Nutritional Composition of the Green Leaves of Quinoa (*Chenopodium quinoa* Willd.)

Safiullah Pathan[1], Frieda Eivazi[1], Babu Valliyodan[1], Kamalendu Paul[2], Grato Ndunguru[1] & Kerry Clark[3]

[1]Department of Agriculture and Environmental Sciences, Lincoln University of Missouri, Jefferson City, MO 65101, USA

[2]Cooperative Extension, Lincoln University of Missouri, Jefferson City, MO 65101, USA

[3]Division of Applied Social Sciences, University of Missouri, Columbia, MO 65211, USA

Correspondence: Safiullah Pathan, Department of Agriculture and Environmental Sciences, Lincoln University of Missouri, Jefferson City, MO 65101, USA. Tel: 1-573-681-5963. E-mail: PathanS@LincolnU.edu

Received: August 31, 2019 Accepted: September 20, 2019 Online Published: October 16, 2019

doi:10.5539/jfr.v8n6p55 URL: https://doi.org/10.5539/jfr.v8n6p55

Abstract

Quinoa (*Chenopodium quinoa* Willd.) grain is often eaten worldwide as a healthy food, but consuming nutrient-rich quinoa leaves as a leafy green vegetable is uncommon. This study evaluated the potentiality of leafy green quinoa as a major source of protein, amino acids, and minerals in the human diet. Also, the study compared the nutrient content of quinoa leaves with those of amaranth and spinach leaves. The proximate analysis of quinoa dry leaves showed a higher amount (g/100 g dry weight) of protein (37.05) than amaranth (27.45) and spinach (30.00 g). Furthermore, a lower amount of carbohydrate (34.03) was found in quinoa leaves compared to amaranth (47.90) and spinach (43.78 g). A higher amount of essential amino acids was found in quinoa leaves relative to those of amaranth and spinach. The highest amounts (mg/100 g dry weight) of minerals in quinoa dry leaves were copper (1.12), manganese (26.49), and potassium (8769.00 mg), followed by moderate amounts of calcium (1535.00), phosphorus (405.62), sodium (15.12), and zinc (6.79 mg). Our findings suggest that quinoa leaves can be consumed as a green vegetable with an excellent source of nutrients. Therefore, we endorse the inclusion of quinoa in the leafy green vegetable group.

Keywords: amino acid, food nutrition, leafy green vegetable, mineral, protein, quinoa (*Chenopodium quinoa* Willd.)

1. Introduction

Green leafy vegetables (GLVs) or leafy greens are plants' young leaves, with or without petioles or shoots, which may be consumed raw (in a salad), stir-fried, stewed, or steamed. Leafy vegetables often contain high amounts of iron, magnesium, potassium, and calcium, and low amounts of sodium, carbohydrate, and fat and are lower in the glycemic index. Also, they contain a higher amount of folate, a B vitamin and antioxidants. The dietary guidelines for Americans recommend five servings of vegetables per day (based on an intake of 2,000 calories), with green leafy vegetables as one of the five recommended servings (HHS & USDA, 2015). Research has shown that more than 3 million children below five years of age die annually due to malnutrition globally (UNICEF, 2018). The most common and popular GLVs (traditional vegetables) are collard greens, kale, spinach, lettuce, and broccoli. Less popular and locally grown GLVs (non-traditional vegetables) are amaranth, Indian spinach, lamb's quarter, watercress, and moringa leaves. The GLVs are common ingredients in the diet of rural people of developing countries as these vegetables are inexpensive, locally grown, seasonally abundant, and often available year-round. A single variety cannot provide all the nutrients for adequate bodily functions; therefore, different types and amounts of vegetables are important for a healthy diet.

A number of researchers have investigated the nutritional quality and health benefits of traditional as well as non-traditional leafy vegetables, and they found that non-traditional leafy vegetables also contain higher amounts of nutrients (Abd El-Samad, Hussin, El-Naggar, El-Bordeny & Eisa, 2018; Adeyinka, Abolaji, & Olukemi, 2014; Akpana, Edward, Henry, & Joseph, 2017; Arowosegbe, Olanipekun, & Adeloye, 2018; Dias, 2012; Yadav, Tomar, Pachauri, & Jain, 2018). Therefore, it is clear that non-traditional leafy vegetables also play a significant role in reducing the micronutrient deficiency of lower-income groups living in distant rural areas, mostly in Asia and Africa. The grain of quinoa (*Chenopodium quinoa* Willd.) is considered to be a novel, healthy food because of its nutritional properties and health benefits. However, the nutritional composition of the green leaves of quinoa as a vegetable are not yet fully known, only a few researchers have mentioned the benefits of consumption of green leaves of quinoa. Recently, Abd El-Samad et al. (2018) reported the suitability of potential use of the young quinoa plant as a new non-traditional leafy vegetable crop in Egypt.

The objective of this study was to determine the proximate, amino acid, and mineral composition of quinoa leaves, and to compare the values with those of spinach, a well-known, widely consumed GLV; and amaranth, a popular GLV of Asia and Africa. The present work highlights the potential benefits of considering quinoa leaves as a rich source of nutrients adequate for good human health. As of our knowledge, this study is the first of its kind in the USA to determine the nutritional components of green leafy quinoa.

2. Materials and Methods

2.1 Plant Materials

During the summer of 2018, three leafy vegetables, quinoa (*Chenopodium quinoa*) var. Ames 13739 (USDA – GRIN), amaranth (*Amaranthus viridis*) var. Green Callaloo (AM126, Baker Creek Heirloom Seed Company, Missouri, USA), and spinach (*Spinacia oleracea*) var. Bloomsdale (SP101, Baker Creek Heirloom Seed Company, Missouri, USA) seeds were planted and grown at the Lincoln University George Washington Carver Farm (38.96N, 92.36W) in Jefferson City, Missouri, United States. The soil at the experimental plots was silt loam with 20% clay content and 0.8% organic matter. Before sowing, the soil fertility was improved by incorporating the inorganic fertilizer NPK (12-12-12) at the rate of 35 lbs. per acre. Seeds of the three species were sown manually in 5-foot-long, four-row plots, with a plant-to-plant and row-to-row distance of 6 inches, in three replications. Plots were irrigated when required, and no pesticides were applied to the plots. During the growing period (first week of June to first week of July), day and night field average temperatures were 83.83 and 72.27°F; and the humidity was 69.93 and 87.56%, respectively.

2.2 Sample Preparation

Fresh leaves that were about a month old of each species (Figure 1A) from replicated plots were collected for nutritional analysis. The sampled leaves were thoroughly washed with distilled water and then left to dry at room temperature. The samples were later dried in an air-circulating oven (Imperial V Laboratory Oven, Barnstead Lab-line, Illinois, USA) at 65°C for 48 hours. Each sample was ground into powder using a grinder (Cyclotec Mill Foss 1093, FOSS A/S, Minnesota, USA). Ground powder was placed in plastic bags, coded for easy identification and stored in a cool dry place until analyses.

Figure 1A. Month-old fresh leaves of (a) quinoa, (b) amaranth, and (c) spinach harvested for drying

2.3 Proximate Analysis

Protein, fat, crude fiber, moisture, and ash in dried leafy vegetables were determined following the procedures described by the Association of Official Analytical Chemists (AOAC, 2006). The proximate analysis was carried out at the Experiment Station Chemical Laboratories (ESCL) of the University of Missouri, Columbia, Missouri, USA (https://aescl.missouri.edu/ContactUs.html). The sample moisture level was determined using AOAC Official Method 934.01. The ash content was determined following the AOAC procedure by the combustion of samples at 600°C for 8 h. Total nitrogen content in the dried leaf samples was determined by the Kjeldahl method following AOAC method 984.13 (A-D). Crude fat and fiber were calculated following AOAC method 920.39 (A) and 978.10, respectively.

The carbohydrate content was estimated using the equation below:

$$\textit{Carbohydrate (\%)} = 100\% - \%\ \textit{(crude protein + ash + crude fat + moisture)} \quad (1)$$

The food value of each sample was determined by multiplying the protein, fat, and carbohydrate contents by the factors 4, 9, and 4, respectively, and adding all the values to get kcal per 100 g (Indrayan, Sharma, Durgapal, N. Kumar, & K. Kumar, 2005).

2.4 Amino Acid Analysis

The complete amino acid composition was analyzed using AOAC (2006) Official Method 982.30 E (a, b, c). Amino acid composition analysis was also carried out at the Experiment Station Chemical Laboratories (ESCL) of the University of Missouri, Columbia, Missouri, USA (https://aescl.missouri.edu/ContactUs.html). In brief, the protein samples were acid-digested into their constituent amino acids. The amino acids were then analyzed using a fully automated liquid chromatographic system. For cysteine and methionine determination, the acid hydrolysis was preceded overnight with cold acid oxidation and tryptophan determination involved alkaline hydrolysis.

2.5 Mineral Analysis

Powdered leaves of quinoa, amaranth, and spinach were digested using an SRC-UltraWAVE™ microwave digestion system (Milestone Inc., Connecticut, USA). Standard reference material (SRM 1547 - peach leaves) was digested along with our samples. All samples, including SRM 1547, were digested in triplicate. For the digestion, an aliquot of each sample (< 0.5 g) was placed in acid-cleaned quartz tube followed by the addition of concentrated nitric acid (5 mL) and hydrogen peroxide (2 mL).

The determination of elements in all samples was performed using the Agilent 5110 inductively coupled plasma - optical emission spectrometer (ICP-OES) instrument (Agilent Technologies Inc., California, USA) equipped with a VistaChip II detector and configured with an SPS 4 autosampler (Kapadnis, Jain, & Vyas, 2016). The elemental concentrations from the ICP-OES were calculated with ICP Expert software (Version 7.4.1. 10449; Agilent).

The recovery (%) of elements in the reference materials was calculated using the following relationship:

$$\textit{Analyte recovery rate (\%)} = \textit{Found value/Certified value} \times 100 \quad (2)$$

2.6 Data Processing

Triplicate measurements were conducted for all samples. The elemental concentrations in quinoa, amaranth, spinach, and the certified reference material were derived from external calibrations. The values were calculated using Agilent ICP Expert software (Agilent Inc., California, USA). The average ± standard deviation values were calculated with Microsoft® Excel 2010 (Microsoft Corporation, USA). All other (protein and amino acid) statistical analyses were performed using SAS® version 9.3 packages (SAS, 2011). Mean differences were determined using Fisher’s least significant difference (LSD); a *p*-value of <0.05 was considered to be significant.

3. Results and Discussion

3.1 Proximate Analysis

The proximate analyses of the three studied GLVs are shown in Figure 1B. Crude protein (CP) content in the dry GLVs ranged between 27.45 and 37.05% on a dry weight (DW) basis. Quinoa leaves have a significantly higher amount of CP (37.05%) compared with 27.45% and 30.00% in amaranth and spinach leaves, respectively. The CP content was similar to those found in other leafy vegetables, such as *Chenopodium quinoa* (28.00 to 32.18%) (Abd El-Samad et al., 2018), *Moringa oleifera* (29.40%) (Gopalakrishnan, Doriya, & Kumar, 2016), and defatted leaves of *Amaranthus hybridus* (32.95%) (Iheanacho & Ubebani, 2009). However, a higher or lower amount of CP was reported in other leafy vegetables, such as Indian spinach (58.80%), *Amaranthus hybridus* (66.60%) (Asaolu, Adehemi, Oyakilome, Ajibulu, & M. Asaolu, 2012), and Amaranthus species (13.25 to 19.80% (Pradhan, Manivannan, & Tamang, 2015; Patricia, Zoue, Megnanou, Dou, Niamke, 2014). Any plant foods that contribute more than 12.00% calorific value from protein are considered a good source of protein (Aberoumand, 2009). Our result suggests that green leafy quinoa is an excellent protein source on par with the legume proteins (e.g. chickpea, lentils). Availability of high protein content play key role in alleviating nutritional deficiency of rural populations. There was a significant difference in crude fat among the studied GLVs and the fat content was

2.02%, 4.50%, and 5.39% in amaranth, quinoa, and spinach dry leaves, respectively. The lowest amount of fat was found in amaranth leaves and the highest amount in spinach. However, the values were within the range reported in other related vegetables including quinoa (Abd El-Samad et al., 2018; Gopalakrishnan et al., 2016; Onuminya, Shodiya, & Olubiyi, 2017; Pradhan & Tamang, 2015). Generally, leafy vegetables are considered poor sources of fat. Total carbohydrate content was lowest in quinoa, 34.03% and highest in amaranth, 47.90%. The carbohydrate amount in quinoa leaves was similar to Moringa leaves (37.55% to 41.20%) (Gopalakrishnan et al., 2016; Moyo, Masika, Hugo, & Muchenje, 2011) but lower than the amount of carbohydrate reported for amaranthus species (58.21 to 64.60%) (Pradhan & Tamang, 2015). In this study, a negative correlation was observed between protein and carbohydrate, where higher protein quinoa had a lower amount of carbohydrates. It is reported that higher plant based protein and lower carbohydrate intake helps in weight control in humans (Samaha et al., 2003). In addition, a moderate level of dietary fiber in quinoa, which is close to the spinach and moringa, contributes to the overall nutritional value. Availability of good sources of dietary fiber helps in many aspects of human health (Wang, Xu, Wang, & Galili, 2017). The energy expressed in terms of food value (kcal/100 g) for quinoa leaves was similar to amaranth and moringa leaves but lower than spinach.

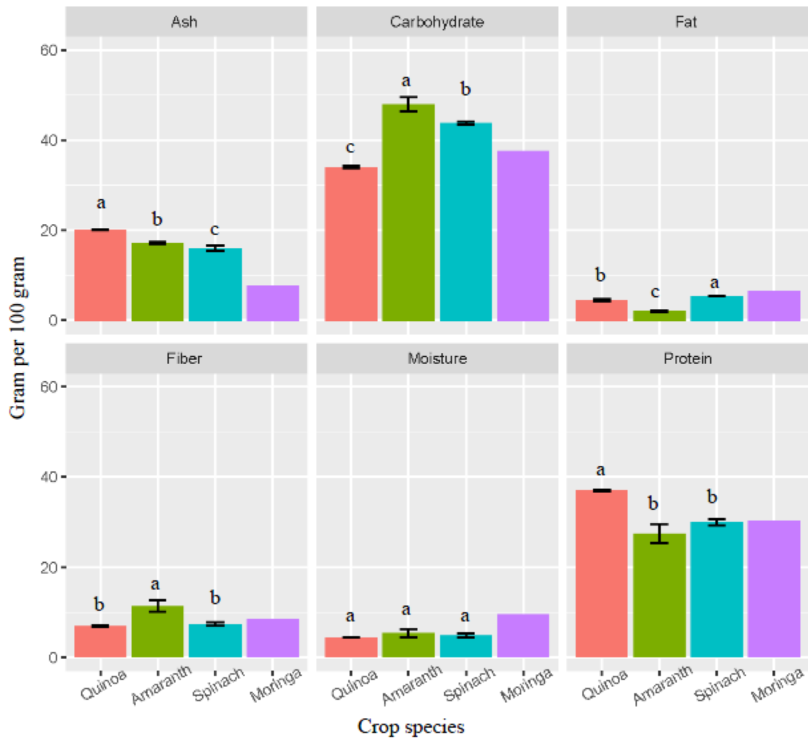

Figure 1B. Proximate analysis (g/100 g DW) of dry leaves of quinoa, amaranth, and spinach compared with moringa dry leaves (Moyoet al., 2011)

[a, b, c] = Different superscript letters for the same trait denote significant difference (*P* < 0.05)

3.2 Amino Acid Composition

The amino acid (AA) composition (g/100g) of dry leaves of quinoa, amaranth, and spinach and their nutritional evaluation are presented in Table 1. Out of the 18 AAs, the nine essential acids (EAAs) that humans cannot synthesize were found in high amounts in all samples. Nutritional quality of the protein is determined by the concentration of essential amino acids. The results showed that the total amino acid (TAA) content (g/100 g DW) was 29.04, 25.02, and 24.45 g in the leaves of quinoa, amaranth, and spinach, respectively. Interestingly, the highest amount of EAAs (13.76 g) and nonessential amino acids (NEAAs) (15.28 g) was found in quinoa leaves, among the studied leaves. The ratio between the EAAs and NEAAs was approximately 90% for all studied leaves. The most abundant EAAs were leucine (2.25 to 2.65 g), lysine (1.59 to 1.89 g), and valine (1.60 to 1.84 g). The most abundant NEAAs were glutamic acid (2.89 to 3.39 g) and aspartic acid (2.50 to 2.83 g), while cysteine was the least abundant in all the three vegetables analyzed (0.45 to 0.49 g). Methionine is generally deficient in green leaves but found in higher levels in quinoa than in amaranth and spinach. In the current work, the values for methionine and cysteine were the least among all AAs. Our findings are in agreement with the results of previous studies on leafy vegetables (Omoyeni, Olaofe, & Akinyeye, 2015), moringa leaves (Moyo et al., 2011; Stadtlander & Becker, 2017), and quinoa grain (Barakat, Khalifa, Ghazal, Shams, & Denev, 2017). It is reported that the green leafy vegetables are deficient in the sulphur-amino acids (Gupta, Barat, Wagle & Chawla, 1989). Comparatively higher concentration of methionine in quinoa leaves helps to improve the protein quality and nutritive value. Methionine and cysteine are powerful antioxidants that help in the detoxification of harmful compounds and protection from radiation (Brisibe et al., 2009). Histidine, an EAA needed for the growth and development of infants, was lower in quinoa leaves than in hen's eggs but was similar to moringa leaves. The amount of histidine was higher in quinoa than in amaranth and spinach. Histidine was the most limited amino acid in all the studied vegetables and in hen's eggs (FAO, 1970). In addition, methionine was limited in all three vegetables studied.

Current results indicate that the amount of TAAs in quinoa leaves (29.04 g) was lower than the hen's egg standard (39.50 g) but was higher than in amaranth, spinach, and the published value of moringa leaves (24.45 to 25.95 g) (Moyo et al., 2011). However, the ratios between EAAs and TAAs, and NEAAs and TAAs were similar among quinoa, amaranth, and spinach as well as for the published results of moringa leaves and hen's eggs (Table 1). The EAA index (EAAI), an indicator of protein quality, was 77% for quinoa leaves, higher than for amaranth or spinach. The index was also lower for moringa leaves, at 60% (Moyo et al., 2011). Another parameter for protein quality determination is the ratio between the individual AA and the TEAA. Scores for tested AAs as well as that of the FAO, which uses the hen's egg as a standard (FAO, 1970) are presented in Table 2. Our results indicated that the amounts of EAAs in quinoa leaves were higher than in the other two vegetables (i.e., amaranth and spinach) but was lower than the scores of EAA in relation to the hen's egg standard.

Table 1. Amino acid composition (g/100 g DW in this study) of dry leaves of quinoa, amaranth, and spinach compared with dry leaves of moringa and hen's egg standard (published literatures)

	This study			Published literatures	
Amino acid	Quinoa	Amaranth	Spinach	Moringa[1]	Hen's egg[2]
Essential AA:					
Histidine (His)	0.70a	0.57c	0.62a	0.72	0.94
Isoleucine (Ile)	1.61a	1.43b	1.26c	1.18	2.44
Leucine (Leu)	2.65a	2.33b	2.25c	1.96	3.44
Lysine (Lys)	1.89a	1.84a	1.59c	1.64	2.70
Methionine (Met)	0.60a	0.53b	0.55c	0.30	1.31
Phenylalanine (Phe)	1.79a	1.45b	1.51c	1.64	2.25
Threonine (Thr)	1.45a	1.16b	1.23b	1.36	2.01
Tryptophan Trp)	1.23a	0.87c	1.00b	0.49	na3
Valine (Val)	1.84a	1.62b	1.60b	1.41	2.69
Non-essential AA:					
Alanine (Ala)	1.89a	1.74b	1.56c	3.03	2.31
Arginine (Arg)	1.71a	1.40b	1.44b	1.78	2.38
Aspartic acid (Asp)	2.83a	2.51b	2.50b	1.43	3.75
Cysteine (Cys)	0.49a	0.47a	0.45a	0.01	0.69
Glutamic acid (Glu)	3.39a	2.89b	2.94b	2.53	3.00
Glycine (Gly)	1.69a	1.45c	1.57b	1.53	1.31
Proline (Pro)	1.51a	1.24c	1.34b	1.20	1.63
Serine (Ser)	1.23a	1.16a	1.09a	1.09	5.00
Tyrosine (Tyr)	0.53a	0.36b	na3	2.65	1.60
Nutritional evaluation:					
EAA	13.76	11.81	11.58	10.70	17.81
NEAA	15.28	13.21	12.87	15.25	21.69
TAA	29.04	25.02	24.45	25.95	39.50
EAA/TAA%	47.38	47.20	47.36	40.12	45.0
NEAA/TAA%	52.62	52.80	52.64	58.77	54.91
EAA/NEAA%	90.05	89.40	89.98	70.16	82.21
EAAI%	77.26	66.31	65.02	60.08	100.00

[a, b, c] = Different superscript letters in the same row denote significant difference ($p < 0.05$);

[1] Moyo et al., 2011; [2] FAO, 1970; [3] na = not available;

EAA = essential amino acid; NEAA = non-essential amino acid; TAA = total amino acid;

EAAI = essential amino acid index [amount of AA in the test sample per unit protein (mg/g) / amount of AA in reference sample (hen's egg) unit protein (mg/g)]

Table 2. Assessment[1] of essential amino acid of quinoa, amaranth and spinach compared to reference amino acid in hen's egg protein (%)

	This study			Published literature
Amino acid	Quinoa	Amaranth	Spinach	Hen's egg (FAO, 1970)
His[2]	39.81	32.42	35.26	53.46
Ile	91.57	81.33	71.66	138.78
Leu	150.72	132.52	127.97	195.66
Lys	107.50	104.65	90.43	156.41
Met	34.13	30.14	31.28	114.32
Phe	101.81	82.47	85.88	127.97
Thr	82.47	65.98	69.96	114.32
Val	104.65	92.14	91.00	153.00
Met + Cys	62.00	56.88	63.13	113.75
First limiting AA	His	His	His	His
Second limiting AA	Met + Cys	Met + Cys	Met + Cys	Met + Cys

[1]Ratio between individual AA in mg to TEAA in hen's egg standard (FAO, 1970);

[2] See Table 1 for abbreviations

3.3 Mineral Analysis

3.3.1 Accuracy of the Results

The instrument readiness and method accuracy check was performed by analyzing SRM 1640a (trace elements in natural water) and SRM 1547 (peach leaves), respectively. The recovery rates of the elements were generally in good agreement with the certified values provided by the National Institute of Standards and Technology (NIST, 2010, 2017) except for the elevated value of only one element, potassium (122%). The recovery values for our independent calibration verification solution and a quality control sample (1 mg/L each of Ca, Cu, Fe, Mg, Mn, Na, and Zn; and 10 mg/L of K) ranged from 100% to 102% and 99% to 107%, respectively.

3.2.2 Mineral Composition Analysis

The average values (mg/100 g DW) of the essential minerals (Ca, Cu, Fe, Mg, Mn, P, K, Na, and Zn) are presented in Table 3. The concentration of different minerals varied among the leaf samples of quinoa, amaranth, and spinach. The most abundant minerals were K (ranged from 5,993.00 to 8,769.00 mg), Ca (1,168.00 to 2,597.00 mg) and magnesium (902.00 to 1,673.00 mg), and the lowest amount was Cu (0.89 to 1.12 mg). Quinoa had the highest concentration of the elements Cu (1.12 mg), K (8,769.00 mg), and Mn (26.49 mg). Ca (2,597.00 mg) and P (477.61 mg) were most abundant in amaranth, while Fe (23.65 mg), Mg (1,673.00 mg), Na (84.47 mg), and Zn (12.29 mg) were most abundant in spinach leaves. Alternately, the lowest concentration identified for Fe (11.55 mg) and Mg (902.00 mg) was in quinoa, while the lowest for Ca (1,168.00 mg) and P (313.25 mg) was in spinach leaves. Our results differed from other published values due to dissimilar growing environments and management practices across the geographical locations as well as the analytical methods used.

Table 3. Mineral composition (mg/100 g DW) in dry leaves of quinoa, amaranth, and spinach compared with published values for moringa and spinach

	This study			Published literatures	
Minerals	Quinoa	Amaranth	Spinach	Moringa[1]	Spinach[2]
Calcium (Ca)	1535.00b	2597.00a	1168.00c	1036	1110
Copper (Cu)	1.12a	1.12a	0.89b	na3	0.59
Iron (Fe)	11.55c	16.77b	23.65a	28.40	13.20
Magnesium (Mg)	902.00c	1171.00b	1673.00a	827	373
Manganese (Mn)	26.49a	23.47a	11.70b	na3	1.67
Phosphorous (P)	405.62b	477.61a	313.25c	513	632
Potassium (K)	8769.00a	5993.00b	6045.00b	5840	296
Sodium (Na)	15.12b	12.84b	84.47a	827	6.70
Zinc (Zn)	6.79b	6.74b	12.29a	5.50	3.10

[1]Edelman and Colt, 2016; [2] Stadtlander and Becker, 2017; [3] na: not available;

[a, b, c] = Different superscript letters in the same row denote significant difference ($P < 0.05$)

In this study, spinach had the highest amounts of Fe, Mg, Na, and Zn (Table 3). Amaranth had the highest amount of Ca and P, following a similar pattern to that reported earlier (Edelman & Colt, 2016; Stadtlander & Becker, 2017) but with different values. Quinoa leaves had the highest amount of K (8,769.00 mg), followed by spinach (6,045.00 mg). The K value of spinach was comparable with that reported by Edelman and Colt (2016). Na and K are important intracellular and extracellular cations, respectively. Potassium appears to improve endothelial, and increasing dietary potassium appears to improve vascular functions in humans (Blanch, Clifton, & Keogh, 2015). Potassium also helps to prevent muscle weakness, respiratory insufficiency, and hypertension in humans (Hathcock, 2014), while Na is involved in regulating the acid-base balance as well as nerve and muscle contractions (Akpanyung, 2005).

Edelman and Colt (2016) reviewed the nutritional compositions for seeds and green leaves that showed that GLVs contain higher amounts of minerals compared with cereal seeds. For example, leafy vegetables of this study have a higher amount of Ca (1,168.00 to 2,597.00 mg), and P (313.25 to 477.61 mg) compared with published results for cereal seeds Ca (6.40 to 34.0 mg), and P (100.00 to 332.00 mg/100 g). A balanced proportion of Ca and P needed in the body, and inadequate Ca-P balance can result in osteoporosis, arthritis, rickets, and tooth decay. A balanced proportion of Ca and P were found in quinoa. Minerals have greater stability during food processing as compared to vitamins and proteins (Kala & Prakash, 2004), but the mineral contents of leafy vegetables is highly dependent on fertilizer application, uptake of minerals by individual plants, and organic soil amendments (Anjorin, Ikokh, & Okolona, 2010).

In this study, concentrations of Fe (11.55 to 23.65 mg/100 g) and Zn (6.74 to 12.29 mg/100 g) were comparable to other leafy vegetables such as kale, spinach, and duckweed (Fe 25.70 to 28.40, Zn 5.50 to 15.00 mg/100 g) (Edelman & Colt, 2016), *Amaranthus viridis* and *Chenopodium album* (Fe 5.40 to 10.80, Zn 8.40 to 9.70 mg/100 g) (Pradhan & Tamang, 2015), and moringa leaves (Fe 13.20, Zn 3.10 mg/100 g) (Stadtlander & Becker, 2017). Wheat, corn, and rice grains have much lower concentration of Fe and Zn, while leafy vegetables, such as kale, spinach, and duckweed (Edelman & Colt, 2016) and the studied vegetables have higher concentrations of Fe and Zn (Table 3). Metal ions are needed by the human body and frequently serve as cofactors in enzymatic reactions and in maintaining protein structure. One-third of human proteins bind with metal ions, and over 10% of enzymes in the human body require Zn for activity (Azia, Levy, Unger, Edelman, & Sobolev, 2015). Iron is a vital trace element in the human body, controlling infection and cell-mediated immunity (Bhashkaran, 2001). Iron deficiency is the most prevalent nutritional deficiency, and anemia caused by iron deficiency is estimated to affect more than one billion people worldwide (Trowbridge & Martorell, 2002). Zinc is another essential micronutrient for growth and immune function, with an estimated 20% of the world population reported to be at risk of insufficient Zn intake (Black, 2003; Brown et al., 2004). Consumption of nutrient-rich leafy green quinoa may prevent nutritional deficiency caused by Fe and Zn.

Daily nutrient requirements for a child (Golden, 2009) and the necessary amount of dry matter intake are presented in Table 4. Quinoa leaves were excellent sources of protein and the macro-elements Ca, Mg, and P. As little as 3.35, 5.80, 1.30, and 16.60 g of leaf powder satisfies 15% of a child's daily protein, Ca, Mg, and P requirements (Tables 3 and 4), respectively. Both Ca and P are essential for a child's bone development for sustainable growth.

Table 4. Daily nutrient requirements[1] for a child and the necessary amount of dry matter intake (g) from quinoa, amaranth, and spinach leaves

				This study		
Nutrient	Unit	Requirement[1]		Quinoa	Amaranth	Spinach
		100%	15%			
Protein	g	22.3	3.35	9.03	12.19	11.15
Calcium	mg	595	89.25	5.81	3.44	11.15
Phosphorous	mg	450	67.50	16.64	14.13	21.55
Magnesium	mg	79	11.85	1.31	1.01	0.71
Potassium	mg	1099	164.85	1.88	2.75	2.73
Sodium	mg	978	146.70	970.23	1142.52	173.67
Iron	mg	17.8	2.67	23.12	15.92	11.29
Zinc	mg	12.5	1.87 2	7.61	27.82	15.26
Manganese	mg	1.2	0.18	0.68	0.77	1.54
Copper	µg	892	133.80	11.95	11.95	15.03
Histidine	mg	430	64.50	9.21	11.32	10.40
Isoleucine	mg	575	86.25	5.36	6.03	6.85
Leucine	mg	1245	186.75	7.05	8.01	8.30
Lysine	mg	116	178.50	9.44	9.70	11.23
Threonine	mg	655	98.25	6.78	8.47	7.99
Tryptophan	mg	175	26.25	2.13	3.02	2.63
Valine	mg	776	116.40	6.33	7.19	7.27

[1]Requirement values from Golden (2009), with data from FAO (1981) where available; otherwise, data from the Institute of Medicine (IMO, 2001)

4. Conclusions

Worldwide, quinoa grain is accepted and consumed as a nutrient-rich pseudocereal. However, the consumption of quinoa leaves is not well reported in the literature, and the nutrient composition is unknown. The current work investigated the nutritional (i.e., protein, amino acid, and mineral) content of the green leaves of quinoa and compared the dataset with those of amaranth and spinach leaves. The results showed that leafy green quinoa is nutritionally rich in protein, amino acids, and mineral content as well as food value. This indicates quinoa's potential as a noble nonconventional vegetable for human nutrition. Among the three studied vegetables, quinoa leaves contained a higher amount of crude protein, a lower amount of carbohydrate, all essential amino acids, and all key minerals. From our study, the nutrient composition of quinoa and amaranth leaves showed more resemblance in nutrient composition than spinach leaves. Due to its rich nutritional qualities, vegetable growers may add quinoa to their crop list as a new specialty GLV, thereby diversifying their farming pattern. Inclusion of vegetable quinoa in the crop list may lead to increased farm income, especially for small vegetable growers, and may help to overcome nutritional deficiencies in end users. Consequently, leafy vegetable quinoa can be considered an alternative to combat malnutrition and may be consumed directly by humans or indirectly by utilizing it as a feed for small ruminants, such as goats and sheep. The high nutritional content found in dried quinoa leaves indicates the usefulness of this vegetable as a potential animal feed that can facilitate both conservation and consumption when food is scarce or during the off-season. To the best of our knowledge, this is the first study of the nutritional components of green leafy quinoa in the US. Green leafy quinoa shows its outstanding potential as a nutrient-rich vegetable. Therefore, we recommend that it should be evaluated further for its nutritional benefits and other characteristics, such as potential anticancer and antidiabetic activity.

Conflicts of Interest Statement

The authors declare no conflicts of interest related to this article. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

The authors would like to thank the United States Department of Agriculture (USDA) - National Institute of Food and Agriculture (NIFA) (Evans-Allen grant to senior author, grant #1006493) and Organic Valley - Farmers Advocating for Organic (FAFO) for partial financial support and USDA - Germplasm Resources Information Network (GRIN) for providing quinoa seeds. We thank Cooperative Research Programs (Lincoln University of

Missouri) for the equipment and other resources used during the study. The authors greatly acknowledge Dr. Abua Ikem's technical support and advice. The contributions of Jimmie Garth, Marianne Dolan-Timpe, Allute Hamisi and Dr. Nancy Browning of Lincoln University and Dr. Hari Krishnan of USDA-ARS, Columbia, Missouri are greatly appreciated.

References

Abd El-Samad, E. H., Hussin, S. A., El-Naggar, A. M., El-Bordeny, N. E., & Eisa, S. S. (2018). The potential use of quinoa as a new non-traditional leafy vegetable crop. *Bioscience Research, 15*(4), 3387-3403.

Aberoumand, A. (2009). Proximate and mineral composition of the marchubeh (*Asparagus officinalis* L.) in Iran. *World Journal Dairy Food Science, 4*(2), 145-149.

Adeyinka, M. O., Abolaji, G. F., & Olukemi, R. A. (2014). Determination of trace element in raw leafy vegetables grown in selected local government of Osun state. *American Journal of Chemistry, 4*(1), 38-41. https://doi.org/10.5923/j.chemistry.20140401.06

Akpana, A. M., Edward, M. J., Henry, J., & Joseph, A. (2017). Mineral and vitamin composition of some lesser known leafy vegetables consumed in northern senatorial district of Cross River state, Nigeria. *American Journal of Food and Nutrition, 5*(2), 51-57. https://doi.org/10.12691/ajfn-5-2-1

Akpanyung, E. O. (2005). Proximate and mineral composition of bouillon cubes produced in Nigeria. *Pakistan Journal of Nutritio, 4*(5), 327-329. http://dx.doi.org/10.3923/pjn.2005.327.329

Anjorin, T. S., Ikokh, P., & Okolona, S. (2010). Mineral composition of moringa leaves, pods and seed from two region of Abuja, Nigeria. *International Journal of Agriculture and Biology, 12*(3), 431-434. Retrieved from http://www.parc.gov.pk/NARC/narc.html

AOAC (2006). *Official Methods of Analysis (18th ed.). Association of Official Analytical Chemist International,* Gaithersburg, MD, USA.

Arowosegbe, S., Olanipekun, M. K., & Adeloye, I. A. (2018). Ethnobotanical survey of indigenous leafy vegetables consumed in Ekiti state, Nigeria. *European Journal of Biology and Medical Science Research, 6*(1), 7-14. http://dx.doi.org/10.3923/sjsres.2018.8.13

Asaolu, S. S., Adefemi, O. S., Oyakilome, I. G., Ajibulu, K. E., & Asaolu, M. F. (2012). Proximate and mineral composition of Nigerian leafy vegetables. *Journal of Food Research, 1*(3), 214-218. https://doi.org/10.5539/jfr.v1n3p214

Azia, A., Levy, R., Unger, R., Edelman, M., & Sobolev, V. (2015). Genome-wide compuational determination of the human metalloproteome. *Proteins. 83*, 931- 939. https://doi.org/10.1002/prot.24790

Barakat, H., Khalifa, I., Ghazal, G. A., Shams, A., & Denev, P. N. (2017). Chemical composition and nutritional value of seeds from new quinoa accessions, cultivated in Egypt. *Bulgarian Chemical Communications, 49*(D), 231-238.

Bhashkaran, P. (2001). Immunobiology of mild nutrient deficiency. *British Journal of Nutrition, 85*, S75-S80. http://dx.doi.org/10.1079/BJN2000297

Black, R. E. (2003). Zinc deficiency, infectious disease and mortality in developing world. *J. Nutr. 133,* S1485-S1489. https://doi.org/10.1093/jn/133.5.1485S

Blanch, N., Clifton, P. M., & Keogh, J. B. (2015). A systematic review of vascular and endothelial function: effects of fruit, vegetable and potassium intake. *Nutrition Metabolism Cardiovascular Disease, 25*(3), 253-66. https://doi.org/10.1016/j.numecd.2014.10.001

Brisibe, E. A., Umoren, U. E., Brisibe, F., Magalhaes, P. M., Ferreira, J. F. S., Luthria, D., Wu, X., & Prior, R. L. (2009). Nutritional characterization and antioxidant capacity of different tissues of *Artmisia Annua* L. *Food Chemistry, 115,* 1240-1246. https://doi.org/10.1016/j.foodchem.2009.01.033

Brown, K. H., Rivera, J. A., Bhutta, Z., Gibson, R. S., King, J. C., Lönnerdal, B., Ruel, M. T., Sandtröm, B., Wasantwisut, E., & Hotz, C. (2004). International Zinc Consultative Group (IZINCG) Technical document no. 1. Assessment of the risk of zinc deficiency in populations and options for its control. *Food Nutrition Bulletin, 25*(1), S94-S203. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/18046856

Dias, J. S. (2012). Nutritional quality and health benefits of vegetables: A review. *Food and Nutrition Sciences, 3,* 1354-1374. http://dx.doi.org/10.4236/fns.2012.310179

Edelman, M., & Colt, M. (2016). Nutrient value of leaf vs. seed. *Frontiers in Chemistry, 4*, 1-32.

https://doi.org/10.3389/fchem.2016.00032

FAO (1970). *Amino acid content of food and biological data on proteins.* FAO nutritional studies no. 24, Rome, Italy. Retrieved from: http://www.fao.org/3/ac854t/AC854T00.htm

FAO (1981). The joint FAO/WHO/UNU Expert Consultation on Energy and Protein Requirement: Infants, Children and Adolescents. Rome, Italy. Retrieved from: http://www.fao.org/3/AA040E/AA040E07.htm

Golden, M. H. (2009). Proposed recommended nutrient densities for moderately malnourished children. *Food Nutrition Bulletin*, *30*, 267-342. https://doi.org/10.1177/15648265090303S302

Gopalakrishnan, L., Doriya, K., & Kumar, D. S. (2016). *Moringa oleifera*: a review on nutritive importance and its medicinal application. *Food Science Human Wellness, 5*, 49-56. https://doi.org/10.1016/j.fshw.2016.04.001

Gupta, K., Barat, G. K., Wagle, D. S., & Chawla, H. K. L. (1989). Nutrient contents and antinutritional factors in conventional and non-conventional leafy vegetables. *Food Chemistry, 31*, 105-116. https://doi.org/10.1016/0308-8146(89)90021-6

Hathcock, J. N. (2014). *Vitamin and mineral safety* (3^{rd} ed.). Council of Responsible Nutrition (CRN), Washington, DC, USA. pp.119-123.

HHS and USDA (U.S. Department of Health and Human Services and U.S. Department of Agriculture). (2015). *2015 – 2020 Dietary Guidelines for Americans* (8^{th} eds). Retrieved from http://health.gov/dietaryguidelines/2015/

Iheanacho, K., & Ubebani, A. C. (2009). Nutritional composition of some leafy vegetables consumed in Imo-State, Nigeria. *Journal of Applied Science and Environmental Management, 13*(3), 35-38. https://doi.org/10.4314/jasem.v13i3.55349

Indrayan, A. K., Sharma, S., Durgapal, D., Kumar, N., & Kumar, M. (2005). Determination of nutritive value and analysis of mineral elements for some medicinally valued plants from Uttaranchal. *Current Science, 89*, 1252-1255.

IOM (Institute of Medicine). (2001). *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. The National Academies Press, Washington, DC, USA. Retrieved from https://www.nap.edu/read/10026/chapter/33

Kala, A., & Prakash, J. (2004). Nutrient composition and sensory profile of differently cooked green leafy vegetables. *International Journal of Food Properties*, *7*(3), 659-669. https://doi.org/10.1081/JFP-200033079

Kapadnis, G., Jain, V., & Vyas, S. (2016). *Determination of elements in drinking* water *as per Bureau of Indian standards 10500, 14543 & 13428 using the Agilent 5100 ICP-OES.* Agilent Technologies India, 5991-6544EN (v2). Retrieved from https://www.agilent.com/cs/library/applications/5991-6631EN.pdf

Moyo, B., Masika, P. J., Hugo, A., & Muchenje, V. (2011). Nutritional characterization of moringa (*Moringa Oleifera* Lam.) leaves. *African Journal of Biotechnology, 10*, 12925-12933. http://dx.doi.org/10.5897/AJB10.1599

NIST (National Institute of Standards and Technology). (2010). *Certificate of analysis: Standard reference material (SRM) 1640a - trace elements in natural water*. NIST, Gaithersburg, Maryland, USA.

NIST (National Institute of Standards and Technology). (2017). *Certificate of analysis: Standard reference material (SRM) 1547 - peach leaves.* NIST, Gaithersburg, Maryland, USA.

Omoyeni, O. A., Olaofe, O., & Akinyeye, R. O. (2015). Amino acid composition of ten commonly eaten indigenous leafy vegetables of South-west Nigeria. *Journal of Nutrition and Health*, *3*(1), 16-21. http://dx.doi.org/10.12691/jnh-3-1-3

Onuminya, T. O., Shodiya, O. E., & Olubiyi, O. O. (2017). Comparative proximate and phytochemical analyses of leafy vegetables of Lagos state. *Nigerian Journal of Pure and Applied Science, 30*(3), 3097-3103. http://dx.doi.org/10.19240/njpas.2017.C06

Patricia, O., Zoue, L., Megnanou, R-M., Dou, R., & Niamke, S. (2014). Proximate composition and nutritive value of leafy vegetables consumed in northern Cote D'ivoire. *European Scientific Journal*, *10*(6), 212-227. http://dx.doi.org/10.19044/esj.2014.v10n6p%25p

Pradhan, S., Manivannan, S., & Tamang, J. P. (2015). Proximate, mineral composition and antioxidant properties of some wild leafy vegetables. *Journal of Scientific and Industrial Research, 74*, 155-159. http://hdl.handle.net/123456789/30726

Pradhan, S., & Tamang, J. P. (2015). Ethnobiology of wild leafy vegetables of Sikkim. *Indian Journal of Traditional Knowledge, 14*(2), 290-297. http://hdl.handle.net/123456789/32086

Samaha, F., Iqbal, N., Seshadri, P., Chicano, K., Daily, D., McGrory, J., … Stern, L. (2003). A low-carbohydrate as compared with a low-fat diet in severe obesity. *New England Journal of Medicine*, *348*, 2074-81. https://doi.org/10.1056/NEJMoa022637

SAS (2011). *SAS Software Version 9.3*. SAS Institute, Cary, NC, USA.

Stadtlander, T., & Becker, K. (2017). Proximate composition, amino and fatty acid profiles and element compositions of four different *Moringa* species. *Journal of Agricultural Science, 9*, 7. https://doi.org/10.5539/jas.v9n7p46

Trowbridge, F., & Martorell, M. (2002). Forging effective strategies to combat iron deficiency: Summary and recommendation. *Journal of Nutrition, 85*, 875-880. https://doi.org/10.1093/jn/132.4.875S

UNICEF (2018). Malnutrition rates remain alarming: stunting is declining too slowly while wasting still impacts the lives of far too many young children. Retrieved from http://data.unicef.org/topic/nutrition/malnutrition/#

Wang, G., Xu, M., Wang, W., & Galili, G. (2017) Fortifying Horticultural Crops with Essential Amino Acids: A Review. *International Journal of Molecular Sciences, 18*(6), 1306. https://doi.org/10.3390/ijms18061306

Yadav, R. K., Tomar, B. S., Pachauri, N., & Jain, V. (2018). Studies of nutritional properties and antioxidant potential in green leafy vegetables. *Journal of the Science of Food and Agriculture, 2*(1), 7-13. https://doi.org/10.26855/jsfa.2018.01.001

Copyrights