

Digestion of the carbohydrates of banana (*Musa paradisiaca sapientum*) in the human small intestine¹⁻³

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ABSTRACT The digestion and absorption from the small bowel of the carbohydrate of banana has been studied by feeding ileostomy subjects banana from six batches of different ripeness and measuring the amounts excreted in the effluent. Starch content of bananas depended on the ripeness being 37% of dry weight in the least ripe and 3% in the most ripe. Excretion of carbohydrate from banana in ileostomy effluent ranged from 4–19 g/day and was directly related to the starch content ($r = 0.99$). Up to 90% of the starch could be accounted for in the effluent. Complete recovery of nonstarch polysaccharides [NSP (dietary fiber)] was obtained. The amount of banana starch not hydrolyzed and absorbed from the human small intestine and therefore passing into the colon may be up to 8 times more than the NSP present in this food and depends on the state of ripeness when the fruit is eaten. *Am J Clin Nutr* 1986;44:42–50.

KEY WORDS Carbohydrate digestion, starch, dietary fiber, small bowel, colon, ileostomy, banana

Introduction

Plant foods contain two broad classes of carbohydrate, free sugars and polysaccharides. Free sugars such as glucose, fructose, and sucrose are found mainly in fruit and vegetables and are rapidly absorbed from the small intestine in healthy humans. Plant polysaccharides can be subdivided into two groups of substances, starch and nonstarch polysaccharides (NSP). NSP are principally the carbohydrates of the plant cell wall (ie, structural carbohydrates) and include a mixture of polymers such as cellulose, pectin, and hemicellulose—all of which are resistant to mammalian α -amylase and, as far as has been ascertained, escape breakdown in the small bowel of man (1). All carbohydrate that is not digested and absorbed from the small intestine is a potential substrate for fermentation by the colonic microflora.

Starch, a plant-storage polysaccharide, is found in many of the world's staple foods such as cereals, legumes, potatoes, and bananas. Most cereal and legume starches are readily hydrolyzed by α -amylase. This process can be speeded up by cooking, in which starch is gelatinized, although food processing may lead

to a retrogradation that renders some starch partly resistant to enzymic digestion (1). When potatoes are used as a food, the starch granules must be gelatinized before they become susceptible to enzymic hydrolysis (2). This resistance to digestion does not normally cause any practical problems inasmuch as potatoes are not eaten raw and the starch granules are readily gelatinized by cooking. However, the α -amylase resistance of some raw starches may have importance for foods that are eaten raw—such as bananas. Experimental studies both in vitro and in animals suggest that banana-starch granules are largely indigestible (3, 4).

The aim of the present study has been to measure the breakdown of banana starch and

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NSP in the small intestine of man using ileostomy patients as a model.

Subjects and methods

Subjects

Three ileostomists (one female) aged 60, 64, and 79 took part in six studies with bananas of various ripeness. All had had total colectomies for ulcerative colitis 10, 22, and 22 yr prior to their taking part in these experiments. At operation, <10 cm of terminal ileum had been removed. None had evidence of Crohn's disease. All were well and only one was taking any medication (metoprolol and hydrochlorothiazide for hypertension). None had taken antibiotics in the months preceding the study. They were recruited through the local branch of the Ileostomy Association. Ethical approval for the work was obtained from the Dunn Nutrition Unit Ethical Committee.

Protocol

Throughout the study, subjects lived in the metabolic suite at the Dunn Clinical Nutrition Centre. Regular periods of exercise were taken.

Diet

The study was divided into 24-h periods starting at 0900 h each day. For breakfast, lunch, and supper on the first day, subjects were given a plant-polysaccharide-free diet prepared in the diet kitchen of the Unit. This comprised milk, eggs, tea, sugar, prawns, mayonnaise, meat, cheese, jelly, and cream and was of the following composition: 7.1 MJ energy, 114 g protein, 104 g fat, and 82 g carbohydrate. On analysis, this diet was shown to contain only traces of starch and NSP. On days 2 and 3, banana (200 g, weighed without skin) was given with breakfast in addition to the plant-polysaccharide-free diet.

The bananas, which originated in the Windward Islands and the West Indies, were purchased locally prior to each study and were of eating quality but varying degrees of ripeness, ranging from fully ripe (yellow with black patches) to just ripe (yellow with some green at the tip). At the time of the test breakfast, duplicate portions of banana were taken and rapidly frozen in dry ice, then freeze-dried and stored for later analysis.

Effluent

Ileostomy effluent was collected by the subjects when they emptied or changed their bags, every 2 h during the day from 0700 h in the morning until they retired at 2300 h. Each sample of effluent was immediately frozen in solid CO₂, weighed, and freeze-dried prior to analysis. Mean transit time (MTT) of the test breakfast was calculated as the transit time of banana NSP-xylose according to the equation:

$$\text{MTT (hours)} = \frac{\sum_{0}^N (\text{amount of xylose in sample}) \times t}{\text{Total xylose recovered}}$$

where *t* is the time interval between the test meal and recovery of xylose in effluent from samples 0 to *N*.

Studies in vitro

Changes in the carbohydrate composition of bananas during ripening were studied by purchasing a large single bunch of unripe (green) bananas that were kept at room temperature for 10 days, during which time they ripened fully. At the time of purchase and at 2-day intervals thereafter, one banana was taken from the bunch, photographed to record the state of ripeness, and then analyzed for carbohydrate content. Digestibility studies in vitro of two varieties of *Musa paradisiaca*, the plantain banana and the sweet banana, were carried out as follows. Samples of both were taken either 1) raw, 2) freshly cooked, 3) cooked and then stored for 16 h at 5°C, or 4) as 3), but recooked for 30 min. All samples were incubated for 16 h at 40°C with 1000 units of pancreatic α-amylase (Pancorex V capsules; Paines and Byrne Ltd, Greenford, Middlesex, England) per 100 mg dry weight of banana.

Chemical methods

Carbohydrate analysis: NSP and resistant starch. The method for measuring NSP and resistant starch (RS) has been described in detail previously (5, 6) and is summarized briefly. Samples of food were analyzed by the following procedures:

1) After gelatinization and incubation with hog pancreatic amylase and pullulanase to hydrolyze starch, the residue was dispersed in 12 *M* H₂SO₄, hydrolyzed with molar H₂SO₄, the individual neutral sugars measured as alditol acetates by gas-liquid chromatography (GLC) (Pye-Unican Series 304 Chromatograph, Pye-Unican, Cambridge, UK) and uronic acids by the colorimetric method of Scott (7). This procedure measured total NSP and resistant starch (RS) together.

2) After a starch-removal procedure identical to that in procedure 1, RS was solubilized with 2 *M* KOH and an aliquot incubated with amyloglucosidase to hydrolyze it to glucose. The remainder was hydrolyzed with molar H₂SO₄ and individual sugars were determined as in procedure 1. This estimated RS and noncellulosic polysaccharides (NCP) separately. A value for NSP was obtained by subtracting the glucose in RS from glucose measured in procedure 1. Cellulose was calculated as the difference between NSP and NCP glucose.

3) After starch removal, the material was extracted with buffer at pH 7, the residue dispersed with 12 *M* H₂SO₄, hydrolyzed with molar H₂SO₄, and individual sugars measured as in procedure 1. This gave a value for NSP insoluble at pH 7, after subtraction of RS.

Starch + dextrins

Starch plus dextrins (excluding RS) were measured as the increase in glucose observed when samples were incubated with amyloglucosidase (shown to be free of β-glucanase activity) after overnight incubation with α-amylase and pullulanase.

Starch

Starch (excluding RS) was measured as the increase in apparent NCP-glucose (procedure 2) when incubation with α-amylase and pullulanase was omitted from the procedure.



Dextrins

Dextrins were defined as the α -linked glucans (excluding maltose) soluble in 80% ethanol. They were measured as the difference between starch and starch + dextrins (but excluding maltose), as outlined above.

Free sugars

Approximately 100-mg dry sample or a corresponding amount of wet sample was accurately weighed into 50-ml screw-topped glass tubes containing a magnetic stirring bar. Then, 10-ml 0.05 *M* acetate buffer pH 5.2 (made up using 50% saturated benzoic acid) containing 1 mg β -phenyl glucoside/ml was added. The tubes were placed in a boiling water bath for 10 min, stirring continuously, and then kept overnight at 45°C, again mixing continuously. The next day, 10-ml ethanol was added to the tubes and the contents were mixed and centrifuged. A small amount (0.3 ml) of the supernatant was transferred to an 0.8-ml auto-injector vial and taken to dryness in a vortex evaporator. TMS-oximes were prepared as previously described (8). Pyridine, 0.2-ml, containing 25 mg hydroxylamine-hydrochloride/ml was added. The vials were placed in a heating block at 70–75°C for 30 min, cooled, and then 0.2 ml *N*-trimethylsilylimidazole was added, vortexed for 30 sec, and left for 30 min. We used 1–2 μ l for GLC.

Effluent

Each sample of effluent was subjected to total carbohydrate determination after Seaman hydrolysis. Detailed

carbohydrate analysis was done on samples bulked together from the time the test meal was given until the effluent was free of xylose. To correct for endogenous carbohydrate (from mucus) in the effluent, the ratio of fucose to galactose was measured during the day on the polysaccharide-free diet. After feeding banana, total galactose recoveries were corrected for galactose from mucus by taking the amount of fucose present and the fucose-galactose ratio from the control period.

Volatile fatty acids were measured by GLC using formic acid entrainment as previously described (9).

Results

The passage of the test meal through the gut was monitored by observing the concentration of NSP arabinose and xylose in each 2-h collection of effluent. Arabinose and xylose are components of banana cell wall but not of the foods in the plant-polysaccharide-free diet or of endogenous secretions. Figure 1 shows glucose (from NSP and starch) and arabinose plus xylose in each sample of effluent over a 38-h period in one subject who, following a 24-h polysaccharide-free diet period, was given 200 g from different batches of banana on days 2 and 3. Effluents were analyzed by procedure

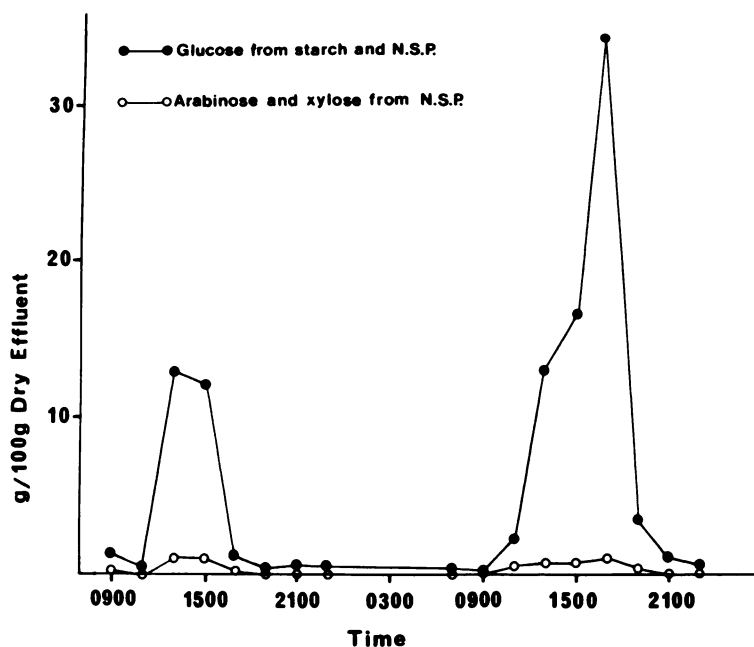


FIG 1. Recovery of carbohydrate (g/100 g dry effluent) over a 38-h period for subject 2 who, after taking a polysaccharide-free diet, ate 200 g of two different batches of banana (banana Nos 3 and 4, Tables 1 and 2) at 0900 h on successive days.

TABLE 1
Composition of effluent and mean transit time

	Control* day	Subject 1		Subject 2		Subject 3	
		Banana 1	Banana 2	Banana 3	Banana 4	Banana 5	Banana 6
Total effluent (g/day)	289.9 ± 45.9	394.1	440.9	436.2	393.9	394.4	473.5
Total solids (g/day)	25.1 ± 0.9	32.6	38.7	42.6	47.9	33.1	35.6
MTT	6.0 ± 1.0	6.6	6.7	5.2	7.2	4.6	5.5
Total carbohydrate (g/day)	2.27 ± 0.36	5.98	13.96	10.42	20.30	6.79	7.58
% N	7.83 ± 0.44	6.28	4.83	5.15	4.76	6.52	5.55
g N/day	1.96 ± 0.18	2.04	1.87	2.19	2.28	2.15	1.97
% N × 6.25	48.95 ± 2.76	39.26	30.20	32.20	29.75	40.78	34.71
N × 6.25, g/day	12.28 ± 1.08	12.80	11.69	13.71	14.25	13.50	12.36
VFA†, mM/day	4.28 ± 0.63	8.93	8.13	4.09	5.37	2.79	5.63
VFA, g/day	0.26 ± 0.04	0.56	0.51	0.25	0.33	0.18	0.35
VFA, mM/9.00–19.00	1.05 ± 0.41	4.30	6.05	2.95	2.19	0.76	1.70
VFA, g/9.00–19.00	0.07 ± 0.02	0.27	0.38	0.18	0.14	0.05	0.11

* Mean ± SD for 3 subjects on polysaccharide free diets.

† Volatile fatty acids.

1, but without the addition of starch-hydrolyzing enzymes, thus giving values for total polysaccharide glucose in the samples. At the time of the first test meal (containing banana No 3, see Table 1) and 2 h afterwards, the effluent was free of arabinose and xylose. The amounts of these sugars rose to a peak at 4–6 h. By 10 h, the effluent was again free of pentose, allowing a further test meal of a different banana (No 4) to be given the next day, when the sequence of events was similar. Glucose appearance in the effluent followed arabinose and xylose closely but the concentration was much greater, reaching 13% of effluent solids with banana No 3 and 34% with the less ripe banana No 4.

Table 1 shows the total amount of effluent excreted per day together with total effluent carbohydrate (endogenous and from food) and mean transit time (MTT). MTT of the test meals averaged 6.0 h. The total amount of effluent excreted was 290 g/day on the control day and 422 g/day when banana was taken ($t = 4.64$, $p < 0.05$). These values are, however, well within the range seen in healthy ileostomists (10). Effluent solids output with banana averaged 38.4 g/day, which was significantly greater than on the control day (25.1 g/day, $t = 4.51$, $p < 0.05$) and was directly related to the amount of starch present in the banana ($r = 0.90$, $p < 0.01$). Total carbohydrate output ranged from 6.0 to 20.3 g/day and had a highly significant relationship to the amount of starch in the bananas (Fig 2) ($r = 0.99$, $p < 0.001$).

Table 2 gives detailed results of carbohydrate excretion on the plant-polysaccharide-free diet and the amount and composition of banana carbohydrate fed and recovered in effluent.

Carbohydrates excreted on the plant-polysaccharide-free diet

On the control day, 1.6 g of carbohydrate was excreted. A very small amount, 0.3 g, was

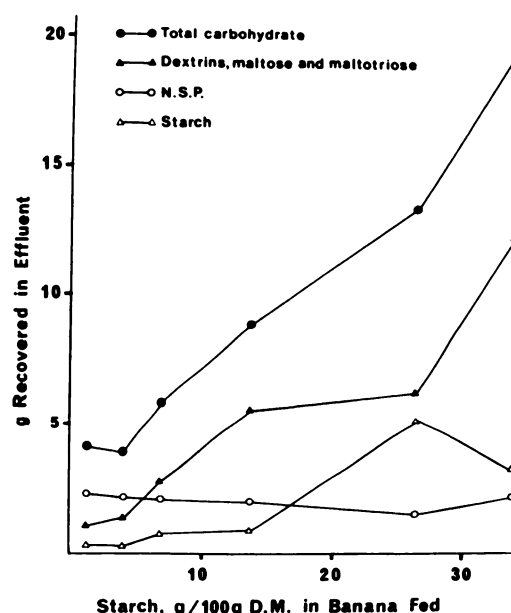


FIG 2. The relationship between carbohydrate recovered in effluent and the amount of starch present in each of the samples of banana fed.

TABLE 2
Carbohydrate fed (F) and recovered (R) in ileostomy effluent (g/day)

	Control* day	Subject 1†				Subject 2†				Subject 3†			
		Banana 1		Banana 2		Banana 3		Banana 4		Banana 5		Banana 6	
		F	R	F	R	F	R	F	R	F	R	F	R
Free sugars	0.14 ± 0.01	39.51	0.56	27.76	2.06	38.32	2.91	29.08	7.30	40.28	1.33	36.55	2.49
Fructose	0.08 ± 0.02	7.44	—	2.56	0.06	4.57	0.07	3.25	0.09	4.74	0.10	6.29	0.09
Glucose	0.04 ± 0.01	6.52	0.10	2.12	0.20	4.46	0.24	3.04	0.32	5.03	0.10	6.74	0.17
Sucrose	0.02 ± 0.01	25.55	0.46	23.08	0.03	29.29	0.03	22.79	0.04	30.51	—	23.52	0.02
Maltose	—	—	—	—	0.91	—	1.37	—	3.11	—	0.66	—	1.39
Maltotriose	—	—	—	—	0.86	—	1.20	—	3.74	—	0.47	—	0.82
Dextrins	0.17 ± 0.15	0.88	0.96	1.20	4.54	1.12	3.13	1.55	6.59	0.83	0.22	1.30	0.67
Starch	0.02 ± 0.01	1.21	0.29	12.69	5.26	7.48	0.86	19.34	3.40	2.13	0.26	3.22	0.75
NSP	1.30 ± 0.41	2.24	2.30	1.73	1.58	2.20	1.98	2.25	2.25	2.18	1.98	1.80	1.97
Total	1.63 ± 0.30	43.84	4.11	43.38	13.44	49.12	8.88	52.22	19.54	45.42	3.79	42.87	5.88
% Carbohydrate recovered			9.37		30.98		18.07		37.41		8.34		13.71
Carbohydrate % of dry matter	6.4	85.7	12.6	89.3	34.7	89.0	20.8	91.1	40.8	85.1	11.4	91.4	16.5

* Mean ± SD for 3 subjects on polysaccharide-free diet.

† Carbohydrate recovered = carbohydrate recovered with banana - carbohydrate recovered on control days.

free sugars and dextrins (Table 2). The remaining 1.3 g was measured as NSP, mainly as fucose and galactose, and was probably derived from mucus.

Carbohydrates in banana fed

The six batches of banana contained very similar amounts of total carbohydrate (46.1 ± 1.5 g/200 g fresh weight) but the composition varied greatly, depending on their ripeness. The results from each test meal have, therefore, been examined separately (Table 2). Free sugars were the main carbohydrate fraction, increasing with ripeness from 56% to 75% of dry matter. Sucrose was the main sugar. As ripeness increased, the amount of starch in the bananas decreased. In the least ripe banana (No 4), there was 19.3 g of starch per 200 g of banana, 33.7% of total solids, while banana No 1 contained only 1.2 g starch, 2.4% of solids. Overall, the ratio of starch to free sugars varied from 0.03 (banana No 1) to 0.66 (banana No 4), a range of over 20-fold.

The amount of NSP was relatively constant, from 3.6% to 4.3% of dry matter. Total carbohydrate ranged from 85% to 91% of dry matter, being highest for the least ripe banana.

Carbohydrate recovery in effluent

The free sugars fed were well-absorbed, only very small amounts (<0.5 g/day) of fructose, glucose, and sucrose being found in the effluent (Table 2 and Fig 2). Of the starch fed, 11% to 41% was recovered in the effluent as starch. However, only 1 g of dextrins was fed but up to 6.5 g was recovered in the effluent after the less ripe bananas. Similarly, up to 6.7 g maltose and maltotriose were found in the effluent, although neither of these sugars was identified in the bananas before feeding. If the maltose, maltotriose, additional dextrins, and starch recovered in the effluent are all assumed to originate from starch in the banana, then on average $69 \pm 9\%$ of starch is recovered with 76, 80, and 91% of that present in the bananas with the highest starch content (Nos 2, 3, and 4, respectively).

Table 3 gives details of the NSP fed and recovered. Of the 2.1 g NSP fed, 2.0 g was recovered. Slightly more soluble NCP was recovered than was fed, while less insoluble NCP was recovered. Together, however, the amount recovered (1.54 g) was virtually the same as

TABLE 3
Recovery of the components of banana NSP

	Control day g/day	Banana NSP fed g/day	Banana NSP* recovered g/day
Total NSP	1.30 ± 0.41	2.07 ± 0.24	2.01 ± 0.25
Cellulose	0.14 ± 0.17	0.48 ± 0.06	0.47 ± 0.06
Soluble NCP	1.00 ± 0.22	1.17 ± 0.19	1.24 ± 0.15
Insoluble NCP	0.16 ± 0.02	0.42 ± 0.05	0.30 ± 0.11
Constituent sugars of total NSP			
Rhamnose	0.03 ± 0.03	trace	trace
Fucose	0.25 ± 0.05	—	—
Arabinose	—	0.13 ± 0.02	0.13 ± 0.02
Xylose	—	0.11 ± 0.01	0.11 ± 0.01
Mannose	0.09 ± 0.02	0.29 ± 0.06	0.23 ± 0.08
Galactose	0.60 ± 0.10	0.09 ± 0.01	0.08 ± 0.10
Glucose	0.23 ± 0.16	0.58 ± 0.06	0.52 ± 0.07
Uronic acid	0.10 ± 0.10	0.87 ± 0.14	0.92 ± 0.14

* Corrected for endogenous carbohydrates as described in text.

that fed (1.59 g). This alteration in solubility of NCP must arise during passage through the stomach and small intestine. Of the constituent NSP sugars, arabinose and xylose were completely recovered. For the other sugars, recovery was virtually complete after correction of endogenous carbohydrate.

Nitrogen excretion in ileostomy effluent was 1.96 ± 0.18 g/day on the polysaccharide-free diet and was not significantly altered by feeding banana (2.08 ± 0.15 g/day). Some volatile fatty acids (VFA) were detectable in the effluent, indicating that fermentation was occurring either in the terminal ileum or in the ileostomy bag. The amounts were very small (0.18–0.56 g/day), compared with the carbohydrate excreted, and most were found in the overnight collection, probably indicating fermentation in the collecting bag rather than in vivo. Ileal fluid obtained directly from the ileostomy stoma contained no detectable VFA.

In vitro studies of banana starch digestibility

Table 4 shows a comparison of the composition of an ordinary banana such as one serves for dessert (analyzed when the skin was green) and an unripe plantain banana such as provides the staple food in parts of Africa and the Caribbean. The most striking feature of the analysis was the similarity in composition of the two bananas, with carbohydrate comprising 94% of the dry weight, the greater part of which was starch. The slightly riper plantain contained less starch and more sucrose. When incubated with pancreatic amylase (Table 5),

50–66% of the starch resisted hydrolysis, but this resistance to digestion was overcome by cooking. However, when the cooked bananas cooled, 8–10% of α -amylase-resistant starch formed. Only a part of this starch was reversed on reheating.

Change in carbohydrate composition during ripening of banana

Table 6 shows that unripe banana (mainly green) consists of 82% starch and 7% sugar. During ripening, starch is converted to sugar so that the most ripe banana contains 88% sugar and only 3% starch. The percentage of dry matter remains constant during ripening.

Discussion

Measurement of the overall digestibility of foodstuffs in the small intestine is difficult be-

TABLE 4
Starch, non-starch polysaccharide, and free sugars in banana (g/100 g dry matter)

	Raw plantain	Green banana
Total NSP	2.74	3.12
Arabinose	0.24	0.16
Xylose	0.22	0.18
Mannose	0.39	0.54
Galactose	trace	trace
Glucose	1.89	2.24
Starch	72.10	88.00
Free sugars		
Fructose	3.04	0.37
Glucose	2.90	0.31
Sucrose	13.50	2.70
Total carbohydrate	94.24	94.52



TABLE 5
Amylase hydrolysis of plantain and green-banana starch in vitro

	% of starch resisting α -amylase
Raw banana	53.6
Freshly cooked banana	0
Cooked and cooled banana	8.1
Cooked, cooled and reheated banana	5.4
Raw plantain	66.7
Freshly cooked plantain	0
Cooked and cooled plantain	10.5
Cooked, cooled, and reheated plantain	3.9

cause of the inaccessibility of the terminal ileum. The ileostomist provides a valuable model for such studies and has been used on many occasions to this end (11–16). Moreover, the use of ileal fistulas is widely practiced in animal digestibility experiments. The ileostomist does not have a normal gut, however, and it is important to be aware of any potential limitations in the interpretation of such experiments. A major difference between the normal ileum and the ileostomy is its microbial population, which is greater in the ileostomist (10^7 – 10^8 bacteria per g) compared with the ileum (10^5 – 10^8) (17, 18). The likely outcome of this increase in colonization is the microbial breakdown of carbohydrate in the ileum. Since these bacteria are anaerobes, this process (fermentation) would be expected to produce short-chain fatty acids as its main end-product. Direct analysis of ileostomy effluent samples taken from the stoma in the present study failed to reveal short-chain fatty acids at >1 – 2 mmol/l concentrations in any subject. This contrasts with the cecum, where bacteria counts are 10^{11} – 10^{12} and short-chain fatty acid levels are around 120–130 mmol/kg (17, 19). Moreover, transit through the small intestine (2–4 h) is too rapid to allow the establishment of a substantial fermentative flora such as that present in the cecum.

In other respects, the digestive function of ileostomists resembles that of the normal gut in that ileal effluent contains substantial excesses of digestive enzymes (20–22) and in that ileal excretion of fat, protein, and carbohydrate from mixed diets is no greater than fecal excretion in normal healthy subjects (10, 16, 22). Gut-hormone responses to test meals are broadly similar in ileostomists and healthy controls (23).

The amount of carbohydrate that escapes digestion and absorption in the small intestine is important because it is a potential substrate for fermentation in the large intestine by the anaerobic microflora. In a recent study (24), it was shown that starch which was resistant to hydrolysis by pancreatic amylase could be fermented by human gut bacteria with the production of short chain fatty acids and bacterial growth. The physiological consequences of fermentation of starch and NSP are very different from those that follow absorption of glucose or other monosaccharides from the small intestine (25), so it is valuable to know the exact site of digestion of particular carbohydrates in man. Of the various dietary carbohydrates, simple sugars are thought to be virtually absorbed in the small intestine and there is no evidence to contradict this in healthy people, except in those who are lactase deficient and continue to drink milk (26). The complete absorption of sugars in this study, from a food with a high sugar content, confirms this general view. The fate of plant polysaccharides in the small bowel, however, is more problematic, particularly that of starch (1, 27, 28).

In the present study of banana, NSP were virtually recovered in ileostomy effluent. We have previously shown (1) that the NSP in cereal foods such as oats, corn, and wheat also escape digestion in the small bowel. Now there is increasing evidence for the belief that these polysaccharides, from whatever source, pass

TABLE 6
Change in carbohydrate composition of banana during ripening

Time (days)	0	2	4	6	8
Description	Mainly green with some yellow	Mainly yellow with some green	Yellow	Yellow with few black spots	Yellow with many black spots and patches
% Dry matter (g/100 g)	28	29	28	27	26
Starch (% dry matter)	82	41	26	9	3
Sugars (% dry matter)	7	48	63	81	88

into the colon (13, 14) where they are fermented (29). Thus, the amount of NSP available for fermentation in the colon may be determined simply by measuring it in food.

Starch digestion and absorption is not so simple. In our study of cereals (1), we observed that starch present in oats was completely absorbed in the small intestine but, in processed food such as cornflakes and white bread, a small fraction (3–5%) had become resistant to α -amylase digestion and this escaped breakdown in the small bowel. The present study of banana identifies a further type of starch that resists breakdown by mammalian α -amylase, namely raw starch present in certain types of granules. Table 2 shows that only 23% of the starch fed was recovered as starch in the ileostomy effluent but that in those cases where there was substantial starch in the banana, a large increase in the recovery of maltose, maltotriose, and dextrin occurred. In the absence of any other likely source, this probably represents partial-hydrolysis products of the banana starch. The products are likely to have been formed in the ileostomy bag, where some microbial activity occurs after the effluent has been passed. Disaccharides such as sucrose and maltose are probably well hydrolyzed and absorbed from the ileum (30). Taken together with the starch recovered, the maltose plus maltotriose plus dextrans account for $69 \pm 9\%$ of the starch ingested.

Katz (31) distinguished three types (A, B, and C) of crystalline structure for starch granules. The A-pattern is characteristic of most cereal starches, the B-pattern of potato and amylo maize starch and of retrograded starch; while the C-pattern is seen in some pea and bean starches (32). The A-type granules found in cereal starches have a low degree of crystallinity, allowing α -amylase to penetrate the surface. When samples of bananas used in this study were incubated in vitro with hog pancreatic amylase, half to two-thirds of the starch resisted digestion unless it was previously gelatinized by cooking (Table 5). When fed to man, this starch is incompletely hydrolyzed and absorbed in the small intestine (Table 2), suggesting that banana starch granules have the highly crystalline B-pattern that gives a compact structure and that does not, or only to a limited degree, allow penetration and hydrolysis with mammalian amylase.

Thus, the fate of banana carbohydrate in man depends very much on the state of ripeness of the fruit (Table 6). As it ripens, so the starch breaks down and is converted to sugars—mainly sucrose, glucose, and fructose—that are readily absorbed. The proportion of starch to free sugars in banana changes rapidly over a few days, making it difficult to predict how much will escape digestion without detailed analysis of the banana. Predicting the physiological effects of a banana-containing diet is therefore difficult. The bananas fed in this study were all ripe enough to be eaten without difficulty. The least ripe (bananas 2 and 4) were yellow, with green at the tip. The most ripe (1) were all yellow with black patches. None would fall outside the category of those normally eaten in the home. Banana carbohydrate recovered in ileostomy effluent in these studies was as high as 19 g (from banana 4), which means that the carbohydrate passing into the colon from this one source alone is equal to the total amount of nonstarch polysaccharides (dietary fiber) present in many Western diets (33).

These studies also allowed an estimation to be made of endogenous carbohydrate secretion from the upper bowel as mucus. On the carbohydrate-free diet, 2.3 g/day of carbohydrate were present in the effluent. Of that amount, 1.3 g was fucose plus galactose that could be clearly identified as arising from mucus. This amount of unabsorbed carbohydrate is relatively little when compared with the amounts potentially derived from cereal and vegetable food, although some hexosamine would also be present. 

References

1. Englyst HN, Cummings JH. Digestion of the polysaccharides of some cereal foods in the human small intestine. *Am J Clin Nutr* 1985;42:778–87.
2. Walker GJ, Hope PM. The action of some α -amylases on starch granules. *Biochem J* 1963;86:452–62.
3. Fuwa H, Takaya T, Sugimoto Y. Degradation of various starch granules by amylases. In: Marshall JJ, ed. *Mechanisms of saccharide polymerization and depolymerization*. New York: Academic Press, 1980: 73–100.
4. Fujita S, Glover DV, Sugimoto Y, Fuwa H. Effects of partially digestible starch-granules on digestive enzymes of rats. *Nutr Rep Internat* 1982;26:175–81.
5. Englyst H, Wiggins HS, Cummings JH. Determination of the non-starch polysaccharides in plant foods by



- gas-liquid chromatography of constituent sugars as alditol acetates. *Analyst* 1982;107:307-18.
6. Englyst HN, Cummings JH. Simplified method for measurement of total non-starch polysaccharides by gas-liquid chromatography of constituent sugars as alditol acetates. *Analyst* 1984;109:937-42.
 7. Scott RW. Colorimetric determination of hexuronic acids in plant materials. *Analyst Chem* 1979;51: 936-41.
 8. Brobst KM, Lott CE. Determination of some components in corn syrup by gas-liquid chromatography of the trimethylsilyl derivatives. *Cereal Chem* 1966;43: 35-43.
 9. McNeil NI, Cummings JH, James WPT. Short-chain fatty acid absorption by the human large intestine. *Gut* 1978;19:819-22.
 10. McNeil NI, Bingham S, Cole TJ, Grant AM, Cummings JH. Diet and health of people with an ileostomy. 2. Ileostomy function and nutritional state. *Br J Nutr* 1982;47:407-15.
 11. Werch SC, Ivy AC. On the fate of ingested pectin. *Am J Dig Dis* 1941;8:101-5.
 12. Holloway WD, Tasman-Jones C, Lee SP. Digestion of certain fractions of dietary fiber in humans. *Am J Clin Nutr* 1978;31:927-30.
 13. Sandberg AS, Andersson H, Hallgren B, Hasselblad K, Isaksson B, Hulten L. Experimental model for in vivo determination of dietary fibre and its effect on small bowel absorption of nutrients. *Brit J Nutr* 1981;45:283-94.
 14. Sandberg AS, Ahderinne R, Andersson H, Hallgren B, Hulten L. The effect of citris pectin on the absorption of nutrients in the small intestine. *Hum Nutr: Clin Nutr* 1983;37C:171-83.
 15. Chapman RW, Sillery JK, Graham MM, Saunders DR. Absorption of starch by healthy ileostomates: effect of transit time and of carbohydrate load. *Am J Clin Nutr* 1985;41:1244-8.
 16. Holgate AM, Read NW. Relationship between small bowel transit time and absorption of a solid meal; influence of metoclopramide, magnesium sulfate and lactulose. *Dig Dis Sci* 1983;28:812-9.
 17. Drasar BS, Hill MJ. Human intestinal flora. London: Academic Press, 1974.
 18. Finegold SM, Sutter VL, Boyle JD, Shimada K. The normal flora of ileostomy and transverse colostomy effluents. *J Infect Dis* 1970;122:376-81.
 19. Cummings JH, Pomare EW, Branch WJ. Short-chain fatty acids (SCFA) in human portal, hepatic and peripheral venous blood. Abstracts of XIII International Congress of Nutrition, Brighton, England, 1985, p 63.
 20. Bohe M, Borgstrom A, Genell S, Ohlsson K. Determination of immunoreactive trypsin, pancreatic elastase, and chymotrypsin in extracts of human feces and ileostomy drainage. *Digestion* 1983;27:8-15.
 21. Goldberg DM, McAllister RA, Roy AD. Studies on human intestinal proteolysis. *Scand J Gastroent* 1968;13:193-201.
 22. Hill GL. Ileostomy: surgery, physiology, and management. New York: Grune and Stratton, 1976.
 23. Kennedy HJ, Sarson DL, Bloom SR, Truelove SC. Gut hormone responses in subjects with a permanent ileostomy. *Digestion* 1982;24:133-6.
 24. Englyst HN, Macfarlane GT. Breakdown of resistant and readily digestible starch by human gut bacteria. *J Sci Food Agric* (in press).
 25. Cummings JH. Fermentation in the human large intestine: evidence and implications for health. *Lancet* 1983;1:1206-9.
 26. Christopher NL, Bayless TM. Role of the small bowel and colon in lactose-induced diarrhea. *Gastroenterology* 1971;60:845-52.
 27. Anderson IH, Levine AS, Levitt MD. Incomplete absorption of the carbohydrate in all-purpose wheat flour. *New Engl J Med* 1981;304:891-2.
 28. Stephen AM, Haddad AL, Phillips SF. Passage of carbohydrate into the colon. *Gastroenterology* 1983;85: 589-95.
 29. Cummings JH. Polysaccharide fermentation in the human colon. In: Kasper H, Goebell H, eds. Colon and nutrition. Falk Symposium 32. Lancaster: MTP Press Ltd, 1982:91-104.
 30. Dahlqvist A, Borgstrom B. Digestion and absorption of disaccharides in man. *Biochem J* 1961;81:411-8.
 31. Katz JR. The amorphous part of starch in fresh bread, and in fresh pastes and solutions of starch. *Recl Trav chim Pays-Bas Belg* 1937;56:785-93.
 32. Greenwood CT. Observations on the structure of the starch granule. In: Blanshard JMV, Mitchell JR, eds. Polysaccharides in food. London: Butterworths, 1979: 129-38.
 33. Englyst HN, Bingham SA, Wiggins HS, et al. Non-starch polysaccharide consumption in four Scandinavian populations. *Nutr Cancer* 1982;4:50-60.