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ORIGINAL CONTRIBUTION

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Effects on parameters of glucose homeostasis in healthy humans from ingestion of leguminous versus maize starches

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Summary *Background:* Due to their lower glycaemic index, leguminous seeds affect human carbohydrate metabolism lesser than do cereals. Problems, however, could arise from side effects, e.g., increasing flatulence.
Aim of the study and methods: In 26 healthy subjects, metabolic and symptomatic responses following acute ingestion of equivalent amounts of pure pea starch (NASTAR (Cosucra BV, Rosendaal/The Netherlands), crude yellow pea flour (CPC Deutschland, Germany), and modified and unmodified cornstarches (SNOWFLAKE and SIRONA, Cerestar/Germany) were assessed, i.e., plasma glucose, serum insulin, C-peptide, hydrogen exhalation, and flatulence.
Results: Pure pea starch elicited less hyperglycaemia (minus 47 %), hyperinsulinaemia (minus 54 %), and C-peptide secretion (minus 37 %) as compared to cornstarch ($p<0.05$), while the responses to modified versus unmodified corn starch were similar (8 subjects, n.s.). Pure pea and corn starches were equally well tolerated, while flatulence and breath hydrogen concentration were increased only after the intake of crude pea flour. Maldigestion of pea flour was calculated to be around 10 % (reference lactulose).
Conclusions: The well-known metabolic advantages of pea starch over cornstarch were confirmed. Tolerability of pure pea starch was excellent, but not of crude pea flour. Provided it has the same technical characteristics, pure pea starch as a "prebiotic" could replace cornstarch in industrial food production.

Key words: Glycaemic index – insulin – diabetes mellitus – blood glucose – digestion – diet – prebiotics

Introduction

Foods containing carbohydrates (CHO) differ substantially in their effect on human glucose homeostasis and insulin production, depending on the accessability to the processes of intestinal digestion and absorption. In this respect, the physico-chemical properties of carbohydrate foods are of utmost importance, which are either inherent of a food stuff (like the amylose content of a starch (17)), or induced by processing procedures like boiling, grinding, baking, freezing, etc.(4, 24). On the other hand, there are individual biological factors which modulate a person's metabolic response to carbohydrate ingestion, e.g., the speed of ingestion, intensity of chewing before swallowing, gastrointestinal motility, and availability of digestive enzymes. These aspects have received considerable attention because they can be differentiated into potentially healthy and unhealthy ones. At present, the so-called slow-release CHO or "lente CHO" (7, 13) seem to offer promising perspectives with regard to disease prevention (10, 13-15, 23), or treatment of diseases like morbid obesity, diabetes mellitus, or colonic disorders. Natural lente CHO per definition have a low digestion rate, like unboiled potato starch; boiled potato starch, by contrast, is a fast-release "rapid CHO" (7, 25). Further-

more, digestible CHO, which are not broken down to glucose, but to some other saccharides not directly affecting human glucose and insulin homeostasis, may also be termed lente CHO (like fructose, or fructoseoligomers (inulin)). Another slow-release CHO is leguminous starch (3, 12, 18) which is hydrolysed only incompletely to glucose monomers in the upper jejunum (i.e. where the absorption of saccharides occurs). Considerable parts of ingested leguminous starch, thus, bypass the upper jejunum. In the colon, they are broken down by bacteria to fatty acids, and partially absorbed by the gut. Whether the digestibility of leguminous starch as such is that complex, or whether natural ingredients, like fibers, phythates (20), enzyme-blockers, proteins, etc. affect digestion of leguminous seeds in humans is not clear. The following study compares the digestibility of different pea starch and maize starch meals in healthy persons, by monitoring the postprandial blood glucose homeostasis and related parameters.

Subjects, materials, and methods

Subjects

26 healthy non-smoking persons were recruited, without a history of gastrointestinal or metabolic diseases. Exclusion criteria were taking any medication, and having random plasmaglucose >125 mg/dl, or HbA1c >5.6 %. Three women and 7 men, aged 26-33 years participated in the first study. In the second study, 4 women and 4 men participated, aged 24-29 years. For these two studies, only non-obese persons with BMI 20-24 kg/m^2, and with significant H_2 exhalation (+20 ppm) in response to 6.5 g Lactulose Sirup (ratiopharm GmbH, Ulm), were recruited. For the third study, 8 severely obese, but otherwise healthy persons were selected (4 women, and 4 men, aged 23-33 years, with a body mass index of 29-39 kg/m^2).

Materials

Four instant starch preparations were studied: 2 maize starch, and 2 pea starch preparations. The maize starch preparations were "Sirona ™" native cornstarch (Cerestar GmbH, Germany) and modified (with Adipinacidanhydrid) waxy cornstarch E 1422 "Snowflake 06309™" (Cerestar, Germany). The pea-starch preparations were "Nastar ™" native pea starch (Cosucra BV, Rosendaal/Nederland) and crude yellow pea flour (CPC Deutschland GmbH, Heilbronn/Germany). The chemical analyses of the starches are summarized in Table 1.

All starch meals were prepared by CPC Deutschland GmbH, Heilbronn/Germany with added fat, salt, and flavors (e.g., celery-carrot flavor) to enhance palatability, and were powderized and packed in paper-aluminium-polyethylene pouches in portions equivalent to 30 g CHO. As the meals were to be consumed as soups, the powder was dissolved in 500 ml cold tap water (600 ml with waxy corn starch), stirred, and boiled for 5 minutes immediately before ingestion. The nutrient composition of the meals as ingested is summarized in Table 2.

Methods

Plasma glucose was measured by Beckman Glucose Analyzer II (Fullerton, CA., USA), Serum insulin was measured by microparticle-enzyme-immunoassay (IMx-Insulin-Assay, Abbott GmbH, Wiesbaden); serum C-peptide was measured by radio-immunoassay (Pharmacia, Uppsala/Sweden). Triglycerides were measured enzymatically by routine laboratory methods. HbA1c was measured by HPLC, normal level <5.6 % of total hemoglobin. H_2 exhalation was measured by gas-chroma- tography using the Microlyzer CM 2 (QuinTron Instruments, Medichek GmbH, Essen). In study 1 and 2, flatulence was recorded by the subjects subjectively without quantitation.

Table 1 Chemical analyses of the starches under study

Name	unmodified CORNSTARCH "SIRONA"	modified WAXY CORNSTARCH E 1422 "Snowflake 06309"	PEA STARCH "NASTAR"	crude PEA FLOUR
	%	%	%	%
MOISTURE	11.0	6.0	8.8	11.3
FAT	0.4	0.0	< 0.1	2.3
PROTEIN	0.3	0.4	0.2	21.7
FIBERS	–	–	–	8.5
ASH	0.07	0.05	0.09	2.9
TOTAL CARBOHYDRATES	88.6	93.0	91.0	53.0
Amylose	24	0.8	35	35
Amylopektin	76	99.2	65	65

Table 2 Composition of the meals (soups)

	unmodified CORNSTARCH	**modified WAXY CORNSTARCH**	**PEA STARCH**	**crude PEA FLOUR**
FLAVOR	Celery-Carrot	Celery-Carrot	Celery-Carrot	Pea
CONCENTRATION	g/500 ml	g/500 ml	g/500 ml	g/500 ml
FAT	12.2	12.1	11.9	13.4
PROTEIN	3.5	3.5	3.4	14.8
GLUCOSE POLYMERS WATERFREE	28.8	25.2	28.6	25.8
SUCROSE	1.9	2.0	1.9	1.3
LACTOSE	2.2	2.3	2.3	n.a.
GLUCOSE	0.1	0.1	0.1	< 0.1
FRUCTOSE	0.1	0.1	0.1	0.25
MANNITOL	0.9	0.9	0.9	n.a.
RAFFINOSE	n.a.	n.a.	< 0.1	0.5
STACHYOSE	n.a.	n.a.	0.06	1.5

Food analyses were done by CPC Heilbronn with the method of Weibull and Stoldt (total fat content (1)), the Kjeldahl method (proteins), and with the ionchromatographic method of Weiss (glucosepolymers (23)). Information on the % amylose content of the starches was obtained from the suppliers (Cosucra BV, Rosendaal/ Nederlande) and the literature (11). For each proband, an individual portion of the soup was prepared from a separate bag in a separate pot. The soup was to be ingested within 15 minutes after boiling.

Study design

Study 1 Randomized, double-blind cross-over comparison of metabolic effects following ingestion of 30 g of fiber-depleted pure pea starch ("Nastar") versus fiber-depleted unmodified maize starch ("Sirona" native cornstarch) in 10 non-obese subjects. After an overnight fast Probands reported to the laboratory, where they were seated comfortably in a chair. For frequent blood sampling, an indwelling cannula was inserted into an antecubital vein and kept patent by 30 ml/h infusion of 0.9 % saline. At time 0, they ingested the starch soups with celery-carrot flavor (Table 2). Before, and after ingestion of the soups, blood was sampled during 6 hours every 15 to 30 minutes for determination of glucose, insulin, and C-peptide levels. H_2 exhalation was also assessed.

Study 2 Randomized, single-blind comparison of metabolic effects of fiber-depleted pure pea starch ("Nastar") versus fiber-depleted unmodified ("Sirona" native cornstarch) and modified ("Snowflake 06309" waxy cornstarch E 1422) maize starches, in 8 severely obese subjects. This study was carried out like study 1 with the variation that 3 (instead of 2) starch soups with celery-carrot flavor were compared (Table 2), and H_2 exhalation was not assessed.

Study 3 Randomized, single-blind cross-over comparison of the breath hydrogen excretion following 5x30 g (= 5 servings of soup) of fiber-depleted pure pea starch ("Nastar") soup versus CPC yellow pea flour soup in 8 healthy subjects during 36 hours. On an afternoon, the probands reported to the laboratory and stayed there until the end of the experiment. No supper was served the night before the starch challenge. At breakfast after an overnight fast, the probands ingested 1 portion (= 30 g CHO) of the test soups (see Table 2), and every 4-6 hours later the other 4 portions, until each proband had consumed a total of 150 g CHO. No other food intake was allowed. Probands were allowed to move around, as no blood sampling was performed. H_2 exhalation was measured repeatedly during the night and the morning before starch ingestion, and the day and the night thereafter. The H_2 exhalation after ingesting the first portion of the starch soups was expressed as a proportion of the person's H_2 exhalation after 6.5 g lactulose, indicative of the amount of maldigested CHO (6.5 g lactulose being 100 % maldigested), according to Flourie et al. (9).

Table 3 Incremental areas under the curve of the glycaemic, insulinaemic, and C-peptide response 0-180 min in healthy normal-weight volunteers, following ingestion of 30 g CHO as soup made of pure pea starch and of unmodified cornstarch. Study 1 (see methods section).

	pea starch	cornstarch
Plasma glucose, mg/dl	645(SD 409)*	1215(SD 812)
relative to cornstarch	53%	100%
Serum-insulin, mU/l	947(SD 425)*	2068(SD 1445)
relative to cornstarch	46%	100%
Serum C-peptide, ng/ml	198(SD 61)*	309(SD 154)
relative to cornstarch	63%	100%

means(SD); * significantly different to cornstarch $p<0.05$

Table 4 Fasting and postprandial peak levels of glycaemia, insulinaemia, and C-peptide in morbidly obese volunteers, before and after ingestion of 30 g CHO as soup made of pure pea starch, of unmodified cornstarch, and of modified cornstarch. Study 2 (see methods section).

	fasting level	postprandial peak level
pea starch ("Nastar™")		
– plasma glucose, mg/dl	93 (SD 6)	122 (SD 10)
– serum insulin, mU/l	6.7 (SD 3.3)	40.9 (SD 21.0)
– serum C-peptide, ng/ml	1.7 (SD 0.4)	4.2 (SD 0.3)
– serum triglycerides, mg/dl	131 (SD 109)	145 (SD 93)
modified cornstarch ("Snowflake™")		
– plasma glucose, mg/dl	95 (SD 5)	126 (SD 18)
– serum insulin, mU/l	7.2 (SD 4.2)	51.4 (SD 31.2)
– serum C-peptide, ng/ml	1.9 (SD 0.7)	4.5 (SD 0.6)
– serum triglycerides, mg/dl	132 (SD 126)	130 (SD 95)
unmodified cornstarch ("Sirona™")		
– plasma glucose, mg/dl	88 (SD 9)	128 (SD 11)
– serum insulin, mU/l	7.7 (SD 5.4)	47.0 (SD 29.6)
– serum C-peptide, ng/ml	2.1 (SD 0.8)	4.6 (SD 0.4)
– serum triglycerides, mg/dl	132 (SD 76)	119 (SD 75)

means (standard derivation)

Statistics

Randomization was carried out using a random-generator program. The incremental areas under the curves (AUC) were calculated using the trapezoid formula. Data are presented as means with standard deviation, or medians with range. Student's t-test or Wilcoxon test was used for comparisons; a p-value <0.05 was considered significant.

Ethics

The study protocol was approved by the Ethics Committee of the Heinrich-Heine University Medical Faculty.

Results

Study 1 Single meal study on metabolic effects of pure pea starch ("Nastar") versus unmodified maize starch ("Sirona" native cornstarch). Both starch preparations (30 g in 500 ml volume) were well tolerated. There was no indication of bloating or flatulence during the 6 hours after ingestion. The H_2 exhalation was essentially similar with both starches (Fig. 1). Premeal concentrations of plasma glucose, serum insulin, and serum C-peptide were identical with both preparations. Postprandially, these parameters had returned to baseline after 180 minutes. Therefore, the incremental areas under the curve 0-180 minutes were compared. Pure pea starch elicited significantly lower postmeal plasma glucose, serum insulin, and

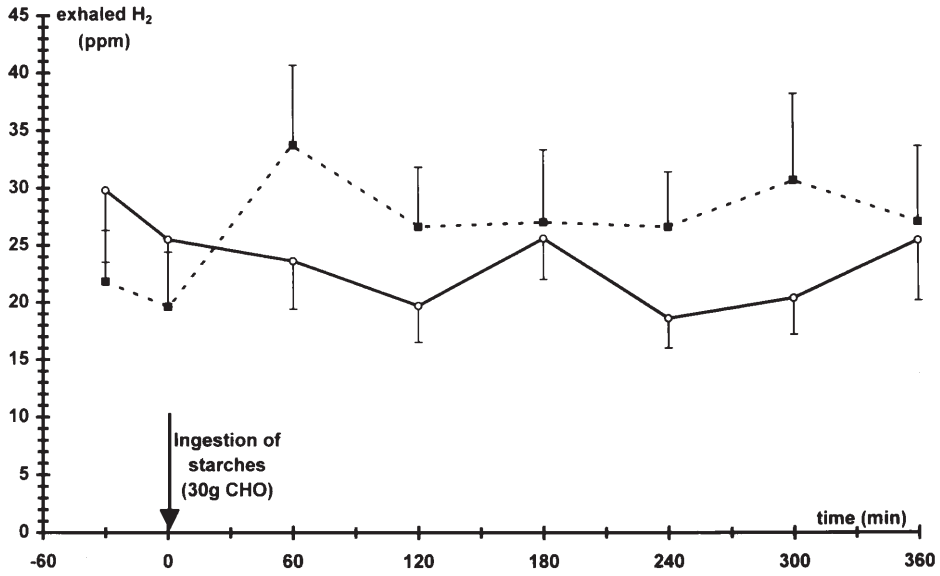

Fig. 1 H_2 exhalation following ingestion of 30 g CHO as soup made of unmodified cornstarch (solid line) and of pure pea starch (broken line). Means are shown with SEM.

C-peptide responses (minus 47 %, minus 54 %, and minus 37%, respectively) than cornstarch ($p<0.05$; see Table 3, Fig. 2).

Study 2 Metabolic effects of a single meal of pure pea starch ("Nastar") compared to unmodified ("Sirona native cornstarch",) and modified ("Snowflake" waxy cornstarch) maize starches in obese subjects. Basal plasma glucose, serum insulin, C-peptide, and triglyceride levels were all identical before the meals. However, peak insulin levels were found to be lower after pea starch soups than after ingestion of modified or unmodified maize starch (see Table 4). Peak C-peptide levels were lower after pea starch than after modified cornstarch or unmodified cornstarch. Basal triglyceride levels were identical before the meals and peaked postprandially at 145 (SD 93) mg/dl after pea starch, at 130 (SD 95) mg/dl after modified cornstarch, and at 119 (SD 75) mg/dl after unmodified cornstarch. Due to the small sample size, these differences failed to reach statistical significance. Hence, the areas under the curves 0-240 minutes were not statistically different.

Study 3 Pea starches challenge: 5 meals with pure pea-starch ("Nastar") versus CPC yellow pea flour during 36 hours. Pure pea starch was better tolerated than pea flour. However, all probands reported fullness after eating more than one portion of each. H_2 exhalation 240 minutes after ingesting the first 30 g portion was significantly higher after pea flour versus pea starch (incremental AUC 1414 (SD 1150) ppm versus 300 (SD 1054) ppm; $p<0.05$). Based on their H_2 exhalation following 6.5 g CHO as lactulose (3155 (SD 1422) ppm), a maldigestion of 3.3 (SD 2.5) g CHO was calculated for pea flour, compared to 1.4 (SD 4.2) g CHO for pure pea starch. Flatulence was more frequently noted with pea flour than with pea starch: pea flour induced flatulence at a median of 8.5 (range 1-18) of the 27 time points, while pea starch induced flatulence at a median of 3 (range 0-23) of 27 time points ($p<0.05$).

Discussion

The present data confirm different metabolic responses to ingestion of pea starch preparations versus maize starch preparations in healthy humans: pea starch meals elicited lesser glycaemic and insulinaemic responses (5, 6, 13). These differences, however, were statistically significant only in non-obese subjects, whereas in a smaller sample of extremely obese subjects statistical significance was not reached. Obviously, the acute effect of the starches was overridden by the insulin resistant state of the obese subjects, indicated by higher plasma glucose and serum insulin levels as compared to the non-obese subjects under study.

Furthermore, the H_2 exhalation differed substantially between all of the pure starch preparations versus the crude, yellow pea flour preparation. While 30 g of pure pea starch or cornstarch rarely increased breath H_2 concentration, 30 g of yellow pea flour heavily increased H_2 exhalation ($p<0.05$) with some degree of maldigestion (11 % of the ingested starches). Ingestion of 5x30 g of pure pea starch over 36 hours induced nearly no flatulence, whereas flatulence was noted frequently following ingestion of 5x30 g of crude pea flour. This indicates that not the pea starch as such, but the yellow pea flour with its natural contaminants of the pea seed (0.5 g raffinose, 1.5 g stachyose, and 14.8 g protein per serving in CPC pea flour, versus <0.1 g of both sugars, and 3.4 g protein

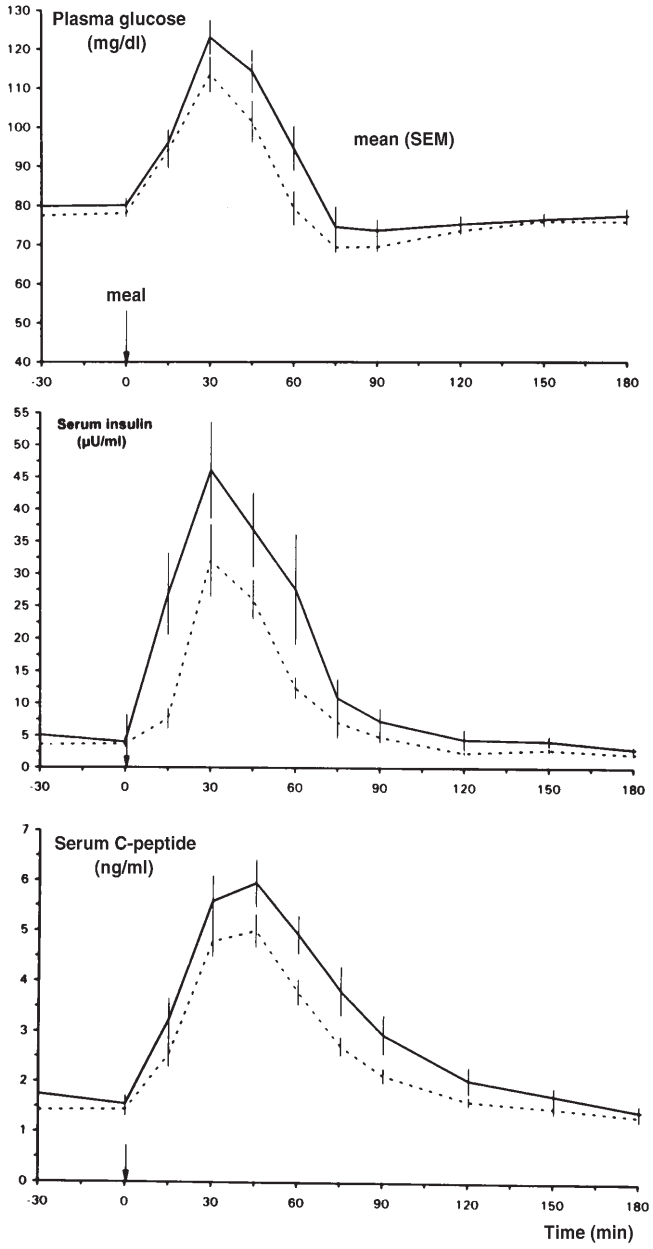

Fig. 2 Postprandial glycaemic (upper pannel), insulinaemic (middle pannel), and C-peptide (lower pannel) responses to CHO soups made of unmodified cornstarch (solid line) and of pure pea starch (broken line). Means are shown plus/minus SEM.

per serving in Nastar™ pea starch) is responsable for its poor tolerability and maldigestion, consistent with the findings of Somirai (19) and Tomlin et al. (21).

The good tolerability of pure pea starch in our study indicates that maldigestion is of pure pea starch is low. Thus, maldigestion is unlikely to contribute to the favorably low glycaemic and insulinaemic response to pure pea starch.

The high amylose content of pea starch, however, may explain our results.

There was no difference in metabolic responses after unmodified cornstarch (0.8 % amylose) and modified cornstarch (24 % amylose), both of which were (albeit insignificantly) higher than after pea starch with 34 % amylose content. Hence, at least 30 % amylose content of a CHO food seems to be necessary to produce a significant attenuation of the metabolic response. This is consistent with a study by Behall et al. (2) comparing CHO meals with 40 % difference in amylose content. On the other hand, it cannot ruled out that the number of subjects in this part of our study was too small for the detection of the (possibly minute) metabolic differences between 0.8 % and 24 % amylose content.

Amylose is less accessible to the intestinal digestion processes than amylopectin. It is, thus, a slowly digested starch according to Cummings and Englyst (7) and evokes an attenuated glycaemic response when compared to rapidly digested starch. Our data show that fiber-depleted, highly purified pea starch is no different from pure cornstarch in terms of flatulence, bloating, and hydrogen excretion; it should, therefore, be as acceptable to the consumer as the widely used cornstarch. However, the metabolic effects of pea starch on glucose homeostasis, as observed in this pilot study, are much more favorable in terms of overall health benefits than those of cornstarch. Reducing the glycaemic response to food intake reduces the strain to the pancreatic beta-cell and increases insulin sensitivity (15, 23), both of which are health-promoting. It may be speculated that this would prolong the function of the gland and reduce the incidence of its failure (which is a characteristic of diabetes mellitus). Replacement of pure cornstarch by pure pea starch in every-day food items would, on the long run, save the human glucose homeostatic mechanism millions of units of insulin. Whether such health promoting prebiotic effects of pure pea starch is as significant as that of fructoseoligomers (8, 14) remains to be proven by larger clinical trials.

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