

Digestion of polysaccharides of potato in the small intestine of man¹⁻³

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ABSTRACT Digestion and absorption from the small intestine of starch and nonstarch polysaccharides (NSP) (dietary fiber) from potato cooked and treated in various ways have been studied in ileostomy subjects. Test meals (300 g) of potato were fed following 24 h on a plant polysaccharide-free diet. Regardless of the treatment the potato had received, > 90% of NSP was recovered in ileostomy effluent. Starch from freshly cooked potato was well digested, only 3% being recovered; however, 12% from cooked and cooled potato escaped digestion in the small intestine. Digestibility of starch made resistant to α -amylase by cooling improved on reheating. Overall, 9, 18, and 14% of total carbohydrate fed was recovered from freshly cooked, cooled, and reheated potato, respectively. Digestibility of cooled potato was identical when eaten as large lumps or as finely sieved potato. In vitro studies with pancreatin also demonstrated incomplete digestion of cooled potato. *Am J Clin Nutr* 1987;45:423-31.

KEY WORDS Starch, fiber, carbohydrate digestion, potato, small intestine

Introduction

Potatoes are an important staple food in many Western and other countries. Quantitatively the main nutrient in potatoes, as in cereals, is the storage-polysaccharide starch. We have previously shown (1) that starch from white bread, porridge oats, and cornflakes is almost completely digested in the small intestine of man with the exception of the small fraction made resistant to pancreatic amylase by food processing. In contrast, the nonstarch polysaccharides (NSP) from these cereal products are totally recovered from terminal ileum. However, starches from different plant sources are by no means uniform (2), and in studies with banana (3) we were able to recover ~80% from terminal ileum of ileostomy subjects.

Fuwa et al (2) have shown that starch granules in uncooked potato, in contrast to those from cereals, are highly resistant to hydrolysis with pancreatic amylase in vitro. In this respect potato starch is similar to banana starch, which is resistant to pancreatic amylase both in vitro and in vivo. However, when potatoes are cooked for consumption, the starch is gelatinized (dispersed), and it becomes susceptible to hydrolysis with α -amylase. In earlier studies with potato in vitro (4) we showed that when cooked and then either cooled, frozen, or dried, potato starch becomes partly resistant

to α -amylase. These experiments together with our previous studies using ileostomy patients (1, 3) have led us to propose a classification of starch for nutritional purposes. **Table 1** shows dietary starch classified into three main types on the basis of susceptibility to α -amylase in vitro: readily digestible starch (RDS), which on current evidence is completely digested in the small intestine; partially resistant starch (PRS), which partly escapes digestion in the small intestine; and resistant starch (RS), which totally escapes digestion in the small bowel. Rate and extent of starch breakdown in the small intestine has a marked effect on glucose absorption and corresponding insulin response. The importance of starch that resists breakdown in the small intestine is that it becomes available for fermentation in the large bowel. The aim of this study is to investigate the breakdown of potato starch and NSP in

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TABLE 1
Nutritional classification of starch

Type of starch, based on susceptibility to pancreatic amylase in vitro	Physical form	Present in	Predicted fate in the small intestine of man
Readily digestible starch (RDS)			
RDS 1	Dispersed starch	Freshly cooked food	Rapidly digested
RDS 2	Crystalline starch with X-ray diffraction pattern A	Most uncooked cereals and gelatinized starch dried at high temperature	Slowly but virtually completely digested
Partially resistant starch (PRS)			
PRS 1	Physically inaccessible starch	Whole or partly milled grains and legumes	Partly digested
PRS 2	Starch granules with X-ray diffraction pattern B or C	Raw potato and banana	Partly digested
PRS 3	Mainly retrograded amylopectin	Cooled cooked potato	Partly digested
Resistant starch (RS)			
RS	Mainly retrograded amylose	Cooled cooked potato, breads and cornflakes	Resists digestion totally

the small intestine of man using ileostomy subjects as a model. Special attention has been given to the effects of cooking and processing on digestibility of starch.

Subjects and methods

Subjects

Five ileostomy subjects (three females) mean age 62 yr (range 35–76) took part in studies with potato treated in six different ways. All the subjects had total colectomies for ulcerative colitis, mean 11 yr (range 7–24), before taking part in these experiments. An average of 6 cm (maximum 21 cm) of terminal ileum was removed and in no case was there evidence of ileal disease. All were well and none had taken antibiotics or similar medication 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

Subjects lived in the metabolic suite at the Dunn Clinical Nutrition Centre throughout the study. Regular periods of exercise were taken.

Diet

The study was divided into 24 h periods starting at 0900 h each day. Commencing the evening before and continuing throughout the study, subjects were given a plant-polysaccharide-free diet prepared in the diet kitchen of the Dunn Clinical Nutrition Centre. This diet included milk, eggs, tea, sugar, prawns, mayonnaise, meat, cheese, jelly, and cream and contained the following (per day): energy, 7.1 MJ (1700 kcal); protein, 114 g; fat, 104 g; and carbohydrate, 82 g. On analysis, this diet was shown to contain only traces of starch and NSP. On days 2 and 3

in addition to the plant-polysaccharide-free breakfast of bacon, egg, and tea with milk, subjects were given test meals of 300 g of potato. For the test meals, potatoes (Maris Piper) of approximately equal size (~100 g) were chosen, peeled, and cooked with salt in boiling water for 30 min; then each potato was divided into four equal pieces. Subjects were fed 300 g of potato prepared in one of the following ways: 1) freshly cooked, served immediately ($n = 5$); 2) cooled (ie, cooked, cooled to 5°C, kept overnight before feeding) ($n = 5$); 3) cooked potato passed twice through a 1 mm mesh stainless steel sieve, fed cold ($n = 3$); 4) cooled potato, reheated by steaming for 20 min, fed hot ($n = 2$); 5) cooled potato with chopped bacon and beaten eggs added, heated in a microwave oven for 5 min, fed hot ($n = 2$); and 6) instant potato (Cadbury's Smash®; Cadbury's Ltd, Birmingham, UK), mixed with boiling water, 300 g fed immediately ($n = 3$).

At the time of the test meals, portions of potato were rapidly frozen in solid CO₂-methanol and stored at -20°C until analysis.

Effluent

Ileostomy effluent was collected by subjects either emptying or changing their bags every 2 h during the day from 0700 h until retiring at 2300 h. Each sample of effluent was immediately frozen in CO₂ pellets, weighed, and freeze-dried. Mean transit time (MTT) of the test breakfast was calculated as transit time of pentose from potato NSP as described previously (1).

Chemical methods

Carbohydrate analysis: NSP and RS. The method for measuring NSP and resistant starch (RS) was described in detail previously (4, 5) and is summarized briefly. Samples of food were analyzed as follows:

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, and individual neutral sugars were measured



as alditol acetates by gas-liquid chromatography (GLC) and uronic acids by the colorimetric method of Scott (6). This procedure measured total NSP and RS together.

2) After an identical starch-removal procedure as in 1), RS was solubilized with 2 M KOH and an aliquot was incubated with amyloglucosidase to hydrolyze it to glucose. The remainder was hydrolyzed with molar H_2SO_4 and individual sugars were determined as in procedure 1). This estimates RS and noncellulosic polysaccharides (NCP) separately. A value for NSP is obtained by subtracting the glucose in RS from glucose measured in procedure 1). Cellulose is calculated as the difference between NSP and NCP glucose.

3) After starch removal the material is extracted with buffer at pH 7, and the residue is dispersed with 12 M H_2SO_4 , hydrolyzed with molar H_2SO_4 , and individual sugars measured as in procedure 1). This gives a value for NSP insoluble at pH 7 after subtraction of RS.

Starch + dextrins (excluding RS). These were measured as 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 (excluding RS). This was measured as increase in apparent NCP glucose when incubation with α -amylase and pullulanase is omitted from the procedure.

Dextrins. These 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 each containing a magnetic stirring bar. Ten 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 portion of the supernatant (0.3 mL) was transferred to a 0.8 mL auto-injector vial and dried in a vortex evaporator. Trimethylsilyl oximes were prepared as previously described (7). Pyridine (0.2 mL) containing 25 mg hydroxylamine-hydrochloride/mL was added. The vials were placed in a heating block at 70–75° for 30 min and then cooled. N-trimethylsilylimidazole (0.2 mL) was added and the vials were placed in a vortex mixer for 30 sec and then left for 30 min. One to 2 μ L was used for GLC.

Nitrogen. Total nitrogen was measured by the Dumas procedure using a Carlo Erba (Milan, Italy) 1500 Nitrogen Analyzer.

Breath hydrogen. End-expiratory air was collected from subjects at hourly intervals using a collapsible polythene tube with a one-way valve (HS Wiggins, unpublished) and hydrogen measured with an electrochemical detector (Exhaled Hydrogen Monitor, GMI, Scotland).

Effluent. Each sample of effluent was subjected to GLC analysis of total carbohydrate after Seaman hydrolysis. Detailed carbohydrate fractionation and analysis was done on samples collected and pooled from the time the test meal was given until the effluent was free of xylose. To correct for endogenous carbohydrate (from mucus) in effluent, the ratio of fucose to galactose was measured during the day on which the polysaccharide-free diet was given.

After the potato test meals, galactose recoveries were corrected for galactose from mucus using the amount of fucose present and the fucose to galactose ratio from the control period. Values for carbohydrate recovered after test meals, in tables and in text, have been corrected for carbohydrate excretion measured when on the plant-polysaccharide-free diet.

In vitro studies. In order to investigate the mechanism whereby starch may become resistant to amylase breakdown, a number of studies of starch digestibility in vitro have been carried out.

Raw potato, equivalent to 200 mg dry wt, was incubated for 16 h at 37°C with 1000 units (100 units/mL) of pancreatic amylase (1 unit = 0.36 mg maltose equivalent produced/min). Similar amounts of potato starch were gelatinized by heating at 100°C for 20 min (cooked) and then were incubated with amylase. Further treatment prior to enzyme incubation included leaving the cooked potato for 2 h at 40°C or at 0°C, freezing the cooked potato rapidly in a CO_2 :methanol mixture, freezing slowly by placing it in a domestic freezer at –20°C, and freeze-drying the extraction with 80% ethanol or with acetone.

Statistics

All results are given as mean $\pm$ 1 SD. Comparisons between diets are made using the *t* test for paired samples.

Results

Plant-polysaccharide-free diet (control day)

The amount and composition of ileostomy effluent on the day when only the plant-polysaccharide-free diet was eaten is given in Table 2 and Table 3 for each part of the study. The average effluent output for all subjects ($n = 7$) was 326 ± 98.7 g/day or 25.0 ± 6.2 g solids/day.

Four each group of subjects in the different parts of the study, amount of carbohydrate excreted on the plant-polysaccharide-free diet was similar at 1.25, 1.27, and 1.56 g/day. The major part of this carbohydrate was in polysaccharides containing fucose and galactose, which are derived from mucus and are measured mainly as soluble noncellulosic polysaccharide. Only traces of free sugars (glucose, mannose, etc) were found. Nitrogen excretion on the control diet was 1.9 ± 0.4 g/day, equivalent to about 12 g of protein and comprising almost 50% of effluent solids.

Digestibility of polysaccharides from freshly cooked and from cooled potato (Preparations 1 and 2 in Methods and Table 2 and Table 4) ($n = 5$)

After the potato test meals, especially the cooled potato, excretion of total solids and



TABLE 2
Composition of effluent, mean transit time (MTT), and breath hydrogen

<i>n</i> = 5	Control day	Freshly cooked potato	Cooled potato
Total effluent, g/day	329 ± 119	322 ± 97	373 ± 118*
Total solids, g/day	24.7 ± 6.1	27.1 ± 4.7	33 ± 4.6*
Total carbohydrate, g/day	1.25 ± 0.3	6.0 ± 0.4	10.5 ± 2.2*
% of solids	4.5	22.1	31.8
Total N g/day	1.8 ± 0.5	1.7 ± 0.4	1.8 ± 0.1
N % of solids	7.5 ± 0.3	6.4 ± 0.4	5.4 ± 0.7
MTT (h)		8.1	6.4
Mean hourly breath H ₂ , ppm	3.3 ± 1.3	3.5 ± 1.0	4.2 ± 1.2

* *p* < 0.05 cooled vs. freshly cooked.

carbohydrate was increased (Table 2). Carbohydrate increased from 5% of solids (1.25 g) on the control day to 22% (6.0 g) with hot potato and 32% (10.5 g) with cold potato. Mean transit time fell by 20% from 8.1 to 6.4 h on changing from hot to cooled potato, but this change was not significant. Nitrogen excretion was unchanged in this study although percentage nitrogen in effluent was higher on the control diet. Breath hydrogen excretion was very low at 3–4 ppm throughout all the studies.

The results of analysis of carbohydrate fed and recovered are shown in Table 4. The overall composition of the two test meals is similar, ~46 g starch, 4 g NSP, and 2 g free sugars. However, the amount of RS (see Table 1) is twice as high for cooled (1.6 g) compared with freshly cooked potato (0.8 g).

Overall, 9% of the carbohydrate in freshly cooked and 18% in cooled potato was recovered in the effluent. NSP recoveries were ~90% (3.3–3.5 g/day) and were very similar for the two test meals. Only small amounts

(0.36 g) of free sugars were recovered after feeding freshly cooked potato but with cooled potato this increased to 2.2 g and was mainly maltose, maltotriose, and glucose. Fructose and sucrose were absorbed completely. Since no maltose or maltotriose was present in potato fed, it is likely that these sugars and the glucose found in the effluent after feeding cooled potato originate from partly hydrolyzed starch. Only 2% of starch (excluding RS) plus dextrans was recovered but most RS survived passage through the intestine. If it is assumed that glucose, maltose, maltotriose, and dextrans recovered in the effluent all originate from starch then, overall, starch excretion is 3% from fresh potato and 12% from cooled potato.

Digestibility of sieved, cooled potato (Preparations 2 and 3 in Methods) (n = 3)

To test whether the physical form of eaten potato affects digestibility of its starch, three subjects were given test meals of cooled potato served either as large pieces (¼ sections of

TABLE 3
Composition of effluent, mean transit time (MTT), and breath hydrogen

<i>n</i> = 2	Control day	Cooked and cooled potato	Cooked, cooled, and reheated (hot pie) potato	Cooked, cooled, and steamed potato
Total effluent, g/day	318 ± 39	426 ± 11	374 ± 15	408 ± 16
Total solids, g/day	25.7 ± 9.1	37.1 ± 4.6	32.1 ± 6.6	34.1 ± 5.4
Total carbohydrate, g/day	1.5	11.1 ± 0.5	8.4 ± 0.3	8.6 ± 0.3
Carbohydrate, % of solids	5.8	29.9	26.2	25.2
Total N, g/day	1.7 ± 0.7	1.6 ± 0.0	1.7 ± 0.4	1.9 ± 0.3
N % of solids	6.4	4.4 ± 0.6	5.5 ± 0.1	4.9 ± 0.2
MTT		5.9 ± 0.1	5.6 ± 0.5	6.2 ± 1.3
Breath H ₂ , ppm	5.3 ± 1.4	5.6 ± 0.1	4.8 ± 0.5	5.3 ± 0.2

TABLE 4
Digestibility of polysaccharides from freshly cooked and from cooled potato*

n = 5	NSP-free diet		Freshly cooked potato				Cooked and cooled potato			
	Recovered		Fed		Recovered		Fed		Recovered	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Total NSP	1.15	0.29	3.76	0.20	3.27	0.39	3.93	0.29	3.52	0.63
Cellulose	0.05	0.05	1.24	0.28	1.10	0.27	1.28	0.28	1.22	0.27
Soluble NCP	0.98	0.28	2.15	0.07	1.81	0.17	2.33	0.36	1.99	0.52
Insoluble NCP	0.12	0.06	0.37	0.17	0.43	0.07	0.36	0.21	0.32	0.13
RS	0.04	0.03	0.82	0.28	0.54	0.04	1.60	0.24	1.48	0.20
Starch†	0.02	0.03	44.54	2.73	0.55	0.08	45.59	1.20	1.60	0.32
Dextrins	0.03	0.03	—	—	0.05	0.07	—	—	0.44	0.35
Free sugars	0.01	0.01	2.13	1.56	0.36	0.10	1.98	1.22	2.24	1.26
glucose	0.01	0.01	0.60	0.60	0.11	0.03	0.52	0.43	0.52	0.29
fructose	—	—	0.45	0.80	—	—	0.38	0.60	—	—
sucrose	—	—	1.08	0.72	—	—	1.08	0.67	—	—
maltose	—	—	—	—	0.18	0.03	—	—	1.15	0.60
maltotriose	—	—	—	—	0.07	0.07	—	—	0.57	0.42
Total carbohydrate, g/day	1.25	0.30	51.25	1.52	4.78	0.42	53.10	0.90	9.29	2.26
% starch recovered‡					3.31				12.20	
% carbohydrate recovered					9.32				18.12	

* NSP = Nonstarch polysaccharides; NCP = Noncellulosic polysaccharides; RS = Resistant starch (see Table 1); SD = standard deviation.

† = excluding RS.

‡ = includes RS, dextrins, and free sugars.

whole potato) or sieved (passed through a 1 mm sieve twice). Total effluent output (g/day) was similar after the two test meals: 373 ± 46 for large pieces (LP) and 365 ± 29 for sieved (S); total carbohydrate (g/day) in the effluent was similar also: 9.8 ± 0.5 (LP) and 10.1 ± 0.9 (S). NSP recoveries were $> 90\%$ from both test meals and percent starch recovered did not differ at 10.8% (LP) and 11.6% (S). These data are very similar to those obtained in the first part of this experiment (Tables 2 and 4) further confirming the incomplete digestion of cooled potato starch shown in this experiment. This change in physical form of the potato by sieving seems to have no effect on the digestive process.

Effect of reheating on the digestibility of cooled potato (Preparations 2, 4, and 5 in Methods) (n = 2)

To observe the effect of reheating, two subjects were given test meals of cooled potato and then cooled potato reheated either in a microwave oven or by steaming for 20 min.

NSP and RS were totally recovered from all three test meals (Table 3 and Table 5). Starch

hydrolysis and absorption were greater when the potato was reheated and the two different forms of reheating improved digestibility to a similar extent. The greater digestibility of reheated potato was accounted for partly by less residual starch and partly by less excretion of maltose, maltotriose, and dextrins. Overall, 12.7, 7.4, and 7.8% of total starch fed was accounted for from cold, microwave-heated, and steamed potato, respectively, compared with only 2.4% from freshly cooked potato.

Digestibility of instant potato (Preparation 6 in Methods) (n = 2)

Digestion of carbohydrate in instant mashed potato was very similar to that in the freshly cooked potato when tested in two subjects. The potato contained 0.6 g RS, which was recovered completely in effluent; 0.7 g other starch plus dextrins, maltose, and glucose was recovered after feeding instant potato and 0.9 g after feeding freshly cooked potato. NSP was recovered completely.

Studies in vitro

To investigate the effect of various treatments on susceptibility of potato starch to

TABLE 5
Effect of reheating on the digestibility of cooled potato*

	NSP-free diet		Cooled potato		Cooled potato (direct)		Hot pie of cooled potato		Steamed then cooled potato	
	Recovered		Fed		Recovered		Recovered		Recovered	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
<i>n</i> = 2										
Total NSP	1.41	0.24	3.34	0.19	3.52	0.64	3.27	0.36	3.35	0.46
Cellulose	0.08	0.06	1.04	0.08	1.05	0.01	1.13	0.07	0.94	0.06
Soluble NCP	1.18	0.26	1.88	0.31	1.97	0.26	1.71	0.09	1.80	0.16
Insoluble NCP	0.15	0.04	0.42	0.20	0.50	0.38	0.44	0.19	0.60	0.36
RS	0.05	0.02	1.33	0.02	1.65	0.03	1.69	0.05	1.63	0.16
Starch†	0.01	0.01	46.23	0.80	1.63	0.10	0.98	0.07	1.31	0.22
Dextrins	0.06	0.03	—	—	0.51	0.09	0.15	0.04	—	—
Free sugars	0.03	0.02	0.97	0.36	2.26	0.15	0.72	0.11	0.75	0.13
glucose	0.03	0.02	0.25	0.16	0.44	0.03	0.22	0.06	0.24	0.04
fructose	—	—	0.32	0.19	—	—	—	—	—	—
sucrose	—	—	0.40	0.00	—	—	—	—	—	—
maltose	—	—	—	—	1.16	0.07	0.32	0.06	0.36	0.03
maltotriose	—	—	—	—	0.66	0.06	0.16	0.02	0.15	0.05
Total carbohydrate, g/day	1.56	0.22	51.87	1.39	9.57	0.53	6.82	0.31	7.03	0.26
% starch recovered‡					12.72		7.44		7.76	
% carbohydrate recovered					18.45		13.15		13.15	

* NSP = Nonstarch polysaccharides; NCP = Noncellulosic polysaccharides; RS = Resistant starch (see Table 1); SD = standard deviation.

† = excluding RS.

‡ = includes RS, dextrins, and free sugars.

pancreatic amylase, a number of experiments were carried out in vitro. Firstly, raw potato was incubated for 16 h at 37°C with 1000 units of pancreatic amylase. Half the starch (49.3%) was unhydrolyzed (ie, insoluble in 80% ethanol). Potato starch granules are therefore highly, although not totally, resistant to pancreatic amylase (ie, Type PRS 2, Table 1).

When potato starch is gelatinized by cooking, it becomes readily available to hydrolysis by pancreatic amylase. However, on cooling to < 60°C, the gelatinized starch begins to retrograde to RS and PRS 3 (see Table 1). The amount and type of retrograded material formed depends on conditions used for cooling and drying.

Table 6 shows the amount of RS formed when raw potato is subjected to various treatments used in food processing, storage, and analytical procedures and also as pretreatment for analytical procedures. Cooling freshly cooked potato to 40°C for 2 h produces 0.66 g RS/100 g dry matter, but cooling to 0°C increases this amount threefold. Freezing at -20°C and freeze-drying produce 1.7 and

2.5 g/100 g, respectively. However, rapid freezing in solid CO₂-methanol does not produce any RS and provides a useful technique for monitoring formation of RS because it prevents further retrogradation.

To determine the rate of formation of RS, 1 g samples of freshly cooked potato were placed in ice water for various times. Formation of RS was initially very rapid with 0.71

TABLE 6
Formation of resistant starch (RS) in potato by treatments used in food processing and analysis

Treatment	RS g/100 g
None (ie, raw potato)	0
Freeze dried	0
Freshly cooked	0
Cooked and left for 2 h at 40°C	0.66
Cooked and left for 2 h at 0°C	1.86
Cooked and rapidly frozen (CO ₂ -Methanol)	0
Cooked and slowly frozen	1.72
Cooked and freeze dried	2.54
Cooked and extracted with ethanol	0.63
Cooked and extracted with acetone	0.60



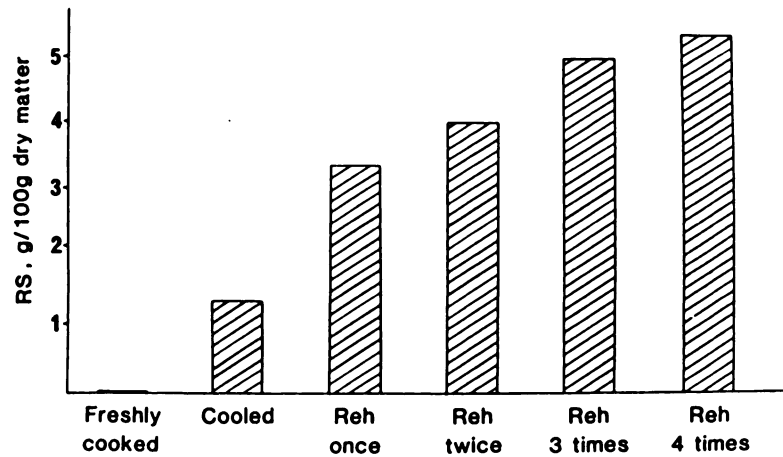


FIG 1. Formation of resistant starch on repeated heating and cooling. Reh = reheating and cooling of cooled potato.

and 1.34 g/100 g produced after 5 and 15 min, respectively, but slowed after 30 min with little additional formation by 4 h.

Figure 1 shows amount of RS produced by repeated heating and cooling of potato. A second heating and cooling cycle doubles the amount of RS produced, but further cycles produce progressively smaller increments.

Digestion in vitro of starch from freshly cooked and from cooled potato by pancreatic amylase is shown in Figure 2. Starch from

freshly cooked potato is more rapidly and completely hydrolyzed than cooled potato starch, especially in early stages of incubation. In further studies it was shown that the susceptibility to amylase in early stages of incubation was improved by reheating.

Discussion

These studies of digestibility of polysaccharides from a number of different potato prep-

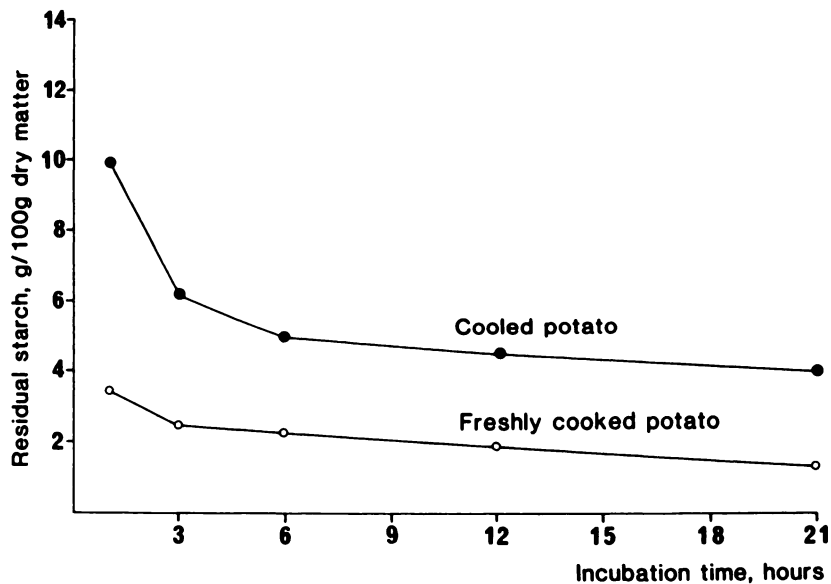


FIG 2. In vitro digestion of freshly cooked and cooled potato with pancreatic amylase.

arations confirm previous observations, with cereal foods (1) and banana (3), in showing that NSP escapes breakdown in the small intestine almost completely. This is in marked contrast to findings from animal models. In the pig, often regarded as the best model for man, studies of the digestibility of NSP from wheat bran, peas, and beet pulp show that only 90, 70, and 62%, respectively, are recovered from the terminal ileum (8) while in a study of swede (9), 30–40% NSP is digested in the stomach and small intestine. These results should not lead to the conclusion that NSP-hydrolyzing enzymes are secreted into the small intestine of pigs. The results simply confirm observations (10) that the stomach and small intestine of the pig, in contrast to man, are heavily contaminated with bacteria capable of fermenting carbohydrates.

Digestion of starch in the small intestine of man is less readily predictable than that of NSP. Studies show that potato starch may be either totally digested or only partly so dependent on presence of amylase-resistant starch. A considerable amount (12%) of starch from cooled potato escapes hydrolysis and absorption in the small intestine (Tables 4 and 5). This is unlikely to be due to presence of starch granules (PRS 2, Table 1) since the potato was well boiled and starch in freshly cooked potato was well hydrolyzed and well absorbed (Table 4). It is possible, however, that the resistant starch was type PRS 1, which is resistant because of incomplete physical access for digestive enzymes. To test this, cooled potato was fed both as large lumps and sieved. The results showed that passing cooled potato through a 1 mm sieve did not improve digestibility of starch. However, we showed previously that digestibility of nitrogen in beans is affected by the physical form of the food (11), and others have shown that carbohydrate digestion is similarly affected by physical state in cereals and legumes (12, 13). While the physical form of food may in some cases affect its digestibility, in potato increased resistance to amylase on cooling must relate to changes in crystallinity of starch rather than to gross physical form. Some resistant starch (1.3–1.7 g) was present in the cooled potato fed and, within experimental error, was completely recovered in ileostomy effluent (Tables 4 and 5). Similar observations were made with RS in cereal

products (1). RS is fully recovered also when cooled potato is reheated and consumed as either hot potato pie or steamed potato (Table 5). These results confirm that RS is fully recovered after treatment at 100°C and that it resists hydrolysis with pancreatic amylase both in vitro and in vivo. Fermentation of RS by the human gut microflora has previously been described (14).

Of the starch from freshly cooked and from cooled potato, 3% and 12%, respectively, escape digestion in the small intestine. However, only about one quarter of this difference can be explained by amount of RS recovered in effluent after the test meal of cooled potato. Carbohydrates in addition to NSP recovered after the meal of cooled potato are starch and the breakdown products of starch, ie, glucose, maltose, maltotriose, and dextrins. This suggests that part of the starch in cooled potato is largely resistant to hydrolysis by pancreatic amylase. Maltose and maltotriose can be hydrolyzed and absorbed together with free glucose from the ileum (15). The recovery of these in effluent may therefore indicate that some hydrolysis of starch is actually taking place in the ileostomy bag rather than the ileum.

Digestibility of starch in cooled potato is greatly increased by reheating (Table 5, Fig 3). When cooled potato was reheated and consumed as hot potato pie, the starch components recovered in the effluent were reduced from 12.7% to 7.4% of the starch fed. Results obtained for steamed potato (Table 5) were very similar to those for potato pie. The partial and more variable breakdown together with improved digestion after reheating suggest that retrograded amylopectin (ie, PRS 3, Table 1) is partly responsible for incomplete digestion of cooled potato.

Digestibility of starch from instant potato is very similar to that from freshly cooked potato and indicates that the type B x-ray diffraction pattern (16), which is less susceptible to pancreatic amylase, has not been formed during processing. The manufacturers confirmed that the instant potato had been produced by drying cooked potato at 105°C, ie, a temperature above that where type B pattern is formed. For this reason, the reduced digestibility observed for cooled potato (Table 2) and for freeze-dried cooked potato in vitro (Table 6) was not seen for instant potato. De-

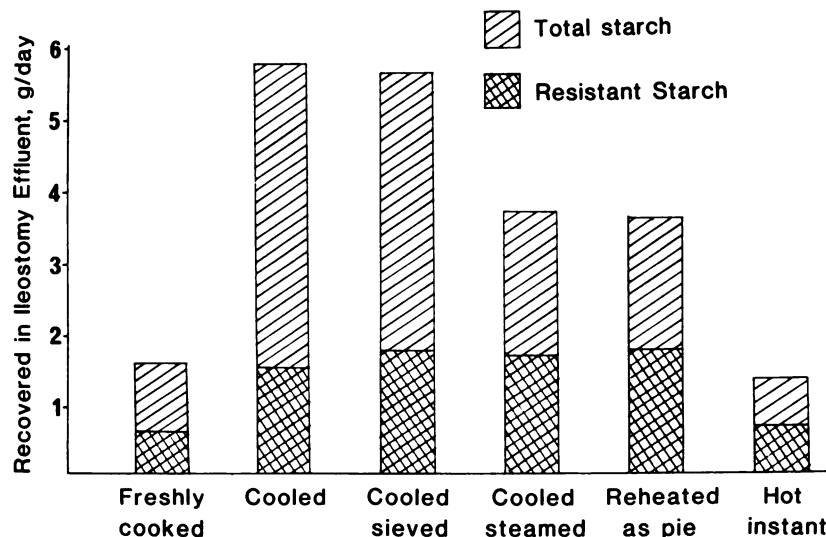


FIG 3. Effect of processing on digestibility of potato starch in the small intestine of man.

pendence of the digestion of potato starch on food processing is summarized in Figure 3.

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