Effects of Processing Methods on Amaranth Starch Digestibility and Predicted Glycemic Index

V.D. CAPRILES, K.D. COELHO, A.C. GUERRA-MATIAS, AND J.A.G. ARÉAS

ABSTRACT: Amaranth has attracted a great deal of interest in recent decades due to its valuable nutritional, functional, and agricultural characteristics. Amaranth seeds can be cooked, popped, roasted, flaked, or extruded for consumption. This study compared the in vitro starch digestibility of processed amaranth seeds to that of white bread. Raw seeds yielded rapidly digestible starch content (RDS) of 30.7% db and predicted glycemic index (pGI) of 87.2, the lowest among the studied products. Cooked, extruded, and popped amaranth seeds had starch digestibility similar to that of white bread (92.4, 91.2, and 101.3, respectively), while flaked and roasted seeds generated a slightly increased glycemic response (106.0 and 105.8, respectively). Cooking and extrusion did not alter the RDS contents of the seeds. No significant differences were observed among popped, flaked, and roasted RDS contents (38.0%, 46.3%, and 42.9%, respectively), which were all lower than RDS content of bread (51.1%). Amaranth seed is a high glycemic food most likely because of its small starch granule size, low resistant starch content (< 1%), and tendency to completely lose its crystalline and granular starch structure during those heat treatments.

Keywords: Amaranthus cruentus, in vitro starch hydrolysis, predicted glycemic index, rapidly digestible starch, resistant starch

Introduction

Amaranth is a pseudocereal that is believed to have originated in Central and South America. For its nutritional and functional potential, brief growth cycle, capability to withstand unfavorable climate and soil conditions, and the food use of the entire plant, amaranth has attracted a great deal of interest of the literature in the last 2 decades.

Amaranth has higher mineral content as compared to cereal grains (Teutonico and Knorr 1985; Breene 1991; Tosi and others 2001; Gamel and others 2006). It has also been reported to exhibit hypcholesterolemic effects (Chaturvedi and others 1993; Qureshi and others 1996; Grajeta 1999; Plate and Aréas 2002). Because it is a gluten-free food, amaranth seeds have been recommended for people with celiac disease (Kupper 2005). Amaranth seeds are commonly consumed as suspensions in either water or milk following various heat treatments or as ingredients in other preparations (Bressani 1988; Breene 1991).

Due to amaranth’s relatively high starch content, small starch granule size (1 to 3 µm), and low amylose concentration (1%), further investigation of functional properties of native and modified amaranth starch is of great interest (Resio and Suarez 2001; Bello-Pérez and others 2006). Amaranth starch has been found to have low viscosity, high solubility, and low gelatinization temperature (Chaturvedi and others 1997; Resio and Suarez 2001).

Starch digestion is an important metabolic response following meal ingestion. Several intrinsic and extrinsic food factors influence the duration and extent of starch digestion. Carbohydrate content, starch granule characteristics, food processing conditions, and presence of some other components are among the intrinsic food factors that affect starch digestion and absorption rates, which in turn may determine the metabolic response to meal ingestion (Englyst and others 1992; Cummings and Englyst 1995; Englyst and Hudson 1996). Due to the high complexity and cost of glycemic index evaluation in humans, in vitro measurement of starch food digestion is useful in predicting the likely body’s glycemic response to food intake (Englyst and Hudson 1996; Goëli and others 1997; Rosin and others 2002).

Since food processing is one of the intrinsic factors that determine starch digestibility, amaranth’s nutritional features are likely to be affected by the type of processing it undergoes. This study investigated the effects of the most common methods of amaranth processing (cooking, popping, roasting, flaking, and extrusion) on amaranth’s digestible and indigestible starch fractions and on the in vitro rate of starch digestion. To predict in vitro effects of different processing methods, an in vitro hydrolysis index based on predicted glycemic indices was also determined.

Materials and Methods

Sample preparation

Amaranthus cruentus seeds were purchased from a local producer in Brasilia, Brazil. The amaranth processing methods were based on Bressani (1988), with adaptations. Cooked seeds were prepared by boiling seeds in water for 10 min. Popped seeds were heated on a hot plate at 90°C for about 10 to 15 s until popping. Seeds were placed on a hot plate at 120°C for about 1 min to prepare roasted seeds. All these conditions were established based on informal sensorial evaluation done by group members. Extruded amaranth was obtained from a defatted flour with moisture adjusted to 15% (db), which was subjected to an extrusion process in a single-screw extruder with L/D ratio 20 and 4 heating zones (INBRA—INBRAMAQ, Indústria de Máquinas Ltda, São Paulo, Brazil),
Table 1 — Treatment effects on amaranth seed proximate composition (g/100 g dry weight).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Raw</th>
<th>Popped</th>
<th>Roasted</th>
<th>Cooked</th>
<th>Flaked</th>
<th>Extruded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>3.39 ± 0.01</td>
<td>3.49 ± 0.15</td>
<td>3.38 ± 0.03</td>
<td>3.28 ± 0.08</td>
<td>3.45 ± 0.08</td>
<td>4.03 ± 0.49</td>
</tr>
<tr>
<td>Lipids</td>
<td>7.57 ± 0.10</td>
<td>5.11 ± 0.40</td>
<td>4.97 ± 0.05</td>
<td>3.69 ± 0.23</td>
<td>5.30 ± 0.09</td>
<td>0.314 ± 0.02</td>
</tr>
<tr>
<td>Protein</td>
<td>16.21 ± 0.58</td>
<td>15.20 ± 0.29</td>
<td>15.45 ± 0.40</td>
<td>16.66 ± 0.02</td>
<td>15.34 ± 0.17</td>
<td>18.20 ± 0.11</td>
</tr>
<tr>
<td>Soluble fiber</td>
<td>2.20 ± 0.34</td>
<td>2.04 ± 0.29</td>
<td>1.87 ± 0.18</td>
<td>1.82 ± 0.33</td>
<td>1.71 ± 0.03</td>
<td>5.22 ± 0.12</td>
</tr>
<tr>
<td>Insoluble fiber</td>
<td>12.64 ± 0.91</td>
<td>12.89 ± 0.50</td>
<td>12.42 ± 0.62</td>
<td>11.97 ± 0.16</td>
<td>11.89 ± 0.20</td>
<td>11.85 ± 0.99</td>
</tr>
<tr>
<td>Total starch</td>
<td>58.00 ± 0.29</td>
<td>60.63 ± 3.61</td>
<td>62.65 ± 3.15</td>
<td>65.25 ± 1.91</td>
<td>62.83 ± 1.22</td>
<td>61.72 ± 0.47</td>
</tr>
</tbody>
</table>

Values are presented in mean ± SD of 3 replicates.
Values in rows not sharing the same superscript are significantly different for P < 0.05.

Proximate composition

Moisture, ash, and protein contents were determined using AACC (2000) methods 44-15A, 08-01, and 46-13, respectively. Soluble and insoluble dietary fiber contents were analyzed by enzymatic-gravimetric method according to Prosky and others (1988). Total lipids were determined using AOMC (2003) method 920.39.

Total, resistant, and digestible starch contents

Total starch content was assessed following the protocol proposed by Göñi and others (1997) while glucose was quantified using glucose oxidase, peroxidase, and ABTS assay (Bergmeyer and Bernet 1974). Resistant starch content was determined according to Göñi and others (1996) and glucose was quantified using glucose oxidase, peroxidase, and ABTS assay (Bergmeyer and Bernet 1974). Starch content was calculated as glucose x 0.9. Digestible starch content was taken to be the difference between total and resistant starch.

In vitro starch digestion rate

The method described by Göñi and others (1997) was employed to evaluate the in vitro rate of starch hydrolysis. The starch digestion rate was expressed as the percentage of total starch hydrolyzed at 30, 60, and 90 min of incubation. The hydrolysis index (HI) was derived from the ratio between the area under hydrolysis curve of the amaranth product and the reference sample (white bread). This HI was found to be a good predictor of glycemic response to food ingestion and highly correlated with the glycemic index (GI) in vivo. From the HI obtained in vitro we therefore estimated the predicted GI using the equation established by Göñi and others (1997): GI = 39.71 + 0.549 (HI), with reported correlation coefficient of r = 0.89, P < 0.05. From the percentage values of starch hydrolyzed after 30 min of incubation, rapidly digestible starch (RDS) contents were calculated. The RDS represents the amount of starch hydrolyzed in 30 min presented in the sample, expressed as dry basis (db), and wet basis (wb). The wb value represents the RDS content as food as eaten.

Statistical analysis

Results were expressed as mean values and standard deviation of 3 determinations. Data were analyzed using one-way analysis of variance (ANOVA). When analysis showed significant differences (P < 0.05), means were compared using Tukey’s tests. Pearson correlation between parameters was determined, and its significance was evaluated by two-tailed Student’s t-test. All statistical analyses were run using SPSS 10.0 software (SPSS Inst. Inc., Cary, N.C., U.S.A.).

Results and Discussion

The proximate composition of amaranth seeds cultivated in Brazil (Table 1) was consistent with the data reported for A. cruentus grown in other countries (Teutonico and Knorr 1985; Breene 1991; Tosi and others 2001; Gamel and others 2006). Processing of amaranth seeds through popping, roasting, cooking, and flaking did not significantly alter their ash, protein, fiber, and starch levels. However, these treatments slightly decreased lipid quantities, possibly due to its interaction with starch. The formation of complexes between amylose and starch occurs during extrusion and other traditional cooking processes (Bhatnagar and Hanna 1994; Kaur and Singh 2000).

Compared to other processed seeds, extruded amaranth contained slightly higher protein levels and the lowest lipid contents due to the defatted flour used in its preparation. The extrusion process also increased soluble fiber contents. Extrusion cooking partially solubilizes the fiber component as already described in the literature (Björck and others 1984; Larrea and others 2005).

Enzymatically assessed total, digestible, and resistant starch contents of the raw and processed amaranth seeds are shown in Table 2. Treatments did not affect total and digestible amaranth starch contents, both of which remained lower than those found in white bread. Resistant starch (RS) values for raw amaranth agreed with previously reported range of 0.48% to 0.65% (Guerra-Matías and others 2007). Starch digestibility of processed amaranth...
type 1 and type 2 might explain the observed reduction in RS values in cooked amaranth seeds. RS type 1 is physically inaccessible starch whereas RS type 2 is native granular starch (Englyst and others 1992) and both are affected by thermal processing. No significant differences were found among RS contents of raw, popped, and extruded amaranth seeds. These dry heat processes were most likely unable to gelatinize RS in amaranth seeds. Guerra-Matias and Aréas (2004) and Gonzalez and others (2007) also observed that extrusion process does not change RS contents in amaranth seeds. There was found an RS increase from 0.50% to 1.36% in amaranth seeds after roasting. The RS found in roasted amaranth could be partly RS type 1 and 2 and also retrograded amylose–RS type 3 (Englyst and others 1992). Amaranth starch presented about 1% of amylose (Bello-Pérez and others 2006) and, possibly after cooling down, retrogradation of amylose chains occurs, increasing RS contents in roasted seeds. However, further investigations on granular and molecular levels would help to understand changes occurring in RS contents during processing of amaranth seeds.

Applying Goñi and others (1996) material classification scheme based on resistant starch content (% dry matter), negligible RS amounts (< 1%) were found in raw, popped, cooked, flaked, and extruded amaranth and only low values (1 to 2.5%) in roasted seeds. Amaranth starch digestion was studied in vitro. Figure 1 displays the behaviors of raw and processed amaranth. Raw seeds presented a lower degree of hydrolysis than the reference sample (white bread) after 30 and 60 min of incubation (P < 0.05). After 90 min, however, the raw material and white bread no longer showed differences in the degree of hydrolysis.

Processing has an important effect on starch digestibility. The treatments may expose seed's starch matrix and promote gelatinization, which in turn increases susceptibility to enzymatic di-
gestion (Figure 1). Starch hydrolysis rate was significantly enhanced by popping, roasting, and flaking processes, while cooking and extrusion did not alter starch digestibility rate from the values found in raw material throughout the assay period.

HI is useful for comparison of starch digestibility values between foods of interest and a reference material (white bread). To predict in vivo effects of different processing methods, a hydrolysis index based predicted glycemic index (pGI) was also determined. The observed HI and pGI for the raw and processed amaranth seeds are presented in Table 3. These data demonstrate a high predicted glycemic response following ingestion of amaranth seeds. Cooked, extruded, and popped amaranth seeds had starch digestibility similar to that of white bread, while flaked and roasted seeds presented a greater increase in glycemic response than did white bread. In agreement with our pGI values, Guerra-Matias and Aréas (2005) observed no significant in vivo starch digestibility differences between extruded amaranth and white bread. Chaturvedi and others (1997) reported a GI value of 97.3 for popped amaranth, but their value could be affected by the milk that was served with the amaranth product.

Englyst and Hudson (1996) recommended RDS expressed as food “as eaten” for the use as a dietary food selection parameter since its values allow for comparison among foods and among foods portions. However, Rosin and others (2002) observed that some foods with reduced solid content, such as polenta and potatoes, yielded low RDS values expressed “as eaten,” despite the high HI and GI. They thus recommended a more cautious interpretation of RDS expressed as food “as eaten” data. Rapidly digestible starch (RDS) contents in amaranth seed products are shown in Table 4. Organized in decreasing order, the dry basis RDS (g/100 g db) values were as follows: flaked seeds > roasted seeds > popped seeds > cooked seeds > raw seeds > extruded seeds. “As eaten” RDS (g/100 g wb) values were flaked seeds > roasted seeds > popped seeds > raw seeds > extruded seeds > cooked seeds. Due to the high moisture levels of cooked seeds (75.2%) the RDS content expressed “as eaten” is much lower (8.93%) than that expressed on a dry basis (36.1%).

![Figure 1](https://example.com/figure1.png)

**Table 3** — Treatment effects on hydrolysis index (HI) and predicted glycemic index (pGI) of amaranth seeds.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>HI</th>
<th>pGI</th>
</tr>
</thead>
<tbody>
<tr>
<td>White bread</td>
<td>100&lt;sup&gt;c&lt;/sup&gt;</td>
<td>94.61&lt;sup&gt;bc&lt;/sup&gt; ± 0.00</td>
</tr>
<tr>
<td>Raw seeds</td>
<td>86.49&lt;sup&gt;c&lt;/sup&gt; ± 2.05</td>
<td>87.19&lt;sup&gt;c&lt;/sup&gt; ± 1.12</td>
</tr>
<tr>
<td>Popped seeds</td>
<td>112.11&lt;sup&gt;c&lt;/sup&gt; ± 3.55</td>
<td>101.26&lt;sup&gt;c&lt;/sup&gt; ± 1.95</td>
</tr>
<tr>
<td>Roasted seeds</td>
<td>120.40&lt;sup&gt;c&lt;/sup&gt; ± 2.89</td>
<td>105.81&lt;sup&gt;c&lt;/sup&gt; ± 0.16</td>
</tr>
<tr>
<td>Cooked seeds</td>
<td>95.90&lt;sup&gt;c&lt;/sup&gt; ± 7.92</td>
<td>92.36&lt;sup&gt;c&lt;/sup&gt; ± 4.35</td>
</tr>
<tr>
<td>Flaked seeds</td>
<td>120.77&lt;sup&gt;c&lt;/sup&gt; ± 0.04</td>
<td>106.01&lt;sup&gt;c&lt;/sup&gt; ± 2.13</td>
</tr>
<tr>
<td>Extruded seeds</td>
<td>93.77&lt;sup&gt;c&lt;/sup&gt; ± 1.02</td>
<td>91.19&lt;sup&gt;c&lt;/sup&gt; ± 0.56</td>
</tr>
</tbody>
</table>

Values are presented in mean ± SD of 3 replicates. Values in columns not sharing the same superscript are significantly different for P < 0.05.

Predicted glycemic index (pGI) = 39.71 + 0.549 HI (Goñi and others 1997).
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There was a significant, positive correlation between the HI and the dry basis RDS values of amaranth seeds (r = 0.99, P < 0.01). This finding was previously described by Rosin and others (2002). However, we also found a significant positive correlation between the HI and the “as eaten” RDS values of amaranth seeds (r = 0.98, P < 0.01), likely due to the low moisture content of the foods evaluated in our study. The HI of amaranth seeds was comparable to the HI values reported for cereal-based foods like polenta (HI = 106), white rice (HI = 82), and spaghetti (HI = 90) by Rosin and others (2002). The RDS contents found in amaranth agreed with the values cited for breakfast cereals (RDS = 45) (Bravo and others 1998).

The in vitro starch digestion assays show that amaranth has high starch digestibility probably because of the small size of its starch granules (1 to 3 μm), low gelatinization temperature, and limited content of resistant starch (Resio and Suarez 2001; Bello-Pérez and others cited for breakfast cereals (RDS = <106), and spaghetti (HI = 90) by Rosin and others (2002). The RDS contents found in amaranth agreed with the values cited for breakfast cereals (RDS = 45) (Bravo and others 1998).

Cooking, popping, roasting, and extruding are quick processes and generate uniform products. These products of amaranth seeds can be valuable for culinary and industrial uses in their whole form or as flour, for direct consumption or as an ingredient. As an example, these heat processes can also be used to modify starch granule structure to produce precooked amaranth flours (González-Verdier and others 1999) and should be further assessed in dietary fiber content and degradation in the rat intestinal tract. Cereal Chem 61(2):174–9.


González-Verdier H. 1999. Effect of amaranth and oat bran on blood serum and liver lipids in celiac patients. But this patient group also has elevated rates of diabetes mellitus (Murray 2005). The development of novel applications for amaranth grains is an important task for future research. Further investigations on granular and molecular levels would help to better understanding these processing effects in amaranth seeds.

Conclusions

The in vitro starch digestion assay showed that amaranth is a high glycemic food. Rapidly digestible starch contents, hydrolysis index, and predicted glycemic index were significantly increased by popping, roasting, and extruding processes, indicating that amaranth seeds treated by the above methods have faster and more complete starch digestion than the raw, cooked, and extruded seeds. Cooked, popped, and extruded amaranth seeds had starch digestibility similar to that of white bread (reference sample), while flaked and roasted seeds had a slightly greater capacity to increase glycemic response. Several amaranth seed properties may explain the observed high starch digestibility. These include small starch granule size, reduced contents of resistant starch and soluble fiber, high levels of amylopectin, and low gelatinization temperature, which when reached during processing leads to a complete loss of the crystalline and granular structure of amaranth starch.

Acknowledgment

We wish to thank State of São Paulo Research Foundation for its financial support.

References


Table 4 --- Treatment effects on rapidly digestible starch contents (g/100 g) of amaranth seeds.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RDS (dry weight)</th>
<th>RDS (wet weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White bread</td>
<td>51.13 ± 2.90</td>
<td>36.77 ± 2.09</td>
</tr>
<tr>
<td>Raw seeds</td>
<td>30.67 ± 1.11</td>
<td>27.18 ± 0.99</td>
</tr>
<tr>
<td>Popped seeds</td>
<td>38.02 ± 0.22</td>
<td>37.57 ± 0.21</td>
</tr>
<tr>
<td>Roasted seeds</td>
<td>42.90 ± 0.65</td>
<td>41.61 ± 0.63</td>
</tr>
<tr>
<td>Cooked seeds</td>
<td>36.10 ± 3.64</td>
<td>8.93 ± 0.90</td>
</tr>
<tr>
<td>Flaked seeds</td>
<td>43.82 ± 0.29</td>
<td>39.36 ± 0.26</td>
</tr>
<tr>
<td>Extruded seeds</td>
<td>28.79 ± 0.00</td>
<td>26.51 ± 0.00</td>
</tr>
</tbody>
</table>

Values are presented in mean ± SD of 3 replicates. Values in columns not sharing the same superscript are significantly different for P < 0.05.
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