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ORIGINAL PAPER

Chemical and Functional Characterization of Kañiwa (*Chenopodium pallidicaule*) Grain, Extrudate and Bran

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Abstract Cereals provide a good source of dietary fibre and other important compounds with nutritional potential, such as phenolic compounds, antioxidants, minerals and vitamins. Although native Andean cereals are known to have high nutritional value, their minor components have not been studied thoroughly. In this study, two varieties of a native Andean crop, kañiwa (*Chenopodium pallidicaule*), were investigated as sources of dietary fibre and specific antioxidant compounds. Two products, an extrudate and bran, were also prepared and their functional properties and bioactive compounds were determined. Both varieties were rich in total dietary fibre and lignin, and the phenolic components analyzed had high antioxidant activity. The extrudates had good functional properties, such as degree of gelatinization, sectional expansion index and water solubility index; the bran was high in bioactive compounds, such as total phenolics. In conclusion, kañiwa may offer an alternative to traditional cereals as a health-promoting food ingredient.

Keywords *Chenopodium pallidicaule* · Dietary fibre · Extrusion · kañiwa

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Abbreviations

CEC	cation exchange capacity
d.b.	dry basis
DG	degree of gelatinization
DPPH	2,2-diphenyl-1-picrylhydrazyl
IIF	insoluble indigestible fraction
SD	standard deviation
SEI	sectional expansion index
SIF	soluble indigestible fraction
TIF	total indigestible fraction
WAI	water absorption index
WSI	water solubility index

Introduction

Kañiwa (*Chenopodium pallidicaule*) is a remarkably nutritious grain from the Andean highlands. Its protein content and quality is exceptional and it is also rich in micronutrients such as iron and calcium. It is grown on Andean highland plateaus at over 4,000 m.a.s.l. For people who live on subsistence agriculture in the *altiplano*, kañiwa is extremely important as a main source of calories and good quality proteins. It is a resistant plant that flourishes in poor and rocky soil and can survive frosts and drought. Kañiwa is usually unaffected by snowstorms and strong winds that destroy fields of barley and even its parent, quinoa (*Chenopodium quinoa*) [1]. When all other crops fail, kañiwa still provides food for highland farmers, thus securing their survival.

Kañiwa is not a true cereal equivalent to its parent crop quinoa. This annual, herbaceous plant is 0.2–0.7 m high and its seeds are 1.0–1.2 mm long. Red, yellow or green colour variation occurs in the stalks and leaves of kañiwa. It also varies in precocity: one kind matures within only 95 days from the sowing date, although most varieties require about 150 days before they can be harvested [2]. At the time of the Spanish conquest, both kañiwa and quinoa were considered very important foods in high Andean highlands. At present, kañiwa is grown mainly in the Peruvian and Bolivian *altiplano*. Kañiwa is mainly grown by families for their own consumption. Kañiwa is normally prepared as *kañi-waco*, toasted kañiwa flour. This nutty-tasting flour is mixed with water or milk and eaten as breakfast. It is taken by local people on their long travels, because of its high caloric and protein value. Kañiwa flour can be used in bread, noodles and pastry. Some varieties of kañiwa expand when toasted and can be included in sweets and snacks. Kañiwa can also be used in weaning food mixtures.

Kañiwa is used in traditional medicine in the Andes, its stem ash, *llipta,* is used when chewing coca leaves. *Llipta* is rich in calcium and provides this essential nutrient to the diet of highland people. The nutritional value of kañiwa has been studied by White et al. [3], deBruin [4] and Gross et al. [5]. White et al. [3] discovered that the nutritional value of kañiwa proteins is equivalent to that of milk proteins. Gross et al. [5] reported that kañiwa contains 15.3% protein and a nutritionally balanced amino acid composition. The chemical score of amino acids in kañiwa is high [6]. Unlike its parent quinoa, which contains bitter tasting saponins, kañiwa can be used directly as food without washing. Although it was thought that it did not contain saponins, Rastrelli et al. [7] found seven triterpene saponins in kañiwa seed; however, the content is very low and the saponins do not give the product a bitter taste. Kañiwa is relatively rich in oil containing mainly unsaturated fatty acids. The content of tocopherols in kañiwa oil is higher than that of corn oil [6].

There are several studies that confirm that whole grain cereals protect the body against age-related diseases such as diabetes, cardiovascular diseases and some cancers [8]. The components responsible for this protective effect include dietary fibre, polyphenols, vitamins and minerals. In general, there are very few studies on the minor components of kañiwa. In one of them, Rastrelli et al. [9] isolated and characterized two new flavanol glycosides in kañiwa. Peñarrieta et al. [10] determined the total antioxidant capacity and the content of phenolic compounds in Bolivian kañiwa varieties. We did not find any study on dietary fibre in kañiwa. Furthermore, there are no studies on processed kañiwa products, their nutritional value and functional properties.

Consequently, the aims of this study were to evaluate two varieties of kañiwa (*Chenopodium pallidicaule*) grain, as sources of dietary fibre and other nutritionally bioactive compounds, and to obtain kañiwa extrudate and bran. The functional properties of these products were determined as well as their content of dietary fibre and bioactive compounds.

Experimental

Materials

Two varieties of kañiwa (*Chenopodium pallidicaule*)—'Cupi' and 'Ramis'—were obtained from the Agrarian Experimental Station Illpa, department of Puno, Peru.

Preparation of Kañiwa Bran The kañiwa grain was cleaned using a sifting machine with sieves of 1.40 and 0.85 mm. After the cleaning the grain was milled in a laboratory mill, Cyclotec 1093 (FOSS Inc. Denmark), using 1.00 mm mesh. The meal was then sieved with sieves of 0.425 and 0.212 mm to obtain bran of two different particle sizes.

Extrusion Process The kañiwa grain was cleaned by sifting with sieve No. 16 US Standard Sieves ASTM. Five hundred grams of cleaned grain were placed in plastic bags for the humectation process. The grain was moistened to three different humidity levels (12, 14, 16%) for extrusion. Three replicates were run for each humidity level.

The extrusion process was carried out at 180 °C, with a screw speed of 254.5 rpm and a residence time of 10–13 s. The extruder was a single screw extruder manufactured by Jarcon del Peru, Huancayo, Peru. No external heat was transferred to the barrel of the screw during extrusion. The aim was to produce results applicable to local conditions where this low cost technology is widely used.

Analysis

Chemical Analysis

Proximate Analysis Water content, proteins (N ×6.25), fat, crude fibre and ashes were determined according to the AOAC [11]. Carbohydrates (CHO) were calculated by difference using the formula $CHO = 100 - (moisture + fat + protein + crude\ fibre + ash)$

Dietary Fibre The total, soluble and insoluble dietary fibre were analyzed by an enzymatic-gravimetric method according to the Approved Method 32–21 [12] using the TDF-100 kit from Sigma Chemical Company (St. Louis, MO, USA).

Lignin Lignin was determined in accordance with the Approved Method 32–25 [13]. The method includes selective enzymatic removal of starch using a thermostable alpha-amylase and an amyloglucosidase; precipitation of soluble polysaccharides with 80% ethanol; and hydrolysis of amylase-resistant polysaccharides (precipitated and insoluble) with sulphuric acid. Klason lignin (sulphuric acid lignin) was calculated gravimetrically as the acid-insoluble residue after correction for ash.

Beta-Glucans The content of beta-glucans was determined according to the AOAC [11], method 995.16. Extracts were hydrolyzed with lichenase and betaglucosidase. Reducing sugars in the aliquots were determined using 3,5-dinitrosalicylic acid reagent. Anhydrous glucose was used as the reference compound.

Resistant Starch Resistant starch (RS) content was analyzed using the methodology according to the Approved Method 32–40, AACC [13].

Phytate Phytic acid was determined according to Schmidt-Hebbel [14]. This method is based on indirect iron (III) complexometry.

Antioxidant Activity Antioxidant activity was determined according to the method of Brand-Williams et al. [15] based on the decrease of absorbance at 515 nm produced by reduction of DPPH (2, 2-diphenyl-1-picrylhydrazyl) by an antioxidant. Trolox was used as the reference compound.

Total Phenolics The content of total phenolics was analyzed according to the method of Swain and Hillis [16]. The phenolic compounds were extracted with methanol and the extract was allowed to react with the Folin–Ciocalteau phenol reagent. The absorbance was measured at 725 nm. Gallic acid equivalents were determined from a standard concentration curve.

Fraction The indigestible fraction was determined according to the *in vitro* method of Saura-Calixto et al. [17]. This is an alternative method to dietary fibre analysis.

Physicochemical Properties

Physicochemical Properties of Extruded Kañiwa

The following indexes and properties were determined:

$$\text{Water absorption index (WAI)} = \frac{\text{g water absorbed}}{\text{g dry sample (1} - \text{soluble fraction)}}$$

$$\text{Water solubility index (WSI)} = \frac{\text{g water soluble matter}}{\text{g dry sample}}$$

The sectional expansion index (SEI) was measured as the ratio of the diameter of the extrudate to that of the die. SEI is dimensionless [18].

Degree of gelatinization (DG) [19]

Density [20]

Physicochemical Properties of Kañiwa Bran

Water-holding capacity was measured according to Robertson and Eastwood [21].

Swelling and oil absorption capacity were measured using the methods proposed by Tamayo and Bermudez [22].

Cationic exchange capacity (CEC) was tested using the methodology of McConnel et al. [23].

Statistical Analysis

Each analysis was done in triplicate and the results are expressed as means and standard deviation (SD).

The data were analyzed by analysis of variance, and Tukey's test (significance of differences $p<0.05$) was used to find significant differences between the samples and treatments.

Results and Discussion

Characterization of Two Varieties of Kañiwa Grain

Table 1 presents the proximate composition and the components of dietary fibre of raw and extruded kañiwa. Both varieties of kañiwa are good sources of protein, fat and especially of dietary fibre. Kañiwa has a higher dietary fibre content than common cereals such as wheat, rye and barley. Nyman et al. [24] reported a total dietary fibre content of 12.1%, 16.1% and 18.8% for wheat, rye and barley, respectively. The content of insoluble dietary fibre was very high for both varieties.

According to this study, kañiwa cannot be considered a good source of betaglucans because the content of this compound was very low (0.04–0.07%). Oat has about 3–7% betaglucans [25]. The lignin content was 6.88% for Cupi and 7.98% for Ramis. This content is relatively high compared to other cereals: 2.0%, 2.1%, 3.5%, 2.5%, 3.9% and 1.4%, for wheat, rye, barley, sorghum, rice and corn, respectively [24].

There were statistically significant differences between the two varieties of kañiwa in moisture, fat, crude fibre and ash content.

The content of phenolic compounds was 2.54 and 2.43 mg of gallic acid equivalent (GAE)/g for Cupi and Ramis, respectively (Table 2). This content is higher than in oat [26], buckwheat, quinoa and rice [27]. Yawadio et al. [27] analyzed the total phenolic compounds in quinoa and amaranth (*A. hypochondriacus*, *A. cruentus*) and found a content between 94.3 and 148 mg/g tannic acid equivalent. Phytate content for the two kañiwa varieties was very similar, at about 8.0 mg/g, which is higher than in amaranth

Table 1 Composition of raw and extruded kañiwa varieties 'Cupi' and 'Ramis'

Component	Raw grain		Extruded	
	Cupi	Ramis	Cupi	Ramis
Moisture %	10.37±0.19	11.79±0.10	4.08±0.56	3.67±0.18
Proteins %	14.41±0.26	14.88±0.46	14.33±0.26	13.93±0.55
Fat %	5.68±0.02	6.96±0.24	5.47±0.08	5.79±0.03
Crude fibre %	11.24±1.15	8.18±0.02	4.33±0.08	4.79±0.42
Ash %	5.03±0.21	4.33±0.26	4.48±0.10	3.98±0.39
Carbohydrates %	63.64	65.65	71.39	71.51
Total dietary fibre %	25.24	25.95	18.93	20.12
Soluble dietary fibre%	2.98±0.42	2.79±0.57	2.00±1.06	2.24±1.59
Insoluble dietary fibre %	22.27±2.30	23.16±0.89	16.93±0.99	17.88±2.40
Resistant starch %	0.24±0.03	0.26±0.04	0.43±0.01	0.31±0.03
Lignin %	6.88±0.34	7.98±1.04	6.30±0.27	5.61±0.22
Betaglucans %	0.07±0.02	0.04±0.04	0.07±0.01	0.01±0.01

All data are the mean ±SD of three replicates. All the contents are shown in g/100 g dry weight except moisture, which is shown in g/100 g fresh weight. Extrusion conditions: temperature 180 °C, moisture 12 g H_2O/100 g dry weight

(3.4–6.1 mg/g [28]) but lower than common cereals. Gualberto et al. [29] found 14.2, 43.2 and 52.7 mg/g of phytate in oat, rice and wheat bran, respectively. Phytic acid has long been considered as an anti-nutrient because it chelates minerals and trace elements. However, its antioxidant potential is now recognized [8].

Antioxidant activities were 4,200 and 4,050, expressed as microgrammes of trolox equivalent (TE)/g for Cupi and Ramis, respectively. These values are high compared with some other products, such as red cabbage (2,500 mcg trolox equivalent/g), potatoes (800 mcg trolox equivalent/g) and sweet potatoes (800 mcg trolox equivalent/g) [30]. Villarreal-Lozoya et al. [31] studied the antioxidant activity of different pecan cultivars using the DPPH method. They found an average antioxidant activity of 97,000 microgrammes of trolox equivalent/g. Lower values than those found in this study have been reported for other grain products: whole wheat flakes 35, whole wheat biscuit 30, whole grain oat flake 27, whole grain puffed oat 26, and corn flakes 20 µmol trolox/g sample [32]. The antioxidant activity of kañiwa is lower than that of blueberries and purple corn. Cevallos-Casals and Cisneros-Zevallos [33] used the same method as us, resulting in a value of 35,232 microgrammes trolox eq./g (dry basis) for blueberries and 23,132 microgrammes trolox eq./g (dry basis) for purple corn. Campos et al. [34] studied the antioxidant activity of Andean native potatoes and other less well-known Andean tubers, mashua, oca and ulluco. They obtained values from 483 to 9,800 mcg trolox eq./g. Peñarrieta et al. [10] analyzed the total antioxidant capacity in ten samples of Bolivian kañiwa using the ABTS and FRAP method; their values were lower than our values. This could be due to the different extraction procedure used.

Table 2 Phenolic compounds, phytates and antioxidant activity in two varieties of kañiwa grain

Variety	Phenolic compounds, mg gallic acid equivalent/g d.b.	Phytate % d.b.	Antioxidant activity microgrammes trolox eq./g d.b.
Cupi	2.54±1.20	0.83±0.03	4200±5.50
Ramis	2.43±1.35	0.84±0.04	4050±5.33

All data are the mean ±SD of three replicates

Characterization of Extruded Kañiwa

The content of fat and crude fibre was reduced during the extrusion process. There was a significant decrease in the total and insoluble dietary fibre content of both varieties of kañiwa. Frolich and Hestangen [35] analyzed the total dietary fibre content in rye grain and extruded rye. They observed a decrease in total dietary fibre from 16.8% to 12.7%. The content of soluble dietary fibre was also significantly decreased in both varieties according to analysis of variance. Björck et al. [36] obtained similar results in extrusion of wheat flour: the content of soluble dietary fibre decreased from 2.3% to 1.7%.

The content of resistant starch was increased during the process of extrusion, from 0.24% to 0.43% in Cupi and from 0.26% to 0.31% in Ramis. Huth et al. [37] also found an increase in resistant starch in barley during the extrusion process, especially at high temperatures (170 °C). The increase in resistant starch during the extrusion process can be explained by the modification of the amylase structure.

Gonzalez-Soto et al. [38] studied the effect of extrusion on the resistant starch content of corn and found between 1.97% and 2.05%, with a decrease as the screw velocity was increased. This is probably due to the increase in shear stress, which causes rupture in the structure of resistant

Table 3 Functional properties of two varieties of kañiwa extrudate

Variety/moisture %	DG %	SEI	Density g/ml	WAI	WSI
Cupi					
12	98.35±1.19	1.98±0.27	0.10±0.00	2.88±0.41	0.48±0.06
14	96.61±0.97	1.77±0.28	0.20±0.02	3.84±0.48	0.36±0.08
16	88.33±1.16	1.61±0.29	0.30±0.01	3.96±0.33	0.32±0.05
Ramis					
12	98.19±0.86	1.87±0.27	0.14±0.01	3.20±0.41	0.45±0.05
14	97.14±1.27	1.63±0.05	0.22±0.01	3.48±0.19	0.39±0.02
16	96.27±2.30	1.39±0.04	0.39±0.01	3.83±0.28	0.32±0.02

All data are the mean + /-SD of three replicates

DG degree of gelatinization, *SEI* sectional expansion index, *WAI* water absorption index (g H_2O/g dry sample). *WSI* water solubility index (g water soluble matter/g dry sample)

starch. Resistant starch acts as soluble fibre in the colon. It is fermented by the intestinal microflora resulting in formation of short-chain fatty acids that are protective to the colon mucosa [37]. The lignin content of Ramis and Cupi varieties was decreased in both cases.

Benchaar et al. [39] also found a decrease in lignin content from 2.3% to 1.1% for raw and extruded horse beans, respectively. The content of betaglucans in extruded kañiwa was not significant.

The three extrudates with different initial moisture were evaluated by degree of gelatinization (DG), sectional expansion index (SEI), water absorption index (WAI), water solubility index (WSI) and density g/ml, with the aim of choosing the best treatment. The results of this evaluation are presented in Table 3.

Table 3 shows that the degree of gelatinization decreased as the initial moisture of grains increased. According to Harper [40], insufficient shear stress for gelatinization of starch is achieved in raw materials with a high moisture content. The highest DG was reached at 12% of initial moisture for both varieties, with a value of 98.4% and 98.2% for Cupi and Ramis, respectively. Dogan and Karwe [18] studied the physicochemical properties of quinoa (*Chenopodium quinoa*) extrudates. They found a maximum DG of 84.4%, which is lower than the values found in our study. They used higher initial moistures (16–24%) and lower temperatures (130–170 °C) than we used (180 °C). In general, starchy materials need low feed moisture and high product temperature to reach a high DG. Materials with a high lipid content, like kañiwa, also need elevated shear stress for effective extrusion cooking [18].

The sectional expansion index decreased as initial moisture content increased. The highest SEI was achieved with the initial moisture of 12%, with values of 1.98 for Cupi and 1.87 for Ramis. The expansion of cereals in extrusion depends on the degree of gelatinization of the starch, as demonstrated here, the highest expansion index was reached at the highest degree of gelatinization. Dogan and Karwe [18] measured SEI in whole meal quinoa extrudates and found values from 0.92 to 3.58. In their study SEI was significantly affected by temperature, feed moisture content and screw speed. A high expansion ratio at low feed moisture content for extruded products is typical for cereals.

The density of the extrudate increased when the initial moisture was increased. Huth et al. [37] discovered that the density of barley extrudate increased when the initial moisture content was high. Similar results were shown by Gambus et al. [41] for corn and wheat extrudates. Lee et al. [42] mentioned that the extruded products generally have a density of between 0.1 and 0.2 g/ml. The extrudates of kañiwa with an initial moisture content of 12% had a density of 0.10 and 0.14 g/ml, for Cupi and Ramis, respectively. Gambus et al. [41] found the following values of density for corn and wheat starch extrudates: 0.23–0.30 and 0.12–0.28 g/ml. They used a higher initial moisture than we used in our study.

The water absorption index (WAI) increased when the initial moisture increased. The WAI depends on the availability of hydrophilic groups and the gel formation capacity of the macromolecules [43]. It is a measure of denatured starch together with protein denaturation and new macromolecular complex formation [18]. Extruded products should have a low WAI to maintain the crispiness of the final product. The lowest WAI was achieved at the initial moisture content of 12% for both varieties. The WAI was 2.88 and 3.20 for Cupi and Ramis, respectively. These values were lower than the values found by Dogan and Karwe [18] for quinoa extrudates.

The water solubility index (WSI) decreased as initial moisture content increased. This fact can be explained by the greater rupture of starch granules at the lower initial humidity. The highest WSI was obtained using an initial moisture of 12% for both varieties. These values were 0.48 and 0.45 for Cupi and Ramis, respectively. There is a direct correlation between the degree of gelatinization and WSI. Low moisture content in the raw material in extrusion enhances the friction and the energy dissipation to the product, causing the dextrinization of the starch and, at the same time, improving the WSI. According to Gutkoski and

Table 4 Physicochemical properties (water-holding capacity, swelling capacity, oil absorption capacity, cation exchange capacity) of kañiwa bran

Properties	Cupi		Ramis	
	Particle size mm		Particle size mm	
	0.425	0.212	0.425	0.212
Water-holding capacity g H_2O/g fibre d.b.	5.42±0.15 a,x	3.54±0.07 a,y	4.66±0.26 b,x	3.30±0.09 b,y
Swelling capacity ml H_2O/g fibre d.b.	4.19±0.28 a,x	3.19±0.02 a,y	0.70±0.14 b,y	2.20±0.28 b,x
Oil absorption capacity g oil/g fibre d.b.	3.57±0.15 a,x	2.36±0.11 a,y	2.09±0.25 b,x	1.61±0.09 b,y
Cation exchange capacity meq H + /g fibre d.b.	0.57±0.05 a,x	0.37±0.01 b,y	0.44±0.04 b,y	0.42±0.04 b,y

All data are the mean ±SD of three replicates

a,*b* significant differences between the varieties; *x*,*y* significant differences between the particle size

El-Dash [44], *WSI* is a parameter that indicates the degradation of starch granules. WSI and WAI are used as parameters for the degree of cooking of cereal products.

Regarding the degree of gelatinization, sectional expansion index, water absorption index, water solubility index and density, the results demonstrated that the initial moisture content of 12% was the optimum to obtain an extrudate with good physicochemical characteristics.

Characterization of Kañiwa Bran

Table 4 presents the physicochemical properties of kañiwa bran of two different particle sizes. The water holding capacity was between 3.30 and 5.42 g H_2O/g. The effect of two factors, variety and particle size, were significant according to analysis of variance. Cupi had a higher water-holding capacity than Ramis, and the fibres of larger particle size also demonstrated a higher capacity than the fibres of smaller particle size. This can be partly explained by the reduction of pores or intercellular spaces in the smaller particles [45]. This property is important for dietary fibre from a technological and physiological point of view. Fibre-rich fractions with high water-holding capacity can be used as functional ingredients to avoid syneresis and to modify viscosity and texture in food products. Physiologically this kind of fibre is related to an increase in faecal bulk and fermentability of fibre in the gut [46]. The hydration properties of fibre depend on the physicochemical nature of the fibre constituents, especially of soluble fibre. Generally cereal fibre has a water-holding capacity between 5 and 10 g H_2O/g of fibre [46].

Cupi had a higher swelling capacity than Ramis. Particle size affected this property differently in the two varieties. In the case of Cupi the swelling capacity decreased with decreasing particle size. In Ramis the effect was the opposite: there was an increase in swelling capacity with smaller particle size.

In both varieties, the oil absorption capacity decreased when the particle size of the bran decreased. Cupi had higher values than Ramis. Generally, these differences were statistically significant. This property is important from the physiological point of view. Fibre with a high oil absorption capacity can have a beneficial effect in intestinal absorption of lipids. Dietary fibre decreases the absorption of lipids due to its effect on increasing intestinal bulk and decreasing the transit time, which hinders the action of digestive enzymes and absorption in the upper gastrointestinal tract [47].

The cation exchange capacity (CEC) decreased with decreasing particle size in Cupi. This variety had a significantly higher capacity than Ramis in the case of particles of 0.44 mm. The CEC of kañiwa bran was higher than the CEC of bran in wheat and similar to that of corn [48]. This property is related to the capacity of some fibres to form insoluble complexes with inorganic ions. This may cause an increase in faecal excretion of some nutritionally important minerals and electrolytes.

Table 5 Indigestible fraction in kañiwa bran of kañiwa varieties Cupi and Ramis

Variety	IIF (% d.b.)	SIF (% d.b.)	TIF (% d.b.)
Cupi	60.91±3.36	0.75±0.15	61.66±3.51
Ramis	54.34±0.54	1.00±0.11	55.34±0.43

All data are the mean ±SD of three replicates

IIF insoluble indigestible fraction, *SIF* soluble indigestible fraction, *TIF* total indigestible fraction

Table 6 Phenolic compounds, phytates and antioxidant activity in kañiwa bran (varieties Cupi and Ramis)

Variety	Phenolic compounds, mg gallic acid equivalent/g d.b.	Phytates % d. b.	Antioxidant activity microgrammes trolox/g d.b.
Cupi	2.18±1.33	1.70±0.00	3109±176
Ramis	2.21±0.74	1.26±0.01	2909±174

All data are the mean ±SD of three replicates

The bran of both varieties of kañiwa presented better physicochemical properties at larger particle sizes than at smaller particle sizes. The former was selected for the analysis of the indigestible fraction, total polyphenols, phytates and antioxidant activity.

The results of the evaluation of the indigestible fraction in kañiwa bran are presented in Table 5. Both varieties had a high proportion of total and insoluble indigestible fractions. The soluble portion was small. The IF is defined as the part of vegetable foods that is neither digested nor absorbed in the small intestine, but reaches the colon, where it is a substrate for the fermentative microflora. It comprises not only dietary fibre, but also other compounds of proven resistance to the action of digestive enzymes, such as a fraction of dietary starch, protein, certain polyphenols, and other associated compounds [17]. Saura-Calixto et al. [17] determined the indigestible fraction in different food samples and found values ranging from 10.28 to 43.67% for the total indigestible fraction. Our values were higher because we used kañiwa bran in this analysis.

Table 6 presents the content of total polyphenols, phytates and antioxidant activity in the bran of the two varieties of kañiwa. The antioxidant activity was reduced in kañiwa bran in comparison to grain in both varieties (Table 2); however, the content of these compounds was still high. The kañiwa bran contained more phytate than the kañiwa grain. This is probably due to the concentration of phytates in the bran fraction of the grain.

Conclusions

Kañiwa is a little known crop and this paper provides scientific information on its nutritional and functional properties and potential uses. Both studied varieties of kañiwa had a high content of protein and dietary fibre, especially of the insoluble fraction. Kañiwa grain is also an excellent source of phenolic compounds and has very high antioxidant activity. The extrudate with a 12% initial moisture level showed the best functional properties, such as the degree of gelatinization, density, sectional expansion index and water solubility index. Kañiwa bran of large particle size presented better functional properties than the bran with small particle size. This bran is an important source of the indigestible fraction, and can be used as an ingredient in healthy foods because of these antioxidant nutrients and dietary fibre. The extrudate of kañiwa also offers an ingredient that should be assessed by the food industry because of its functional properties and high nutrient content.

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References

1. National Research Council (1989) Lost crops of the Incas: Little-known plants of the andes with promise for worldwide cultivation. National Academy Press, Washington, DC
2. Gade D (1970) Ethnobotany of cañihua (*Chenopodium pallidicaule*), rustic seed crop of the Altiplano. Econ Bot 24:55–61
3. White P, Alvistur E, Dias C, Vinas E, White H, Collazos C (1955) Nutrient content and protein quality of quinoa and cañihua, edible seed products of the Andes mountains. J Agric Food Chem 6:531–534. doi:10.1021/jf60052a009
4. DeBruin A (1964) Investigation of the food value of quinoa and cañihua seed. J Food Sci 26:872–876
5. Gross R, Koch F, Malaga I, de Miranda A, Schöneberger H, Trugo L (1989) Chemical composition and protein quality of some local Andean food sources. Food Chem 34:25–34. doi:10.1016/0308-8146(89)90030–7
6. Repo-Carrasco R, Espinoza C, Jacobsen S-E (2003) Nutritional value and use of the Andean crops quinoa (*Chenopodium quinoa*) and kaniwa (*Chenopodium pallidicaule*). Food Rev Int 19:179–189. doi:10.1081/FRI-120018884
7. Rastrelli L, De Simone F, Schettino O, Dini A (1996) Constituents of *Chenopodium pallidicaule* (canihua) seeds: isolation and characterization of new triterpene saponins. J Agric Food Chem 44:3528–3533. doi:10.1021/jf950253p
8. Fardet A, Rock E, Remesy C (2008) Is the *in vitro* antioxidant potential of whole-grain cereals and cereal products well reflected *in vivo*. J Cer Sci 48(2):258–276. doi:10.1016/jcs.2008.01.002
9. Rastrelli L, Saturnino P, Schettino O, Dini A (1995) Studies on the constituents of *Chenopodium pallidicaule* (canihua) seeds. Isolation and characterization of two new flavonol glycosides. J Agric Food Chem 43:2020–2024. doi:10.1021/jf00056a012
10. Peñarrieta M, Alvarado A, Åkesson B, Bergenståhl B (2008) Total antioxidant capacity and content of flavonoids and other phenolic compounds in canihua (*Chenopodium pallidicaule*): An Andean pseudocereal. Mol Nutr Food Res 52:708–717. doi:10.1002/mnfr.200700189
11. AOAC (1995) Official methods of analysis, 15th edn. Association of Official Analytical Chemists, Washington, DC
12. AACC (1995) Approved Methods of the AACC, 10th edn. American Association of Cereal Chemists, St. Paul
13. AACC (2000) Approved Methods of the AACC, 10th edn. American Association of Cereal Chemists, St. Paul
14. Schmidt-Hebbel H (1986) Toxicos quimicos en alimentos: Avances en su identificación, prevision y deintoxicacion. Editorial Fundacion Chile, Santiago
15. Brand-Williams W, Cuvelier M, Berset C (1995) Use of free radical method to evaluate antioxidant activity. Lebenson Wiss Technol 28:25–30. doi:10.1016/S0023-6438(95)80008-5
16. Swain T, Hillis E (1959) The phenolic constituents of *Prunus domestica*. J Sci Food Agric 10:63–68. doi:10.1002/jsfa.2740100110
17. Saura-Calixto F, Garcia-Alonso A, Goñi I, Bravo L (2000) *In vitro* determination of the indigestible fraction in foods: An alternative to dietary fiber analysis. J Agric Chem 48:3342–3347. doi:10.1021/jf0000373
18. Dogan H, Karwe M (2003) Physicochemical properties of quinoa extrudates. Food Sci Technol Int 2:101–114. doi:10.1177/1082013203009002006
19. Birch G, Priesty R (1973) Degree of gelatinization of cooked rice. Stärke 25:98–103. doi:10.1002/star.19730250308

20. Muller H (1978) Introducción a la Reología de los Alimentos. Editorial Acribia, Zaragoza
21. Robertson J, Eastwood M (1981) A method for measure the water-holding properties of dietary fiber using suction pressure. Br J Nutr 46:247–255. doi:10.1079/BJN19810030
22. Tamayo Y, Bermudez A (1998) Los residuos vegetales de la industria de jugo de naranja como fuente de fibra dietetica. In: Lajolo F, Wenzel E (eds) Temas en Tecnología de Alimentos. Cyted, Sao Paolo, pp 181–189
23. McConnel A, Eastwood M, Mitchell W (1974) Physical characteristics of vegetable foodstuffs that would influence bowel function. J Sci Food Agric 25:1457–1464. doi:10.1002/jsfa.2740251205
24. Nyman M, Siljeström M, Pedersen B, Bach Knudsen K, Asp N, Johansson C, Eggum O (1984) Dietary fiber content and composition in six cereals at different extraction rates. Cer Chem 61:14–19
25. Charalampopoulus D, Wang R, Pandiella S, Webb C (2002) Application of cereals and cereal components in functional foods: A review. Int J Food Micr 79:131–141. doi:10.1016/S0168-1605(02)00187-3
26. Gorinstein S, Medina Vargas O, Jaramillo N, Arnao Salas I, Martinez Ayala A, Arancibia-Avila P, Toledo F, Katrich E, Trakhtenberg S (2007) The total polyphenols and the antioxidant potentials of some selected cereals and pseudocereals. Eur Food Res Technol 225:321–328. doi:10.1007/s00217-006-0417-7
27. Yawadio Nsimba R, Kikuzaki H, Konishi Y (2008) Antioxidant activity of various extracts and fractions of *Chenopodium quinoa* and *Amaranthus spp*. seeds. Food Chem 106:760–766. doi:10.1016/j.foodchem.2007.06.004
28. Guzman-Maldonado S, Paredes-Lopez O (1998) Functional products of plants indigenous to Latin America. Amaranth and quinoa, common beans and botanicals. In: Mazza G (ed) Functional foods. biochemical and processing aspects. Technomic Publishing Company, Lancaster, pp 293–328
29. Gualberto D, Bergman C, Kazemzadeh M, Weber C (1997) Effect of extrusion processing on the soluble and insoluble fiber and phytic acid contents of cereal brans. Plant Foods Hum Nutr 51:187–198. doi:10.1023/A:1007941032726
30. Reyes F, Villareal E, Cisneros-Zevallos L (2007) The increase in antioxidant capacity after wounding depends on the type of fruit or vegetable tissue. Food Chem 101:1254–1262. doi:10.1016/j.foodchem.2006.03.032
31. Villarreal-Lozoya J, Lombardini L, Cisneros-Zevallos L (2007) Phytochemical constituents and antioxidant capacity of different pecan [*Caraya illinoinensis* (Wangenh.) K. Koch] cultivars. Food Chem 102:1241–1249. doi:10.1016/j.foodchem.2006.07.024
32. Miller H, Rigelhof F, Marquart L, Prakash A, Kanter M (2000) Whole grain products and antioxidants. Cereal Foods World 45:59–63
33. Cevallos-Casals B, Cisneros-Zevallos L (2003) Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweet potato. J Agric Food Chem 51:3313–3319. doi:10.1021/jf034109c
34. Campos C, Noratto G, Chirinos R, Arbizu C, Roca W, Cisneros-Zevallos L (2006) Antioxidant capacity and secondary metabolites in four species of Andean tuber crops: native potato (*Solanum* sp.), mashua (*Tropaeolum tuberosum* Ruiz & Pavo' n), Oca (*Oxalis tuberosa* Molina) and ulluco (*Ullucus tuberosus* Caldas). J Sci Food Agric 86:1481–1488. doi:10.1002/jsfa.2529
35. Frochlich W, Hestangen B (1982) Dietary fiber content of different cereal products in Norway. Cer Chem 60:82–83
36. Björck M, Nyman M, Asp N (1984) Extrusion cooking and dietary fiber. Effects on dietary fiber content and on degradation in the rat intestinal tract. Cer Chem 61:174–179
37. Huth M, Dongowski G, Gebhardt E, Flammet W (2000) Functional properties of dietary fiber enriched extrudates from barley. J Cereal Sci 32:115–128. doi:10.1006/jcrs.2000.0330
38. Gonzalez-Soto R, Sanchez-Hernandez L, Solorzaferia J, Nuñez-Santiago C, Flores-Huicochea E, Bello-Perez A (2006) Resistant starch production from non-conventional starch sources by extrusion. Food Sci Technol Int 12:5–11. doi:10.1177/1082013206060735
39. Benchaar C, Vernay M, Bayourthe C, Moncoulon R (1994) Effects of extrusion of whole horse beans on protein digestion and amino acid absorption in dairy cows. J Dairy Sci 77:1360–1371
40. Harper J (1981) Extrusion of foods. Volume I and II. CRC, Boca Raton
41. Gambus H, Golachowski A, Bala-Piasek A, Ziobro R, Nowotna A, Surowka K (1999) Functional properties of starch extrudates. Part 1. Dependence of extrudate properties on starch water content. Electronic Journal of Polish Agricultural Universities. Food Sci Technol 2:1–6
42. Lee E, Ryu G, Lim S (1999) Effects of processing parameters on physical properties of corn starch extrudates expanded using supercritical CO_2 injection. Cer Chem 76:63–69. doi:10.1094/CCHEM.1999.76.1.63
43. Gomez M, Aguilera J (1983) Changes in the starch fraction during extrusion cooking of corn. J Food Sci 48:378–381. doi:10.1111/j.1365-2621.1983.tb10747.x
44. Gutkoski L, El-Dash A (1999) Effect of extrusion process variables on physical and chemical properties of extruded oat products. Plant Foods Hum Nutr 54:315–325. doi:10.1023/A:1008101209353
45. Fernandez M, Rodriguez J (2001) Tecnologia para la obtencion de fibra dietética a partir de materias primas regionales. La experiencia en Cuba. In: Lajolo F, Saura-Calixto F, Wittig E, Wenzel E (eds) Fibra Dietética en Iberoamérica: Tecnologia y Salud. Editorial Varela, Sao Paulo, pp 211–236
46. Lopez G, Ros G, Rincon F, Periago M, Martinez C, Ortuño J (1997) Propiedades funcionales de la fibra dietética. Mecanismos de acción en el tracto gastrointestinal. Arch Latinoam Nutr 47:203–207
47. Ramos S, Moulay L, Granado-Serrano A, Vilanova O, Muguerza B, Goya L, Bravo L (2008) Hypolipidemic effect in cholesterol-fed rats of a soluble fiber-rich product obtained from cocoa husk. J Agric Food Chem 56(16):6985–6993. doi:10.1021/jf8009816
48. Zambrano M, Melendez R, Gallardo Y (2001) Propiedades funcionales y metodologia para su evaluacion en fibra dietetica. In: Lajolo F, Saura-Calixto F, Wittig E, Wenzel E (eds) Fibra Dietetica en Iberoamérica: Tecnologia y Salud. Varela, Sao Paulo, pp 195–209