Food Chemistry **34** (1989) 25–34

Chemical Composition and Protein Quality of Some Local Andean Food Sources

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(Received 11 May 1988; revised version received and accepted 21 November 1988)

ABSTRACT

The chemical composition of tubers of Tropaeolum tuberosum, Oxalis tuberosa, Iliacus tuberosum *and the seeds of* Chenopodium quinua, Chenopodium padillicaule, Amaranthus caudatus *and* Lupinus mutabilis *was studied. The protein efficiency ratios (PER) of* quinua, *amaranth and lupin were also investigated. The results show that the native Andean tubers constitute sources of highly digestible carbohydrates, whereas the cereal-like grains are characterized by a protein content higher than that found in cereals, and an excellent protein quality. The Andean lupin possesses the advantage of an extremely high protein and energy density, although protein quality is low; this advantage, however, can be overcome by mixing with other traditional Andean food crops. It can be concluded that diets based on well-combined local food sources consititute an inexpensive, ecologically useful and physiologically adequate contribution to combat widespread malnutrition in the Andean area.*

INTRODUCTION

In contrast to the Old World, where animal food sources were much more common, the diet of the Andean population of South America was based

Food Chemistry 0308-8146/89/$03·50

mainly on plants rather than on animal products (Gross, 1986). Animal domestication was limited to the lama (*Lama glama*), the alpaca (*Lama pacus*) and the guinea pig. However, plant breeding underwent a remarkable development, resulting in a large variety of food plants until the conquest of Peru by Spain.

South American crops, such as potatoes (*Solanum tuberosum*), manioc (*Manihot esculenta*) and groundnut (*Arachis hypogaea*) are some examples which were readily adopted by Old World agriculture. However, even now the chemical composition and nutritional value of many pre-Columbian food sources are not well established.

Therefore, it is the purpose of this paper to assess the nutritional value of seven traditional Andean food items as part of a major technical co-operation project involving the Republic of Peru and the Federal Republic of Germany, the purpose of which is to decrease the genetic erosion of pre-Colombian crops and consequently to make food production more compatible with food habits and local ecology (Schoeneberger *et al.*, 1987). This effort is designed to improve the nutritional situation of small-holder families by increasing the utilization of local available food sources.

MATERIALS AND METHODS

Table 1 lists the products investigated according to their taxonomic and local names. All raw products were bought from local production sources in Cuzco, Peru. The tubers were sliced and carefully dried overnight at 60°C. The grain samples were ground in a hammer mill (100 mesh = 0·149 mm) and then homogenized. The grain samples used in the biological tests to measure the protein quality were first boiled for 30 min to destroy any

TABLE 1
Taxonomic and Local Names of the Andean Plants Studied

Plant material	*Taxonomic name*	*Local names*
Tubers	*Tropaeolum tuberosum*	*mashua, añu, año, isaña*
	Oxalis tuberosa	*oca, uncke, uncha, apilla*
	Ullucos tuberosum	*olluco, ulluco, papaliza, ulluma, ruba, melloco*
Seeds	*Chenopodium quinua*	*quinua*
	Chenopodium padillicaule	*kañihua*
	Amaranthus caudatus	*kiwicha, achita, millima*
	Lupinus mutabilis	*tarwi, tauri, chocho*

existing antinutritive substances. In the case of Andean lupin (*tarwi*), the seeds were boiled and then steeped in running water for 4 days to remove the bitter taste originating from toxic alkaloids. The saponins of *quinua* and *kañihua* were removed by soaking the seeds in running water for several hours until no foam was observed in the water. After the leaching process the seeds were dried and milled as described above.

Moisture, nitrogen, fat, crude fibre and ash were determined following AOAC procedures (Williams, 1984). Since no studies on protein characterization are available for the surveyed food sources the factor N × 6·25 was used to convert nitrogen into crude protein. Amino acid contents were determined by ion-exchange chromatography using the method described by Spindler *et al.* (1984), with norleucine as an internal standard. To convert methionine and cystine to the stable forms methionine acid and cysteic acid, the samples were treated with performic acid reagent for 16 h and, after this, hydrolyzed with 6N hydrochloric acid for 24 h. Analysis was carried out with an amino acid analyzer (Biotronic LC 2000) and computed with the Integrator (Spectra Physics 4270). Tyrosine, phenylalanine and histidine were analyzed without oxidation pretreatment. Tryptophan was determined after alkaline hydrolysis with lithium hydroxide (4·3 mol/litre) by HPLC detection. For separation a reversed phase column (RP 18) was used, followed by UV-detection at 217 nm.

Monosaccharides and oligosaccharides were determined by high pressure liquid chromatography (HPLC), using the method described by Macrae & Zand-Moghaddam (1978) using a KNAUER chromatograph with a Spherisorb-NH_2 column (250 × 4·6 mm id) and a refractive index detector. Acetonitrile/water (72:18) was used at a flow rate of 1·5 ml/min.

All samples were analyzed twice, and the average of both analyses was taken as the result. When the data of the two analyses differed by more than 5% a third analysis was carried out to check variation within limits of acceptance.

In the animal experiments, 10 weanling albino rats of the Sprague-Dawley strain were used per diet. The animals were bred and maintained in the experimental laboratory, and received an adaptation diet consisting of equal parts of their maintenance diet and the test diet for 3 days prior to the experiments. The protein efficiency ratio (PER) and apparent digestibility were determined following the AOAC method, using casein, soluble in alkali (Merck, Darmstadt, West Germany) for the control diet and corn oil instead of cottonseed oil up to 5%. Protein contents of all diets were adjusted to 10% of dry weight, and the moisture contents were 10%. For the calculation of apparent digestibility the fecal excretion of nitrogen was measured during the last week of the PER assay.

The serum urea concentration was then taken as a second parameter for

evaluating the protein quality of the seeds (Schoeneberger & Gross, 1982). When only small amounts of seed were available, protein quality was evaluated biologically from the serum urea concentration, using the short term urea assay (STUA) (Gross *et al.*, 1982). Groups of 10 animals were sacrificed and blood was collected for determination of urea, using the method of Fawcett & Scott (1960).

RESULTS

On the basis of their main constituents shown in Table 2, the food sources investigated may be separated into three groups: rich in carbohydrates; rich in proteins and carbohydrates; and rich in lipids and proteins. The tubers represent the first group. Due to a high water content (> 80%), these samples display a very low energy density in fresh material.

The grains of *quinua*, *kañihua* and amaranth (*kiwicha*), representing the second group, offer carbohydrates and significant amounts of protein (about 15%), which are higher than the protein contents of cereals. In the case of the amaranth grains 13 different varieties were studied for variability of protein content. This was found to range from 14·6 to 19% of dry matter (mean: 16·2; SD: 1·3).

The lupin grain represents the third group, with a very high protein and energy content. Protein and lipid together represent more than 60% of the dry seed.

Table 3 shows the composition of monosaccharides and oligosaccharides found in the food sources surveyed. Again the three groups of food sources can be differentiated according to their saccharide constituents. The main free sugar of the *quinua–kañihua–kiwicha* group was sucrose at 2 to 3% of

TABLE 2
Proximate Composition of the Plant Samples Investigated

	Quinua	Kañihua	Kiwicha	Tarwi	Mashua	Oca	Olluco
Moisture (%)	9·5	9·8	10·2	9·8	84·5	86·2	87·6
Protein[a] (N × 6·25)	15·5	15·3	15·5	43·1	7·7	5·6	8·5
Oil[a]	8·2	7·8	7·6	20·9	1·0	1·0	1·4
Fibre[a]	6·5	7·0	4·7	6·8	0·7	1·4	0·5
Ash[a]	3·5	3·5	3·4	2·8	4·8	4·1	5·4
Carbohydrates[b]	66·3	66·4	68·8	26·4	85·8	87·9	84·2

[a] As % dry matter.
[b] Calculated by difference.

TABLE 3
Saccharide Pattern of the Plant Samples Studied

Mono- and oligosaccharides	Quinua	Kañihua	Kiwicha	Tarwi	Oca	Olluco
Fructose	0	0	0	0	0	11·13
Glucose	0·19	0·14	0·06	0	3·63	13·18
Sucrose	2·79	3·03	2·11	1·56	20·92	6·08
Raffinose	0·15	0·16	0·79	1·24	0·18	0·74
Stachyose	0·08	0·06	0·20	4·67	0·68	0
Verbascose	0	0	0	3·87	0	0
α-Galactosides	0·23	0·22	0·99	9·87	0·86	0·74

Results are quoted in g% dry matter.

dry weight. The indigestible α-galactoside content did not exceed 1%. The tubers also showed a low α-galactoside content, which was again less than 1%. Sucrose was identified as the main sugar in *oca* (21%), whereas glucose and fructose dominated in *olluco*, giving in both cases a very high content of digestible free sugars. The third group, represented by the lupin sample, showed a very high content of α-galactosides (about 10%) with the only detectable digestible sugar being sucrose, at about 1·5%.

TABLE 4
Amino Acid Pattern of the Plant Samples Tested
(Results are expressed in g/16 gN)

Amino acid	Quinua[a]	Kañihua[a]	Kiwicha[b]	Tarwi[a]	Mashua	Oca	Olluco	*FAO*[c]
Isoleucine	4·1	3·7	3·6	4·7	2·9	2·6	3·9	4·0
Leucine	7·6	6·7	5·9	7·1	4·1	3·7	5·5	7·0
Lysine	6·7	5·8	6·4	5·8	5·0	4·1	3·7	5·5
Methionine	2·9	2·1	2·5	0·9	1·1	1·1	1·7	
Cystine[d]	1·8	2·0	2·3	1·1	1·4	1·0	1·4	
Met + Cys	4·7	4·1	4·8	2·0	2·5	2·2	3·1	3·5
Phenylalanine	4·3	3·9	3·9	3·8	2·9	3·2	4·0	
Tyrosine	3·3	2·9	3·3	4·0	2·3	2·2	3·0	
Phe + Tyr	7·6	6·8	7·2	7·8	5·2	5·4	7·0	6·0
Threonine	4·5	3·7	3·6	3·8	3·3	3·1	3·7	4·0
Tryptophan	1·0	1·0	1·2	0·8	1·2	1·0	1·0	1·0
Valine	5·3	4·8	4·6	4·1	5·5	4·0	5·0	5·0

[a] Boiled, leached and dried.
[b] Boiled and dried.
[c] Reference protein pattern according to FAO/WHO (1973).
[d] Cystine/cysteine.

The amino acid composition of all seven food sources tested is shown in Table 4, in comparison with the FAO reference pattern. According to this pattern the grains of *quinua* obviously present the best amino acid profile, since there is no deficiency of any essential amino acid. The seeds of *kañikua* also show an excellent amino acid pattern, although some of them are present in amounts slightly lower than those recommended. The limiting essential amino acids of the grains of amaranths are isoleucine, leucine and valine. The first three grains show the common characteristic of a higher percentage of sulphurous amino acids and lysine, which are often lacking in plant food sources for human consumption. In contrast to the first group of samples studied, tubers showed many amino acids below the FAO recommendation. The protein of *olluco* comes closest to the FAO reference pattern. The lupin seeds show the typical characteristic of a grain legume protein, with sulphurous amino acids being the most unbalanced.

Table 5 gives the results of the determination of the protein efficiency ratio (PER) and the apparent digestibility of some grains in comparison to casein. The best protein quality was found in the seeds of *quinua* with a PER equal to that of casein. This outstanding result is based not only on the amino acid profile (see above), but also on the high apparent digestibility. The excellent protein quality is confirmed by the very low serum urea concentration found in the tested rats.

The grains of amaranth gave a lower PER (2·59), a low apparent digestibility (72·6) and a lower serum urea concentration in the rats. In a second experiment, the protein quality of 8 different varieties of amaranth grains was biologically assessed by STUA for variability. In this study, the serum urea concentration varied between 12·1 and 16·2 mg/ml. This difference was statistically significant ($p < 0{\cdot}05$). A correlation of $r = 0{\cdot}67$

TABLE 5
Protein Efficiency Ratio (PER), Apparent Digestibility and Serum Urea Concentrations in Rats ($n = 10$)

Grains	*PER*	*Apparent digestibility*	*Serum urea (mg/ml)*
Quinua	3·09 ± 0·09	84·1 ± 2·25	11·3 ± 3·4
Kiwicha	2·59 ± 0·13	72·6 ± 3·80	22·6 ± 3·7
Tarwi	1·53 ± 0·18	80·4 ± 2·35	47·4 ± 8·5
Quinua–Tarwi (2:1)	2·91 ± 0·08	80·0 ± 0·99	13·9 ± 4·6
Maize–*Tarwi* (1:1)	2·76 ± 0·12	76·7 ± 1·30	21·2 ± 5·4
Quinua–Maize–*Tarwi* (1:1:1)	2·98 ± 0·07	—	13·6 ± 1·9
Casein	3·10 ± 0·09	87·5 ± 1·60	25·5 ± 3·8

was found between the protein content of the amaranth grains and the serum urea concentration, although the protein concentration was balanced in all diets to within 10%, according to the STUA-method. This means that seeds with a higher protein content showed a lower protein quality.

The poorest PER and the highest serum urea concentration were observed with lupin grains. However, the apparent digestibility (80·4%) was higher than in other grains.

The PER of a *quinua*–lupin protein mixture (2·91) showed a complementary effect, since the theoretically anticipated PER of the mixture was only 2·56. The protein quality of the mixture of maize with lupin was slightly lower. When maize was substituted for *quinua* in the mixture as a third protein source, the protein quality improved to 2·98. The serum urea concentration corresponded inversely to the values of the PER in the protein mixtures, decreasing with increasing protein quality.

DISCUSSION

To date, no consistent comparisons have been made regarding the major nutrients of native Andean food sources. Only determinations of some groups of nutrients of isolated food sources of unknown genetic and geographical origin are available. In many cases a detailed description of analyses is not available. In this study, seven major Andean food crops which were produced under known conditions were analyzed using the same analytic methodology.

The native tubers studied constitute an excellent source of carbohydrates, which should be highly digestible for monogastrics because of the low content of α-galactosides and fibre and high content of digestible free sugars. The results found here are consistent with data cited by Bateman (1961), with the exception of fibre which was found to be much lower in the present study. Kays *et al.* (1979) studied the carbohydrate and protein contents of *oca*. At least 50% of the dry matter has been identified as starch. About one third of the analyzed nitrogen was of non-protein origin. Therefore, in the case of the tubers the protein content given in Table 2 seems to be too high and the conversion factor from nitrogen to protein content should be corrected to less than 6.

The chemical composition of the three seeds studied indicates that these native foodstuffs represent not only a good energy but also a valuable protein source for human consumption. As found in this study, several authors have reported protein contents in quinua grains of between 12 and 19% of dry matter (DM) (Cardozo & Bateman, 1961; De Bruin, 1964; Mahoney *et al.*, 1975; Telleria Rios *et al.*, 1978; Oke, 1978; Scarpati &

Briceno, 1980; Romero *et al.*, 1985). The protein content of *kañihua* seeds was found to be within the same range (de Bruin, 1964; Scarpati & Briceno, 1980). According to Afolabi *et al.* (1981) and Paut (1983), the protein content of amaranth grains ranged from 11 to 18% DM. All these values confirm the findings of this study and demonstrate that these cereal-like grains have a higher protein content than cereals.

Generally all Andean cereal-like grains show a high content of lysine in their protein. Oke (1978) confirms this observation in the case of *quinua* (6·6 g/16 gN). Mahoney *et al.* (1975), who published the amino acid profile of the low saponin *quinua* variety 'Sajama', found much less threonine and sulphurous amino acids than in the grains shown in Table 4. These differences might be explained by different protein hydrolyzation and chromatographic techniques used to determine the amino acid contents.

The amino acid pattern of amaranth grains reported by Carlsson (1980) was similar to the composition found in this study, with the exception of lysine, which was found to be only 5·3 g/16 gN. Oke (1978) identified 6·2 g lysine/16 gN. Afolabi *et al.* (1981) found much smaller amounts of sulphurous amino acids, lysine and histidine than shown in Table 4, probably again due to differences in methodology. According to this study, the amaranth protein is high in lysine and sulphurous amino acids, whereas isoleucine is still below FAO standards.

As well as supplying protein, the three cereal-like grains studied are an excellent source of carbohydrate. This is not only because of the high content which ranged between 66 and 69%, but also because of the high digestibility, due to the fact that the α-galactoside contents are below 1%. This was confirmed by Becker *et al.* (1981) in the case of amaranth.

The seeds of the Andean lupin are an excellent protein and energy source but, as well as their alkaloid content, the higher amounts of non-digestible α-galactosides constitute a negative characteristic (Arai *et al.*, 1978; Hudson *et al.*, 1976; Macrae & Zand-Moghaddam, 1978; Schoeneberger *et al.*, 1982). These oligosaccharides are eliminated during the traditional leaching process of alkaloid extraction (Trugo *et al.*, 1988).

The excellent amino acid profile of the native Andean cereal-like grains is confirmed by the high PER compared to cereals. The best protein quality was found in *quinua*, which was confirmed by the findings of Mahoney *et al.* (1975) and Heiser & Nelson (1974). These authors reported that the PER in cooked and leached *quinua* seed was slightly higher than or similar to that of milk. Only Romero *et al.* (1985) identified a lower PER of cooked and leached *quinua* seed, which was only 86% of that of casein.

The slightly lower PER of amaranth may be due to the lower isoleucine content and apparent digestibility of the protein.

Much has been discovered about the protein quality of the seed of the

Andean lupin. According to Schoeneberger *et al.* (1982), the lower PER is caused by a marked deficiency of sulphurous amino acids, but the protein shows a high digestibility, superior to that of most other plant proteins. Lopez de Romaña *et al.* (1983) and MacLean *et al.* (1983) reported the same findings in children.

Based on the high content of lysine in the seed of *quinua* amaranth, some authors have recommended the supplementation of cereals such as wheat with *quinua* flour (Vela & Cabrera, 1984; Weber, 1978) and several bakery products have been developed on a pilot scale. However, wheat is not produced on a large scale by the self-sufficient small-scale farmers of the Andean highlands. Therefore, those products will find their market only in urban areas. On the other hand, the data on the chemical composition and the biological surveys of the Andean food stuffs prove the excellent quality of the native plants. Deficiencies in nutrients in single species can be balanced by mixing different traditional food sources.

Although these crops are still an important food source for the small farmers in the Andean region, some decline in the utilization of these plants for human consumption has been observed. This may be due mainly to the lower yields obtained by the use of traditional production techniques, and also to the presence of different bitter and anti-nutritive substances in all the grains studied here. Although technologies are available to reduce or eliminate those undesirable substances by food processing or breeding, more interdisciplinary research is needed in agriculture and food science to overcome the disadvantages of these traditional crops in comparison with the modern food crops used in the industrialized world.

In conclusion, the data furnished by this study demonstrate that the native Andean plants are an excellent food source for the population. Therefore, from the nutritional point of view, there is little justification for an introduction and expansion of new food sources which first have to be adapted both ecologically and culturally.

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