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NUTRITIVE VALUES OF CROPS

Nutrient Content and Protein Quality of Quinua and Cañihua, Edible Seed Products of the Andes Mountains

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Quinoa (*Chenopodium quinoa,* Willd) and cañihua (*Chenopodium pallidiculae*) produce edible seeds that have been included in the diets of the Andean Indians for centuries. They are cultivated by primitive methods, usually at altitudes above 8000 feet. The total estimated production of both quinoa and cañihua in Peru is approximately 50,000 tons. Rat growth studies using either young rats or depleted adult rats showed that at equal levels of protein intake the proteins of quinoa and cañihua produced weight gains equal to or superior to those obtained with dried whole milk. Mixtures of quinoa and milk did not produce greater gains than quinoa alone. The excellent over-all nutritive value of these products and particularly the high quality of their proteins are emphasized.

Quinua (*Chenopodium quinoa*, Willd) and cañihua (*Chenopodium pallidiculae*) are plants which have been growing, either wild or cultivated, in the high Andes Mountains since long before the time of the Inca Empire. While believed by many to be native to this area, these or similar plants are found in many regions of the world (*17*). They are stock plants, 4 to 6 feet high, with large clusters of small seeds produced at the end of the stock. The seeds of both are edible and have been included in the diets of Andean Indians for centuries, although probably less so now than in the time of the Incas. Primitive agricultural methods are still used by the indigenous population in the cultivation of these products. The nature of the plants and the fact that the small seeds (2 to 4 mm. in diameter) are very loosely attached to the stock would probably make mechanized production difficult. Among other than the Andean Indians these foods have low prestige value. Many varieties of each are known; certain types of quinua possess the disadvantage that the seeds are covered with a saponin, which has a very bitter taste and must be removed prior to use by vigorous washing and scrubbing.

The total yearly production of quinua in Peru is estimated as approximately 40,000 tons and that of cañihua as 10,000 tons (*4*). Yields of quinua in the order of 440 to 800 pounds per acre are obtained with the primitive methods employed for the major proportion of its production, but yields as high as 4400 pounds per acre have been obtained under experimental conditions (*11, 13*). Although the average yield is about the same as that of wheat, quinua may be produced on land that will not support common cereals, and most of the quinua produced in Peru is grown at altitudes over 8000 feet above sea level. It may be grown at altitudes as high as 13,000 feet above sea level. It is a sturdy plant resistant to frosts and blights, and needs little water. Depending upon the variety, quinua matures in from 5 to 7 months. Although of lesser importance than quinua in terms of total production, cañihua is produced under similar conditions.

There have been several reports of the high food value of these plants, particularly that of quinua. Alcazar

Table I. Composition of Experimental Diets[a]

	Protein, %	Cal./Gram	Powdered[b] milk	Quinua	Cañihua	Sucrose	Cotton-seed oil	Cod[c] liver oil
			Grams per Kilogram of Diet					
Growth Studies (See Table IV)								
Group I	6	3.76	...	600	...	320	...	40
Group II	6	3.96	191	...	...	729	...	40
Group III	6	3.79	31	500	...	389	...	40
Group IV	9	3.54	...	900	...	20	...	40
Group V	9	3.93	281	...	...	639	...	40
Group VI	9	3.67	46	750	...	123	...	40
Depletion-Repletion Studies (See Table V)								
Depletion diet	..	...	...	...	...	700[d]	240	20
Quinua diet	9	4.1	...	750	...	95.5	94.5	20
Cañihua diet	9	4.1	...	...	662	165	113	20
Milk diet	9	4.1	337	...	...	603	...	20

[a] Each kilogram of diet contained 40 grams salts IV (*9*), 8 mg. riboflavin, 4 mg. thiamine, 40 mg. niacin, 20 mg. calcium pantothenate, 4 mg. pyridoxine, 3 mg. α-tocopherol.
[b] All powdered milk used for "growth studies" was defatted; that employed in milk diet for depletion-repletion studies was powdered whole milk (Klim).
[c] One gram contained 1800 I.U. of vitamin A and 180 I.U. of vitamin D.
[d] Cornstarch employed instead of sucrose in depletion diet.

(*2*) quoted preliminary investigations by Stare and Hegsted who showed better rat growth with either washed or unwashed quinua than with an equivalent amount of protein from casein. Mazzocco (*14*) reported that unwashed quinua when tested with weanling rats had a low biological value but, without supporting data, stated that the washed product gave growth responses equal to those obtained with whole wheat. Llanos (*11*) and Martinez (*13*) have summarized analytical data for quinua from various sources and have emphasized its high protein content. Viñas and others (*20*) reported the essential amino acid content of quinua, and a preliminary report has described rat studies designed to determine the nutritive value of this seed (*3*). This paper presents rat growth studies designed to test the nutritional quality of the proteins in quinua and cañihua, together with analytical data on amino acids and various other nutrients. Excellent overall nutritional quality is evident from the analyses. Rat growth studies demonstrate that the proteins of quinua and cañihua are equal to those of dried whole milk.

Methods and Materials

Samples of quinua and cañihua were obtained from various areas of the Andes Mountains and from the markets of Lima. Several varieties of each were used for the determination of chemical and amino acid composition. The animal studies were carried out using varieties of quinua and cañihua known as "común" (common).

Two of the quinua samples (sweet-rose and sweet-white) were free of the saponin; all other samples were carefully washed free of the soapy material and dried prior to analysis or incorporation into animal diets.

The chemical composition was determined using standard methods. Microbiological methods were used for the amino acids. Tryptophan was determined by the method of Woolley and Sebrell (*22*), using enzymatic hydrolysis and *L. arabinosus* 17–5 as the test organism. The remaining amino acids were determined using an acid hydrolyzate (24 hours' reflux with approximately 6 volumes of 4*N* hydrochloric acid). Methionine was determined employing a medium containing oxidized casein (*15*) with *L. arabinosus* 17–5; *L. mesenteroides* P-60 was employed for the determination of lysine, histidine, leucine, phenylalanine, and isoleucine; *Strep. faecalis* 8043 was used for arginine, threonine, and valine. For three samples of cañihua *L. arabinosus* was substituted for *L. mesenteroides* in the determination of isoleucine, using the medium of Schweigert and others (*18*). The basal medium used for the other determinations was essentially that of Horn and others (*10*).

Preliminary cystine analyses were made on samples in which the carbohydrate was digested with salivary amylase (*5*, p. 336). The protein was refluxed for 6 hours with 30 volumes of 2*N* hydrochloric acid and appropriate dilutions of the hydrolyzate were analyzed microbiologically, using *L. mesenteroides* as the test organism and employing a medium containing oxidized peptone (*12*). The nitrogen content of the hydrolyzates was determined by nesslerization. All methods were initially checked with a sample of purified casein. Results were in satisfactory agreement with literature values.

Animal studies were carried out using albino rats of the Wistar strain from a colony maintained in the laboratory. Animals were housed individually in cages with raised, galvanized wire floors. The temperature of the animal room was maintained at 21° ± 2° C.

The composition of the diets used in the different experiments is given in Table I. Water was offered ad libitum. The latter half of the table shows the diets used when the depletion-repletion method of Cannon and others (*6*) was used to study the "protein quality" of quinua and cañihua. In these experiments young adult male rats were maintained for 14 days on the low-protein diet of Silber and Porter (*7*, p. 77), which contained 0.032 gram % of nitrogen. The diet was offered ad libitum, and food consumption was good. At the end of this period the animals were divided into two groups. One group was offered a diet containing 9% of the protein to be tested, and the other group was given a control diet containing 9% milk proteins (Klim, powdered whole milk, was used as the source of milk proteins). The diets were isocaloric and cottonseed oil was used in the test diets to supply fat equivalent to that of the milk fat in the Klim diet. Each animal received 15 grams of diet equivalent to 1.35 grams of protein daily. Food consumption was excellent and in only few cases was it incomplete. The repletion period during which the animals were maintained on the 9% protein diets was also of 14 days' duration. Weight gained during repletion was used to evaluate protein quality.

Table II. Nutrient Composition of Quinua and Canihua[a]

(Per 100 grams)

Nutrient	Cañihua	Quinua
Protein (N × 6.25), g.	14.1	11.0
Fat (ether-solubles), g.	4.1	5.3
Fiber, g.	10.7	4.9
Ash, g.	4.6	3.0
Calcium, mg.	126	131
Phosphorus, mg.	461	424
Iron, mg.	18.8	6.8
Thiamine, mg.	0.78	0.52
Riboflavin, mg.	0.55	0.31
Niacin, mg.	1.34	1.60

[a] All values corrected to moisture content of 12%.

Chemical and Amino Acid Composition

Table II shows the average chemical composition of 14 samples of quinua and 6 samples of cañihua. With respect to nutrient composition these products compare favorably with common cereals such as wheat, corn, oats, and rice. In general quinua and cañihua have higher contents of protein, fat, calcium, iron, and the B vitamins than the above cereals.

Six samples of quinua and four samples

of cañihua were analyzed for their contents of essential amino acids and the average values are shown in Table III. Results are expressed on the basis of 16 grams of nitrogen. For comparative purposes similar values for whole wheat, taken from Block and Bolling (*5*, p. 492), have been included in the table. The lysine content of quinua and cañihua is about double that of wheat and is higher than that of other cereals such as rice, corn, and oats (*5*). Except for slightly lower contents of phenylalanine, quinua and cañihua compare favorably with wheat with respect to amino acid contents. Preliminary cystine analysis has given values of 1.1 and 0.98 gram % of this amino acid for the proteins of single samples of cañihua and quinua, respectively.

Table III. Essential Amino Acid Composition of Quinua, Cañihua, and Whole Wheat

(Calculated to 16.0 grams of nitrogen)

Amino Acid	Quinua, %	Cañihua, %	Whole Wheat (5, p. 492), %
Arginine	7.4	7.9	4.3
Histidine	2.7	2.5	2.1
Lysine	6.6	6.0	2.7
Tryptophan	1.1	0.8	1.2
Phenylalanine	3.5	3.6	5.1
Methionine	2.4	1.8	2.5
Threonine	4.8	4.8	3.3
Leucine	7.1	5.8	7.0
Isoleucine	6.4	6.8	4.0
Valine	4.0	4.6	4.3

Protein Quality of Quinua and Cañihua

In an initial experiment six young rats (average initial weight, 76 grams) were maintained for 50 days on a diet of whole quinua supplemented only with vitamins A and D (2 to 3 drops of cod liver oil twice weekly). All animals gained weight and maintained a healthy appearance throughout the experiment. The average weight at the end of 50 days was 334 grams. These results indicated that quinua alone has a high food value, supplying adequate quantities of protein, calories, minerals, and the B vitamins to support rat growth.

In another experiment the nutritive value of quinua protein was compared to that of milk, using Nestlé's skim milk powder to provide the different levels of milk proteins. The composition of the diets used is given in Table I. Food and water were offered ad libitum. Thirty 35-day-old rats were separated into six groups of five rats each; groups receiving 6% protein included 4 males and 1 female, while those with 9% protein included 3 males and 2 females, each.

All animals ate well and remained healthy throughout the 54-day duration of the experiment. The results in terms of weight gains and the nitrogen efficiency of the diets are shown in Table IV. The animals maintained on the 6% quinua protein diet gained significantly more weight than did the group fed 6% milk proteins (t = 3.94, P = 0.01). Supplementation of the quinua, low-protein diet with a small amount of milk proteins (Group III, Table IV) did not produce improvement in weight gains. The difference in weight gains between Groups IV and V, with 9% protein from quinua and milk, respectively, is not significant. Again, milk supplementation of the quinua diet produced no beneficial effects.

The results of this experiment suggested that at the levels employed the quality of the quinua protein was at least equal to that of milk proteins. This was confirmed in additional experiments in which the depletion-repletion method of Cannon (*6*) was employed (see above). The composition of the test diets is given in Table I, and the results of two experiments each with quinua and cañihua are shown in Table V.

The weight gained during 14 days of repletion was excellent for diets supplying only 1.35 grams of protein daily. In experiment 1, animals receiving the 9% milk protein diet gained an average of 38 grams, while those in the group receiving quinua protein at the same level gained an average of 49 grams. The superiority of the quinua diet in replenishing body stores of nitrogen following nitrogen depletion was statistically significant at the 1% level (t = 9.175; P = 0.01). In the second depletion-repletion experiment (Table V) average weight gains during repletion were 45 and 47 grams, respectively, for the groups receiving milk proteins and quinua protein. There was no statistically significant difference between the two groups (t = 1.207, P = 0.20).

Similar depletion-repletion experiments carried out with cañihua as the protein source gave comparable results. The diets (Table I) and the methods used were similar to those used for the quinua studies. As shown in Table V, experiment 3, the group of animals receiving 9% cañihua protein gained an average of 52 grams during 14 days of repletion, while the group on the milk protein diet gained an average of 46 grams. In experiment 4 (Table V), the cañihua and milk groups gained 27 and 30 grams, respectively. In neither of these experiments was the difference between groups statistically significant (experiment 3, t = 1.681, P = 0.1; experiment 4, t = 1.374, P = 0.2). The weight

Table IV. Comparison of Rat Weight Gains on Diets of 6 and 9% Protein from Quinua and from Milk[a]

Group	Protein %	Protein Source	Av. Initial Weight, G.	Av. Final Weight, G.	Weight Gain, G. ± S.D.	Nitrogen Efficiency[b]
I	6	Quinua	74.6	161.2	87.0 ± 9.6	10.38 ± 1.48
II	6	Milk	74.2	127.2	53.0 ± 15.9	9.12 ± 1.91
III	5.5 0.5	Quinua Milk	73.4	156.8	83.4 ± 19.2	11.25 ± 1.58
IV	9	Quinua	74.4	211.0	136.4 ± 50.1	9.77 ± 2.14
V	9	Milk	71.4	177.8	106.4 ± 21.3	10.02 ± 1.39
VI	8.1 0.9	Quinua Milk	74.4	209.8	135.4 ± 37.3	9.34 ± 1.49

[a] Five animals per group. Experimental diets fed for 54 days.
[b] $\frac{\text{G. gained}}{\text{g. N consumed}} \pm$ s.d.

Table V. Depletion-Repletion Studies Comparing Quinua and Cañihua Proteins with Milk Proteins[a]

	Average Weight, Grams: Initial	After 14 days' depletion	After 14 days' repletion	Gain during repletion
Experiment 1				
Milk protein, 9%	230 ± 16.3[b]	191 ± 15.0	229 ± 16.4	37.7 ± 6.37
Quinua protein, 9%	225 ± 15.8	188 ± 12.6	237 ± 16.7	48.9 ± 6.99
Experiment 2				
Milk protein, 9%	218 ± 14.0	180 ± 9.5	225 ± 11.6	45.4 ± 6.37
Quinua protein, 9%	218 ± 11.2	183 ± 15.8	230 ± 16.3	46.9 ± 6.69
Experiment 3				
Milk protein, 9%	164 ± 20.6	133 ± 19.5	179 ± 19.5	46.2 ± 4.98
Cañihua protein, 9%	164 ± 20.5	133 ± 22.7	185 ± 23.1	52.0 ± 9.08
Experiment 4				
Milk protein, 9%	217 ± 27.2	186 ± 27.6	216 ± 26.1	30.2 ± 4.32
Cañihua protein, 9%	216 ± 28.4	185 ± 28.4	212 ± 24.2	26.6 ± 6.02

[a] Experiments 1 and 2, 7 rats per group; experiment 3, 10 per group; experiment 4, 9 per group.
[b] Standard deviation.

gained during repletion was less in the last experiment, but the animals were older and weighed more at the beginning.

The studies with quinua and cañihua demonstrated that under the conditions employed the proteins of these two seed products have a nutritive value at least equal to that of the proteins of dried whole milk. There are few commonly used vegetable foods other than beans and peas that have a higher protein content than these cereal-like products. Their high protein contents plus the high quality of the proteins cause quinua and cañihua to be ranked high among vegetable foodstuffs as sources of protein.

In Table VI the relative proportion of essential amino acids necessary for rat repletion as reported by Steffe and others (*19*) has been compared with the relative proportions found in the proteins of wheat, whole milk, quinua, and cañihua; tryptophan content has been assigned a value of 1. Data for milk and wheat have been calculated from the average amino acid contents listed by Block and Bolling (*5*); those for quinua and cañihua, from the average values of Table III. The similarity of the amino acid proportions in the proteins of milk and the proteins of quinua and cañihua is evident. In all cases methionine is limiting; the relative proportion in the four proteins listed is about 80% of the required proportion. In wheat, lysine is even more limiting, being about 55% of the required amount. In calculating the desired proportion of methionine, no account has been taken of the cystine content of the proteins. Womack and Rose (*21*) have found that cystine will replace about one sixth of the methionine for the growing rat and a much larger proportion in the adult human (*16*). Thus, there is little likelihood of a total sulfur-amino acid deficiency. The amino acid studies lend support to the high biological values found in the rat studies.

The fact that the protein quality of quinua and cañihua is at least equal to that of milk suggests that these foods should be of value as supplementary protein sources. Surveys made in rural areas of the Andes Mountains (*7, 8*) have shown that the diets of the Andean Indians are largely vegetarian. The inclusion of quinua and cañihua in such diets might be expected to improve the protein quality of the mixed vegetable diets typical of these regions.

Summary

Chemical studies of quinua and cañihua have shown that these seed products native to the high Andes Mountains are equal to or superior to common cereals with respect to nutrient and essential amino acid composition. Growth studies with the white rat have demonstrated that the protein quality of quinua and cañihua is equal to that of the protein of whole dried milk.

Table VI. Relative Proportions of Amino Acids in Quinua, Cañihua, Wheat, and Milk Compared with Proportions Utilized in Rat Repletion

Amino Acid	Rat Repletion (18)	Milk	Quinua	Cañihua	Wheat
Tryptophan	1.0	1.0	1.0	1.0	1.0
Arginine	...	2.8	6.7	9.9	3.6
Histidine	1.4	1.7	2.5	3.1	1.7
Isoleucine	4.2	5.0	5.8	8.5	3.3
Leucine	5.0	7.3	6.5	7.3	5.8
Lysine	4.0	5.8	6.0	7.5	2.2
Methionine	2.7	2.1	2.2	2.3	2.1
Phenylalanine	3.1	3.7	3.2	4.5	4.2
Threonine	3.0	3.1	4.4	6.0	2.7
Valine	3.5	4.7	3.6	5.8	3.6

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