Digestibility and Protein Quality of Quinua:
Comparative Study in Children Between
Quinua Grain and Flour

TO:
Samuel G. Kahn, Ph.D.,
Science Research Officer
Office of Nutrition
Agency for International Development
Washington, D.C. 20523

FROM:
Guillermo Lopez de Romana
Instituto de Investigacion Nutricional
Apartado 55
Miraflores (Lima), PERU

and

George G. Graham, M.D.,
William C. MacLean, Jr., M.D.
615 North Wolfe Street
Baltimore, Maryland 21205

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Summary

Based on the hypothesis that quinoa seed digestibility is the limiting factor in the utilization of nutrients from this staple, two quinoa-based diets were prepared using quinoa seeds and quinoa flour. These diets were offered to children recovering from malnutrition. The digestibility and protein quality of the quinoa diets were compared to those of a casein control diet by analyzing the children's metabolic balance. Results show that the digestibility of quinoa seed is the limiting factor on the utilization of protein and energy, and that milling improves significantly the digestibility of fat and carbohydrates. Results also confirm that quinoa protein quality is adequate for human consumption.
INTRODUCTION

Quinua (Chenopodium quinoa) is a food native to the Andean region of South America that traditionally, with potatoes and corn, has been an important part of the diets for this population.

It is grown in cold weather and in altitudes that vary from 8,700 to 13,000 feet and for this reason competes little for land area with other food crops. The edible portion is the seed or grain, whose approximate composition is 58% starch, 5% sugar, 12 to 19% protein and 4-5% fat.

Most of the research done on this grain has been oriented to the analysis of its protein quality, leading to the conclusion that quinua could be a source of protein superior to most of the true cereals (1). Nevertheless there is little information in the human being about its digestibility, a factor that, based on studies with other staple foods, could be limiting in the utilization of nutrients (2).

We believe that digestibility could be a problem with quinua. In a previous study done with a quinua-oats diet we noticed that the germ of the quinua seed was recovered intact from the stools of the children that consumed the diet. Protein and fat digestibility was also found to be poor with this diet.

The present study was designed to analyze in human beings the digestibility and protein quality of the quinua grain, the form in which it is usually consumed, in comparison to quinua flour. Since the germ is fractionated by milling, we believe that if the working hypothesis is correct digestibility of flour should be superior.
MATERIALS AND METHODS

Patients:

Six male children with a mean age of 13.8 months (range: 10-18 months) participated in the study (Table 1). All were admitted to the Instituto de Investigacion Nutricional (Nutrition Research Institute) because of severe malnutrition (Grade III of Gomez) for treatment of acute complications and long-term nutritional rehabilitation. Before their participation all children fulfilled the following criteria: free of infections and diarrhea, steady rate of weight gain while consuming regular diets, no evidence of malabsorption in previous metabolic balances and a serum albumin level above 3.5 mg/dl.

Diets:

Three diets were prepared; two of them with quinoa and the third one, used as a control, with casein (Table 2). Two commercially available quinoa products were used; quinoa grain seeds and quinoa flour. Both quinoa products were obtained from the same crop and processed in homogeneous batches to minimize changes in composition. The variety utilized was "sajama primera". Quinoa seeds were classified according to the size of the grain, dehulled and "polished". This product was further milled to obtain the flour. Two isocaloric, isonitrogenous quinoa diets were prepared using these two products. Protein content was adjusted so that 6.4% of total caloric content was provided by quinoa protein as the only source of nitrogen. Fat content was also adjusted to provide 25% of total energy using a 50:50 blend of soybean-cottonseed oils. Total energy content was completed with sucrose.
A control diet was prepared with casein as the only source of nitrogen. Total nitrogen, fat and energy content were adjusted to parallel the quinoa diets. The same oil blend was used, but in this diet the total caloric content was completed by the addition of dextrimaltose and sucrose in equal proportions to diminish the sweetness of the diet.

Quinoa grain was washed in cold water three times and cooked in boiling water for 60 minutes. This is the recommended cooking time for this product (4). Quinoa flour was dissolved in cold water and cooked for 30 minutes. All three diets were supplemented with vitamins and minerals to meet or exceed Recommended Dietary Allowances (5). Na and K contents were adjusted to 2 and 3 mEq/kg body weight/day, respectively to minimize artefactual changes in body weight due to changes in body water.

**Design and Analysis:**

The study consisted of four dietary periods of 9 days each. During the first and last periods children received the control diet. Quinoa diets were alternated during the intermediate periods following a predetermined sequence. Calorie intake was determined before the beginning of the study on the basis of the individual calorie intake required to maintain a steady rate of weight gain of between 3 and 5 g/kg body weight/day. Calorie intake remained constant throughout the study. The first three days of each metabolic period were used for adaptation to the new diet. During the following six days, two separate metabolic collections of 3 days each were carried out. Children were weighed daily (8 AM) and the rate of weight gain was
calculated for each dietary period. A blood sample was obtained at the beginning of each dietary period to determine serum total protein (Biuret) and albumin concentrations (acetate gel electrophoresis). Diets were analyzed weekly to verify that the \( N, Na \) and \( K \) intakes were as planned. Stool wet weight and dry weight were obtained. Total \( N \) content of stools and urine was determined by the micro-Kjeldahl (6) method. Stool fat content was determined by the method of van de Kamer et al (7). Total fecal energy was determined by bomb calorimetry and from this value, carbohydrate content of stool was computed using the formula:

\[
Pecal\ CHO\ g = \frac{E-(N/g \times 6.25 \times 5.65) -(F/g \times 9.4)}{4.15}
\]

where

- \( CHO\ g \) = carbohydrate in grams
- \( E \) = fecal energy by bomb calorimetry
- \( N/g \) = fecal nitrogen in grams
- \( F/g \) = fecal fat in grams

5.65 - 9.4 - 4.15 = are the accepted energy conversion factors for protein, fat and carbohydrates respectively (3).

Apparent \( N \) retentions obtained during the consumption of the quinua diets were compared to the control periods and used as the indicator of protein quality. The last control period was used to look for exaggerated nitrogen retention (rebound phenomenon) after the consumption of quinua diets and to compensate with high quality protein for any protein deficiency that could occur with the quinua diets. Apparent nitrogen retentions obtained during the consumption of the two quinua diets were
compared with each other and with the control periods; the control periods were compared with each other as well, by two tailed paired "t" tests.

Apparent N absorption, stool wet weight, stool dry weight and total energy, fat and carbohydrate content in stool were used as indicators of digestibility. The casein used in the control diet and the vegetable oil and carbohydrate mixtures used in both control and quinua diets are highly digestible and can be assumed to have been virtually completely absorbed. As a consequence, differences in digestibility among control and study diets could be attributed to the form of quinua in the diet. The approach to the analysis of digestibility have been used successfully in previous studies (9,10). Statistical analysis of parameters of digestibility was carried out comparing values from both quinua dietary periods with each other and with those from both of the control periods; values from both control periods were also compared with each other. The "t" test for paired data (two tailed) was used in all instances.

RESULTS

All diets were well accepted and tolerated. All children were able to consume the calorie intake planned and no adverse reactions such as vomiting or diarrhea were observed. Results of apparent N retentions are presented in Table 3. Mean apparent N retention obtained during the consumption of the quinua grain diet was inferior to that obtained with the quinua flour diet or the control diets but the differences were not statistically significant. The higher apparent N retention obtained during the last control period suggested a compensatory retention of N but the difference was not significant.
No significant diet-related changes in serum albumin concentrations were observed during the different metabolic periods.

Results of weight gain and digestibility parameters are presented in Table 4. Results of both control periods are presented as a single mean value since no statistical differences in any of the parameters were found. Weight gain during each metabolic period was as planned and differences were not significant. When digestibility parameters were compared between quinua diets and the control diet, there were significant differences in all cases. Apparent N absorption during the consumption of the quinua diets was inferior to that from control diet. Mean stool wet weight, stool dry weight, energy content of stools and carbohydrate content were all higher. Mean fat content of stools during the quinua flour period was significantly lower than that during the control period. In contrast, mean fat content of stool observed during consumption of the quinua grain diet was significantly higher.

When the two quinua diets were compared with each other there were statistically significant differences in all parameters of digestibility except one, apparent nitrogen absorption. Mean stool wet weight, stool dry weight, calories, fat and carbohydrates total contents in stool were higher during the consumption of the quinua grain diet.

DISCUSSION

The results of this study show that quinua grain is not easily digested by the human being, resulting in the loss of a considerable part of its nutritive value in stools. When the grain is broken, by
milling, its digestibility improves significantly.

Apparent nitrogen absorptions obtained with the quinua diets suggest that protein digestibility is probably the limiting factor in nitrogen utilization. When N absorption is expressed as a percentage of the control diet, results obtained with the quinua grain diet (80.2%) and with the quinua flour diet (94.1%) are inferior to those reported for similar diets based on potatoes (92.4%) (10) and wheat-noodles (95.5%) (9). Apparent protein digestibility observed with the quinua diets was similar to that reported for rice (78%) (2) in which most of the protein is in the form of protein bodies (11) that remain intact during cooking and are poorly digested (12). Milling improves protein digestibility somewhat but not significantly so.

The protein quality of quinua is probably adequate for human consumption because it has a good balance between essential and non-essential amino acid (13); in previous studies no limiting amino acid was demonstrated (14). The small differences in apparent nitrogen retention among the three diets, although not statistically significant, primarily reflected differences in nitrogen absorption. When N retention is expressed as a percentage of absorption (biological value) the values obtained with the quinua grain (43.4%), quinua flour (50.7%) and casein (45.8%) diets are similar. This finding confirms the good protein quality of quinua for human consumption.

Fat balance data showed that during the consumption of the quinua flour diet the excretion of fat in stools was less than during consumption of the control diet. In contrast, during the quinua grain period fecal fat excretion was 87% higher than control. This difference in fat
absorption, determined by milling is nutritionally important in terms of energy losses. The major differences in digestibility found among diets were related to carbohydrate digestibility. During the quinua flour dietary period, losses of carbohydrate in stools were 463% higher than during the control periods. This percentage increased to 910% during consumption of the quinua grain diet. These exaggerated losses of carbohydrate in stool not only represent an important loss of energy, but also, because of the osmotic effect of the unabsorbed carbohydrates produce exaggerated losses of water and electrolytes that can be physiologically important in small children. This phenomenon also explains the difference in wet weight found among diets.

In the previous study done with quinua and oats, mentioned above, the poor protein and fat digestibilities obtained were attributed to poor digestion of the quinua germ. We suggested that further studies of quinua with increased cooking time be carried out and that the possible effect of saponins on the digestive process be considered. In the present study the cooking time for the quinua flour was shorter than that used for the quinua grain diet. This and the fact that the quinua flour was not washed before cooking may have resulted in a higher concentration of saponins in the quinua flour than in the grain diet. The results of digestibility obtained with the quinua flour diet were nevertheless significantly superior. For these reasons it is more likely that the quinua seed germ, like the protein bodies in rice, is not affected by cooking and is poorly digested by human beings. Although milling improves digestibility of the quinua grain, when the results of
digestibility obtained in the present study are compared to those obtained with similar diets based on potato, wheat and rice, quinoa digestibility is still somewhat inferior.
Table 1

Characteristics of subjects participating in the study

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex</th>
<th>Age mos</th>
<th>Height Age mos</th>
<th>Weight Age mos</th>
<th>Serum (Albumin) g/dl</th>
<th>Energy Intake Kcal/kg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>575</td>
<td>M</td>
<td>12</td>
<td>4.4</td>
<td>4.5</td>
<td>4.47</td>
<td>3.77</td>
</tr>
<tr>
<td>576</td>
<td>M</td>
<td>11</td>
<td>2.5</td>
<td>1.1</td>
<td>4.06</td>
<td>3.95</td>
</tr>
<tr>
<td>579</td>
<td>M</td>
<td>18</td>
<td>11.2</td>
<td>9.8</td>
<td>3.71</td>
<td>3.78</td>
</tr>
<tr>
<td>583</td>
<td>M</td>
<td>10</td>
<td>7.8</td>
<td>4.8</td>
<td>4.41</td>
<td>4.14</td>
</tr>
<tr>
<td>589</td>
<td>M</td>
<td>18</td>
<td>12.5</td>
<td>10.5</td>
<td>3.78</td>
<td>3.74</td>
</tr>
<tr>
<td>599</td>
<td>M</td>
<td>14</td>
<td>7.3</td>
<td>4.8</td>
<td>3.69</td>
<td>3.53</td>
</tr>
</tbody>
</table>

*Differences not statistically significant by paired "t" test*
<table>
<thead>
<tr>
<th></th>
<th>Quinua grain</th>
<th>Quinua flour</th>
<th>Casein control diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinua</td>
<td>g</td>
<td>13.9</td>
<td>13.8</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>mg</td>
<td>256.0</td>
<td>256.0</td>
</tr>
<tr>
<td>Energy</td>
<td>Kcal</td>
<td>50.0</td>
<td>50.1</td>
</tr>
<tr>
<td>Casein</td>
<td>g</td>
<td>-.</td>
<td>-.</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>mg</td>
<td>-.</td>
<td>-.</td>
</tr>
<tr>
<td>Energy</td>
<td>Kcal</td>
<td>-.</td>
<td>-.</td>
</tr>
<tr>
<td>Sucrose</td>
<td>g</td>
<td>8.0</td>
<td>7.9</td>
</tr>
<tr>
<td>Energy</td>
<td>Kcal</td>
<td>32.0</td>
<td>31.6</td>
</tr>
<tr>
<td>Dextri-Maltose</td>
<td>g</td>
<td>-.</td>
<td>-.</td>
</tr>
<tr>
<td>Energy</td>
<td>Kcal</td>
<td>-.</td>
<td>-.</td>
</tr>
<tr>
<td>Soybean-Cottonseed Oil</td>
<td>ml</td>
<td>2.27</td>
<td>2.3</td>
</tr>
<tr>
<td>Energy</td>
<td>Kcal</td>
<td>18.0</td>
<td>18.3</td>
</tr>
</tbody>
</table>

**TOTALS**

| Nitrogen | g      | 256.0       | 256.0       | 256.0       |
| Energy   | Kcal   | 100.0       | 100.0       | 100.0       |
| Protein (N x 6.25) | % Energy | 6.4         | 6.4         | 6.4         |

1 Minerals were supplemented in all diets to provide intakes of 2 mEq Na/kg body weight/day using a mineral mixture without potassium of the following composition (w/w): NaCl, 30.701%; MgSO₄·7H₂O, 22.804%; CaHPO₄, 41.615%; FeC₆H₅O₇·3H₂O, 3.549%; CuSO₄·5H₂O, 0.625%; ZnSO₄·7H₂O, 0.355%; MnSO₄·H₂O, 0.277%; KI, 0.025% and NaF, 0.50%.

2 Vitamins were supplemented by a single daily dose of 0.06-1.2 ml of Poly-Vi-Sol (Mead Johnson, Evansville, IN). The composition (per ml) of this preparation is as follows: retinyl palmitate, 1,500 IU; ergocalciferol, 400 IU; Vitamin E, 5 IU; ascorbic acid, 35 mg; thiamin, 0.5 mg; riboflavin, 0.6 mg; niacin, 8 mg; vitamin B-6, 0.4 mg, and vitamin B-12, 1 μg. Patients also received a single dose of 191 mg choline, 180 mg myo-inositol, 200 μg folic acid and 500 mg PABA.

3 Casec, Mead Johnson, Evansville, IN. 1.88 g Casec was used to provide 1.6 g casein.

4 Dextri-Maltose, Mead Johnson, Evansville, IN. Reducing sugars (as maltose) 56%, Dextrin 41%, humidity 3%.
Table 3

Apparent nitrogen retention as percentage of intake

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Casein #1</th>
<th>Quinua Grain</th>
<th>Quinua Flour</th>
<th>Casein #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>575</td>
<td>46.5</td>
<td>33.0</td>
<td>43.0*</td>
<td>51.0</td>
</tr>
<tr>
<td>576</td>
<td>23.5</td>
<td>23.5</td>
<td>27.0*</td>
<td>52.0</td>
</tr>
<tr>
<td>579</td>
<td>35.0</td>
<td>15.0*</td>
<td>26.5</td>
<td>32.5</td>
</tr>
<tr>
<td>583</td>
<td>33.0</td>
<td>30.5*</td>
<td>33.5</td>
<td>35.5</td>
</tr>
<tr>
<td>589</td>
<td>42.5</td>
<td>27.0*</td>
<td>43.0</td>
<td>38.0</td>
</tr>
<tr>
<td>599</td>
<td>21.0</td>
<td>44.5</td>
<td>39.5*</td>
<td>45.0</td>
</tr>
</tbody>
</table>

\( \bar{x}^a = 33.6 \) \( \pm 10.1 \)
\( \bar{x} = 28.9 \) \( \pm 9.9 \)
\( S.D. = 7.6 \) \( \pm 8.2 \)

\( ^a \) Differences not statistically significant by paired "t" test, \( p>0.05 \).

\( ^* \) This indicates which of the two quinua periods came first in sequence for each child.
Table 4

Weight gain and parameters of digestibility used in the evaluation of study diets

<table>
<thead>
<tr>
<th>Stool</th>
<th>Δ Weight g/kg/d</th>
<th>Nitrogen Absorption % Intake</th>
<th>Wet Wt g/d</th>
<th>Dry Wt g/d</th>
<th>Energy Kcal/d % Intake</th>
<th>Fat g/d % Intake</th>
<th>CHO g/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casein*</td>
<td>5.4 ±2.4</td>
<td>83.0 ±3.0</td>
<td>87.8 ±25.9</td>
<td>11.1 ±0.9</td>
<td>51.1 ±9.3</td>
<td>5.5 ±1.6</td>
<td>3.0 ±0.8</td>
</tr>
<tr>
<td>(n = 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quinua flour</td>
<td>3.5 ±1.6</td>
<td>69.8±7.3</td>
<td>108.5±25.5</td>
<td>18.2±2.6</td>
<td>83.8±13.7</td>
<td>8.8±1.6</td>
<td>2.3±0.8</td>
</tr>
<tr>
<td>(n = 6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quinua grain</td>
<td>3.7 ±2.3</td>
<td>66.6±6.1</td>
<td>152.4±28.7</td>
<td>31.1±4.2</td>
<td>152.4±23.6</td>
<td>16.4±2.8</td>
<td>5.6±0.9</td>
</tr>
<tr>
<td>(N = 6)</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

* Significantly different from casein control period by paired "t" test p<0.05
  b Significantly different from casein control period by paired "t" test p<0.01
  c Significantly different from casein control period by paired "t" test p<0.001
  d Significantly different from quinua flour period by paired "t" test p<0.05
  e Significantly different from quinua flour period by paired "t" test p<0.01
  f Significantly different from quinua flour period by paired "t" test p<0.001
* Single mean value of both casein control periods.
BIBLIOGRAPHY


