An Evaluation of the Protein Quality of Quinoa

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The quality of quinoa (*Chenopodium quinoa willd.*, Sajama variety) protein was evaluated in terms of rat response and amino acid composition. Cooking of quinoa improved the nitrogen efficiency for growth (NEG) by 40%, the weight gain by 100%, and protein efficiency ratio (PER) by 29%. Mixing 20% quinoa with 80% wheat flour improved the NEG by 43%, weight gain by 11%, and PER by 72% over wheat flour alone. Baking the mixture into bread decreased the NEG by 9%, weight gain by 14%, and PER by 19%. The improved NEG, weight gain, and PER of the cooked over the uncooked quinoa did not reflect a corresponding change in amino acid composition. There were some differences in body composition and relative organ weights among the diets. Methionine was the most limiting amino acid in the Sajama variety of quinoa. Mixing 20% quinoa with 80% wheat flour improved rat response equivalent to a 0.2% supplement of lysine.

Quinoa, *Chenopodium quinoa willd.*, is one of the wonder plants of the Incas. Together with potatoes and corn, it is a major staple food for the cultures developed in the Andes. It grows at elevations up to 4400 m in dry desert or semi-desert climates. Quinoa flowers and seeds where the days are short.

Quinoa grain is well suited as the flour or whole grain for preparation into a variety of foods. Because of its versatility, growth habits, and use as a staple food by many peoples, Bolivia and other countries are expanding production of quinoa and developing new varieties. However, there is very little information about the nutritional quality of these new varieties or even quinoa in general. White *et al.* (1955) reported that the quality of quinoa protein was equal to that of whole dried milk protein when fed to rats. Cardozo (1959) reported that pigs fed cooked quinoa grew as well as those fed dried skimmed milk.

The essential amino acid content of several varieties of quinoa has been reported (Vinas *et al.*, 1953; White *et al.*, 1955; Chiriboga and Velasquez, 1957; Van Etten *et al.*, 1963). These data indicated that quinoa protein contains high amounts of lysine and methionine even though there is considerable variation between these varieties in the content of the essential amino acids. No information is available on the amino acid content of the Sajama variety of quinoa recently developed in Bolivia. Information is not available on the effects of cooking and baking on the amino acid content of quinoa products. Thus, this report describes the effects of cooking and baking on amino acid composition and protein quality of the Sajama variety of quinoa for growing rats.

METHODS AND MATERIALS

The recently developed Sajama variety of quinoa was obtained from the Patacamaya Agricultural Experiment Station, Lapaz, Bolivia. The quinoa was washed vigorously by hand in cold running water and dried overnight at 60°, prior to chemical analyses and incorporation into the animal diets.

Thirty-six weanling male Sprague-Dawley rats (Simonsen Laboratories, Inc., Gilroy, Calif.) were randomly assigned to seven groups. They were fed laboratory chow for 5 days to adapt. Six groups (5 rats per group) were fed the diets shown in Table I. Rats were fed diet and distilled water *ad libitum*. They were caged individually in glass metabolism cages. Feces were collected weekly for 4 consecutive weeks in glass containers and dried at 105°. Fresh food and water were given on alternate days. Food consumption was recorded each feeding and computed on a weekly basis. Body weight data were recorded weekly. The rats, groups I–VI, were killed at the end of the 4-week test period. The seventh group (6 rats) was killed at the start of the experiment to provide initial body composition data.

All the diets (Table I) were balanced as closely as possible at 10% crude protein, 2% fat, and 3% fiber. Vitamins and minerals were added to ensure adequate quantities in all diets. The rats in group I were fed a diet prepared from washed and dried quinoa that was ground into flour. Group II was fed a diet prepared from a mixture of 20% quinoa flour prepared as above and 80% commercial wheat flour. This mixture of flours is commonly used in Bolivia. Group III rats were fed a bread diet prepared from the 20% quinoa–80% wheat flour mixture. The bread dough was prepared from 1000 g of quinoa flour, 4000 g of wheat flour, 150 g of sucrose, 150 g of vegetable shortening, 72 g of sodium chloride, 96 g of yeast, and 3240 g of water. The dough was baked at 204° for approximately 20 min. After the bread was cool, the loaves were broken and dried at 60° before grinding for diet preparation. The rats in group IV were fed a diet prepared from cooked quinoa. The washed quinoa was cooked in boiling water for 30 min in a ratio of 450 g of dry quinoa to 2 l. of water. The cooked quinoa was dried at 60° overnight before grinding and diet preparation. The rats in groups V and VI were fed diets using casein and commercial wheat flour as the respective protein sources. Amino acid analysis (Analytical Biochemistry Laboratories, Columbia, Mo.) was done on acid-hydrolyzed samples. The finely ground samples were placed in 6 *N* hydrochloric acid, evacuated and flushed with nitrogen gas several times to remove oxygen, and placed in an oven at 105–110° for 21 hr in a nitrogen atmosphere. The amino acids in the hydrolysate were quantitated by gas–liquid chromatography (Gehrke *et al.*, 1971; Kaiser *et al.*, 1974).

At the end of the 4-week test period, blood was taken by capillary tube from the retro-ocular sinus and the rats were decapitated. Livers, hearts, spleens, adrenals, and kidneys were removed, freed from adhering tissue, weighed, and returned to the eviscerated carcass. The carcasses were then frozen in individual plastic bags.

The carcass contents of solids and lipids were determined by the method of Sarett and Jandorff (1947) after autoclaving and homogenizing in a blender. Approximately 10-g samples of homogenate were ignited at 600° for ash analyses. Carcass iron and calcium were determined by atomic absorption spectrophotometry on the acid solubilized ash. Carcass phosphorus was quantitated on the solubilized ash (Gömörri, 1942).

The nitrogen content of the quinoa grain, diets, and ev-

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Table I. Composition of Experimental Diets[a]

Diet	I, quinoa flour (100%)	II, quinoa flour (20%)–wheat flour (80%)	III, bread quinoa flour (20%)–wheat flour (80%)	IV, quinoa cooked (100%)	V, casein (100%)	VI, wheat flour (100%)
Quinoa[b]	68.00	16.60	16.60	68.00		
Wheat flour		68.20	68.20			89.90
Casein					10.50	
Corn starch	22.09	4.48	4.48	22.09	78.50	
Corn oil	2.00	2.00	2.00	2.00	2.00	2.00
α-Cellulose	1.91	2.72	2.72	1.91	3.00	2.10
Vitamin mix[c]	2.00	2.00	2.00	2.00	2.00	2.00
Mineral mix[d]	4.00	4.00	4.00	4.00	4.00	4.00
Crude protein[e]	10.58	10.60	10.41	10.42	9.29	10.83
Isoleucine	254	259	282	252	208	254
Leucine	378	413	414	402	396 (584)	404
Lysine	313	183	174	306	572	121
Phenylalanine	230	277	282	222	430	277
Arginine	449	253	234	378	256	185
Histidine	171	159	156	126	182 (58)	138
Methionine	89	88	54	84	121 (99)	69
Threonine	171	142	156	174	269 (232)	127
Tryptophan	53	71	60	60	148 (120)	69
Valine	295	277	288	300	554 (390)	271
Alanine	242	200	210	258	114 (198)	173
Glycine	313	254	246	318	222	213
Proline	207	584	576	222	390 (673)	687
Serine	183	183	198	162	289 (350)	185
Hydroxyproline	18			12		
Aspartic acid	484	312	324	474	612 (439)	231
Glutamic acid	821	1768	1753	888	2274 (1383)	1979
Tyrosine	165	142	174	168	390 (311)	138
Cystine	12	12	30	12		23

[a] All values except the amino acid values are expressed in g per 100 g of diet. The amino acid values are expressed as mg per g of nitrogen. Values in parentheses are from FAO (1970). [b] By analysis quinoa flour contains (in g/100 g): crude protein (N × 6.25), 14.4; ether extract, 4.7; ash, 2.4; cell walls, 3.1; hemicellulose, 0.7; cellulose, 1.7; lignin, 0.1; phosphorus, 0.89; and (mg/100 g) calcium, 26.1; magnesium, 91.4; iron, 4.06; zinc, 3.39; copper, 0.41. [c] Vitamin diet fortification mixture, Nutrition Biochemicals Corporation, Cleveland, Ohio. Mixture contained (in g/100 g of mixture): vitamin A concentrate (200,000 IU retinyl acetate/g), 4.5; vitamin D concentrate (400,000 IU calciferol/g), 0.25; α-tocopherol, 5.0; ascorbic acid, 45.0; inositol, 5.0; choline·HCl, 75.0; menadione, 2.25; *p*-aminobenzoic acid, 5.0; niacin, 4.5; riboflavine, 1.0; pyrodoxine·HCl, 1.0; thiamin·HCl, 1.0; calcium pantothenate, 3.0; and (in mg/kg) biotin, 20; folic acid, 90; vitamin B_{12}, 1.35. [d] Mineral mixture contained: (in g/kg of mixture) $CuSO_4 \cdot 5H_2O$, 0.290; $FeSO_4 \cdot 7H_2O$, 2.48; KCl, 200.0; $NaHPO_4 \cdot H_2O$, 360.0; $MgCO_3$, 37.6; $CaCO_3$, 395.0; KI, 0.79; $MnSO_4 \cdot H_2O$, 3.78; $ZnSO_4 \cdot 7H_2O$, 0.275; $CoCl_2 \cdot 6H_2O$, 0.0226; $Na_2MoO_4 \cdot 2H_2O$, 0.0417. [e] Actual analysis for crude protein and amino acids.

iscerated carcasses was determined by the Kjeldahl procedure. Crude protein content was estimated by multiplying the nitrogen content by 6.25.

The content of plant cell walls, hemicellulose, cellulose, and lignin, in the quinoa was determined as described by Fonnesbeck and Harris (1970a,b, 1971).

The data were analyzed by analysis of variance using the Duncan's multiple range test (Steel and Torrie, 1960) to determine differences between group means.

CHEMICAL AND AMINO ACID COMPOSITION OF QUINOA

Table I shows the chemical composition of the Sajama variety of quinoa. The protein and fat contents are similar to those reported by White *et al.* (1955). The whole grain of quinoa contains very little cell wall material or lignin as compared to corn, wheat, and barley grains (P. V. Fonnesbeck and L. E. Harris, unpublished data).

The amino acid composition of the whole quinoa grain is shown in Table II. Amino acid values for other varieties of quinoa and wheat taken from the published literature are included for comparative purposes. There is considerable variation in the amino acid content among varieties of quinoa. The Sajama variety contains less methionine than the other varieties while the Blanca variety contains less lysine. When compared to the FAO reference pattern, methionine and tryptophan are the only limiting essential amino acids in the Sajama variety. Quinoa protein is high in lysine, the amino acid that is limiting in most plant proteins.

RESULTS AND DISCUSSION

The amino acid content of quinoa protein (Sajama variety) is shown in Table II along with other quinoa varieties and wheat. Compared to the FAO reference pattern, methionine is the most limiting amino acid in the Sajama variety. The Sajama variety contains less methionine than the other varieties of quinoa shown. The methionine and threonine contents of quinoa published by the FAO (1970) were 125 and 219 mg/g of nitrogen, respectively, as compared to 78 and 174 mg/g of nitrogen in the Sajama variety. However, the Sajama variety contained equivalent or greater amounts of other essential amino acids per unit of nitrogen. The Sajama variety contained approximately two times as much lysine as whole wheat on a weight basis.

Table II. Amino Acid Composition of Quinoa and Wheat

Amino acid[a]	Quinoa				Whole wheat[e]	FAO[f]	Casein[g]
	Sajama	Real[b]	Six varieties[c]	Blanca[d]			
Isoleucine	295 (1.7)	301 (1.1)	401 (1.4)	250 (1.4)	204 (1.1)	250 (1.0)	1.81
Leucine	451 (2.6)	282 (1.1)	349 (1.2)	237 (1.3)	417 (2.3)	440 (1.8)	9.00
Lysine	343 (1.9)	366 (1.4)	406 (1.4)	259 (1.4)	179 (1.0)	340 (1.4)	2.12
Phenylalanine	256 (2.5)	230 (1.9)	219 (0.7)	203 (2.1)	282 (2.5)	380 (1.5)	1.60
Tyrosine	178 (*h*)	282 (*h*)		174 (*h*)	187 (*h*)		1.45
Cystine	Trace	282 (*h*)		228 (*h*)	159 (*h*)		
Methionine	78 (0.45)	207 (1.8)	156 (0.5)	179 (2.3)	94 (1.4)	220 (0.9)	0.45
Threonine	174 (1.0)	268 (1.0)	292 (1.0)	179 (1.0)	183 (1.0)	250 (1.0)	1.00
Tryptophan	69 (0.4)	33 (0.1)	68 (0.2)	31 (0.2)		60 (0.2)	0.65
Valine	330 (1.9)	244 (0.9)	250 (0.9)	210 (1.2)	276 (1.5)	310 (1.2)	2.20
Alanine	273				226		
Glycine	347				245		
Proline	230				621		
Serine	156				287		
Hydroxyproline	17						
Aspartic acid	529				308		
Glutamic acid	885				1866		
Arginine	408	462			288		
Histidine	204	169			143		

[a] Expressed as mg/g of nitrogen. The Sajama variety contains 14.4% crude protein. Values in parentheses are used in comparison to the FAO reference pattern which combines values for phenylalanine and tyrosine and for methionine and cystine. [b] From White *et al.* (1955). [c] From Vinas *et al.* (1953). [d] From Chiriboga and Velasquez (1957). [e] From FAO (1970). [f] From FAO/WHO (1973). [g] Based on amino acid composition of diet V in Table I. [h] The values for tyrosine are combined with phenylalanine and the values of cystine are combined with methionine.

Table III. Quinoa, Casein, and Wheat as Protein Sources for Growth by Rats[a]

Diet	I, quinoa flour (100%)	II, quinoa flour (20%)–wheat flour (80%)	III, bread quinoa flour (20%)–wheat flour (80%)	IV, quinoa cooked (100%)	V, casein (100%)	VI, wheat flour (100%)	Pooled SE
Initial body wt, g	62^{a}	68^{a}	65^{a}	67^{a}	67^{a}	68^{a}	1.4
Final body wt, g	109^{wx}	104^{wy}	89^{yz}	156	123^{x}	85^{z}	1.8
Total gain, g	43^{wx}	36^{xy}	24^{yz}	89	57^{w}	17^{z}	2.9
NEG[b]	29.6^{y}	18.7^{az}	17.1^{abz}	41.6	32.3^{y}	13.1^{z}	1.77
PER	2.09	1.48^{yz}	1.20^{y}	2.71^{z}	2.67^{z}	0.86	0.05
Digestibility							
Dry matter, %	89^{a}	92^{a}	89^{a}	88^{a}	93^{a}	93^{a}	0.2
Protein, %	80^{x}	84^{y}	80^{x}	80^{x}	88^{y}	86^{y}	0.5
Food intake/wt gain	4.6^{y}	6.4^{z}	8.2^{z}	3.6^{y}	4.0^{y}	10.8	0.19
Liver, % of BW	3.04^{a}	3.02^{a}	3.16^{a}	2.83^{b}	2.73^{b}	3.11^{a}	0.10
Kidney, % of BW	0.77^{a}	0.88	0.98^{b}	0.70^{a}	0.72^{a}	0.93^{b}	0.02
Adrenal, % of BW	0.022^{a}	0.022^{a}	0.022^{a}	0.012	0.016^{b}	0.018^{b}	0.002
Carcass composition							
Moisture, %	82^{z}	82^{z}	82^{z}	78	82^{z}	83^{z}	0.6
Lipid, %	4.1^{z}	4.4^{z}	4.3^{z}	7.1	4.1^{z}	3.2^{z}	0.5
Nitrogen, %	2.97^{x}	3.15^{x}	2.27^{y}	1.34^{z}	1.66^{z}	2.44^{y}	0.12
Ash, %	5.0^{a}	5.2^{a}	5.5^{a}	4.6^{a}	4.5^{a}	5.3^{a}	0.1

[a] There were five observations per mean. Means with the same letter at the beginning of the alphabet are not significantly different ($P < 0.05$); means with the same letter at the end of the alphabet are not significantly different ($P < 0.01$). [b] For method of calculation, see footnote 2 in the text.

The values for mean weight gain during the experimental period are shown in Table III. The Sprague-Dawley rats fed uncooked quinoa in this experiment gained approximately 9 g/week during the first 2 weeks on test. In comparison, Quiros-Perez and Elvehjem (1957) reported that their weanling rats (Holzman) gained 19 and 24 g/week in two 2-week experiments. They used a saponin-free variety of quinoa fed at 10.58% crude protein in the diets. In this experiment the Sajama variety, which was washed to remove the bitter saponin, was fed uncooked at 10.13% crude protein, diet I. However, rats fed quinoa that had been cooked by boiling (diet IV) gained approximately 22 g/week. The difference in weight gains by rats fed uncooked quinoa between this experiment and the Quiros-Perez and Elvehjem (1957) experiment probably is due to a higher level of saponin or bitter substances in the Sajama variety that were eliminated or destroyed during boiling.

Although rats fed uncooked quinoa gained slightly less weight than those fed casein, the difference in weight gain

was not statistically significant. The rats fed cooked quinoa diet consumed 60% more diet ($P < 0.01$) and gained 106% more weight ($P < 0.01$) than those fed the uncooked quinoa diet. Rats fed the wheat flour diet gained less weight than the other groups. Mixing 20% quinoa with 80% wheat flour improved weight gain 111% ($P < 0.01$) over wheat alone. The rats fed the 20% quinoa–80% wheat flour, diet II, gained slightly less weight than those fed quinoa alone, diet I. Baking the 20% quinoa–80% wheat flour mixture into bread, diet III, decreased weight gain by 33% ($P < 0.05$) as compared to rats fed the uncooked mixture, diet II.

Expressing the growth promoting value of the diets as the efficiency of converting absorbed nitrogen into carcass nitrogen (nitrogen efficiency for growth, NEG),[2] it was found that the proteins from uncooked quinoa and casein were similar. Cooking the quinoa improved its NEG by 40% which was not associated with a significant change in its amino acid composition (Table I). Wheat flour protein had the lowest NEG. Mixing 20% quinoa with 80% wheat flour resulted in a 43% improved NEG ($P < 0.05$) as compared to wheat flour alone. There was no statistically significant difference between the NEG of 20% quinoa–80% wheat flour mixture and the same mixture prepared into bread even though the bread had about 39% less methionine (Table I). The amount of food required per unit weight gained was inversely related to the NEG.

The PER values show that the protein quality of cooked quinoa, diet IV, is nearly identical with casein (Table III). In both protein sources the limiting amino acid is methionine (Table II). The PER of the cooked quinoa was 30% greater ($P < 0.01$) than the uncooked quinoa even though the amino acid composition of the two diets was identical. However, the rats consumed approximately 60% more ($P < 0.01$) of the cooked quinoa diet than the uncooked quinoa diet. Such a difference in food intake would cause different protein intakes which in turn could cause this difference in PER (Morrison and Campbell, 1960; Frape *et al.*, 1968). Mixing 20% with 80% wheat flour, diet II, improved the PER by 72% ($P < 0.01$) over wheat flour alone (Table II). This mixture contained 50% more lysine than wheat flour alone (Table I) which is sufficient to explain the improved PER value. Baking the mixture into bread resulted in a slightly decreased lysine content and PER value.

The protein quality of uncooked quinoa and casein would be rated similar on the basis of NEG and different on the basis of PER (Table III). Also, the protein quality of cooked quinoa would be rated better than casein on the basis of NEG but similar to casein on the basis of PER. In the computation of the PER, it is assumed that the composition of the body weight gained is similar for all groups. This was not true for all groups of rats in this experiment (Table III). On the other hand the NEG is concerned only with the gain in body nitrogen relative to the nitrogen digested and absorbed. Differences in the percentages of other body components such as fat would be expected to affect it less than the PER. The NEG also takes into account differences in the digestibility of protein. Thus, NEG would be a better measure of protein quality than PER whenever significant differences in body composition exist.

The digestibility of the proteins in the casein, wheat flour, and 20% quinoa–80% wheat flour, diet II, were higher ($P < 0.01$) than the other protein diets (Table III). There were no significant differences in the digestibility of the dry matter among the diets.

There were significant treatment effects on relative organ weights and body composition. Those rats fed the cooked quinoa and casein diets tended to have smaller relative organ weights, lower percentages or carcass nitrogen and ash, and higher percentage of carcass lipid than the other groups of rats.

Using weight gain, NEG, PER, and food intake per unit gain as criteria, the protein diets used in this experiment would be rated in order of decreasing quality: cooked quinoa, casein, uncooked quinoa, 20% quinoa flour–80% wheat flour (diet II), quinoa–wheat flour bread, and wheat flour. This is a qualified observation because even though there was an apparent difference in the growth promoting response (Table II) between the uncooked quinoa and the cooked quinoa diets the amino acid composition of these diets was nearly identical (Table I). Although the above order of the diets does not change, the protein quality of the quinoa and casein is not significantly different. The observation agrees well with the data of White *et al.* (1955), who reported that the growth promoting value of quinoa protein, prepared similarly to that used in this laboratory, was equal to whole dried milk protein. The fact that casein substitution for quinoa protein in diets fed weanling rats did not result in any changes in growth as compared to quinoa alone (Quiros-Perez and Elvehjem, 1957) suggests that the two protein sources are equal in quality.

Mixing 20% quinoa with 80% wheat flour improved the growth promoting value equivalent to adding 0.2% lysine to the wheat flour (FAO, 1970).

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[2] (Carcass N_{final} − carcass $N_{initial}$)/(N intake − N fecal) × 100 = NEG. The initial carcass nitrogen was estimated for each animal by determining the quantity of nitrogen per gram body weight (0.0127 g of N/g BW) in five randomly selected rats at the start of the experiment.