Minerals and polyphenols content of quinoa (Chenopodium quinoa Willd.) plant

Zawartość minerałów i polifenoli w komosie ryżowej (Chenopodium quinoa Willd.)

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Wprowadzenie. Komosa ryżowa (Chenopodium quinoa Willd.) zaliczana jest do pseudozbóż i rośnie zainteresowanie tą rośliną z powodu jej wysokiej wartości żywieniowej. Jest bogata w białko, witaminy i inne związki biologicznie czynne. Traktowana jest jako żywność funkcjonalna i ma zastosowanie w diecie bezglutenowej. Istnieje niewiele prac dotyczących składu mineralnego i zawartości antyoksydantów w nasionach komosy ryżowej, a brak jest informacji o tych składnikach w całej roślinie.

Cel pracy. Analiza składu mineralnego części naziemnej komosy ryżowej oraz zawartości całkowitej polifenoli w roślinach komosy odmian Olav oraz Sandoval.

Materiał i metody. W próbkach naziemnej części komosy (łodyga, liście, kwiatostan wraz z nasionami) oznaczano zawartość minerałów metodą AAS oraz stężenie polifenoli stosując odczynnik Folin-Cicalteau. Całkowitą zawartość polifenoli oznaczano kolorymetrycznie po uprzedniej kwaśnej hydrolizie materiału, a wyniki przedstawiono w postaci równoważników kwasu galusowego.

Wyniki. Komosa ryżowa wydaje się być dobrym źródłem minerałów, w tym także cynku. Również zawartość polifenoli w przeliczeniu na suchą masę jest wysoka, ale ulega obniżeniu w trakcie wegetacji. Przedstawiono wyniki zawartości cynku i polifenoli w łodygach, liściach i kwiatostanach (wraz z nasionami) od 77 do 180 dnia wegetacji komosy.

Wnioski. Uzyskane wyniki sugerują, że komosa ryżowa może być dobrym źródłem nie tylko białka lecz również minerałów i antyoksydantów. Z powodu spadku zawartości cynku i polifenoli w czasie wegetacji wydaje się, że w żywieniu celowe jest stosowanie młodszych roślin.

Słowa kluczowe: *komosa ryżowa, pseudozboża, związki mineralne, cynk, polifenole*

Introduction. Quinoa (Chenopodium quinoa Willd.) is a pseudo-cereal that has received increased interest because it is a good source of different nutrients including proteins, vitamins and other biologically active compounds, and especially as functional gluten-free ingredient of human diet. There are also only limited data concerning the concentration of minerals and antioxidants in quinoa seeds and practically no information concerning composition of whole quinoa plant.

Aim. To characterize the mineral composition and total polyphenol content of quinoa cultivar (Olav and Sandoval varieties) grown in central Poland.

Material & methods. Samples of the quinoa aboveground parts obtained from: leaves, stem, infructescence (flowers and seeds) were analyzed. The minerals were determined by flame atomic absorption spectrometry and total polyphenols using the Folin-Cicalteau reagent. A colorimetric assay was conducted following acidic hydrolysis and the final results were expressed as gallic acid equivalents.

Results. Quinoa was found to be a good source of minerals, including zinc. Its polyphenol content expressed per weight of dry matter was found to be relatively high, but decreasing during the vegetation period. The differences in concentrations of zinc and polyphenols among stem, leaves and infructescence during the 77th and 180th day of quinoa vegetation were presented.

Conclusions. The obtained results of mineral analysis and estimation of total polyphenols suggest that quinoa might be used not only as a good source of proteins but also as source of minerals and antioxidants. Because of observed decrease in the concentration of zinc and polyphenols noticed in older plants the use of younger plants might be reasonable.

Key words: *quinoa, pseudo-cereals, minerals, zinc, total polyphenols*

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Introduction

Quinoa which is one of the most nutritious traditional food crops in the world was reintroduced in South-America and since a half of decade its production has been increasing in USA, Canada and also in Europe. It is a dicotyledonous seed not belonging to cereal grains. Beyond traditional markets for quinoa, such as seeds and flour production, also starch forming very small granules, saponins for their insecticidal and fungicidal properties and oil low in saturated fatty acids cause increasing interest of farmers. A growing market of food sector towards patients suffering celiac disease or diabetes, as well as, organic, non-GMO and non-allergic foods, stimulate quinoa production [1, 2]. Quinoa does not have gluten-forming protein and may be used for infant cereal production [3]. It is also suggested that quinoa (pseudo-cereal), as well as many other alternative crops (oat, barley, buckwheat) seem to posses higher satiating efficiency indices with respect to traditional cereal foods [4, 5].

There are more than 2000 varieties of quinoa ranging in size of plant, color of leaves and seeds (e.g. ivory, pink, red) and the amount of saponin naturally coating the seeds. These saponins might be removed during the seeds processing [6]. New whiter varieties of quinoa were obtained by selective breeding in order to produce sweeter (less saponins), bigger and more palatable crop. However they are hard to collect because such seeds are very attractive to birds. The average protein content in quinoa seeds is ranging from 12 to 19% and what is very important its amino acids composition is very well balanced and, in contrast to main grains, posseses high lysine concentration [7, 8]. Quinoa flour contains high level of carbohydrates and moderate (ca 8-10%) of crude fiber which enhances its nutritional value. The average oil content in seeds is ca. 6% and the oil press cake high in protein content might be used as excellent animal foodstuff component.

Whole grains are good sources of dietary fiber; they also contain minerals, vitamins, essential fatty acids, and phytochemicals such as polyphenols. Polyphenol classes present in the different cereal types are phenolic acids, flavonoids and resorcinols. Most polyphenols occur in the outer layers of the grain and they are largely lost during refining. That is why refined flour contains very low amounts of polyphenols. Much higher antioxidant activity was found in 100% whole grain bread as compared with white bread [9]. In wheat flour Arranz et al [10] found 6 times lower concentration of extractable polyphenols than in wheat bran.

The polyphenol content in cereals and pseudo-cereals varies according cultivars and growing conditions and such factors as soil pH, rainfall and temperature have higher impact on total polyphenol content then the plant genotype. Also increased air-drying temperature reduces total polyphenol content and antioxidant capacity of quinoa seeds [11].

There is only limited information concerning composition of quinoa plant. Such data are very important because of potential use of whole plant in animal nutrition. A relatively high crude protein content (g) per dry matter (kg) 140÷166 or 40÷45g/kg fresh product and estimated digestibility of 63÷69% was obtained in organic dairy farm in Aver Heino Centre in Netherland [12].

There are also only limited data concerning the concentration of antioxidants in quinoa seeds. Relatively high antioxidant potential of quinoa seeds was shown by Paśko et al [13], but we were not able to find any data concerning antioxidant properties of quinoa plant.

The objective of this study was to characterize the mineral composition and antioxidant capacity of quinoa cultivar grown in central Poland.

Material and Methods

The field experiment was conducted 35 km north of Warsaw (Poland). Seeds of two different varieties of quinoa (Q1 – Olav, Q2 – Sandoval) were sown, in the beginning of May, at a depth 1.5-2.0 cm, in rows spaced 40 cm. Germination started within 2 days after sowing and seedling emerged in c.a. five days. During June up to the middle of July no water precipitation occurred. Wet conditions during seed maturation period (September, October) prevented leaves from drying and complete seed maturation. The field was fertilized with 150 kg N/ha.

Samples of plants were randomly collected from different parts of quinoa field (n=10) to estimate weight and dry matter content of different parts of plants (stem, leaves, infructescence).

Samples of the quinoa aboveground parts: leaves, stem, infructescence (flowers and seeds) (0.5 g) were mineralised with the mixture of 5 ml HNO_3 (Merck 1.00441), 1 ml $HClO_4$ (Merck), and 1 ml HF (Merck) in hermetic teflon vessels in microwave oven (Milestone Ethos 900). We had used the mixture of HNO_3 and H_2O_2 but we could not mineralise the material properly. Minerals were determined by flame atomic absorption spectrometry (Perkin-Elmer 1100B) using hollow cathode lamp. The analysis of each sample was done in three repetitions to decrease dispersion rate.

The total contents of polyphenols (μg/g DW) were extracted with 1.2 M HCl in 50% methanol (water solution). Total phenolics were determined using the Folin-Cicalteau reagent, as described by Emmons et al [14]. A colorimetric assay was conducted in a mixture of 2.7 ml of deionised water, 0.3 ml of extract, 0.3 ml of 7% Na_2CO_3 and 0.15 ml of the Folin-Cicalteau reagent. A standard curve was prepared using gallic acid and the final results were given as gallic acid equivalents (GAE).

For statistical evaluation a one-way and multi-way analysis of variance (GLM procedure) was performed (SPSS software). The Bonferoni test was used for evaluation of differences between means at $p \leqslant 0.05$.

Results and Discussion

For humans not only seeds but also leaves of quinoa are edible and may be used for direct consumption or cooked similarly as spinach. However, in human nutrition practically only seeds are considered as important in form of flour or whole seeds added e.g. to different sort of salads. It might be important, because mineral density was found to decrease in wheat grain over the last 160 years [15]. The data concerning the mineral and vitamin content of quinoa seeds and flour as well as green parts of quinoa are rather scarce. Quinoa seeds were found to be a good source of main minerals (phosphorus, iron, magnesium, manganese), and their level was higher than in most of common grains [16]. Ranhotra et al [17] found the following mineral composition (mg%) of flour obtained from dehulled quinoa seeds: Ca-70, P-462, K-855, Mg-161, Fe-6.3, Mn-3.5, Zn-3.2, Cu-0.7. Similarly Ruales and Nair [16] noticed the following concentrations in seeds: Ca-87, P-530, K-1200, Cu-1 (Tab. I).

The average content of minerals is presented in table 1. Whole plants of Chenopodium quinoa were found to have high concentrations of calcium and magnesium. The lowest concentrations noticed were of copper and chromium. No differences between the Olav and Sandoval varieties were found in case of Mg, Fe and Cu concentrations. In the Sandoval (Q2) plant variety higher average concentrations of Zn, Cr, Ca and Mn were noticed (Tab. II).

The Zn concentration decreased during vegetation period in all parts of quinoa plants. Similar tendency was observed in wheat. In quinoa the highest zinc concentration appeared in stem, followed by infructescence and leaves. Haslett et al [18] in wheat found also stem to be a reservoir of zinc. They also observed effective transport of this microelement from stem and leaves to developing grain. The differences between the quinoa varieties were observed only in infructescence. The Zinc concentrations were higher in the Sandoval variety in 96, 167 and 180 d of farming.

Table I. Average concentration of minerals in plants of Chenopodium quinoa var. Olav (Q1), var. Sandoval (Q2), in samples collected during 77 and 180 d of vegetation period, expressed as mg of minerals/kg DM. n=10
Tabela I. Średnie stężenie pierwiastków w roślinach Chenopodium quinoa var. Olav (Q1), var. Sandoval (Q2) w próbkach zbieranych przez 77 I 180 dni okresu wegetacyjnego wyrażone w mg pierwiastka/kg DM. n=10

Minerals /Pierwiastki	Minerals in whole parts of plant /Pierwiastki w całej części rośliny	
	Q1	Q2
Zn	89.7[a]	115.3[b]
Cu	10.03[b]	10.12[b]
Fe	377.6[b]	442.3[b]
Cr	2.49[a]	3.51[b]
Ca	13951[a]	17189[b]
Mg	4730.9[b]	4779.1[b]
Mn	391.6[a]	564.1[b]

Values with different superscript letter differ at p≤0.05

Polyphenol compounds have been extensively researched in the last decade because their health promoting properties [19]. Phenolic acids in cereal

Table II. Concentrations of Zn in plants of Chenopodium quinoa var. Olav (Q1), var. Sandoval (Q2), in samples of the quinoa above ground parts: collected during 77 and 180 d of vegetation period, expressed as mg Zn/kg DM. n=10
Tabela II. Stężenie cynku w roślinach Chenopodium quinoa var. Olav (Q1), var. Sandoval (Q2) w próbkach części naziemnej zbieranych przez 77 I 180 dni okresu wegetacyjnego wyrażone w mg pierwiastka/kg DM. n=10

Day of vegetation /Dzień wegetacji	Stem /Łodyga		Leaves /Liście		Infructescence /Owoc	
	Q1	Q2	Q1	Q2	Q1	Q2
77	164.7±13.2 [b]	165.2±13.2 [b]	71.7±12.7 [a]	69.3±9.7 [a]	–	–
96	210.3±8.1 [b,c]	228.9±17.3 [c]	36.9±1.3 [a]	64.3±6.4 [a]	182.5±13.6 [b]	256.6±12.1 [c]
109	218.6±11.2 [c]	196.4±4.2 [c]	43.9±11.2 [a]	33.0±5.3 [a]	70.8±7.6 [b]	83.2±1.4 [b]
141	125.9±13.5 [c]	214.2±10.9 [d]	27.1±1.2 [a]	25.8±1.3 [a]	82.7±3.3 [b]	80.9±5.0 [b]
167	47.7±2.5[b]	62.4± 7.2 [c]	37.9±2.5 [a]	42.3±11.2 [a,b]	55.2±5.1 [b,c]	80.8± 4.5 [d]
180	77.8±7.1 [c]	66.2±1.4 [c]	28.5±2.2 [a]	29.9±1.3 [a]	54.9±2.5 [b]	67.3± 6.5 [c]

Values with different superscript letter differ at p≤0.05

Table III. Poliphenols content in plants of Chenopodium quinoa var. Olav (Q1), var. Sandoval (Q2), in samples collected during 77 and 180 d of vegetation period, expressed as mg GAE/kg DM. n=10
Tabela III. Zawartość polifenoli w roślinach Chenopodium quinoa var. Olav (Q1), var. Sandoval (Q2) w próbkach zbieranych przez 77 I 180 dni okresu wegetacyjnego wyrażone w mg pierwiastka/kg DM. n=10

Day of vegetation /Dzień wegetacji	Stem /Łodyga		Leaves /Liście		Infructescence /Owoce	
	Q1	Q2	Q1	Q2	Q1	Q2
77	0.94±0.09 [a]	0.81±0.13 [a]	6.62±0.54 [b]	5.93±0,46 [b]	-	-
96	1.05±0.14 [a]	1.09±0.12 [a]	4.65±0.42 [c]	5.40±0.44 [c]	2.94±0.22 [b]	2.84±0.32 [b]
109	0.96±0.10 [a]	1.08±0.09 [a]	4.28±0.39 [c]	3.96±0.34 [c]	3.07±0.31 [b,c]	2.42±0.33 [b]
141	0.75±0.15 [a]	0.91±0.14 [a]	3.98±0.43 [d]	3.50±031 [d]	2.77±0.33 [c]	1.93±0.26 [b]
167	0.82±0.16 [a]	0.78±0.08 [a]	3.38±0.31 [d]	2.78±0.28 [c,d]	2.55±0.26 [c]	1.50±0.22 [b]
180	0.54±0.09 [a]	0.48±0.09 [a]	2.80±0.23 [d]	2.05±0.22 [c]	2.72±0.29 [d]	1.48±0.28 [b]

Values with different superscript letter differ at p≤0.05

grains are distributed as free, soluble-esterified, and insoluble-bound forms either esterified or etherified to the cell wall constituents. The soluble-esterified phenolic acids are estimated in the same extracts after alkali or acid hydrolysis. The insoluble-bound phenolic acids remaining in the extraction residue are quantified after a similar hydrolysis of the solids. Gomez-Caravaca et al [20] have shown that irrigation 25% of full water restitution of quinoa fields was associated with increased free phenolic compounds in seeds. Paśko et al [13] in quinoa seeds observed a relatively high concentration of total phenolics 3.75 mg gallic acid equivalents per g DM when in Amaranthus seeds this concentration was ca. 20% lower. Similar results were obtained in study of Goristein et al [21], however concentrations were a few times lower, probably because of differences in extraction methodology. They conclude that in pseudo-cereals polyphenols are the main antioxidants, but also proteins play significant role in overall antioxidant capacity. This is not in agreement with the study of Nsimba et al [22] showing relatively low correlation between the phenolic concentration and antioxidant potency of extracts of quinoa seeds. These authors calculated R^2 of total phenols content versus the radical scavenging activity to be only 0.48 which suggests that in case of quinoa other compounds are responsible for a big part of antioxidant properties. Kulczak et al [23] found total polyphenol concentration 2.3 mg gallic acid equivalents/g DM in buckwheat groats and much lower in barley and oats groats. In our study the highest concentrations of phenolics were observed in quinoa leaves in July (77th day of cultivation) (Tab. III). During further cultivation the concentration of these compounds constantly decreased and the lowest was found during harvest. Similar tendency was observed also in stem and infructescence of quinoa plant. Comparing the phenolic concentration in different parts of plant in each time point of quinoa cultivation, the highest concentration of this compounds was stated in leaves, followed by infructescence and stem. In the phenolic amount no big differences between examined quinoa varieties were observed except for higher level of phenolics observed in infructescence of Q1 (Olav var.).

The use of whole plant of Chenopodium quinoa as a feed source for animals is becoming popular because of its high nutritional value. The results of the mineral analysis and estimation of total polyphenols suggest that this pseudo-cereal might be also used as a good source of minerals and antioxidants. Because of observed decrease in concentration of zinc and polyphenols observed in older plants the use of younger plants might be reasonable.

Piśmiennictwo / References

1. Alvarez-Jubete L, Arendt EK, Gallagher E. Nutritive value of pseudocereals and their increasing use as functional gluten-free ingredients. Trends Food Sci Technol 2010, 21: 106-13.
2. Ranilla LG, et al. Evaluation of indigenous grains from the Peruvian Andean region for antidiabetes and antihipertension potential using in vitro methods. J Med Food 2009, 12: 704-13.
3. Abugoch JL. Quinoa (Chenopodium quinoa Willd.): composition, chemistry, nutritional, and functional properties. Adv Food Nutr Res 2009, 58: 1-31.
4. Berti C, et al. In vitro starch digestibility and in vivo glucose response of gluten-free foods and their gluten counterparts. Eur J Nutr 2004, 43: 198-204.
5. Berti C, et al. Effect on appetite of minor cereal and pseudocereal products. Br J Nutr 2005, 94: 850-8.
6. Pappier U, et al. Effect of processing for saponin removal on fungal contamination of quinoa seeds (Chenopodium quinoa Willd.). Int J Food Microbiol 2008, 125: 153-7.
7. Alvarez-Jubete L, Arendt EK, Gallagher E. Nutritive value and chemical composition of pseudocereals as gluten-free ingredients. Int J Food Sci Nutr 2009, 60: 240-57.
8. Ogungbenle HN. Nutritional evaluation and functional properties of quinoa (Chenopodium quinoa) flour. Int J Food Sci Nutr 2003, 54: 153-8.
9. Miller HE, et al. Antioxidant content of whole grain breakfast cereals, fruits and vegetables. J Am Col Nutr 2000, 19: 312S-319S.
10. Arranz S, Calixto FS. Analysis of polyphenols in cereals may be improved performing acidic hydrolysis: a study in wheat flour and wheat bran and cereals of the diet. J Cereal Sci 2010, 51: 313-18.
11. Miranda M, et al. Impact of air-drying temperature on nutritional properties, total phenolic content and antioxidant capacity of quinoa seeds (Chenopodium quinoa Willd). Ind Crops Prod 2010, 32(3), 258-63.
12. Van Schooten HA, Pinxterhuis JB. Quinoa as an alternative forage crop in organic dairy farming. Optimal Forage Systems for Animal Production and the Environment Grassland Science in Europe 2002, 8, 1-4. www.biologischeveehouderij.nl/biobieb/pdf/Quinoa
13. Paśko P, et al. Anthocyanins, total polyphenols and antioxidant activity in amaranth and quinoa seeds and sprouts during their growth. Food Chem 2009, 115: 994-8.
14. Emmons CL, Peterson DM, Paul GL. Antioxidant capacity of oat (Avena sativa L.) extracts. 2. In vitro antioxidant activity and contents of phenolic and tocol antioxidants. J Agric Food Chem 1999, 53: 6818-6913.
15. Fan MS, et al. Evidence of decreasing mineral density in wheat grain over the last 160 years. J Trace Elem Med Biol 2008, 22: 315-24.
16. Ruales J, Nair BM. Content of fat, vitamins and minerals in quinoa (Chenopodium quinoa Willd.) seeds. Food Chem 1993, 48: 131-6.

17. Ranhotra GS, et al. Composition and protein nutritional quality of quinoa. Cereal Chem 1993, 70: 303-5.
18. Haslett BS, Reid RJ, Rengel Z. Zinc mobility in wheat: uptake of zinc applied to leaves or roots. Ann Botany 2001, 87: 379-86.
19. Scalbert A, et al. Dietary polyphenols and the prevention of diseases. Crit Rev Food Sci Nutr 2005, 45(4): 287-306.
20. Gomez-Caravaca AM, et al. Phenolic compounds and saponins in quinoa samples (Chemopodium quinoa Willd.) grown under different saline and nonsaline irrigation regimens. J Agric Food Chem 2012, 60(18): 4620-27.
21. Gorinstein S, Medina Vargas OJ, Jaramillo NO, et al. The total polyphenols and the antioxidant potentials of some selected cereals and pseudocereals. Eur Food Res Technol 2007, 225: 321-28.
22. Nsimba RY, Kikuzaki H, Konishi Y. Antioxidant activity of various extracts and fractions of Chenopodium quinoa and Amaranthus spp. seeds. Food Chem 2008, 106: 760-66.
23. Kulczak M, Przygoński K, Remiszewski M. Aktywność antyoksydacyjna wybranych ekstrudowanych produktów zbożowych. Bromat Chem Toksykol 2011, 44(3): 939-44.