Caloric Value of Inulin and Oligofructose[1]

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ABSTRACT Dietary carbohydrates, which are absorbed as hexose, (glucose, fructose) have a caloric value of 3.9 kcal/g (16.3 kJ/g), and their cellular metabolism produces ~38 mol ATP/mol. However, chicory inulin and oligofructose resist digestion and they are not absorbed in the upper part of the gastrointestinal tract. After oral ingestion, they reach the colon intact where they become hydrolyzed and extensively fermented by saccharolytic bacteria, which produce short-chain carboxylic and lactic acids as electron sinks. Depending on both the degree of their colonic fermentation and the assumptions of the model used, the caloric value of such nondigested but fermented carbohydrates varies between 0 and 2.5 kcal/g. Through the catabolism of the absorbed short-chain carboxylic and lactic acids, they may produce up to 17 mol ATP/mol of fermented sugar moiety. Because the daily intake of these dietary carbohydrates is likely to remain relatively small (<10% and probably often not >5% of total daily calorie intake), it is of low relevance nutritionally to give them a precise caloric value. On the basis of biochemical balance charts for carbon atoms, metabolic pathways and energy yields to the host, the caloric value of a fructosyl residue in chicory inulin and oligofructose has been calculated to be ~25–35% that of a fully digested and absorbed fructose molecule. For the purpose of food labeling, it is recommended that chicory inulin and oligofructose, like all the other carbohydrates that are more or less completely fermented in the human colon, should be given a caloric value of 1.5 kcal/g (6.3 kJ/g). J. Nutr. 129: 1436S–1437S, 1999.

KEY WORDS: • *inulin* • *prebiotic* • *caloric value*

Inulin-type fructans are composed of β-D-fructofuranoses attached by β-2→1 linkages. The first monomer of the chain is either a β-D-glucopyranosyl or β-D-fructopyranosyl residue. They constitute a group of oligosaccharides derived from sucrose or isolated from natural vegetable sources. Generally, the product with a degree of polymerization (DP) from 2 to 60^+ is labeled as inulin (Raftiline), whereas oligofructose, which is produced by partial enzymatic hydrolysis of inulin, is defined as DP < 10 (Raftilose). The inulin from which the small molecular weight oligomers have been eliminated is called inulin HP (Raftiline HP). As discussed extensively in other papers of these proceedings, inulin and oligofructose are nondigestible oligosaccharides (Delzenne and Roberfroid 1994) with dietary fiber properties (Roberfroid 1993). They resist digestion in the upper part of the gastrointestinal tract (Bach Knudsen and Hessov 1995, Ellegärd et al. 1997) but are quantitatively hydrolyzed and fermented by the bacteria in the colon (Roberfroid et al. 1998). Consequently, in terms of caloric value, inulin and oligofructose do not behave like digestible carbohydrates, which have been assigned a caloric value of 3.9 kcal/g (16.3 kJ/g) and which are fully metabolized to produce ~38 ATP/mol or 0.21 mol ATP/g. Indeed, because their colonic fermentation produces short-chain carboxylic acids (acetate, propionate and butyrate) and lactic acid and serves to provide the bacteria with both the material and energy needed to proliferate and grow, their contribution to the metabolic energy of the host is reduced and indirect. Nevertheless, that fermentation is an efficient way in which to salvage part of their energy content.

Evaluation of the caloric value of inulin and oligofructose

To evaluate the caloric value of a nondigestible carbohydrate such as inulin and oligofructose, four questions have to be answered.

Question 1. What is the percentage of the ingested dose that reaches the colon? Because of the β configuration of the anomeric C_2 that participates in their osidic linkages, inulin and oligofructose are resistant to hydrolysis by the human digestive enzymes. With the use of stomach fluid, purified sucrase-maltase preparations and intestinal mucosa, in vitro tests have indeed revealed that this is the case (Nilsson et al. 1988, Oku et al. 1984, Ziesenitz and Siebert 1987). Moreover, inulin and oligofructose are never recovered in the urine, indicating that they are not absorbed to any significant extent. In ileostomy patients, in vivo human studies have shown that 86–88% of the ingested dose of these nondigestible oligosaccharides is recovered at the end of the small intestine; the 12–14% loss is likely due to fermentation by bacteria that colonize the distal part of the small intestine in these patients (Bach Knudsen and Hessov 1994, Ellegärd et al. 1997).

In summary, in a normal gastrointestinal tract, the transfer

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of inulin and oligofructose into the colon is likely to be quantitative (~100%).

Question 2. What percentage of the dose reaching the colon is fermented? With the use of human fecal slurries, in vitro analysis as well as fermentation studies, it has been demonstrated that inulin and oligofructose both disappear rapidly (~4–5 h) and that they are, quantitatively, fermented (Roberfroid et al. 1998). Moreover, the analysis of fecal samples of volunteers fed a diet supplemented with inulin and oligofructose has always failed to recover any significant amount of these dietary fibers (such as oligosaccharides). It can thus be concluded that they are quantitatively fermented in the large intestine.

Questions 3 and 4. What is the efficiency of microbial mass production and how much of the C atoms and energy are lost during the fermentation process? What is the ATP yield of the metabolism of short-chain carboxylic acids by the host ? These are, by far, the most difficult parts of the exercise because the fermentation process is likely to be dependent on the composition of the microflora and to vary among individuals. Evaluating the caloric value of polyols, a FASEB/LSRO (1994) expert group has applied the so-called "factorial method," which calculates that parameter according to the following formula:

$$\text{kcal (kJ)} = (A - B) \times (1 - C) \times (1 - D) \times E$$

where A is the kcal (kJ) entering the colon as fermentable substrate, B is the kcal (kJ) excreted in feces, C is the proportion of C atoms from fermentable substrate going into bacterial mass, D is the loss of C atoms and energy due to fermentation and E is the efficiency of utilization of short-chain carboxylic acids by the host compared with glucose.

According to the report of the FASEB/LSRO (1994) and on the basis of what is known for inulin and oligofructose (see above), $A = 3.9$ kcal (16.3 kJ)/g, $B = 0$, $C = 0.15–0.21$, $D = 0.25–0.30$ and $E = \sim 0.70$

The calculated caloric value for these two nondigestible oligosaccharides is thus the following:

$$3.9\ (16.3\ \text{kJ}) \times [1 - (0.15 \text{ or } 0.21)] \times [1 - (0.25 \text{ or } 0.30)] \times 0.70 = 1.5–1.7\ \text{kcal/g or } 6.3–7.3\ \text{kJ/g}$$

On the basis of experimental data and theoretical biochemical considerations concerning both the bacterial fermentative and the host's metabolic balances, Roberfroid et al. (1993) have calculated that the caloric value of inulin and oligofructose should be between 1.1 (4.6) and 1.7 (7.3) kcal/g (kJ/g). Similarly, using ^{14}C-labeled low-molecular-weight inulin-type fructans and a radiochemical balance study in humans, Hosoya et al. (1988) have established a caloric value of 1.5 (6.3) kcal/g (kJ/g).

CONCLUSION

As summarized above, a reasonable caloric value for inulin and oligofructose is estimated to be ~1.5 (6.3) kcal/g (kJ/g) or ~38% that of a digested hexose molecule. In addition to the uncertainty factors discussed above concerning the efficiency of the fermentation process, it must also be kept in mind that, as discussed in other papers of these proceedings, inulin and oligofructose may have additional gastrointestinal effects (transfer of energetic molecules from the small to the large intestine, bulking effects or increased fecal excretion of energy) as well as systemic ones, especially on the metabolism and deposition of fats, which may influence the energy balance of the host. It has indeed been reported that the nondigestible/dietary fiber-like carbohydrates often interact with digestion of proteins and fats, thus lowering the caloric value of the diet as a whole (Livesey and Elia 1995). The energy value proposed is thus likely to be at the upper limit.

The daily intake of these dietary carbohydrates (nondigestible oligosaccharides, non-starch polysaccharides and resistant starch) is likely to remain relatively small, i.e., <10% and probably often not >5% of total daily calorie intake (Cummings and Frölich 1993). Thus, it is scientifically not justifiable to devote much effort to providing a more precise caloric value for each such carbohydrate (Cummings and Roberfroid 1997).

For the purpose of nutrition labeling, it is thus recommended that inulin and oligofructose, as well as all of the nondigestible oligosaccharides that are largely or completely fermented in the colon, be given a caloric value of 1.5 (6.3) kcal/g (kJ/g).

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