete protein with a high concentration of essential amino acids,essential fatty acids, and considered a

* Corresponding author.
E-mail address: ialamri@ut.edu.sa (E. Alamri).

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

https://doi.org/10.1016/j.jksus.2022.102427

great source of vitamin C, E, and B complex**, q**uinoa is a grain alternative in gluten-free diets, and the majority of people acquire the majority of their B vitamins from baked products. Like milk protein, quinoa protein content is ranged between 14 and 18 %. **(**Bastidas et al.,2016**).** Quinoa also contains calcium, magnesium, zinc, and iron as well as quinoa is the excellent nutrient characterization; furthermore, seeds are a good and main source of energy because the high contain of starch, lipids (unsaturated fats), dietary fiber and good-quality protein**.** Some studies mentioned that quinoa seeds contain high number of phytochemicals that play an important role as antioxidants i.e., phenolic acids, flavonoids, fat soluble vitamins, trace elements, and fatty acids (Kilinc et al., 2016**).** The literature showed that feeding diabetic rats with quinoa for 42 days showed a significant reduction in glucose level. (Graf et al., 2015**)** revealed that quinoa-fortified diet decreased blood sugar levels for hyperglycemic rats compared to those without quinoa supplementation. However, limited studies focused on this issue. Therefore, the current study aims to assess the chemical composition and biological effects of quinoa seeds on hyperglycemic rats.

2. Materials and methods

2.1. Source of quinoa seeds

Quinoa seeds were purchased from Desert Research Center, Cairo, Egypt.

2.2. Chemicals and kits

All chemicals utilized in the experiment were of analytical quality and had been purified prior to use. Folin-Ciocalteau reagent and caffeic acid were obtained from Gerbsaure Chemical Co. ltd., Germany and Sigma-Aldrich (St. Louis, MO, USA), respectively. Kits for aspartate aminotransferase (AST), alkaline phosphatase (ALP), alanine aminotransferase (ALT), creatinine, bilirubin, and uric acid were purchased from Borhringer Ingelheim GmbH, Ingelheim, Germany.

2.3. Experimental rats

Twenty-four (n = 24) healthy male rats weighing 100–150 g and aged 7–9 weeks were procured from Cairo university, Egypt. Every-four rats were kept in plastic cages at room temperature (25 ± 2 °C) with 12-hour light/dark cycles. Rats were isolated for a week to adapt to lab conditions before being fed a standard commercial pelleted meal (Lab Diet No. 500; PMI Feeds Inc, St. Louis, MO, USA) with a chemical composition of fat, 6.0 %,24 % protein, 5.7 %, 8.0 % ash fiber, and 58 % carbohydrate, as well as water was available.

2.4. Nutritional value

Moisture, protein, carbohydrates, lipids, fibers, and ash contents of quinoa seeds were estimated as a standard method AOAC (2016) **and** expressed as g/100 g on a dry basis. Carbohydrate was calculated by difference.

2.5. Fatty acids composition

The quantitative measurements of fatty acids in quinoa seed oil were performed from the lipid extraction of the section previous using a capillary gas chromatograph (HP 6890) and expressed in proportional area percent. Once the extraction was carried out, it was methylated following the method AOAC (2016). In a 100 ml flask, 0.1 g of the quinoa seed oil is dissolved in heptane (2 ml) with methanolic potash solution (0.2 ml, 2 N) to trans esterified into carboxylic acid methyl esters by shaking. A gas chromatograph with a DB-23 (5 % - cyanopropyl–methyl poly siloxane) capillary column (60mx 0.32 mm X0.25 m film thickness) and flame ionization detector used to identify the obtained methyl esters of fatty acids. The retention periods of carboxylic acid methyl esters were compared to a known carboxylic acid reference combination. An integrator calculated peak areas directly.

2.6. Determination of total polyphenolic and total flavonoids

The total polyphenol levels in quinoa seeds were evaluated according to Žilić et al., (2012) using caffeic acid as standard and presented results calculated as mg caffeic equivalent/kg of quinoa (mg CE/kg as ppm). Total flavonoids content was assessed by aluminum chloride test (Kim et al., 2006), results were calculated as mg quercetin equivalent/kg of quinoa (mg QE/kg as ppm).

2.7. Minerals content

The minerals content was estimated as a standard method **(**AOAC 2016**)** by using atomic absorption (NC.9423–400-30042 England).

2.8. Amino acid analysis

Acid hydrolysate of the quinoa seed by 6 N HCl used to determine amino acids as professional method AOAC (2016), by using an amino acid analyzer (LC 3000 amino acid analyzer, high-performance system, a product of LC biochrom Eppdrop, Germany).

2.9. Diabetes type 2 induction

Streptozotocin injections are used to induce overnight fasting lab rats with type 2 diabetes by intraperitoneal injection of a single dose (60 mg/kg) of streptozotocin (Sigma-Aldrich Crop, St, Louis, MO, USA). Food and water are freely available in injected rats. Within four days, diabetes mellitus developed and stabilized in streptozotocin-treated rats. Diabetic rats were defined as those rats with a fasting blood glucose level greater than 300 mg dL and considered as model rats with diabetes.

2.10. Experimental nutrition design

The rats were randomly spilt into 3 groups, eight rats per group. The control rats in group 1, diabetic rats in group 2, and diabetic quinoa seed treated at concentrations (25 %) in group 3.

2.11. Analysis of blood serum

After four weeks for rats, the water is anesthetized with diethyl ether and the rats are prevented from eating for 8 h. Blood samples are drawn from the orbital veins without the use of heparin. The level of glucose in the serum of rats measured by the method of Barham and Trinder (1972). The activities of Aspartate aminotransferase AST (E. C. 2. 6. 1. 1), Alanine aminotransferase ALT (E. C. 2. 6. 1. 2), and Alkaline phosphatase ALP (E. C. 3. 1. 3. 1) were determined using the procedures illustrated by Kachmar and Moss (1976), Bergmryer and Harder (1986), Varley et al. (1980) respectively. Bilirubin, creatinine, and uric acid were measured by the technique of Goryachkovskiy (1998). The cholesterol levels were measured using the procedures described by Assmann (1979).

2.12. Statistical analysis

The average ± SD of the triplicates was recorded for all analyses, with regard to the biological analyses that were estimated on the serum of rats, analyzed by Duncan's multiple range test at $p < 0.05$ by using SPSS Inc. program version15 (2006). Differences (one-way ANOVA) were considered significant at a p-value below 0.05.

3. Results and discussion

3.1. Chemical composition

Proximate chemical composition and minerals content of quinoa seeds are recorded in Table 1. Chemical composition revealed that the percent of moisture, protein, fat, fiber, ash and calculated carbohydrates were 11.20 %, 13.64 %, 5.89 %, 6.7 %, 3.1 % and 70.67 % respectively. Nascimento et al., (2014) found that the values of protein, fat, fiber and ash in quinoa seeds were 12.1, 6.3. 10.4 and 2.01 %, db, respectively. Bhargava, et al., (2006) reported that the fat level of quinoa was 6.31 %, db. Current results satisfied with Sciarini, et al., 2020 and Repo-Carrasco et al., 2010 about the protein content (11 to 22 %) in quinoa seeds. Quinoa is characterized by its high mineral content; calcium content was 650 mg/100 g seeds. Sodium content was 176 mg/100 g quinoa seeds. Potassium content was 830 mg/100 g whereas phosphorus content was 122 mg/100 g quinoa seeds. Iron content was 14.50 mg/100 g. Zinc found in quinoa seeds at level of 45 mg/100 g. Magnesium and manganese are found in sufficient amounts at 326 and 194 mg/100 g respectively, and in bioavailable forms to maintain a balanced human diet.

Our statistics result is consistent with that disclosed by Gordillo-Bastidas, et al., (2016) especially for iron (9.47 mg/100 g db), calcium (87 mg/100 g dm), magnesium (362 mg/100 g db), and potassium (907 mg/100 g db). Thus, we have confirmed what El Sohaimy et al., (2018) concluded, which is quinoa was perfectly equilibrated minerals specially (K, Na, Mg, Ca and Fe). A slight difference between the quinoa content of (K) and obvious difference of (Ca, P, Fe, Zn, and Mg) in the current study and that recorded by Stikic et al., (2012) for quinoa grower in north-west of Serbian may be due to the difference in the variety and cultivation conditions.

Quinoa (Chenopodium quinoa) are pseudo cereal grains rich in micronutrients including phytochemicals. The data in Table 2 shows the most essential phytochemicals in quinoa seeds (ppm), and the total polyphenols present in quinoa seeds were 435.0 ppm. According to (liu, et al., 2021), phenolic compounds are largely found in the seed coat of quinoa seeds and make up most of the secondary plant metabolites that lead to several functional properties. Quinoa contains more phenols than whole cereals and considered the highest phenols concentration of ferulic acid and quercetin in quinoa seeds (Gordillo-Bastidas et al, 2016). Recently, researchers are interested in studying the biological effects of phenolic materials because of their association with fibers, Suriano et al., 2018 and liu et al., 2021 found that the highest rates of α-glucosidase and α-amylase inhibition of bound phenols after digestion, which contributes to lowering blood sugar. Repo-Carrasco-Valencia et al., (2010) determined total polyphenols and total flavonoids in quinoa and found that the polyphenols were 131.8 ± 10.3 mg 100 g^{-1} and flavonoids were 62.07 ± 5.1 mg 100 g^{-1}. Quinoa is characterized by its high content of total tocopherol (vitamin E), as its concentration reached 520 ppm, the most common tocopherol in quinoa seeds were γ -tocopherol 350 ppm followed by α-tocopherol 55 ppm then β-tocopherol at the concentration of 18.9 ppm. The tocopherols content of quinoa is essential and acts as an antioxidant at the level of the cell membrane, defending the membranes' fatty acids against oxidative stress. Values of phytochemical content in quinoa seeds indicate that quinoa can serve as a natural antioxidant and necessary to avoid the chronic and degenerative diseases (liu et al., 2021**).**

Table 1
Proximate chemical composition and minerals content of quinoa seeds.

Ingredients	quinoa seeds
Proximate chemical composition (%)	
Moisture	11.20 ± 0.33
Protein	13.64 ± 0.36
Fat	5.89 ± 0.21
Fiber	6.70 ± 0.25
Ash	3.10 ± 0.01
Carbohydrates	70.67 ± 4.13
Minerals (mg/100 g):	
Ca	650 ± 6.73
Na	176 ± 4.11
K	830 ± 0.71
P	122 ± 0.10
Fe	14.50 ± 1.43
Zn	45.0 ± 0.70
Mg	326 ± 5.62
Mn	194 ± 4.31

Table 2
Essential phytochemicals in quinoa seeds.

Phytochemicals	Quinoa seeds
Total polyphenols (ppm)	435.00 ± 11.98
Total flavonoid (ppm)	259.00 ± 8.45
Total tocopherols (ppm)	520.00 ± 12.50
α-tocopherol (ppm)	55.00 ± 2.02
β-tocopherol (ppm)	18.90 ± 0.97
γ -tocopherol(ppm)	350.00 ± 9.35

3.2. The amino acid compositions of quinoa seeds

Data in Table 3 carried out the amino acid composition of quinoa seeds. Obtained data illustrated that the total essential amino acid of quinoa seed was 4.88 g/100 g sample, and the total non-

Table 3
Amino acid composition of quinoa seeds.

Amino acids		Quinoa seeds (mg/100 g quinoa)
Essential amino acids	Isoleucine	0.64 ± 0,10
	Leucine	1.16 ± 0.12
	Lysine	0.43 ± 0.10
	Methionine	0.25 ± 0.10
	Phenyl alanine	0.69 ± 0.11
	Tryptophan	0.35 ± 0.01
	Threonine	0.40 ± 0.15
	Valine	0.78 ± 0.06
	Cystine	0.18 ± 0.03
Total Essential Amino Acids		**4.88**
Non-essential amino acids	Glutamic	1.69 ± 0.37
	Arginine	1.76 ± 0.11
	Aspartic	1.45 ± 0.19
	Alanine	0.64 ± 0.08
	Cysteine	0.19 ± 0.05
	Tyrosine	0.52 ± 0.21
	Serine	0.47 ± 0.01
	Glycine	0.30 ± 0.05
	Proline	0.86 ± 0.01
	Histidine	0.36 ± 0.01
Total Non-Essential Amino Acids		**8.24**

essential amino acids was 8.24 g/100 g. Quinoa is rich in lysine (0.43 mg/100 g quinoa) and threonine (0.40 mg/100 g quinoa), which are the most often deficient amino acids in cereal. The present results are comparable to described by Starzyńska-Janiszewska et al., (2016), regarding the lysine content of quinoa. Therefore, quinoa has a high nutritional value and belongs to the category of complete proteins (Okon, 2021). Plus, it contains a relatively complete and balanced formula of essential amino acids, which makes it complementary to most cereals, even some legumes (Okon, 2021).

Table 4 illustrates the results acquired from the present study regarding fatty acids. The fat contents showed a varied composition of fatty acids, most of them linoleic acid (omega-6 polyunsaturated fatty acids) as the highest fatty acid (56.31 %) found in quinoa seeds, followed by oleic acid (22.00 %) then α-linolenic acid (9.20 %). In general, total saturated fatty acids is low in quinoa seeds (9.60 %), whereas monounsaturated fatty acids are found in 24.54 %, but the highest fatty acid content was for polyunsaturated fatty acids (65.61 %). The results of linolenic acid in quinoa are close to those obtained by Rosero et al. (2013) 44.5–56.4 %, confirmed that linoleic acid was present in abundance in the polyunsaturated fatty acids found in different types of quinoas. Regarding to α-linolenic acids, Rosero et al., (2013) and Nasir et al., (2015) found that quinoa contained between 3.8 and 8.8 % confirming the results of current study. On the other hand, Gordillo-Bastidas et al., (2016) scored different value with the current results for unsaturated fatty acids (24.0–27.7 % oleic acid, 38.9–57 % linoleic acid and 4 % α-linolenic acid).

With regard to the vitamins content in quinoa seeds which are essential compounds for human health, quinoa seeds have significantly higher content of numerous vitamins compared to the most common cereals such as wheat, barley and rice. The results of Table 5 showed that every 100 g of quinoa seeds contains: 55.04 mg of vitamin A in the form of carotenoids, 15.06 mg of ergocalciferol, 10.2 mg of vitamin C. The concentration of vitamin B1 was 1.5 mg/100 g, vitamin B2 was 2.17 mg/100 g and the niacin reached to 1.1 mg/100 g which is vital for body health. Also, every 100 g of quinoa seeds contains 5.6 mg of vitamin B5, 0.32 mg of pyridoxine, 6.5 mg of folic acid and 0.23 mg of vitamin B12, which is not found in cereals. Bhargava et al. (2006), reported that the quinoa flour has 23.5 g folic acid (B9), 0.61 mg pantothenate (B5), and 0.2 mg pyridoxine (B6) in terms of a 100 g flour. El Sohaimy et al. (2018) confirmed that quinoa flour is high in vitamin C (1.93 mg/ Kg), B3 (0.15 mg/ Kg), B6 (11.22 mg/ Kg), and B12 (0.09 mg/ Kg), which are the essential nutrients required for the metabolism of practically all known living organisms. Thus, eating quinoa prevents scurvy and cold infection.

Table 4
Fatty acids composition of quinoa seeds.

Name of fatty acids	Quinoa seeds (%)
C14:0	0.31 ± 0.01
C16:0	8.10 ± 0.98
C16:1	0.17 ± 0.02
C18:0	0.80 ± 0.05
C18:1	22.00 ± 1.23
C18:2	56.31 ± 2.14
γ-C18:3n6	0.10 ± 0.01
α-C18:3n3	9.20 ± 0.90
C20:0	0.22 ± 0.01
C20:1	0.87 ± 0.11
C22:1	1.50 ± 0.40
Σ Saturated Fatty acids	9.43 ± 1.90
Σ Monounsaturated fatty acids	24.54 ± 0.99
Σ Polyunsaturated fatty acids	65.61 ± 6.15

Table 5
Vitamins content in quinoa seeds.

Vitamins	Quinoa seeds (mg/100 g)
Vitamin A (Carotenoids)	55.40 ± 2.71
Vitamin D2 (Ergocalciferol)	15.06 ± 0.58
Vitamin C (Ascorbic acid)	10.20 ± 0.53
Vitamin B1 (Thiamine)	1.50 ± 0.11
Vitamin B2 (Riboflavin)	2.17 ± 0.25
Vitamin B3 (Niacin)	1.10 ± 0.13
Vitamin B5 (Pantothenic acid)	5.60 ± 0.13
Vitamin B6 (pyridoxine)	0.32 ± 0.00
Vitamin B9 (Folate)	6.50 ± 0.32
Vitamin B12 (Cobalamin)	0.23 ± 0.04

3.2.1. Serum glucose level

Diabetes mellitus, regularly recognized so diabetes, is a metabolic disease up to expectation motives high gore sugar. The hormone insulin moves grit beside the blood within cells in accordance with lie saved and ancient for energy (Guo and Guo 2017). With diabetes, physique both would not edit adequate insulin and cannot correctly usage of the insulin that does make. Untreated excessive blood grit beside diabetes execute harm thy nerves, eyes, kidneys, yet ignoble organs (Neuman et al., 2017).

In this study, quinoa seeds at a concentration of 2 % was used as a blood sugar reducer in rats with hyperglycemia. A significant elevate in glucose level in the blood was detected in diabetic rats of group 2 (310.09 ± 10.13 mg/dL) compared to the control rats of group 1. It was interesting to note that the low level of glucose in the serum of hyperglycemic rats fed quinoa seeds. Two weeks of feeding the rats with hyperglycemia on quinoa seeds, the blood sugar decreased to (90.13 ± 4.19 mg/dL) compared to the level of sugar (310.09 ± 10.13 mg/dL) that was recorded for the rats with high blood sugar, and this decrease continued throughout the duration of the experiment. (Table 6). Quinoa possesses many chemicals which might be linked to its hypoglycemic impact. Firstly, fiber might alter the postprandial insulin response as it causes satiety and certain epidemiological research has shown an inverse connection between dietary fiber consumption and type II diabetes increase (Graf et al., 2015). Moreover, this bioactivity is attributable to specific polyhydroxylated steroids. The primary cause of the blood glucose decrease was the quantity of TPCs and tocopherols in daily ingestion of the cereal bar (Paśko et al., 2010). The concentration of quinoa protein was also associated with the low glycemic index, because this macronutrient slows digestion (Shin et al., 2013). Khan et al., (2016) previously discovered that the digestive enzymes (α-glucosidase and α-amylase) were responsible for the hydrolysis of polysaccharides into glucose. The association of phenolic substances with the digestive enzymes of polysaccharides reduces and delays their breakdown into glucose thus reduces the level of glucose in the blood (Etxeberria et al., 2012).

3.3. Serum ALT, AST and ALP level

The level of AST, ALT and ALP enzymes are essential liver function assessment indications. Statistically increases were reported

Table 6
Effect of quinoa seeds on glucose level of diabetic rats.

Experimental period	Control	Diabetes	Quinoa seeds
Glucose ($mgdL^{-1}$)			
0	90.00 ± 4.50a	90.00 ± 4.50a	90.00 ± 4.50a
2	91.00 ± 4.11b	310.09 ± 10.13a	90.13 ± 4.19b
4	98.90 ± 4.09b	310.33 ± 10.71a	89.70 ± 4.19c
6	98.99 ± 4.20b	310.50 ± 10.81a	89.66 ± 4.20c
8	90.00 ± 4.13b	310.21 ± 10.00a	90.11 ± 4.00b

in the level of serum AST, ALT and ALP in diabetic rats of group 2 (14.85 ± 0.71, 15.00 ± 0.63and 75.12 ± 4.65 (IUL^{-1})) respectively, compared with normal rats of group1. On the other hand, the levels of ALT, AST, ALP was statistically unchanged in diabetic rats treated with quinoa seeds compared with control rats (Table 7**).** The elevated serum transaminases might be attributed to cell damage caused by high level of glucose blood (group 2) induced oxidative stress and inflammation. In the present study, high level of glucose blood (group 2) induced increases in AST, ALT, and ALP activities were reduced by Chenopodium quinoa seeds (group 3) without significant differences compared with the control (group 1). These results are in the line with others found by Cao et al., (2020), who shown that feeding quinoa for 8 weeks improved liver tissue and the level of transaminases such as ALT and AST in rats fed a high-fat diet. Perhaps due to the abundance of proteins, minerals, dietary fibers, essential amino acids, and bioactive compounds in quinoa seeds, which protect the liver from oxidative stress caused by high blood glucose levels. Betacyanins, rutin,quercetin, and other flavonoids also present in quinoa, according to earlier studies. These compounds were proven to have an antiinflammatory effects, perform as an antioxidative and established to decrease lipid peroxidation, hepatic lipid accumulation, inflammation and oxidative stress, (Zhao et al. 2018; Abdel-Wahhab et al., 2021).

3.4. Serum total lipids, total cholesterol, LDL-Cholesterol and HDL-Cholesterol

In all experimental groups, blood total lipids, total cholesterol, LDL-cholesterol and HDL-cholesterol were measured (Table 8). In diabetic rats of group 2, blood total lipids, LDL-Cholesterol and total cholesterol, levels were significantly elevated, whereas HDL-Cholesterol levels were reduced, compared to control rats of group 1. Otherwise, no significant effect was observed in these parameters between the rats in group 3 and the control group. The Quinoa seeds (Chenopodium quinoa) showed hepato protective effects induced damage lab rats.

The present results indicated that most of the fourth week of quinoa seed intake among diabetic rats had a hypoglycemic effect but caused the best changes with respect to cholesterol, LDL and HDL levels. Streptozocin-induced diabetes leads to some alterations in the level of metabolic enzymes in relation to insulin, and consequently leads to hyperglycemia. Diabetes induces half of the irrational modifications in plasma lipids. However, lipoproteins, such as partial body tissues especially the lungs, play a huge role in the intentional fair fatty acids in the blood, and subsequently the oxidation and metabolic modifications of these fatty acids in combination with unwanted cholesterol,molecules, and phospholipid synthesis, yet the secretion of some proteins in plasma. HDL is a particular transport system of lipids that reverses the transportation of cholesterol by eliminating it from tissues (Maranhão et al., 2018). In addition, an increase in the levels of LDL cholesterol and triglycerides. Yanardag et al., (2002) illustrated that the high levels of glucose in diabetic rats may increase triglycerides, VLDL and LDL, do not directly reduce HDL. Furthermore, quinoa has a high fiber content, which binds to bile acid and increases cholesterol degradation (Escudero, et al., 2006) as well as the fermentation of fiber in the colon produces short chain fatty acids and reduces cholesterol synthesis in the liver (Graf et al., 2015; Aniess et al., 2020). Cao et al., (2020) showed anti-hyperlipidemia benefits in rats treated with a high-fat diet after eating quinoa for 8 weeks.

Table 7
Effect of quinoa seeds on AST, ALT, and ALP activities in diabetic rats.

Experimental period	Control	Diabetes	Quinoa seeds
Alanine aminotransferase **ALT** (IUL^{-1})			
0	13.10 ± 0.60a	13.10 ± 0.60a	13.10 ± 0.60a
2	13.02 ± 0.58b	14.85 ± 0.71a	13.10 ± 0.60b
4	13.13 ± 0.61b	14.90 ± 0.74a	12.93 ± 0.59b
6	12.99 ± 0.59b	14.90 ± 0.74a	13.09 ± 0.61b
8	13.10 ± 0.60b	15.05 ± 0.80a	13.00 ± 0.59b
Aspartate aminotransferase **AST** (IUL^{-1})			
0	12.90 ± 0.45a	12.90 ± 0.45a	12.90 ± 0.45a
2	12.95 ± 0.46b	15.00 ± 0.63a	12.88 ± 0.43b
4	12.93 ± 0.50b	15.03 ± 0.66a	13.01 ± 0.45b
6	13.00 ± 0.55b	15.00 ± 0.65a	12.98 ± 0.47b
8	12.87 ± 0.54b	15.90 ± 0.70a	12. 90 ± 0.47b
Alkaline phosphatase **ALP** (IUL^{-1})			
0	65.01 ± 3.50b	65.01 ± 3.50a	65.01 ± 3.50b
2	65.09 ± 3.46b	75.12 ± 4.65a	65.19 ± 3.62b
4	65.81 ± 3.64b	76.00 ± 4.14a	65.13 ± 3.00b
6	65.28 ± 3.41b	76.85 ± 4.59a	65.00 ± 3.41b
8	65.11 ± 3.32b	77.32 ± 4.91a	65.30 ± 3.23b

Table 8
Effect of quinoa seeds consumption on **total lipids, total cholesterol, LDL-Cholesterol and HDL- Cholesterol** in diabetic rats.

Experimental period	Control	Diabetes	Quinoa seeds
Total lipids ($mgdL^{-1}$)			
0	288.00 ± 9.50a	288.00 ± 9.50a	288.00 ± 9.50a
2	289.00 ± 9.11b	320.09 ± 10.13a	289.13 ± 9.19b
4	289.90 ± 9.09b	320.33 ± 10.71a	289.70 ± 9.19b
6	289.95 ± 9.20b	320.50 ± 10.81a	289.66 ± 9.20b
8	289.99 ± 9.13b	320.21 ± 10.00a	290.11 ± 9.00b
Total cholesterol ($mgdL^{-1}$)			
0	163.00 ± 3.13b	163.00 ± 3.13a	163.00 ± 3.13b
2	163.19 ± 3.11b	174.55 ± 4.50a	163.81 ± 3.33b
4	163.20 ± 3.32b	174.14 ± 4.56a	163.01 ± 3.72b
6	163.50 ± 3.35b	174.00 ± 4.71a	163.85 ± 3.90b
8	163.95 ± 3.45b	174.87 ± 4.53a	163.05 ± 3.83b
High density lipoprotein cholesterol ($mgdL^{-1}$)			
0	100.01 ± 2.95a	100.01 ± 2.95a	100.01 ± 2.95a
2	100.53 ± 2.87a	100.00 ± 2.80a	100.90 ± 2.93a
4	100.67 ± 2.98a	100.19 ± 2.85a	100.97 ± 2.94a
6	100.00 ± 2.00a	100.03 ± 2.10a	100.00 ± 2.09a
8	100.90 ± 2.90a	100.81 ± 2.01a	100.80 ± 2.13a
Low density lipoprotein cholesterol ($mgdL^{-1}$)			
0	47.00 ± 1.33a	47.00 ± 1.33a	47.00 ± 1.33b
2	47.09 ± 1.39b	55.19 ± 1.81a	47.50 ± 1.40b
4	47.90 ± 1.51b	56.11 ± 1.91a	47.90 ± 1.55b
6	47.30 ± 1.42b	55.90 ± 1.83a	47.31 ± 1.62b
8	47.00 ± 1.63b	56.13 ± 1.91a	47.81 ± 1.65b

3.5. Serum total bilirubin, uric acid and creatinine

Table 9 shows the blood total bilirubin, uric acid and creatinine levels in all experimental groups.

Table 9
Effect of quinoa seeds on Total Bilirubin, Creatinine, and uric acid levels of rat serum.

Experimental period	Control	Diabetes	Quinoa seeds
Total Bilirubin ($mgdL^{-1}$)			
0	0.09 ± 0.03a	0.09 ± 0.03a	0.09 ± 0.03a
2	0.10 ± 0.01b	0.15 ± 0.10a	0.10 ± 0.01b
4	0.11 ± 0.02b	0.15 ± 0.10a	0.10 ± 0.02b
6	0.11 ± 0.05b	0.16 ± 0.10a	0.11 ± 0.02b
8	0.11 ± 0.05b	0.17 ± 0.10a	0.11 ± 0.01b
Creatinine ($mgdL^{-1}$)			
0	0.50 ± 0.01b	0.50 ± 0.01a	0.50 ± 0.01b
2	0.50 ± 0.01b	0.70 ± 0.05a	0.50 ± 0.01b
4	0.50 ± 0.01b	0.71 ± 0.05a	0.51 ± 0.01b
6	0.51 ± 0.01b	0.71 ± 0.05a	0.51 ± 0.01b
8	0.51 ± 0.01b	0.72 ± 0.05a	0.51 ± 0.01b
Uric acid ($mgdL^{-1}$)			
0	1.70 ± 0.33b	1.70 ± 0.33a	1.70 ± 0.33b
2	1.71 ± 0.39b	2.40 ± 0.51a	1.70 ± 0.40b
4	1.71 ± 0.41b	2.42 ± 0.61a	1.71 ± 0.45b
6	1.72 ± 0.42b	2.42 ± 0.63a	1.72 ± 0.42b
8	1.72 ± 0.43b	2.43 ± 0.61a	1.72 ± 0.45b

High creatinine levels show a person with kidney failure, as Barakat and Mahmoud (2011) have documented, due to higher cholesterol. When compared to normal group 1 diabetic rats, serum total bilirubin, uric acid,creatinine and levels were statistically improved in group 2 diabetic rats. In the serum of group 3 diabetic rats, minor differences in total bilirubin, creatinine, and uric acid levels were detected. Certain quinoa vitamins, minerals and fiber are necessary because of their function as antioxidant substances in the membranes of renal cells, such as selenium, magnesium, folic acid and tocopherols (Altunkaynak et al., 2008). The most obvious limitation of the present study is that,some procedures were not available in the laboratory, thus we transfer some samples to other laboratory to complete the analysis.

4. Conclusion

Quinoa is perfectly balanced in its content of proteins, fats, fibres, minerals and vitamins. Feeding hyperglycemic rats lowered blood sugar levels. The levels of ALT, ALP and AST, were statistically unchanged in diabetic rats treated with quinoa seeds compared with control rats. Further studies are required to investigate the impact of quinoa on patients with hyperglycemia and its applications.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abdel-Wahhab, K.G., Mannaa, F.A., Ashry, M., Khaled, D.M., Hassan, L.K., Gomaa, H. F., 2021. Chenopodium quinoa ethanolic extract ameliorates cyclophosphamide®-induced hepatotoxicity in male rats. Comp. Clin. Pathol. 30 (2), 267–276.

Altunkaynak, M.E., Özbek, E., Altunkaynak, B.Z., Can, İ., Unal, D., Unal, B., 2008. The effects of high-fat diet on the renal structure and morphometric parametric of kidneys in rats. J. Anat. 212 (6), 845–852.

Aniess, W.I., Gohari, S.T., Goma, A.A., Ahmad, W.A., 2020. Protective effect of the red quinoa seeds versus oxidative stress induced by alloxan and carbon tetrachloride in experimental rats. Bull. Natl. Nutr. Institute Arab Republic of Egypt 55 (1), 1–38.

Aoac, 2016. Association of Official Analytical Chemist. Official Methods of Analysis. Washington D.C, USA.

Assmann, G., 1979. Cholesterol determination in high density lipoproteins separated by three different methods. Internist 20, 559–604.

Barakat, L., Mahmoud, R., 2011. The antiatherogenic, renal protective and immunemodulatory effects of purslane, pumpkin and flax seeds on hypercholesterolemic rats. North American J. Medical Sci. 3 (9), 351–357.

Barham, D., Trinder, P., 1972. Enzymatic colorimetric method for determination uric acid in serum plasma and urine. Analyst 97, 142–146.

Bastidas, E.G., Roura, R., Rizzolo, D.A., Massanés, T., Gomis, R., 2016. Quinoa (Chenopodium quinoa Willd), from nutritional value to potential health benefits: an integrative review. J. Nutr. Food Sci. 6 (3).

Bergmryer, H.U., Harder, M., 1986. A colorimetric method for determination of serum glutamic oxaloacetic and glutamic pyruvic transaminase. Clin. Biochem. 24, 28–34.

Bhargava, A., Shukla, S., Ohri, D., 2006. Chenopodium quinoa- An Indian perspective. Indian Crops Production 23 (1), 73–87.

Cao, Y., Zou, L., Li, W., Song, Y., Zhao, G., Hu, Y., 2020. Dietary quinoa (Chenopodium quinoa Willd.) polysaccharides ameliorate high-fat diet-induced hyperlipidemia and modulate gut microbiota. Int. J. Biol. Macromol. 163, 55–65.

Escudero, N.L., Zirulnik, F., Gomez, N.N., Mucciarelli, S.I., Mucciarelli, S.I., Giménez, M.S., 2006. Influence of a protein concentrate from Amaranthus cruentus seeds on lipid metabolism. Exp. Biol. Med. 231 (1), 50–59.

Etxeberria, U., Laura, D.L.G.A., Campión, J., Alfredo, M., Milagro, F., 2012. Antidiabetic effects of natural plant extracts via inhibition of carbohydrate hydrolysis enzymes with emphasis on pancreatic alpha amylase. Expert Opin. Therapeutic Targets 16 (3), 269–297. https://doi.org/10.1517/14728222.2012.664134.

Gordillo-Bastidas, E., Díaz-Rizzolo, D.A., Roura, E., Massanés, T., Gomis, R., 2016. Quinoa (Chenopodium quinoa Willd), from nutritional value to potential health benefits: an integrative review. J. Nutr. Food Sci 6 (497), 10–4172.

Goryachkovskiy, A.M., 1998. Clinical Biochemistry. Astroprint, Odesa, p. 608. in Russian.

Graf, B.L., Rojas-Silva, P., Rojo, L.E., Delatorre-Herrera, J., Baldeón, M.E., Raskin, I., 2015. Innovations in Health Value and Functional Food Development of Quinoa (Chenopodium quinoa Willd.). Comprehensive Rev. Food Sci. Food Saf. 14 (4), 431–445.

Guo, C.A., Guo, S., 2017. Insulin receptor substrate signaling controls cardiac energy metabolism and heart failure. J. Endocrinol. 233 (3), R131–R143.

Kachmar, J.F., Moss, D.W., 1976. Enzymes. In: Tiez, N. (Ed.), Fundamentals of Clinical Chemistry. W. B. Saunders Co., Philadelphia, PA, pp. 666–672.

Khan, S.A., Al Kiyumi, A.R., Al Sheidi, M.S., Al Khusaibi, T.S., Al Shehhi, N.M., Alam, T., 2016. In vitro inhibitory effects on α-glucosidase and α-amylase level and antioxidant potential of seeds of Phoenix dactylifera L. Asian Pacific J. Tropical Biomed. 6 (4), 322–329. https://doi.org/10.1016/j.apjtb.2015.11.008.

Kilinc, O.K., Ozgen, S., Selamoglu, Z., 2016. Bioactivity of triterpene saponins from quinoa (Chenopodium quinoa willd). Res. Rev.: Res. J. Biol. 4 (4), 25–28.

Kim, K.H., Tsao, R., Yang, R., Cui, S.W., 2006. Phenolic acid profiles and antioxidant activities of wheat bran extracts and the effect of hydrolysis conditions. Food Chem. 95 (3), 466–473.

Liu, M., Liu, X., Luo, J., Bai, T., Chen, H., 2021. Effect of digestion on bound phenolic content, antioxidant activity and hypoglycemic ability of insoluble dietary fibre from four Triticeae crops. J. Food Biochem., e13746

Maranhão, R.C., Casela Filho, A., Sigal, G.A., Chagas, A.C.P., da Luz, P.L., 2018. HDL and endothelium. Endothelium Cardiovasc. Dis.: Vascular Biol. Clin. Syndromes 297–317. https://doi.org/10.1016/B978-0-12-812348-5.00022-2.

Nascimento, A.C., Mota, C., Coelho, I., Gueifão, S., Santos, M., Matos, A.S., Castanheira, I., 2014. Characterization of nutrient profile of quinoa (Chenopodium quinoa), amaranth (Amaranthus caudatus), and purple corn (Zea mays L.) consumed in the North of Argentina: Proximate, minerals and trace elements. Food Chem. 148, 420–426.

Nasir, M.A., Pasha, I., Butt, M.S., Nawaz, H., 2015. Biochemical characterization of quinoa with special reference to its protein quality. Pak. J. Agric. Sci 52 (3), 731–737.

Neuman, J.C., Fenske, R.J., Kimple, M.E., 2017. Dietary polyunsaturated fatty acids and their metabolites: implications for diabetes pathophysiology, prevention, and treatment. Nutr. Healthy Aging 4 (2), 127–140.

Okon, O.G., 2021. The Nutritional Applications of Quinoa Seeds. In: Biology and Biotechnology of Quinoa. Springer, Singapore, pp. 35–49.

Paśko, P., Zagrodzki, P., Bartoń, H., Chłopicka, J., Gorinstein, S., 2010. Effect of quinoa seeds (Chenopodium quinoa) in diet on some biochemical parameters and essential elements in blood of high fructose-fed rats. Plant Foods Hum. Nutr. 65 (4), 333–338. https://doi.org/10.1007/s11130-010-0197-x.

Repo-Carrasco-Valencia, R., Hellström, J.K., Pihlava, J.-M., Mattila, P.H., 2010. Flavonoids and other phenolic compounds in Andean indigenous grains: Quinoa (Chenopodium quinoa), kañiwa (Chenopodium pallidicaule) and kiwicha (Amaranthus caudatus). Food Chem. 120 (1), 128–133.

Rosero, O., Marounek, M., Břeňová, N., 2013. Phytase activity and comparison of chemical composition, phytic acid P content of four varieties of quinoa grain (Chenopodium quinoa Willd.). Acta Agronómica 62 (1), 13–20.

Sciarini, L.S., Steffolani, M.E., Fernández, A., Paesani, C., Pérez, G.T., 2020. Gluten-free breadmaking affected by the particle size and chemical composition of quinoa and buckwheat flour fractions. Food Sci. Technol. Int. 26 (4), 321–332.

Shin, H.S., Ingram, J.R., McGill, A.T., Poppitt, S.D., 2013. Lipids, CHOs, proteins: can all macronutrients put a "brake" on eating? Physiol. Behav. 120, 114–123. https://doi.org/10.1016/j. physbeh.2013.07.008.

Sohaimy, S., Mohamed, S., Shehata, M., Mehany, T., Zaitoun, M., 2018. Compositional analysis and functional characteristics of quinoa flour. Annu. Res. Rev. Biol. 22 (1), 1–11.

Starzyńska-Janiszewska, A., Duliński, R., Stodolak, B., Mickowska, B., Wikiera, A., 2016. Prolonged tempe-type fermentation in order to improve bioactive potential and nutritional parameters of quinoa seeds. J. Cereal Sci. 71, 116–121.

Stikic, R., Glamoclija, D., Demin, M., Vucelic-Radovic, B., Jovanovic, Z., Milojkovic-Opsenica, D., Milovanovic, M., 2012. Agronomical and nutritional evaluation of quinoa seeds (Chenopodium quinoa Willd.) as an ingredient in bread formulations. J. Cereal Sci. 55 (2), 132–138.

Suriano, S., Iannucci, A., Codianni, P., Fares, C., Russo, M., Pecchioni, N., Marciello, U., Savino, M., 2018. Phenolic acids profile, nutritional and phytochemical compounds, antioxidant properties in colored barley grown in southern Italy. Food Res. Int. 113, 221–233. https://doi.org/10.1016/j.foodres.2018.06.072.

Varley, H., Gewnlock, A., Bell, M., 1980, Practical clinical biochemistry, fifth ed., Vol. 1, pp. 741, 897. London: Williams Heinemen Medical Books, Ltd.

Yanardag, R., Bolkent, S., Ozsoy-sacan, O., Karabulut-Bulan, O., 2002. The effect of chard (beta vulgaris L. var. cicla) extract of the kidney tissue, serum urea, and creatinine level of diabetic rats. Phytother. Res. 16, 758–761.

Zhao, L., Zhang, N., Yang, D., Yang, M., Guo, X., He, J., Wu, W., Ji, B., Cheng, Q., Zhou, F., 2018. Protective effects of five structurally diverse flavonoid subgroups against chronic alcohol-induced hepatic damage in a mouse model. Nutrients 10, 11.

Žilić, S., Serpen, A., Akıllıoğlu, G., Janković, M., Gökmen, V., 2012. Distributions of phenolic compounds, yellow pigments and oxidative enzymes in wheat grains and their relation to antioxidant capacity of bran and debranned flour. J. Cereal Sci. 56 (3), 652–658.