Original Article

Measurement of carbohydrate components and their impact on energy value of foods

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Abstract

In order to expand data on the Brazilian Food Composition Database Web site (TBCA-USP), the present work aimed to complement information about carbohydrate content in foods as well as to evaluate the influence of different carbohydrates on energy value. The sugars (glucose, fructose and sucrose) and the indigestible fractions (IF) (total, soluble and insoluble) were quantified in 11 starchy foods usually consumed by the Brazilian population. The total IF content found was bigger than the total dietary fiber (DF) for all foods. Consequently, when the IF was subtracted on the estimate of “available” carbohydrate by difference, it resulted in lower values. Similar results were found in relation to the energy values. The method applied to the IF analysis is relatively simple and considerably reproducible, representing an alternative for the analysis of indigestible components. However, this method does not discriminate each component individually. The total sugar content was lower than 0.5% (fresh wt.) for all foods. The “available” carbohydrate content and energy amount were similar in all 11 foods either when carbohydrates were analyzed individually or by difference subtracting DF in the difference. However, when the carbohydrates are analyzed individually, they provide information about several carbohydrates that are differently utilized in the gastrointestinal tract. Efforts must be driven towards a better differentiation among the different carbohydrate fractions, aiming to insure the quality of carbohydrate and energy information on food composition databases.

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Keywords: Indigestible fraction; Sugar; Energy; “Available” carbohydrates

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1. Introduction

The carbohydrates of food have a high degree of acceptability in human diets. Different types of carbohydrates are associated with several positive physiological effects for human body (FAO/WHO, 1998; Wahlqvist, 2002). Most food composition databases show total carbohydrates data measured by difference, which does not specify each carbohydrate component. It also must be emphasized that the estimate of the food energy value might suffer variation firstly because of the several components that are part of the carbohydrate fraction, then for the different terminologies utilized to express its content in food, which can result in ambiguous and misinterpreted information (Monro and Burlingame, 1996; Burlingame, 1996).

In order to expand food composition databases, initiatives to quantify carbohydrates in an individual and detailed way have been taken (Menezes and Lajolo, 2000; Rosin et al., 2002; Li et al., 2002). Li et al. (2002) evaluated the individual sugars, soluble and insoluble dietary fiber (DF) contents of 70 high-consumption American foods. Rosin et al. (2002) have accomplished the partial characterizations of 11 Brazilian starchy foods. In this work, the total starch, resistant starch, rapidly and slowly digestible starch, amylose and soluble and insoluble DF contents were determined in the same 11 common starchy Brazilian foods. The analysis of other carbohydrates, such as mono- and disaccharides and indigestible fraction (IF) of foods, seems pertinent because of the lack of national information on those components.

The IF is defined as the part of plant foods that is not digested nor absorbed in the small intestine. The IF is a substrate for fermentative microflora when it reaches the colon, and it is mainly composed not only of DF, but also of resistant starch and resistant protein (Saura-Calixto et al., 2000). Other components that are also resistant to digestive enzymes such as polyphenols and other associated components are included in IF’s composition as well. In other words, the IF is composed of the main substrates for the fermentative microflora with important physiological effects and it is always expected to be greater than DF content.

Hence, this study was carried out to determine the IF and mono- and disaccharides contents in 11 Brazilian starchy foods (used by Rosin et al., 2002). Also, the influence of different carbohydrate components on energy value was assessed in these foods.

2. Materials and methods

In the present work, the same 11 foods and conditions previously utilized by Rosin et al. (2002) were adopted, aiming to complement information on the chemical composition of those foods.

The 11 test foods usually consumed by the Brazilian population were: polished and whole rice from Supra Alimentos S.A; corn meal, dried peas, dried lentils and dried chick-peas from Hikari Ind. Com. Ltda; beans from Broto Legal Com. Imp. Exp. Ltda; white spaghetti from Quaker Brasil Ltda; green corn, white bread and potatoes from local market. A sample of each food (0.5–1 kg) was bought in Sao Paulo-SP. The foods were cooked during enough time for consumption and with open kettle. The time of cooking of each food was the following: polished and whole rice (28 min), green corn* (45 min), corn meal (90 min), white spaghetti (20 min), potatoes (33 min), peas (30 min), beans* (36 min), lentils* (21 min) and chick-peas* (70 min). After the removal of a portion from each sample for moisture determination, the samples were dried
under 60°C for 18 h, milled to a particle size of <0.250 mm and stored (at ambient temperature) until the analysis proceeds, that means, for approximately 30 days. The white bread was subjected to the same process from the drying procedure. The foods identified with an asterisk above were previously soaked in water under 4°C for 18 h prior to cooking.

The IF was determined as the sum of insoluble IF and soluble IF according to a process previously described by Saura-Calixto et al. (2000). Samples (300 mg of dry food) were homogenized in 10 mL of 0.1 M HCl-KCl buffer under controlled conditions and incubated (40°C, 60 min, pH 1.5) with pepsin (0.1 mL (30 mg/mL), Sigma P-7012) in a water bath with constant shaking. Then, 9 mL of 0.1 M TRIS-Maleato buffer (pH 6.9) were added and the pH was checked. α-Amylase was added (1 mL (120 mg/mL), Sigma A-3176), and the samples were incubated in water bath (37°C, 16 h). The samples were centrifuged (3000 g, 15 min) and the supernatants were removed. The residues were washed twice with 10 mL of distilled water and all supernatants were combined. The residues were dried (105°C, overnight) and quantified gravimetrically as insoluble IF. Supernatants were dialyzed against water (25°C, 48 h) (Dialysis membrane, 12,000–14,000 MWCO, Spectra/Por® Regenerated Cellulose, Spectrum® Laboratories Inc., USA). Dialysates were freeze-dried, and the soluble IF was quantified gravimetrically.

Sugars were extracted successively with three portions of boiling 80% (v/v) aqueous ethanol. The supernatants were combined and the ethanol was evaporated under vacuum. The mono- and disaccharides contents were analyzed by high-performance liquid chromatography (HPLC-PAD) (Dionex, Sunnyvale, CA), using a PA1 column (Dionex) in an isocratic run, with 18 mM NaOH (25 min).

Certain components, such as total starch, resistant starch, DF and the proximate composition were not tested as part of this study. Results were obtained from previous study (Rosin et al., 2002) for comparison and energy calculation purpose. The analytical methods used were the following: total starch (Goñi et al., 1997), resistant starch (Goñi et al., 1996), DF (Prosky et al., 1988). The data on protein, lipids and ash were calculated from the Brazilian Food Composition Database Web site (USP, 1998). The moisture was determined by drying in a vacuum oven for 3.5 h (60°C).

Results were expressed by means of values ± standard deviations of three separate determinations. Linear regression and P-value for correlation were estimated using the Minitab-Windows.

3. Results and discussion

3.1. Indigestible fraction (IF) in starchy foods

The IF content of 11 Brazilian starchy foods was determined. The results were compared to literature and to other DF analyses previously done on those foods.

Table 1 shows the total IF, insoluble IF and soluble IF contents of 11 foods and the literature data. The total IF (dry wt.) of legumes ranged between 26.40% (lentils) and 36.09% (beans). For the other foods, the total IF ranged between 7.74% (white spaghetti) and 25.43% (corn). Comparing such results with the one obtained by Saura-Calixto et al. (2000), the variations observed are justified by the difference in food type, food process and food preparation. For foods in which comparison was possible, the linear regression analysis between the total IF results found
Table 1
Indigestible fraction (IF) content of cooked starchy foods, expressed as % of dry and fresh weight

<table>
<thead>
<tr>
<th>Food</th>
<th>Indigestible fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total* (% dry wt.)</td>
</tr>
<tr>
<td>Whole rice</td>
<td>—</td>
</tr>
<tr>
<td>Polished rice</td>
<td>12.13 ± 0.83</td>
</tr>
<tr>
<td>Corn</td>
<td>—</td>
</tr>
<tr>
<td>Corn meal</td>
<td>11.61 ± 0.11</td>
</tr>
<tr>
<td>White spaghetti</td>
<td>14.01 ± 0.82</td>
</tr>
<tr>
<td>White bread</td>
<td>13.80 ± 0.45</td>
</tr>
<tr>
<td>Potatoes</td>
<td>12.18 ± 0.89</td>
</tr>
<tr>
<td>Peas</td>
<td>42.30 ± 3.58</td>
</tr>
<tr>
<td>Beans</td>
<td>35.59 ± 0.51</td>
</tr>
<tr>
<td>Lentils</td>
<td>29.15 ± 0.047</td>
</tr>
<tr>
<td>Chick-peas</td>
<td>28.03 ± 0.92</td>
</tr>
</tbody>
</table>

Mean of values ± s.d (standard deviation) (n = 3).

* Results obtained by Saura-Calixto et al. (2000).

Fig. 1. Comparison between the total IF of cooked foods obtained by the present study (*) and IF results obtained by Saura-Calixto et al. (2000) (**). The following foods were included in the linear regression analysis: A—polished rice, corn meal, white spaghetti, white bread, potatoes, peas, beans, lentils, chick-peas; B—polished rice, corn meal, potatoes, beans, lentils, chick-peas.

(dry wt.) and those from Saura-Calixto et al. (2000) showed a significant positive correlation 

\[ y = 0.736x + 4.240 \]

\[ r = 0.858, P \leq 0.003, n = 9 \]

When peas, bread and white spaghetti were excluded from the correlation, because of the differences above described, an increase in the \( r \) value was found 

\[ y = 0.895x + 3.810 \]

\[ r = 0.971, P \leq 0.005, n = 6 \] (Fig. 1).

For the 11 test foods, the total IF content was bigger than the content of total DF, which ranged from 13% to 64% of the IF content (Fig. 2).

The linear regression analysis showed a significant positive correlation between total IF and total DF 

\[ y = 1.250x + 8.610 \]

\[ n = 0.943, P \leq 0.001, n = 11 \] and between insoluble IF and insoluble DF 

\[ y = 1.230x + 4.820 \]

\[ r = 0.959, P \leq 0.001, n = 11 \]. No correlation was found between soluble IF and soluble DF. It can be explained by the fact that soluble DF was quantified by Prosky et al. (1988) method, which uses a high temperature and includes precipitation with ethanol. On the other hand, Saura-Calixto et al. (2000) observed correlation between their soluble
IF and soluble DF data. In this case, the soluble DF was quantified by the modified method of Prosky et al. (1988) (Mañas et al., 1994), where the precipitation with ethanol is substituted for dialysis, which is also utilized in IF determination.

The IF analysis represents an alternative for the evaluation of the fraction of foods that is not digested by the human organism. The methodology proposed by Saura-Calixto et al. (2000) for IF determination is relatively simple and with good reproducibility; however, it does not individually discriminate the IF components that have different physiological action.

### 3.2. Sugar

Data on mono- and disaccharides contents in national foods are scarce. In Table 2 there are data on the glucose, fructose and sucrose contents of the test foods. The contents (fresh wt.) ranged between 3.07 and 38.42 mg/100 g for glucose, 3.77 and 55.90 mg/100 g for fructose and 9.39

Table 2

<table>
<thead>
<tr>
<th>Food</th>
<th>Glucose (mg/100 g fresh wt.)</th>
<th>Fructose (mg/100 g fresh wt.)</th>
<th>Sucrose (mg/100 g fresh wt.)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole rice</td>
<td>35.02 ± 0.90</td>
<td>13.73 ± 0.54</td>
<td>51.84 ± 2.16</td>
<td>100.59</td>
</tr>
<tr>
<td>Polished rice</td>
<td>3.07 ± 0.34</td>
<td>4.60 ± 0.01</td>
<td>9.39 ± 1.32</td>
<td>17.05</td>
</tr>
<tr>
<td>Corn</td>
<td>25.26 ± 2.66</td>
<td>54.41 ± 5.31</td>
<td>33.03 ± 2.64</td>
<td>112.70</td>
</tr>
<tr>
<td>Corn meal</td>
<td>38.42 ± 1.93</td>
<td>17.86 ± 0.02</td>
<td>89.83 ± 3.96</td>
<td>146.10</td>
</tr>
<tr>
<td>White spaghetti</td>
<td>15.57 ± 2.17</td>
<td>12.18 ± 1.26</td>
<td>39.53 ± 5.35</td>
<td>67.29</td>
</tr>
<tr>
<td>White bread</td>
<td>26.11 ± 0.76</td>
<td>55.90 ± 0.60</td>
<td>n.d.</td>
<td>82.01</td>
</tr>
<tr>
<td>Potatoes</td>
<td>36.13 ± 2.73</td>
<td>23.13 ± 2.01</td>
<td>125.55 ± 10.94</td>
<td>184.81</td>
</tr>
<tr>
<td>Peas</td>
<td>n.d.</td>
<td>3.77 ± 0.44</td>
<td>191.19 ± 11.08</td>
<td>194.96</td>
</tr>
<tr>
<td>Beans</td>
<td>3.62 ± 0.84</td>
<td>8.30 ± 0.98</td>
<td>368.27 ± 7.97</td>
<td>380.19</td>
</tr>
<tr>
<td>Lentils</td>
<td>5.78 ± 0.01</td>
<td>13.97 ± 0.27</td>
<td>145.80 ± 5.71</td>
<td>165.55</td>
</tr>
<tr>
<td>Chick-peas</td>
<td>3.82 ± 0.91</td>
<td>6.74 ± 0.62</td>
<td>359.60 ± 52.17</td>
<td>370.16</td>
</tr>
</tbody>
</table>

Mean of values ± s.d. (standard deviation), (n = 3).

n.d.: non-detected.
and 368.27 mg/100 g for sucrose. Because these are starchy foods, with 42.32–87.36% (dry wt.) of total starch (Rosin et al., 2002), the low values of total sugar were already expected (<0.5% fresh wt.). The results obtained in this work are close to the ones found by Li et al. (2002) for the majority of foods. It is worth emphasizing that, although the test foods had low sugar content, it is still important to know its value once they belong to the carbohydrate fraction. In this way, such information complements data, following the present tendency which is to determine each component of the carbohydrate fraction and to evaluate foods on a case-by-case (Monro and Burlingame, 1996; Li et al., 2002). At the same time, this information should be included in food composition databases to improve the food planning in order to control the glycemic response as well as the chronic non-infectious diseases (Miller et al., 1995; Jenkins et al., 2002).

3.3. “Available” carbohydrate and energy value

The food composition databases present a considerable variation among the carbohydrates content. Such variation is partly due to the terminology applied to express carbohydrates and to the components that are considered in their estimation. The carbohydrates have a great potential for being presented in an ambiguous way because of their wide number of components and the several analytical methods that can be used to analyze them. Monro and Burlingame (1996) identified more than 80 tagnames to express carbohydrates of food. When the aggregation of proximate components is done, the carbohydrates are usually referred simply as “carbohydrates”. However, there are at least five commonly used methods for measuring and/or expressing carbohydrates, each of which is official although would reach different values for the same food.

In the present work, an estimation of the “available” carbohydrates was made considering the following components for the calculation: IF (Table 1), glucose, fructose and sucrose (Table 2), total starch, resistant starch and DF (Rosin et al., 2002) and other macronutrients (USP, 1998). Table 3 presents the “available” carbohydrate content estimated by three different ways (A, B and C) and their respective values of energy (Ae, Be, Ce). Procedure A expresses “available” carbohydrate by summation of different fractions (glucose, fructose, sucrose and total starch minus resistant starch). Procedure B was obtained by difference subtracting total DF (100 g minus the sum of grams of water, protein, lipids, ash and DF). Procedure C was also obtained by difference but, in this case, total IF was subtracted instead of DF. It could be noted that there was no relevant difference between the “available” carbohydrate content estimated by procedure A, which is the summation of “available” carbohydrate, and procedure B, where DF is also subtracted in the difference. The same was noted in their respective energy values.

However, when the IF was subtracted in the difference on the estimate of the “available” carbohydrate (procedure C), lower values were obtained in nine out of the 11 test foods, when comparing to the estimated values found by procedures A and B. It happened because the IF includes other components besides RS and the DF. Therefore, the values of “available” carbohydrates obtained when subtracting IF are closer to the real ones than when subtracting DF in the difference. In the case of energy, the same results were observed. The decrease in the “available” carbohydrate observed in procedure C leads to a decrease in the energy value (Ce), comparing to procedures A and B. For example, the legumes showed an overestimation on the energy value of 16% (procedure Ae) and 20% (procedure Be).
4. Conclusions

Once the IF includes several indigestible components, it presents higher content than the DF. Consequently, when subtracting the IF in the difference on the estimate of the “available” carbohydrates, lower values are obtained than when subtracting DF. Similar results were found in relation to the energy values. The IF analysis used in this work is relatively simple and has good reproducibility, and hence it can represent an alternative for the proximate composition determination, although it does not provide information about each indigestible component.

For the 11 test starchy foods, the total sugar content was low and there was no considerable difference on the energy value when the “available” carbohydrates were estimated by the summation of the different “available” carbohydrates or by difference subtracting DF.

The analysis of several individual components that constitute the carbohydrate fraction must be encouraged, aiming to insure the quality of carbohydrate and energy information in food composition databases.

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