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Energy value of a low-digestible carbohydrate, NUTRIOSE® FB, and its impact on magnesium, calcium and zinc apparent absorption and retention in healthy young men

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Summary *Background* Long-term consumption of imbalanced diets, poor in dietary fibres, resulted in the prevalence of several nutritional pathologies. However, low digestible carbohydrates (LDC) have many beneficial effects, especially on energy intake, digestive physiology, and mineral absorption. *Aim of the study* To determine the digestive effects of a LDC, called NUTRIOSE® FB, its metabolisable energy (ME) value, and its effects on mineral absorption in humans. *Methods* Ten healthy young men were fed for 31 d periods a maintenance diet supplemented with either dextrose or the LDC at a level of 100 g DM/d, in six equal doses per d according to a cross-over design. After a 20 d adaptation period, food intake was determined for 11 days using the duplicate meal method, and faeces and urine were collected for10 d for further analyses. *Results* Ingestion of the LDC did not cause severe digestive disorders, except excessive gas emission, and flatulence and slight abdominal pain in some subjects for intakes above 50 g DM/d. Wet and dry stool outputs increased by 45 and 70 %, respectively ($P < 0.02$). In vitro enzymatic digestibility of the LDC was 15 (SD 1.5) %, and 9.2 (SD 8.3) % of the LDC was excreted in faeces ($P < 0.001$). The ME value of the LDC was 14.1 (SD 2.3) kJ/g DM, that is 14 % less than the tabulated values of sucrose and starch. Its net energy value (NEV), estimated using three prediction equations, was 8.7, 8.9, and 11.4 kJ/g DM. Ingestion of the LDC significantly increased the relative apparent absorption of Mg, and Mg retention by 67 % and 31 mg/d, respectively, tended to increase Ca apparent absorption ($P = 0.110$) and Ca retention ($P = 0.059$), but did not significantly alter Zn parameters. *Conclusion* NUTRIOSE® FB can be used as a "bulking" agent, and substituted up to 50 g/d for usual maltodextrins without causing digestive disorders in healthy subjects. It would reduce intestinal transit disorders and energy intake, and improve magnesium and calcium absorption and retention.

Key words low digestible carbohydrate – NUTRIOSE® FB – digestive effect – energy value – mineral balance – humans

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Introduction

Occidental industrialized countries are characterized by societies of abundance submitted, during the last thirty years, to severe shifts of lifestyle and food habits. This results in a reduction of physical activity, and excessive consumption of energy supplied by refined food products or ready-cooked dishes rich in saturated fat and sucrose, and poor in vegetables and fruit. The long-term consumption of imbalanced diets together with increasing life expectancy has resulted in the prevalence of various pathologies such as obesity, diabetes, cardiovascular diseases, colon cancer or, more frequently, intestinal transit disorders [1].

In addition to their effects on satiation [2], energy intake regulation [3] and digestive transit regulation [4], low-digestible carbohydrates (LDC) have various beneficial health effects on digestive transit, epithelia of ileum and colon, and against acute colitis and colorectal cancer [5] through the regulatory role of volatile fatty acids (VFA) [6]. In addition, they have been shown to enhance calcium and magnesium absorption in rats [7] and humans [8–11]. Furthermore, ingestion of fruit, vegetables, cereals or processed LDC resulted in decreased apparent digestibility of dietary energy and lower metabolizable energy (ME) content [12–13]. Finally, for the same dietary ME intake, substitution of LDC for starch or dextrose induced significant increases in energy expenditure (EE) in healthy human subjects, resulting in low net energy value (NE) of LDC [14, 15].

The objectives of the present study were to determine 1) the digestive effects of a LDC called NUTRIOSE® FB (Roquette Frères, Lestrem, France), 2) its digestible (DE) and ME contents, 3) its effects on magnesium, calcium and zinc apparent absorption and balance in healthy young men, as compared with dextrose.

Subjects and methods

Subjects

The study protocol was approved by the regional Medical Faculty Ethical Committee (CCPPRB n° AU 318). Volunteers received a complete explanation of the purpose and procedures of the investigation and signed an informed consent form. Ten healthy young men, without any medical history of renal, vascular, digestive, endocrine or currently evolving disease, 23.6 (SD 2.6) years of age, nonsmokers (height: 1.79 (SD 0.08) m; body weight: 71.6 (SD 7.5) kg, BMI: 22.3 (SD 1.6) $kg \cdot m^{-2}$) were enlisted after a normal physical examination. Those who had a BMI higher than 25 kg/m^2 were excluded. During the study, the subjects lived at home. They had lunch and dinner at the Human Nutrition Laboratory during the periods of food control. Extra food items, such as alcoholic and energy containing beverages, were not permitted. Volunteers received a payment.

Methods

Experimental design

The study was composed of two successive parts: a preliminary study and the main study. The preliminary study aimed at determining the tolerance of the LDC, and training subjects to the experimental design. Faeces were collected over a 5-day period before ingestion of the tested product to determine faecal output and dry matter (DM) content. The LDC was then offered over a 25-day period. The latter consisted of a 20-day adaptation period and a 5-day measurement period. The LDC was offered at increasing doses from 20 to 100 g/d for 20 d. It was diluted (100 g product + 200 g water) and ingested in six equal doses at breakfast, 10.00h, lunch, 16.00h, dinner and 22.00h. Subjects were asked to complete a diary containing the occurrence and intensity (4 levels) of the following symptoms: gas emission, intestinal gurgle, flatulence, abdominal pain, diarrhoea. They were met and the diary was examined every day by the investigators during the experimental period. Stools were collected during five days after the end of the adaptation period to determine fecal output and DM content.

In the main study subjects were offered two diets according to a cross-over design with a wash out period of 4 weeks between the two treatment periods. The basal diet was supplemented either with dextrose (diet D) or the LDC (diet N). Each experimental period, lasting for 31 days, 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 13 d with a constant intake of the tested products. Food intake was determined by the duplicated meal method. Each balance period covered 11 d (days 21–31) and involved total collection of faeces and urine.

Experimental diets

Four daily balanced low-fibre diets were composed by the dietician 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 food habits assessed during the preliminary period to avoid a sensation of hunger. It was the same for the two treatments.

NUTRIOSE®FB is a purified dextrin manufactured by Roquette Frères (62080 Lestrem, France). This glucose polymer is processed from starch heated at high temperature and adjusted to a low moisture level in the presence of an acid catalyst. The dextrin obtained is purified with activated carbon and demineralized by

Table 1 Composition of experimental diets (g)*

Day 1		Day 2		Day 3		Day 4	
Lunch		Lunch		Lunch		Lunch	
Vegetable mix	(100)	Carrot, raw	(120)	Tomatoes, raw	(100)	Lettuce, raw	(50)
Mayonnaise	(11)	Olive oil	(13)	Salad dressing	(10)	Sweet corn, canned	(30)
Ground beef	(116)	Lemon juice	(14)	Turkey breast	(110)	Salad dressing	(20)
Pasta, egg	(250)	Cod, steamed	(181)	Light cream (15 %)	(15)	Roast beef	(120)
Tomato sauce	(57)	Mashed potato	(300)	Rice, white, boiled	(65)	Semolina	(60)
Yoghurt, fruit	(125)	Butter	(10)	Butter	(15)	Butter	(12)
Peaches, canned	(173)	Roquefort cheese	(28)	Camembert cheese	(40)	Pea, canned	(50)
Bread	(58)	Pineapple, canned	(153)	Chocolate custard	(100)	Uncured cheese	(100)
		Madeleine biscuits	(42)	Ladyfinger biscuits	(12)	Pears, canned	(200)
		Bread	(50)	Bread	(40)	Bread	(40)
Dinner		Dinner		Dinner		Dinner	
Chicken breast	(75)	Ham, cooked	(54)	Frankfurter sausage	(47)	Dry sausage	(30)
Mayonnaise	(3)	Green beans	(200)	Pasta, egg, boiled	(250)	Butter	(8)
Rice, white, boiled	(245)	Sunflower oil	(7)	Butter	(5)	Potato, boiled	(250)
Butter	(10)	Uncured cheese	(91)	Petit-Suisse	(109)	Butter	(8)
Babybel cheese	(32)	Fruit, canned	(200)	Sugar	(13)	Emmental cheese	(31)
Orange	(150)	Brioche	(40)	Orange	180)	Apple compote	(162)
Bread	(30)	Fruit jelly	(17)	Bread	(30)	Bread	(45)
		Bread	(30)				

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

exchange resins. Afterwards the product is chromatographed, and the high molecular weight fraction is retained and spray dried. The number-average molecular weight (Mn) is 2480 corresponding to an average degree of polymerization of glucose units equal to 18, whereas the weight average molecular weight (Mw) is 5344.

During cooking, a partial hydrolysis of starch occurs followed by random rearrangements resulting in the production of highly branched molecules which are a well known characteristic of starch dextrins. This last point confers to NUTRIOSE®FB a resistance against the action of glucidolytic enzymes and permits classification of the product among the soluble dietary fibres [16]. Charge number EO 102 was used in this study. Its chemical composition was the following: water: 3.4 %; reducing sugars: 2.3 %; free glucose: 0.1 %; protein: < 0.2 %; ash: < 0.5 %; heavy metals: < 5 mg/kg. The cristalline anhydrous dextrose (purity at least 98 %) used was produced by total hydrolysis from wheat starch.

Sample treatment

Representative food samples were prepared during the last 11 d of each experimental period. Duplicate meals and leftovers were homogenized using metal-free materials, 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 homogenised using metal-free materials for the 10 d balance period, freeze-dried and stored at –18 °C until analysis.

Analytical methods

The DM content of LDC was determined using a modified Karl Fisher method [17]. 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).

The *in vitro* enzymic digestibility of the LDC was determined according to a method derived from that of Prosky et al. [18], as described by Sinaud et al. [15]. In addition, the LDC residue in faeces was assessed by determining the faecal residual glucose. To do that, soluble carbohydrates were extracted from faeces using a 0.1 % (w/v) chloramphenicol water solution, and centrifuged. Free glucose was determined enzymatically in the supernatant using a glucose oxidase kit (Roche, 38242 Meylan, France). Total glucose (polymerized plus free glucose) was determined after acid hydrolysis (HCl 4 N)

45 minutes at 100 °C using the same reagent kit. The LDC residue was estimated by deducting the faecal free glucose from the total fecal glucose after hydrolysis.

Determination of mineral contents: about 0.5 g of tested products or diets or 0.25 g of faeces were dry-ashed at 500 °C for ten hours. HCl (6 M) was added to the dry residue, diluted adequately in 1 N-HCl for Zn measurement and in 0.1 % lanthanum chloride solution for Ca and Mg analysis. Urine was analyzed directly with simple dilution in 1 N-HCl for Zn measurement and in 0.1 % lanthanum chloride solution for Ca and Mg measurements. Ca, Mg and Zn were assayed by flame atomic absorption spectrometry (Perkin Elmer 560, Paris, France) with an air-acetylene flame and hollow cathode lamps at wavelengths 422, 285, 214 nm, respectively. Mineral levels were calculated from standard curves of mineral solutions (Merck, Lyon, France). Analytical quality was checked using total diet control standards (NIST) for dietary mineral measurements, home constructed human faeces for faecal mineral measurements, and Seronorm® urine (Nycomed, Oslo, Norway) for urinary mineral measurements. All measurements were performed at least in duplicate.

Calculations

Computation of nutrient and energy intake was as previously described [19]. 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.

The apparent digestibility of the LDC in the whole digestive tract was calculated as the ratio between LDC intake minus faecal LDC residue and LDC intake.

Dietary ME was calculated as: digestible energy – urinary energy. The digestible energy (DEV_N) and metabolisable energy (MEV_N) values of the LDC were calculated for each subject from the corresponding values obtained with diet N and diet D, assuming that dextrose was totally absorbed from the small intestine and that digestibility and metabolizability of food (except LDC or dextrose) were the same in the two experimental periods. Differences in DE and ME contents between diet N and diet C were ascribed to the LDC as in previous studies [14, 15].

$$DEV_N = \frac{\left[GEI_{\text{diet N}} \times \left(\frac{DEI}{GEI}\right)_{\text{diet N}}\right] - \left[\left(GEI_{\text{diet N}} - GEI_N\right) \times \left(\frac{DEI}{GEI}\right)_{\text{diet D}}\right]}{\text{Quantity of N ingested}}$$

$$MEV_N = \frac{\left[GEI_{\text{diet N}} \times \left(\frac{MEI}{GEI}\right)_{\text{diet N}}\right] - \left[\left(GEI_{\text{diet N}} - GEI_N\right) \times \left(\frac{MEI}{GEI}\right)_{\text{diet D}}\right]}{\text{Quantity of N ingested}}$$

In the above equations DEV and MEV are expressed in kJ/g DM; the quantity of LDC ingested (N) is expressed as g DM/d; GEI is gross energy intake (kJ/d); DEI is digestible energy intake (kJ/d), and MEI is ME intake (kJ/d).

Absolute apparent absorption (mg/d) of minerals was calculated as follows: daily mineral intake – daily mineral faecal excretion. Relative apparent absorption (%) was calculated as follows: 100 x {(daily mineral intake – daily mineral faecal excretion)/(daily mineral intake)}. Mineral retention (mg/d) was calculated as follows: (daily mineral intake) – (daily mineral faecal excretion + daily mineral urinary excretion).

Statistical analysis

Data were analysed by ANOVA using PROC GLM of SAS software [20] according to the following model: $y = \mu + \alpha$ subject $+ \beta$ experimental period $+ \delta$ dietary treatment. The least square means (LSMEANS) statement was used to calculate the adjusted means. LSMEANS and SE of LSMEANS were compared using the "TDIFF" option (t values for the hypotheses H0: LSMEAN (i) = LSMEAN (j) and the corresponding probabilities) and "stderr" option (standard error of the LSMEAN and the probability level for the hypothesis H0: LSMEAN = 0). Differences in mineral apparent absorption and retention were also analysed using the Wilcoxon test [20]. Differences were considered significant at $P < 0.05$.

Results

Tolerance of the tested products

The ten volunteers completed the preliminary study and the main study. They ingested, on average, 99.8 (SD 0.7) g DM of LDC, and 104.7 (0.6) g DM of dextrose per day after the adaptation period. These products contributed to 14.4 and 14.6 % of gross energy intake, respectively. Summing up of digestive symptoms showed that ingestion of 100 g DM of the LDC per day, after progressive adaptation, did not cause severe digestive disorders (Table 2). Eight of the ten subjects mentioned excessive gas emission, especially for LDC intakes above 50 g/d. Four subjects mentioned slight flatulence, two subjects slight intestinal gurgle, three subjects slight abdominal pain, and two subjects mentioned diarrhoea one day. Interestingly, digestive symptoms diminished after 20 days, when the LDC intake had reached a plateau.

Effect of LDC intake on faeces output, and diet digestibility and metabolizability

The number of defecations was slightly but not significantly increased. However, wet faeces output was increased by 45 %, on average ($P < 0.05$; Table 3). In addi-

Table 2 Occurrence and intensity of digestive symptoms caused by ingestion of 100g dry matter of NUTRIOSE®FB during the preliminary study and the main study

Period	Preliminary study		Main study	
Number of subjects	10		10	
Symptoms	Occurrence	Intensity	Occurrence	Intensity
Gas emission	2/10	/	2/10	/
	5/10	+	4/10	+
	1/10	++	1/10	++
	2/10	+++	2/10	+++
Gurgle	1/10	+	1/10	+
Flatulence	2/10	+	2/10	+
Abdominal pain	2/10*	+	1/10	+
Diarrhoea	2/10 (once)	+	0/10	/

Symptom intensity: +: low; ++: medium; +++: intense; /: No symptom
* Abdominal pain persisted after the end of NUTRIOSE®FB ingestion in one subject

tion, the DM content was significantly increased by 3.8%, on average ($P < 0.02$). Consequently, dry faeces output was increased by 70% on average ($P < 0.02$). The increase in wet faeces output was due to increased DM output (for 38%) and increased water output (for 62%). Daily intake of 100 g DM of LDC resulted in significant reductions of energy digestibility (–2.4%, $P < 0.02$) and nitrogen digestibility (–2.8%, $P < 0.02$) of diets. Urinary energy losses were not significantly altered by LDC ingestion. Consequently, energy metabolizability of diet N was significantly lower (–2.2%) than that of diet D ($P < 0.05$, Table 3).

Digestion and energy value of the LDC

The in vitro digestibility tests indicated that 15 (SD 1.5) % of LDC was enzymatically digested, resulting in glucose production (ROQUETTE, unpublished data). In addition, the polymerized glucose fecal output averaged 9.20 (SD 8.3) g/d with diet N, compared to 0.13 (SD 0.04) g/d with diet D ($P < 0.001$; Table 3). Consequently, the apparent digestibility of the LDC was 90.8%, and about 76% of the LDC was fermented. Digestible (DEV) and metabolizable (MEV) energy values of the LDC, calculated as indicated above, were similar and averaged 14.4 (SD 2.3) kJ/g DM, that is 8 and 14% less than the estimated values of dextrose (15.6 kJ/g DM), and sucrose and starch (16.7 kJ/g DM).

Impact of LDC ingestion on Mg, Ca, and Zn apparent absorption and balance

Magnesium. Daily individual Mg intake varied from 172 to 256 mg/d. Mg faecal excretion was significantly lower with N diet than with D diet ($P = 0.033$). Consequently, both relative and absolute apparent Mg absorptions were greater after ingestion of the LDC than after dextrose ingestion ($P = 0.007$, and $P < 0.001$, respectively, Table 4). This improvement in apparent Mg absorption was accompanied by significant increases in Mg urinary excretion ($P < 0.001$) and Mg retention ($P = 0.024$) with LDC ingestion.

Calcium. Daily individual Ca intake ranged from 547 to 876 mg. Ca faecal excretion ranged from 211 to 756 mg/d. According to the results of ANOVA the mean values were not significantly different between the two treatments ($P = 0.603$). Consequently, both absolute (mg/d) and relative (%) apparent Ca absorption were not significantly affected by the dietary treatment ($P = 0.093$ and $P = 0.191$, respectively, Table 4). Neither daily Ca urinary excretion nor daily Ca retention differed significantly between the treatments ($P = 0.247$

Table 3 Daily intake, faecal excretion, apparent digestibility of energy and nitrogen and metabolizability of energy of the dextrose (D), and NUTRIOSE®FB (N) diets (LSMeans and SE of LSM)

Diet	D		N		Statistical significance
	Mean	SE	Mean	SE	P
Energy intake (MJ/d)	11.27	0.52	11.46	0.52	0.95
Protein intake (g/d)	101	5	102	5	0.81
Number of defecations/d	0.76	0.04	0.84	0.04	0.27
Wet faecal weight (g/d)	92.8	10.4	130.6	10.4	0.05
Faecal dry matter content (%)	24.2	0.08	28.8	0.08	0.02
Dry faecal weight (g/d)	22.7	3.2	37.4	3.2	0.02
Faecal energy (MJ/d)	0.46	0.06	0.72	0.06	0.02
Energy apparent digest.	0.960	0.005	0.936	0.005	0.02
Urinary energy (MJ/d)	0.40	0.01	0.38	0.01	0.10
Energy metabolizability	0.925	0.008	0.903	0.008	0.05
Nitrogen apparent digest.	0.898	0.005	0.872	0.005	0.05
Total glucose faecal excretion (g/d)	0.13	1.85	9.20	1.85	0.01

Table 4 Effects of long-term ingestion (32 days) of NUTRIOSE®FB on apparent absorption and retention of calcium, magnesium and zinc (LSMeans and SE of LSM)

Diet	D		N		Statistical significance
	Mean	SE	Mean	SE	P
Calcium					
Dietary intake, mg/d	685	26	743	28	< 0.001
Faecal excretion, mg/d	498	58	475	25	0.603
Apparent absorption, mg/d	187	39	269	29	0.093
Apparent absorption, %	28.8	6.6	37.4	4.9	0.191
Urinary excretion, mg/d	148	17	158	23	0.247
Retention, mg/d	39.3	35	111	36	0.122
Magnesium					
Dietary intake, mg/d	212	6	232	7	< 0.001
Faecal excretion, mg/d	148	12	116	10	0.033
Apparent absorption, mg/d	65	12	117	4	0.001
Apparent absorption, %	30.4	5.7	50.9	3.6	0.007
Urinary excretion, mg/d	65	4	86	6	< 0.0001
Retention, mg/d	–0.3	11.2	30.9	5.2	0.024
Zinc					
Dietary intake, mg/d	9.25	0.30	9.60	0.32	0.090
Faecal excretion, mg/d	6.80	0.53	7.25	0.64	0.407
Apparent Mg absorption, mg/d	2.45	0.50	2.34	0.45	0.882
Apparent absorption, %	26.5	5.5	25.2	5.0	0.848
Urinary excretion, mg/d	0.46	0.05	0.49	0.04	0.555
Retention, mg/d	1.99	0.50	1.87	0.47	0.848

D: dextrose diet; N: NUTRIOSE® FB diet

and P = 0.122, respectively). However, for 9 of the 10 subjects Ca retention was higher with diet N than with diet D. Therefore, the paired data were analysed using the Wilcoxon test. The probability of the null hypothesis was P = 0.110 for Ca apparent absorption, and P = 0.059 for Ca retention.

Zinc. Daily individual Zn intake was from 7.6 to 11.2 mg. Individual Zn faecal excretion varied from 3.8 to 10.4 mg/d, but the mean values were not significantly different between the two treatments (P = 0.407). Consequently, both absolute (mg/d) and relative (%) apparent Zn absorption were unaffected by dietary treatment (P > 0.85). Neither daily Zn urinary excretion nor daily Zn retention differed significantly between the two treatments (P = 0.555 and P = 0.848, respectively, Table 4).

Discussion

The results of the present study show that by providing a progressive adaptation, and distribution in six equal doses per day, ingestion of 100 g DM/d of the tested LDC did not cause serious digestive disorders, induced a significant decrease in dietary energy digestibility, improved significantly magnesium absorption and retention, and tended to improve Ca apparent absorption and retention in healthy subjects. Furthermore, the ME value of the LDC was 14 % less than the tabulated values of sucrose and starch.

Tolerance of the tested LDC

Even if the product is a food dextrin based on the process and the analytical characteristics, some toxicological studies were performed. This LDC did not induce any toxicity by the oral route in rodents at dosage as high as 2 g/kg bodyweight, when given to animals in an acute manner or during 90 days. No mutagenic activity was detected by the Ames test or by the mutation assay at the TK locus in L5178Y mouse lymphoma cells (Roquette, unpublished data).

The diluted LDC was palatable. All subjects ingested the solution without having to eat anything. The large inter-individual differences in sensitivity (one subject did not mention any symptom of discomfort) agreed with results obtained in previous studies [21]. The main digestive symptoms reported by eight of the ten subjects were excessive gas emission. Flatulence and slight abdominal pain was mentioned by four of the ten subjects. According to them, it was mainly due to the impossibility of voiding gases during group activities or gatherings. Diarrhoea occurred only once in one subject and may not have resulted from LDC ingestion. Interestingly, digestive symptoms diminished after 20 days adaptation, when the LDC intake had reached a plateau. These observations are in accordance with those previously described [16]. In addition, the DM content of faeces increased significantly. Finally, it is noteworthy that the great quantity (100 g DM/d) of the tested products ingested for experimental reasons was far above the ex-

pected intake in practice, and symptoms of excessive gas emission and flatulence were reported for an intake of more than 50 g/d.

The type, frequency and intensity of digestive symptoms were similar to those mentioned in a previous study with two LDC offered at the same level (100 g DM/d) during and after the same adaptation period [15]. The good tolerance of the LDC tested in the present study could be explained by the following: 1) its *in vitro* enzymatic digestibility averaged 15 %, and faecal output averaged 9 %, which means that 76 g/d of LDC were submitted to microbial digestion in the colon; 2) because of its high DP this LDC should not be very osmotically active and should be slowly fermented; 3) administration of progressively increasing doses over an 18-day-period favoured the adaptation of the microbial population in the colon; 4) the partition of the daily supply between six equal doses regulated the fermentation rate [21, 22]. In the present study intakes of LDC averaged 1.38 g/d per kg body weight (BW) or 0.23 g/meal/kg BW (half during meals, and half between meals).

Digestive effects of the tested LDC

Ingestion of 100 g DM/d of LDC did not significantly alter the number of defecations, but increased significantly by 45 and 70 % wet and dry stool weights, respectively. The effects were similar to those obtained with two LDC in the same conditions [15]. The increase in dry stool weight (+ 15.7 g/d on average) could be partly explained by the higher polymerized glucose faecal excretion (from 3.9 to 25.9 g/d; + 9.1 g/d, on average). It probably results from an increased bacterial mass excretion which contributes to more than 50 % of dry stool weight [14]. In addition, the 2.6 g/d increase in faecal crude protein excretion did not indicate a poor utilization of dietary protein. It may result from ammonia utilization for bacterial growth at the expense of urinary nitrogen excretion [14].

Energy value of the tested LDC

The DEV and MEV of the tested LDC were determined in healthy young men from total collection of faeces and urine. However, energy lost as hydrogen and methane could not be determined directly, but was estimated at 2 % of LDC gross energy from the results of in vitro fermentation [23], assuming that 76 % of the LDC was fermented in the colon. Thus, the MEV of the tested LDC can be estimated at [14.4 – (16.5 x 0.02)] 14.1 kJ/g DM.

The net energy value (NEV) of the LDC for maintenance could not be determined directly, because it requires measurement of energy expenditure of subjects offered diet N and diet D. The results of two studies in healthy young men showed that ingestion of 100 g DM/d of similar LDC [14], and 50 g DM/d of sugar beet pulp or commercial inulin [15] induced significant increases in energy expenditure. The latter may result from increases in gastro-intestinal motility [24] and digestive tissue weight [5], and lower energetic efficiency of VFA utilization compared to glucose. As a matter of fact, maltitol ingestion induced significant enlargement and thickening of caecal and colonic tissues in rats [25–27]. Similarly, ingestion of sugarbeet or carrot fibre (15–25 % of dietary DM) or inulin (8–13 % of dietary DM) caused significant increases in small intestine (14 to 19 %), caecum (78 to 132 %) and colon (55 to 116 %) tissue weight in growing rats (Cubizolles and Vermorel, unpublished data). These tissues indeed have a rapid turn-over and a high metabolic rate and contribute 25 % of fasting metabolism or daily EE in pigs [28]. Finally, the weighted efficiency of energy utilization for maintenance was 15 % lower for VFA than for glucose [29–31].

Direct determination of NEV of LDCs is difficult, mainly because they are consumed in small quantities, and consequently induce small differences in energy expenditure. Therefore, literature data are generally estimates of DEV, MEV, and NEV from measurements of LDCs fermentability, breath tests, and hypotheses on gas, microbial mass and VFA production, and efficiency of VFA energy utilization [1]. In the present study, the NEV of the tested LDC has been estimated using three prediction equations [31, 32] (Cf Appendix). The estimated NEVs were 11.4, 8.9 and 8.7 kJ/g DM. They were very close to the estimated NEV of the hydrogenated polysaccharide fraction of Lycasin® HBC (11.5, 8.6 and 8.4 kJ/g DM), and to its NEV (10.7 kJ/g DM) determined in healthy young men using the energy balance method by whole body indirect calorimetry [15]. They were also close to the NEV of fructo-oligosaccharides estimated in humans, using the same prediction equations: 9.5, 9.0 and 9.2 kJ/g DM [33].

Since 1977 the potential beneficial effects of fermentable carbohydrates on mineral absorption and status, in particular Ca and Mg, have been intensively investigated by our group [34, 35] and by other workers [7, 36]. The animal studies clearly showed a beneficial effect of fermentable carbohydrates on intestinal absorption of Ca and Mg, although this effect was less marked for Ca than for Mg and often depended on experimental conditions. Few, if any, studies have so far been devoted to Zn absorption.

The main result of the present study regarding mineral metabolism was that the tested LDC significantly improved apparent Mg absorption and retention, and tended to increase Ca apparent absorption and retention, whereas the intestinal absorption and the balance of Zn were not significantly altered. Many human studies showed that fermentable carbohydrates consistently improved intestinal Mg absorption [9, 11], and in-

creased [37, 38] or did not modify [10, 39] Ca absorption, but failed to modify intestinal absorption of Zn [40] or iron [39]. The positive effect of fermentable carbohydrates on intestinal mineral absorption is attributed mainly to the high production of VFA [41] which produces a decrease in the luminal pH and an increase in the concentration of ionized minerals in the caecum. Consequently, the mineral solubility is increased and the active and passive diffusion of minerals across the intestinal cells is enhanced. As a consequence, these fermentation-induced changes theoretically ought to improve the intestinal absorption of nearly all minerals in the hindgut. The mechanism and the site of intestinal Mg absorption largely differ from those of Ca and Zn, which may explain the different impact of fermentable carbohydrates on the apparent absorption of these minerals.

Intestinal Mg absorption occurs mainly in the lower parts of the intestine, especially in the jejunum and ileum [42]. The mechanisms involved in intestinal Mg absorption are a saturable process and passive diffusion. The component of intestinal Mg absorption from the distal part of the intestine by passive diffusion is very large. The absorption efficiency of dietary Ca and Zn depends on two major factors: its regulation by physiological factors, and its interaction with the other dietary constituents [43]. A possible explanation for the improvement of Mg absorption the tendary to improvement of Ca absorption and retention, and the lack of any effect of fermentable carbohydrates on Ca and Zn intestinal absorption in this study is a down-regulation of the active intestinal absorption of the latter in the upper part of intestine after several weeks of fermentable carbohydrate intake "fed-back phenomenon" [9].

Conclusion

Providing a progressive adaptation, and distribution in six equal doses per day, ingestion of 100 g DM of NUTRIOSE® FB per day did not cause severe digestive disorders, even in sensitive subjects. It did not significantly alter the number of defecations, but significantly increased wet and dry stool output. The metabolizable, and estimated net energy values of this LDC averaged 14.1 and 9.6 kJ/g DM, and were 14 % and 42 % lower than those of sucrose and starch. In addition, ingestion of 100 g/d of DM of the LDC significantly improved magnesium absorption and retention (+ 52 mg/d), and tended to increase calcium apparent absorption and retention, but did not significantly alter zinc absorption and retention. Therefore, NUTRIOSE® FB can be used as a "bulking" agent, and substituted up to 50 g/d for usual maltodextrins or sucrose in some human foods to limit risks of dental caries, reduce daily food energy intake, exert a beneficial effect on the colonic mucosa through the production of VFA, and improve magnesium and calcium absorption and retention without causing digestive disorders in healthy subjects.

Appendix

Estimation of the net energy value (NEV) of the tested LDC using three prediction equations

1) According to [31]: The MEV of the tested LDC was estimated from its ME content as determined in the present study, assuming that hydrogen and methane energy losses accounted for 5 % of the fermented carbohydrate energy, and fermentation heat also for 5 %. VFA energy was estimated as "Estimated ME value – Glucose energy" (derived from enzymic digestion). The efficiencies of glucose energy and VFA energy utilization are estimated at 1 and 0.85, respectively: NEV = (Gross energy x Enzymatic digestibility) + (VFA energy x 0.85)
2) According to [32]
   2a) Carbohydrate substitutes method: The enzymically digested fraction is assumed to produce glucose used with an energetic efficiency of 1. Fermentable carbohydrates are assumed to supply 8 kJ NE/g. (NEV = (Gross energy x Enzymic digestibility) + (Fermentable carbohydrates x 8))
   2b) Minimal methodology for net metabolisable energy: The apparent digestibility of fermentable carbohydrates is used to estimate VFA production, assuming that 65 % of actually "fermented energy" is recovered as VFA. The efficiency of ME utilisation from fermentable carbohydrates is assumed to be 0.76. (NEV = (Gross energy x Enzymic digestibility) + (Fermentable carbohydrates x Unavailable carbohydrate digestibility x 0.65 x 0.76)).

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