Net energy value of two low-digestible carbohydrates, Lycasin®HBC and the hydrogenated polysaccharide fraction of Lycasin®HBC in healthy human subjects and their impact on nutrient digestive utilization

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The metabolizable energy content of low-digestible carbohydrates does not correspond with their true energy value. The aim of the present study was to determine the tolerance and effects of two polyols on digestion and energy expenditure in healthy men, as well as their digestible, metabolizable and net energy values. Nine healthy men were fed for 32 d periods a maintenance diet supplemented either with dextrose, Lycasin®HBC (Roquette Frères, Lestrem, France), or the hydrogenated polysaccharide fraction of Lycasin®HBC, at a level of 100 g DM/d in six equal doses per d according to a 3×3 Latin square design with three repetitions. After a 20 d progressive adaptation period, food intake was determined for 12 d using the duplicate meal method and faeces and urine were collected for 10 d for further analyses. Subjects spent 36 h in one of two open-circuit whole-body calorimeters with measurements during the last 24 h. Ingestion of the polyols did not cause severe digestive disorders, except excessive gas emission, and flatulence and gurgling in some subjects. The polyols induced significant increases in wet (+45 and +66 % respectively, $P<0.01$) and dry (+53 and +75 % respectively, $P<0.002$) stool weight, resulting in a 2 % decrease in dietary energy digestibility ($P<0.001$). They resulted also in significant increases in sleeping (+4·1 %, $P<0.03$) and daily energy expenditure (+2·7 and +2·9 % respectively, $P<0.02$) compared with dextrose ingestion. The apparent energy digestibility of the two polyols was 0·82 and 0·79 respectively, their metabolizable energy value averaged 14·1 kJ/g DM, and their net energy value averaged 10·8 kJ/g DM, that is, 35 % less than those of sucrose and starch.

Low-digestible carbohydrate: Dietary fibres: Polyols: Energy expenditure: Energy value: Man

People in industrialized countries generally have an excessive consumption of energy, especially as fat and sucrose, and a low dietary fibre intake. Various pathologies may result from these nutritional imbalances, such as obesity, diabetes, cardiovascular diseases, colon cancer and, more frequently, intestinal transit disorders (Burkitt & Trowell, 1975; Alfieri *et al.* 1995). In addition to their well-known effects on satiation (Blundell & Burley, 1987), energy intake regulation (Burton-Freeman, 2000) and digestive transit regulation (Cummings *et al.* 1978), low-digestible carbohydrates (LDC) exert numerous beneficial health effects (Scheppach *et al.* 2001) especially on colonic mucous membrane development through the regulatory role of volatile fatty acids (VFA) (Breuer *et al.* 1991), and improve absorption of some minerals (Coudray *et al.* 1997). Furthermore, ingestion of fruit, vegetable and cereal fibre decreased apparent digestibility of dietary energy, crude protein and lipids (Göranzon *et al.* 1983;

Wisker *et al.* 1997). Finally, energy expenditure (EE) was increased by sugar-beet fibre and inulin ingestion in healthy human subjects which resulted in low net energy (NE) values (Castiglia-Delavaud *et al.* 1998), whereas ingestion of an additional 26 g LDC did not alter significantly EE in men (Poppitt *et al.* 1998).

Measuring the energy value of LDC is difficult, mainly because they are consumed in small quantities. The results published in the literature are generally estimates of their digestible energy (DE) value, metabolizable energy (ME) value or NE value calculated from measurements of fermentability, breath tests, etc. and hypotheses on gas, microbial mass and VFA production, and efficiency of VFA energy utilization (Livesey, 1992). The advantages and disadvantages of various methods were discussed pertinently by a group of experts (Federation of American Societies for Experimental Biology, 1994). No indirect method is satisfactory. The energy balance method by whole-body indirect calorimetry allows measurement of all energy losses associated with LDC intake. However, it requires ingestion of high doses of LDC to obtain an accurate NE value of the tested compound (Federation of American Societies for Experimental Biology, 1994).

Increasing attention has been paid to LDC by the food industry. Polyols and various starchy products have sweetening properties, but are poorly digested in the small intestine and partially fermented in the large intestine. They could thus prevent dental caries, reduce energy intake and stave off or delay some pathologies. The objectives of the present study were to determine: (1) the digestive effects of two LDC (a maltitol syrup, called Lycasin®HBC (Roquette Frères, Lestrem, France) and the hydrogenated polysaccharide fraction (HPF) of Lycasin®HBC); (2) their DE and ME values; (3) their effects on EE which influences their NE value, as compared with dextrose in healthy human subjects.

Subjects and methods

Subjects

Fifteen healthy young men, without any medical history of renal, vascular, digestive, endocrine or currently evolving disease, 20·5 (SD 0·5) years of age, non-smokers, and weighing 68·4 (SD 8·1) kg, were enlisted after a normal physical examination. Those who had a BMI $>25 \text{ kg/m}^2$ were excluded. Each subject received a complete explanation of the purpose and procedures of the investigation and signed an informed consent form. The study protocol was approved by the regional Medical Faculty Ethical Committee (CCPPRB no. AU 205). During the study, the subjects lived at home. They had lunch and dinner at the Human Nutrition Laboratory (Clermont-Ferrand, France) during the periods of food control. Extra food items, such as alcoholic and energy-containing beverages, were not permitted.

Methods

Experimental design. The study was composed of two successive parts: a preliminary study and the main study. The preliminary study aimed at: (1) determining the tolerance of the tested products; (2) training subjects to

Table 1. Composition of experimental diets*†

Day 1		Day 2		Day 3		Day 4	
Item	Weight (g)	Item	Weight (g)	Item	Weight (g)	Item	Weight (g)
Lunch							
Red beets	71	Semolina	57	Strasbourg sausage	73	Turkey	105
Tuna, canned	33	Chicken	108	Boiled potatoes	306	Sunflower oil	5
Salad dressing	18	Tomato sauce	52	Butter	10	Light cream	20
Ground beef	104	Carrots	38	Blue cheese	36	Mustard	18
Sunflower oil	4	Sunflower oil	5	Kiwi fruit	160	Pasta, egg	272
Green beans	210	Butter	10	Bread	65	Butter	8
Butter	5	Yoghurt	125			Chabichou cheese	28
Babybel cheese	20	Sugar	10			Custard, canned	91
Sponge cake	48	Madeleine biscuits	38			Bread	58
Chocolate, dark	20	Bread	58				
Bread	58						
Dinner							
Turkey breast	67	Tomatoes, raw	95	Quiche Lorraine	170	Tomatoes, raw	95
Sunflower oil	3	Salad dressing	43	Spinach, steamed	262	Green beans	95
Rice, boiled	257	Tuna, canned	86	Light cream	18	Boiled rice	164
Courgette, boiled	95	Pasta, egg	156	Chocolate custard	115	Egg, hard-boiled	100
Butter	5	Emmental cheese	18	Sponge fingers	21	Salad dressing	40
Emmental cheese	29	Brie cheese	33	Bread	65	St-Nectaire cheese	28
Pineapple, canned	105	Compote	172			Pear, canned	112
Bread	58	Bread	58			Bread	65

* The quantities of the different components are indicative of the actual quantities consumed, which were weighed accurately for each subject during each dietary period.
† Breakfast was composed of (g): sweetened instant cocoa powder 20, semi-skimmed milk 280, sandwich loaf bread 65, butter 10, jam 60. In addition, the volunteers had a milk roll (70 g) for a snack.

the experimental design; (3) adapting them to living in the calorimetric chambers; (4) determining their EE in standardized conditions in order to enable calculation of the quantities of food offered to each of them during the main study. Three groups of five subjects were offered either Lycasin®HBC, HPF of Lycasin®HBC or dextrose at increasing doses from 20 to 100 g DM/d for 25 d. The tested products were diluted (100 g product – 200 g water) and ingested in six equal doses at breakfast, at 10.00 hours, at lunch, 16.00 hours, at dinner and at 22.00 hours. Subjects were asked to complete a diary containing the occurrence and intensity of the following symptoms: gas emission, gurgling, flatulence, abdominal pain, diarrhoea. The diary was examined every day by the investigators during each experimental period. Stools were collected for 5 d before product ingestion and at the end of the adaptation period to determine DM content. During the second 5 d period subjects spent 36 h in the calorimetric chambers.

Nine of the fifteen subjects had been recruited to participate in the main study. They were offered three diets according to a Latin square design (3 × 3) with three repetitions. The basal diet was supplemented either with dextrose (diet D), Lycasin® HBC (diet L) or HPF of Lycasin® HBC (diet HPFL). Each experimental period, lasting for 32 d, comprised 18 d with a progressive adaptation to the tested products from 20 g DM/d up to a maximum of 100 g DM/d, followed by 14 d with a constant intake of the tested products. Food intake was determined by the duplicate meal method. The balance period covered 10 d (days 23–32) and involved total collection of faeces and urine. EE was measured over 36 h using whole-body calorimetry during the final week.

Experimental diets. Four daily balanced low-fibre diets were devised by the dietitian of the Human Nutrition Laboratory (Table 1). They were distributed in rotation to subjects during each balance period. The ME supply to each subject was calculated from their EE as measured during the preliminary period and their food habits to avoid a sensation of hunger.

The tested products were produced by Roquette Frères. The maltitol syrup, Lycasin®HBC, is composed of 50 % (DM basis) maltitol and 50 % hydrogenated polysaccharide syrup. The latter (HPF) is obtained by heating, at high temperature, starch adjusted to a low moisture level in the presence of an acidic catalyst. The product is then decolourized with activated C and demineralized by exchange resins. Afterwards, it is chromatographed and the high molecular mass fraction is retained and hydrogenated in contact with Raney Ni catalyst to obtain an hydrogenated polysaccharide syrup. The number-average molecular weight (Mn) is 2787 g/mol, corresponding to an average degree of polymerization of 17·2, whereas the weight-average molecular weight (Mw) is 4970 g/mol, corresponding to a polydispersity coefficient (Mw/Mn) of 1·8. During cooking, a partial hydrolysis of starch occurs followed by random rearrangements resulting in the production of highly branched molecules. The distribution of C–C bonds is is as follows (%): 1–2 13, 1–3 14, 1–4 41, 1–6 32. These structural modifications induce a decrease in digestibility by glucidolytic enzymes.

The tested products were diluted into water and offered in six equal doses per d as described earlier, to prevent a bulky input of fermentable compounds in the large intestine.

Sample treatment. Representative food samples were prepared during the last 10 d of each experimental period. Duplicate meals and leftovers were homogenized, freeze-dried and analysed separately. Urine was collected in plastic bottles and weighed daily during the last 10 d of each control period. Representative samples (50 ml/l) were pooled in acid-washed plastic bottles and stored at −18°C until analysis. Faeces were collected in plastic pots, stored at −18°C, then homogenized for the 10 d balance period, freeze-dried and stored at −18°C until analysis.

Analytical methods. The DM contents of Lycasin®HBC and HPF of Lycasin®HBC were determined using a modified Karl Fisher method (International Standards Organization, 1994). The DM content of dietary and faecal samples was determined after drying at 80°C for 48 h. The gross energy content of dietary samples, faeces and urine was analysed using an adiabatic bomb calorimeter (Gallenkamp, London, UK) calibrated with benzoic acid. Total N content of faeces and urine was analysed using the Dumas method (AFNOR V 18120, March 1997 Saint-Denis-La Plaine, France).

The *in vitro* enzymatic digestibility of the two hydrogenated polysaccharides was determined according to a method derived from that of Prosky *et al.* (1985) using Sigma-Aldrich (Saint-Quentin-Fallavier, France) reagents. To summarize, about 1 g product was placed in a beaker with phosphate buffer (pH 6). Thermostable α-amylase (100 μl) was added and the beaker was placed in a water bath at 95°C for 45 min. The beaker was then cooled at room temperature and the pH adjusted to 4·3. Amyloglucosidase (300 μl) was added and the beaker was placed at 60°C in a water bath for 30 min. After cooling at room temperature, the total sorbitol and glucose concentrations were evaluated using Boehringer-Manheim-France kits (hexokinase, sorbitol dehydrogenase; Meylan, France). The initial sorbitol and glucose concentrations were evaluated in the products not digested by α-amylase and amyloglucosidase. The differences between the total concentrations and the initial concentrations reflected the amounts of sorbitol and glucose liberated by the enzymatic action and permitted to calculate the non-digestible part of Lycasin®HBC and of HPF of Lycasin®HBC.

Soluble carbohydrates were extracted from faeces using water – chloramphenicol (1 ml/l). Faeces were washed twice and centrifuged. Analyses were performed on the supernatant fraction. Glucose and sorbitol were determined enzymatically using glucose oxidase and sorbitol dehydrogenase Boehringer kits respectively. Maltitol was analysed by GC after sililation (70°C for 5 min) of the samples by addition of bis-silyltrimethyltrifluoroacetamide. GC was carried out on a Varian 3400 chromatograph (Chromatography System, Walnut Creek, CA, USA) coupled with flame ionization detection, using a split-splitless injector liner split equipped, and He (69/kPa) as carrier gas. The sililated samples and inositol (internal standard) were injected on a DB-17 capillary column (J and W Scientific, Folsom, CA, USA; length 30 m, i.d. 0·32 mm, phase thickness 0·25 μm). Chromatographic conditions were: column temperature 150–185°C

with an increasing rate of 5°C/min, injector temperature 210°C, flame ionization detection temperature 280°C.

Emissions of H_2 and CH_4 could not be determined directly. They were estimated from the results of *in vitro* fermentation (Jouany & Lassalas, 2000; JP Jouany and B Lassalas, unpublished results), on the basis that 60 % Lycasin®HBC and 84 % HPF Lycasin®HBC were fermented in the large intestine.

Energy expenditure measurements. Whole-body indirect calorimetry was used to determine EE. The two

Calculations

Computation of nutrient and energy intake was as previously described (Vernet & Vermorel, 1993). Apparent digestibility of dietary energy was calculated as: ((gross energy intake − gross energy content of faeces)/gross energy intake). An analogous equation was used for N apparent digestibility. Dietary ME was calculated as: DE − urinary energy − estimated H_2 and CH_4 energy. The DE and ME values of LDC were calculated as follows assuming that dextrose was completely used in the small intestine:

$$DE_{LDC} = \frac{(GEI_{LDCdiet} \times (DEI/GEI)_{LDCdiet}) - (GEI_{LDCdiet} - GEI_{LDC}) \times \left(\frac{DEI_{dextrose\ diet} - GEI_{dextrose}}{GEI_{dextrose\ diet} - GEI_{dextrose}}\right)}{LDC}, \quad (1)$$

and

$$ME_{LDC} = \frac{(GEI_{LDCdiet} \times (MEI/GEI)_{LDCdiet}) - (GEI_{LDCdiet} - GEI_{LDC}) \times \left(\frac{MEI_{dextrose\ diet} - GEI_{dextrose}}{GEI_{dextrose\ diet} - GEI_{dextrose}}\right)}{LDC}, \quad (2)$$

open-circuit calorimetric chambers used were airtight (inflatable seals), continuously ventilated by atmospheric air, and equipped with an air-conditioning system controlling air temperature at $22\cdot0 \pm 0\cdot5°C$ and relative humidity at $50 \pm 2\%$. O_2 consumption and CO_2 production were measured continuously using differential gas analysers: CO_2 0–1 %, O_2 21–20 % (Mahiak, Hamburg, Germany). At the end of each balance period, subjects spent 36 h in the calorimetric chambers under cardiac supervision, one evening and one night for adaptation to the chambers' environment and for 24 h EE measurement. During each measurement period, volunteers followed precisely a standardized activity programme with four 20 min periods of walking at 5 km/h on a treadmill. All physical variables such as air temperature, relative humidity, flow and composition, as well as heart rate, were recorded every minute. The validity of gas exchange measurements was checked by infusions of CO_2 and N_2 into the chambers for 8 h after equilibrium (Vermorel *et al.* 1995). Recovery averaged 99·5 (SD 0·6) % for CO_2 and O_2.

where DE_{LDC} and ME_{LDC} are expressed in kJ/g DM, LDC is expressed as g DM/d, GEI is gross energy intake (kJ/d), DEI is DE intake (kJ/d), and MEI is ME intake (kJ/d).

EE was calculated using the Brouwer (1965) formula: $(16\cdot18\ O_2\ (litres) + 5\cdot02\ CO_2\ (litres) - 6\cdot00\ urinary\ N\ (g))$. Retained energy was calculated as: ME – EE. ME requirement values (ME_{mRE}) were calculated for the mean quantity of energy retained (1·79 MJ/d) by the volunteers with the three dietary treatments. They were calculated individually from retained energy assuming that ME efficiency was 0·95 for maintenance (negative energy balance) and 0·90 for fattening (positive energy balance) (Van Es *et al.* 1984). Differences in ME_{mRE} between the experimental diets and the D diet were considered to result from differences in efficiency of LDC ME utilization for maintenance. The maintenance NE value of LDC (NE_{LDC}) was calculated as follows:

$$NE_{LDC} = \frac{ME_{LDC} - \Delta ME_{mRE}}{LDC}, \quad (3)$$

Table 2. Occurrence and intensity of digestive symptoms caused by ingestion of 100 g DM Lycasin®HBC* and hydrogenated polysaccharide fraction (HPF) of Lycasin®HBC during the preliminary study and the main study†

Period...	Preliminary study				Main study			
Tested product...	Lycasin®HBC (n 5)		HPF of Lycasin®HBC (n 5)		Lycasin®HBC (n 9)		HPF of Lycasin®HBC (n 9)	
Symptoms...	Occurrence	Intensity	Occurrence	Intensity	Occurrence	Intensity	Occurrence	Intensity
Gas emission	5/5	+	3/5	+	9/9	++	7/9	++
Gurgling	1/5	+	1/5	+	1/9	++	3/9	++
Flatulence	2/5	+	0/5	−	1/9	+	3/9	+
Abdominal pain	1/5	+	1/5	+	2/9	+	4/9	+
Diarrhoea	1/5 (once)‡	+	1/5 (once)‡	+	0/9	−	0/9	−

Symptom intensity: +, low; ++, medium; +++, intense; − , no symptom.
* Roquette Frère, Lestrem, France.
† For details of diets, subjects and procedures, see Table 1 and pp. 132–133.
‡ Diarrhoea was also mentioned once by one subject when offered dextrose.

where ME$_{LDC}$ is the ME supplied by LDC (kJ/d). Thus, the NE value of LDC was ME content minus the difference in ME$_{mRE}$ between experimental and D diets (ΔME$_{mRE}$).

Statistical analysis

Data were analysed statistically according to a Latin square design (3 × 3) with three repetitions. Comparison between experimental diets was by ANOVA using the general linear models procedure of Statistical Analysis Systems Inc. (1987; Cary, NC, USA), according to the following model: μ + α diet + β repetition + δ subject (repetition) + γ order + ε where order is the order (1, 2 or 3) of measurement of EE in the calorimeters for each diet. The 'LS MEAN' statement was used to calculate the adjusted means, and the 'CONTRAST' statement to compare the three diets.

Results

The fifteen volunteers completed the preliminary study and the nine volunteers completed the main study. However, one subject did not collect all faeces when given diet L, and another subject did not follow exactly the activity programme during the alert period in the calorimeter when given diet D, and the corresponding value of EE was discarded. The missing data were estimated by the statistical model.

Tolerance of the tested products

The quantities of products ingested amounted to 98·7, 99·9 and 97·5 g DM/d for D, L and HPFL diets respectively. Summing up digestive symptoms showed that ingestion of the tested products at this level did not cause severe digestive disorders (Table 2) both during the preliminary and the main study: no diarrhoea, slight abdominal pain in two and four subjects respectively, slight flatulence, and moderate gurgling in one and three subjects respectively.

The main symptom in all subjects was excessive gas emission, which was mentioned from a dose of about 65 g DM/d. Intensity was similar for L and HPFL diets.

In vitro digestibility of the tested products

In vitro digestibility averaged 39·8 (SD 4·0) and 16·0 (SD 1·6) % for Lycasin®HBC and HPF of Lycasin®HBC respectively.

Faecal weight and apparent digestibility of diets

Ingestion of about 100 g Lycasin®HBC DM or HPF of Lycasin®HBC DM did not alter significantly either the number of defecations or the % DM in stools. However, wet stool weight was increased significantly by 45 % (P<0·015) and 66 % (P<0·001), and dry stool weight by 53 % (P<0·002) and 75 % (P<0·001) by ingestion of L and HPFL diets respectively (Table 3). Furthermore, there were large ranges in wet stool weights, from 87 to 228 g/d with both tested products. Increases in wet stool weight were caused by 72 and 68 % increases in water content for L and HPFL diets respectively.

Increases in faecal DM output were accompanied by 49·5 and 62·6 % increases in faecal energy excretion (P = 0·002) with L and HPFL diets respectively. The corresponding increases in faecal N excretion were 37·4 and 35·5 % respectively (P<0·02). Apparent digestibility of energy and N was reduced by 2·0 (P<0·001) and 3·2 (P<0·02) percent units respectively (Table 3). There were no significant differences between L and HPFL diets.

Faecal excretion of maltitol and sorbitol was <0·04 and 0·1 g/d respectively, which indicated that more than 99·9 and 99·8 % maltitol and sorbitol respectively consumed as Lycasin®HBC were digested. Mean faecal excretion of free glucose was <0·7 g/d with the three diets, but significantly higher with diets L and HPFL than with diet D (P=0·002). Similarly, mean total glucose faecal excretion was higher

Table 3. Daily intake, faecal excretion, apparent digestibility of energy and nitrogen and metabolizability of energy of the dextrose (D), Lycasin®HBC* (L), and hydrogenated polysaccharide fraction (HPF) of Lycasin®HBC (HPFL) diets†

(Mean values and standard deviations)

Diet...	D Mean	SD	L Mean	SD	HPFL Mean	SD	Statistical significance of effect of diet: P
DM intake (g/d)	544	147	537	103	567	121	NS
Gross energy intake (MJ/d)	12·97	2·3	13·22	1·85	13·81	1·74	NS
Protein intake (g/d)	109	18	111	14	114	18	NS
Number of defecations/d	0·98	0·31	1·06	0·40	1·02	0·23	NS
Wet faecal weight (g/d)	105	29	153	49	166	44	0·01
Faecal DM content (%)	24·05	4·58	26·49	6·43	25·37	3·26	NS
Dry faecal weight (g/d)	25·0	6·5	38·6	13·1	42·0	11·9	0·002
Faecal energy (MJ/d)	0·51	0·12	0·77	0·21	0·84	0·21	0·002
Energy apparent digestibility	0·960	0·008	0·942	0·017	0·939	0·014	0·001
Urinary energy (MJ/d)	0·44	0·07	0·46	0·08	0·44	0·09	NS
Energy metabolizability	0·926	0·009	0·905	0·017	0·905	0·016	0·008
Nitrogen apparent digestibility	0·912	0·020	0·880	0·029	0·881	0·026	0·02
Free glucose faecal excretion (g/d)	0·26	0·24	0·46	0·21	0·69	0·27	0·002
Total glucose faecal excretion (g/d)	0·33	0·24	3·96	3·55	8·25	6·33	0·001

* Roquette Frère, Lestrem, France.
† For details of diets, subjects and procedures, see Table 1 and pp. 132–133.

Table 4. Daily metabolizable energy (ME) intake, retained energy and metabolizable energy required for the mean quantity of energy retained by subjects (ME$_{mRE}$) when offered the dextrose diet (D), the Lycasin$^{®}$HBC diet* (L), and the hydrogenated polysaccharide fraction of Lycasin$^{®}$HBC diet (HPFL)†

(Mean values and standard deviations)

Diet...	D		L		HPFL		Statistical significance of effect of diet: *P*
	Mean	SD	Mean	SD	Mean	SD	
ME intake (MJ/d)	12·50	1·72	11·97	1·75	12·50	1·60	NS
Energy expenditure (MJ/d)	10·32	0·87	10·63	0·780	10·61	0·89	0·02
Sleeping energy expenditure (MJ)	2·29	0·15	2·38	0·12	2·39	0·19	0·01
Retained energy (MJ/d)	2·19	1·07	1·34	1·26	1·89	1·19	NS
ME$_{mRE}$	12·08	0·91	12·41	0·74	12·44	1·01	0·03

* Roquette Frère, Lestrem, France.
† For details of diets, subjects and procedures, see Table 1 and pp. 132–133.

with L and HPFL diets than with D diet ($P=0.05$ and 0.001 respectively, Table 3). In addition, it tended to be higher with diet HPFL than with diet L ($P=0.10$). Ingestion of 100 g Lycasin$^{®}$HBC DM or HPF of Lycasin$^{®}$HBC DM induced increases of 3·63 (SD 3·45) and 7·15 (SD 6·31) g in faecal excretion of total glucose respectively, corresponding to 3·6 and 7·3 % of the ingested quantities of the tested products respectively. Consequently, the apparent digestibility of Lycasin$^{®}$HBC and HPF of Lycasin$^{®}$HBC in the whole digestive tract should be, on average, 96 and 93 % respectively.

Metabolizable energy content of diets

Increases in H_2 and CH_4 energy losses calculated from *in vitro* fermentation of Lycasin$^{®}$HBC and HPF of Lycasin$^{®}$HBC were estimated to be 38 (SD 17) and 29 (SD 13) kJ/d with L and HPFL diets respectively. These losses corresponded to 0·27 and 0·22 % dietary gross energy intake, and 2·3 and 1·7 % Lycasin$^{®}$HBC and HPF of Lycasin$^{®}$HBC gross energy intake.

Urinary energy losses were not significantly different between the three diets, and averaged 3·35 % gross energy intake. Consequently, the metabolizability of dietary energy was 2·1 and 2·0 percent units lower with diets L and HPFL respectively, than with diet D ($P<0.01$, Table 3).

Energy expenditure of volunteers

EE *v.* heart rate of volunteers during the three experimental periods was compared to make sure that there was no bias in physical activity or sleep of volunteers. The order of measurement of EE in the calorimetric chambers did not have a significant effect on EE during sleep. The latter was similar for diets L and HPFL, and 4·1 % higher than sleeping EE obtained with diet D. By contrast, EE during the alert period was significantly ($P=0.03$) affected by the order of measurement in the calorimetric chambers. EE was 2·3 % higher during the first period than during the two following periods. After adjustment for order of measurement, EE during the alert period was not significantly different between diets L and HPFL. However, it was 2·6 and 2·9 % higher with diets L and HPFL respectively, than with diet D ($P<0.02$). Thus, ingestion of 100 g Lycasin$^{®}$HBC DM and HPF of Lycasin$^{®}$HBC DM induced significant increases in EE.

Energy retained by the volunteers

Retained energy was calculated as the difference between ME intake and EE adjusted for the order of measurement in the calorimetric chambers. Retained energy was not significantly different between the three diets and averaged 1·79 MJ/d. ME requirement for this mean retained energy (ME$_{mRE}$) was similar for diets L and HPFL but higher than

Table 5. Calculation of the net energy (NE) value of the two tested low-digestible carbohydrates (LDC): Lycasin$^{®}$HBC* and hydrogenated polysaccharide fraction (HPF) of Lycasin$^{®}$HBC†

(Mean values and standard deviations)

Tested product...	Lycasin$^{®}$ HBC		HPF of Lycasin$^{®}$ HBC	
	Mean	SD	Mean	SD
LDC DM intake (g/d)	99·94	0·59	97·54	1·54
LDC ME intake (kJ/d)	1410	210	1375	193
Difference in ME$_{mRE}$ (kJ/d)	323	151	341	367
NE$_{LDC}$ (kJ/g)	10·9	2·1	10·7	5·0

ME, metabolizable energy; ME$_{mRE}$, ME required for the mean quantity of energy retained.
* Roquette Frère, Lestrem, France.
† For details of diets, subjects and procedures, see pp. 132–133.

Table 6. Energy values (kJ/g DM) of Lycasin®HBC* and hydrogenated polysaccharide fraction (HPF) of Lycasin®HBC†

(Mean values and standard deviations)

Tested product...	Lycasin® HBC		HPF of Lycasin® HBC	
	Mean	SD	Mean	SD
Gross energy value	17·26	0·09	17·36	0·002
Digestible energy value	14·8	1·9	14·3	1·6
Metabolizable energy value	14·1	2·1	14·1	2·0
Net energy value	10·9	2·1	10·7	5·0

* Roquette Frère, Lestrem, France.
† For details of diets, subjects and procedures, see and pp. 132–133.

that obtained with diet D ($P=0·033$, Table 4). This means that more ME was required with diets L and HPFL than with diet D to obtain the same retained energy. Calculation of the NE value of the two tested products is presented in Table 5.

Energy values of Lycasin®HBC and hydrogenated polysaccharide fraction of Lycasin®HBC

The gross energy, DE and ME values of Lycasin®HBC and HPF of Lycasin®HBC were similar (Table 6). Their ME value (14·1 kJ/g DM) was 9·6 % lower than that of dextrose (15·6 kJ/g DM), and 15·5 % lower than the estimated values of sucrose and starch (16·7 kJ/g DM).

The NE values of Lycasin®HBC and HPF of Lycasin®HBC were also similar (10·8 kJ/g DM), but 35 % lower than that of dextrose if one assumes a 100 % efficiency of ME utilization for maintenance.

Discussion

The results of the present study show that following a progressive adaptation, and distribution in six equal doses per d, ingestion of 100 g Lycasin®HBC DM and HPF of Lycasin®HBC DM/d did not cause serious digestive disorders, induced a significant decrease in energy digestibility, and significant increases in sleeping EE and daily EE of healthy subjects.

Tolerance of Lycasin®HBC and hydrogenated polysaccharide fraction of Lycasin®HBC

In spite of large inter-individual differences in sensitivity, the main digestive symptoms reported by the subjects were excessive gas emission and flatulence. A slight abdominal pain was mentioned by two of the nine subjects. According to them, it was mainly due to the impossibility of voiding gases during group activities or gatherings. In addition, there were no symptoms of diarrhoea. On the contrary, the DM content of faeces tended to increase. Finally, it is noteworthy that the great quantity (100 g DM/d) of the tested products ingested for experimental reasons was far greater than the expected intake in practice, and that symptoms of excessive gas emission and flatulence were reported for an intake of about 65 g/d.

The good tolerance of high doses of Lycasin®HBC and HPF of Lycasin®HBC agreed with the results of Beaugerie

et al. (1990) showing that ingestion of 57 g maltitol/d after the three main meals did not cause symptoms of digestive disorders in six healthy subjects adapted to maltitol intake. It could be explained by the following: (1) *in vitro* enzymatic digestibility of Lycasin®HBC and HPF of Lycasin®HBC averaged 39·8 and 16·0 % respectively, which means that only 60 and 82 g/d of these products respectively were submitted to microbial digestion in the colon; (2) because of their high degree of polymerization, these LDC should not be very osmotically active and should be slowly fermented; (3) administration of progressively increasing doses over a 20 d period favoured the adaptation of the microbial population in the colon and complete fermentation of polyols; (4) the partition of the daily supply between six equal doses regulated the fermentation rate (Livesey, 2001*b*; Marteau and Flourie, 2001). In the present study, intakes of the tested LDC averaged 0·24 g/meal per kg body weight (half during meals and half between meals), whereas the estimated laxative thresholds (maximum no-effect dose) are 0·29 g/meal per kg body weight for maltitol in drinks and 0·42 and 0·46 g/meal per kg body weight for maltitol and polydextrose respectively, in foods (Livesey, 2001*a*).

Digestive effects of Lycasin®HBC and hydrogenated polysaccharide fraction of Lycasin®HBC

Ingestion of 100 g tested products DM/d did not alter significantly the number of defecations, but increased significantly wet and dry stool weights. Increases in dry stool weight (0·40–0·45 g/g tested products) were intermediate between those obtained with citrus fibre (0·3 g/g) on the one hand, and fruits and vegetables (0·7 g/g; Wisker *et al.* 1997) and sugar-beet fibre (0·75 g/g; Castiglia-Delavaud *et al.* 1998) on the other hand, but much lower than those obtained with barley fibre or wholemeal rye bread (1 g/g; Wisker *et al.* 1997).

Increases in faecal output resulted in significant decreases in energy and protein apparent digestibility which could not be explained by the small excretion of the undigested tested products. The 2·0 % unit reduction of dietary energy apparent digestibility may result from digestive interactions between LDC and dietary compounds and increased bacterial mass excretion which contributes to more than 50 % dry stool weight (Castiglia-Delavaud *et al.* 1998). As a matter of fact, maltitol ingestion caused an increase in ileal excretion of dietary compounds (Langkilde *et al.* 1994) which are not totally digested and contribute to faecal output. In addition, the 3·2 % unit reduction of protein apparent digestibility did not indicate a poor utilization of dietary protein. It may result from NH_3 utilization for bacterial growth at the expense of urinary N excretion (Castiglia-Delavaud *et al.* 1998).

Energy lost as H_2 and to a lesser extent as CH_4 averaged 2 % LDC gross energy, in agreement with the proposals of Livesey & Elia (1988).

Effects of the tested low-digestible carbohydrates on energy expenditure of subjects

Ingestion of 100 g Lycasin®HBC DM and HPF of Lycasin®HBC DM both induced significant increases in

sleeping EE and daily EE. The Latin square design and the statistical model used allowed us to take into account the effects of subject and order of measurement of EE. Increases in EE were slightly greater than those obtained with young adults fed 50 g sugar-beet fibre DM/d or commercial inulin DM (Castiglia-Delavaud *et al.* 1998). However, ingestion of 7 or 22 g LDC/d did not alter significantly EE in healthy men in crossover designs (Ryttig *et al.* 1990; Poppitt *et al.* 1998). The latter results might be explained by the relatively small amount of additional LDC ingested compared with the 50 g sugar-beet fibre or inulin, and the 100 g Lycasin®HBC DM and HPF of Lycasin®HBC DM in the present study.

Rises in EE may result from increases in gastrointestinal motility (Cherbut *et al.* 1994) and digestive tissue weight, and lower energetic efficiency of VFA utilization compared with glucose. As a matter of fact, maltitol ingestion induced significant enlargement and thickening of caecal and colonic tissues in rats (Zhang *et al.* 1990; Tamura *et al.* 1991; Oku & Kwon, 1998). Similarly, ingestion of sugar beet or carrot fibre (15–25 % dietary DM) or inulin (8–13 % dietary DM) caused significant increases in small intestine (14–19 %), caecum (78–132 %) and colon (55–116 %) tissue weight in growing rats (C Cubizolles and M Vermorel, unpublished results). These tissues indeed have a rapid turnover and a high metabolic rate and contribute 25 % of fasting metabolism or daily EE in pigs (Yen *et al.* 1989). Finally, the weighted efficiency of energy utilization for maintenance was 15 % lower for VFA than for glucose (Armstrong & Blaxter, 1957; Krebs, 1960; Livesey, 1992). It is noteworthy that the effect of LDC ingestion on EE during sleep was greater than during the alert period. This result could be explained by the fact that microbial digestion and VFA production are enhanced during sleep, whereas enzymatic digestion and absorption decrease, and physical activity and EE are reduced.

Energy values of Lycasin®HBC and hydrogenated polysaccharide fraction of Lycasin®HBC

Differences between energy values of these two LDC and those tabulated for sucrose or starch increased from −2 % for gross energy to −13 % for ME and −35 % for NE because of increases in faecal energy losses, H_2 and CH_4 production caused by LDC. The ME and maintenance NE values of the tested products determined in the present study were compared with those predicted from fibre digestibility, estimated energy lost as microbial mass, H_2, CH_4 (for ME), and fermentation heat as well as the efficiency of VFA utilization (for NE) (Livesey, 1992). The predicted ME values were close to the measured values (13·4 *v.* 14·1 kJ/g DM). The predicted NE values were slightly but not significantly higher than the measured values (11·95 *v.* 10·8 kJ/g DM).

In conclusion, following a progressive adaptation to ingestion, and distribution in six equal doses per d, intake of 100 g Lycasin®HBC DM or HPF of Lycasin®HBC DM/d did not cause severe digestive disorders in healthy human subjects. The two products were almost totally digested or fermented. The ME and NE values were similar between the products, but 13 and 35 % lower than those of sucrose or starch respectively.

Lycasin®HBC and HPF of Lycasin®HBC are expected to be consumed in pratice in much smaller quantities than in the present study. Ingestion of < 50–60 g LDC/d should not induce digestive discomfort in healthy adults, could improve the digestive transit through an increase in stool output, reduce dental caries and reduce NE intake compared with sweet (candy) consumption.

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