Food physical factors have different metabolic effects in nondiabetics and diabetics[1,2]

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ABSTRACT Physical properties of food may account for differences in glycemic and other metabolic responses to food with similar amounts of carbohydrate, fat and protein. Blending of cooked beans made no difference to plasma glucose, insulin, or GIP (gastric inhibitory polypeptide) responses in nondiabetics, NIDD (noninsulin-dependent diabetics), and IDD (insulin-dependent diabetics). The cooked blended beans gave a greater plasma glucose response and a lesser hormonal response than a cooked flummery (containing cornstarch, protein and fat) in nondiabetics. In NIDD and IDD, however, the reverse applied for plasma glucose. In nondiabetics, cooked flummery gave a lesser glycemic response at some time points than uncooked flummery. In NIDD the opposite occurred. Cooking led to no significant change in insulin response in nondiabetics, but to a lesser insulin response in NIDD. The effect of some physical properties of food on diabetic control cannot be inferred from findings in nondiabetics. *Am J Clin Nutr* 1985;42:462–469.

KEY WORDS Nondiabetes, diabetes, legumes, physical properties, dietary fibre, glucose, insulin, GIP

Introduction

The acute postprandial glucose and hormone responses to a mixed meal are the probable outcome of complex interactions of physical food factors (1, 2) and the component nutrients (3, 4, 5) of food. In a number of studies (6, 7) the glycemic responses of single food items have been compared against quantitatively matching pure glucose loads. No attempt has been made in these studies to standardize for the types of carbohydrate or the macronutrient content. The relative contribution of physical factors and nutrient interaction in the overall response to these food items is difficult to evaluate.

Many of the studies (2, 3, 5, 7) have examined nondiabetics. There are limited data on the effect of these factors in diabetics (8, 9, 10, 11) although meals which minimize the postprandial glycemic response in these subjects require definition.

In the present study we have defined a standard comparison meal composed principally of cornstarch, protein, and fat, and have examined the effect of physical factors (bean integrity, dietary fiber/starch granule characteristics, cooking) on the glycemic and hormonal meal responses. Moreover, we have studied nondiabetics, noninsulin dependent diabetics (NIDD), and insulin dependent diabetics (IDD) separately to examine the possibility that these groups are not similarly responsive to the various physical food factors. In a subsequent paper we report on the relative contributions of macronutrient interaction in this meal in these subjects.

Materials and methods

Subjects

Nine nondiabetic subjects (6 female and 3 male, age 31.9 ± 2.8 yr (mean ± SEM), 129.0 ± 5.9% ideal body weight (IBW—Metropolitan Life Insurance Co, 1959))

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were compared against stable outpatient diabetic volunteers. The patients consisted of 11 noninsulin-dependent diabetics (NIDD—2 female, 9 male, age 61.2 ± 1.8 yr, 118.0 ± 5.7% IBW, duration of disease 6.6 ± 1.9 yr, 6 receiving sulphonylureas and 5 diet alone), and 8 insulin-dependent diabetics, ketosis-prone (IDD—1 female, 7 males, age 35.9 ± 5.5 yr, 115.9 ± 4.7% IBW, duration of disease 9.3 ± 2.1 yr). One patient (an IDD) had mild postural hypotension, but none had symptomatic gastroparesis. The investigations were performed in accordance with the principles of the Declaration of Helsinki and were approved by the Research (Advisory and Ethics) Committee of Prince Henry's Hospital.

Metabolic studies

Patients were fasted overnight before each meal test was performed, commencing between 0800 and 0900 h. Antidiabetic drugs were withheld on the morning of each test to minimize the number of variables. Each subject was given four meals, administered in a random order on different mornings. The meals were consumed over 15 min, although individuals differed and the actual time taken was recorded and standardized for all meals for each individual patient. Prior to ingestion of a meal an indwelling cannula was inserted into a large antecubital vein for collection of free-flowing samples during the test. After collection of two baseline specimens, blood sampling was then carried out at 15 or 30 min intervals (see results).

Test meals

The test meals consisted of *1*) whole beans (Phaseolus vulgaris) on toast, a mixture of red kidney beans and haricot beans; *2*) blended beans on toast; *3*) cooked flummery and *4*) uncooked flummery. A flummery is an artificially flavored gelatinous food composed of carbohydrate (principally starch and sucrose), protein (gelatin) and fat (usually cream) prepared either cooked or uncooked and eaten as a dessert in Australia. The composition of the beans meals (12, 13, 14) and flummeries are outlined in **Tables 1 and 2** respectively. The major macronutrients apart from dietary fiber were matched between the beans meals and flummeries. The beans were soaked in 100 ml of water for 24 h and then cooked in a pressure cooker (20 min) to render them soft and edible. Salt, pepper, and tomato were added to improve the palatability of the meal. The blended beans meal was prepared by blending the cooked beans prior to ingestion. The cooked flummery was also prepared by soaking and cooking of the carbohydrate in the same manner as the beans. All meals were made up to the same vol (500 ml) with water.

Analytical method

Blood samples were collected into sodium fluoride tubes for analysis of plasma glucose (glucose analyzer—Yellow Springs Instruments Model 23Am, Yellow Springs, OH). Blood was also collected in heparinized tubes for radioimmunoassay of insulin (charcoal separation of unbound insulin) (15) and heparinized tubes with 3 mg aprotinin (Trasylol® per 10 ml blood) for assay of gastric inhibitory peptide (GIP (16), a presumed incretin (17)) (anti-GIP antibody obtained from Guilford, Surrey University, England, G/R/34111G; tracer kindly provided by Dr K O'Dea, Repatriation General Hospital, Melbourne, Victoria, Australia, sp act 173 μCi/μg).

The fiber content of the beans was analyzed by a modification of the Englyst method (18) in the Department of Human Nutrition at Deakin University, Geelong, Australia. The total fiber content (cellulose, lignin and noncellulosic nonstarch polysaccharides) found for 50 g cooked red kidney beans was 10.1 g and for 25 g cooked haricot beans was 5.3 g. The major monosaccharide in the nonstarch polysaccharide component of these beans is a pentose and this is arabinose.

Data analysis

The results are presented as mean ± standard error of the mean ($\bar{x}$ ± SEM). Two-way analyses of variance

TABLE 1
The nutrient composition of the beans on toast meal as derived from published tables

	Glucose	Fructose	Sucrose	Lactose	Starch	Total ABS CH*	Fiber	Protein	Fat
	g	g	g	g	g	g	g	g	g
Wholemeal bread (21 g)	0.45	—	—	—	8.34	8.79	1.79	1.70	0.51
Butter (9 g)	—	—	—	—	—	Tr†	—	0.08	7.13
Tomato, raw (100 g)	1.10	1.20	0.10	—	Tr	2.40	1.50	1.00	0.30
Red kidney beans (50 g)	—	—	1.50	—	21.00	22.50	12.50	11.10	0.85
Haricot beans (25 g)	0.25	0.35	0.15	—	10.68	11.43	6.35	5.50	0.38
Onion (50 g)	1.05	0.55	0.45	—	—	2.05	0.65	0.60	0.10
Pepper (0.5 g)	—	—	—	—	—	0.34	—	0.05	0.04
Lactose	—	—	—	1.63	—	1.63	—	—	—
Salt (2 g)	—	—	—	—	—	—	—	—	—
Cocoa (5 g)	—	—	—	—	—	2.13	—	0.97	1.23
3 Gelatin capsules	—	—	—	—	—	—	—	1.00	—
1 Saccharin	—	—	—	—	—	—	—	—	—
TOTAL	2.85	2.10	2.20	1.63	40.02	51.20	22.80	21.40	10.50

* ABS CH, absorbable carbohydrate.
† Tr = trace.

TABLE 2
The nutrient composition of the flummeries derived from the calculated composition of the beans meal

	Glucose	Fructose	Sucrose	Lactose	Starch	Total ABS CH	Fiber	Protein	Fat
	g	g	g	g	g	g	g	g	g
Glucose	2.85	—	—	—	—	2.85	—	—	—
Fructose	—	2.10	—	—	—	2.10	—	—	—
Sucrose	—	—	2.20	—	—	2.20	—	—	—
Starch (cornflour)	—	—	—	—	40.20	40.20	—	—	—
Gelatin (8.5 g)	—	—	—	—	—	—	—	7.28	0.01
Cream (14.5 g)	—	—	—	0.44	—	0.44	—	0.31	5.51
Cocoa (5 g)	—	—	—	—	—	2.13	—	0.97	1.23
Creamed cottage cheese (85 g)	—	—	—	1.19	—	1.19	—	11.56	3.57
Pepper (0.5 g)	—	—	—	—	—	0.34	—	0.05	0.04
Salt (2 g)	—	—	—	—	—	—	—	—	—
1 Saccharin	—	—	—	—	—	—	—	—	—
3 Gelatin capsules	—	—	—	—	—	—	—	1.00	—
TOTAL	2.85	2.10	2.20	1.63	40.20	51.40	—	21.20	10.30

(two-way Anova) were performed to compare fasting levels and the overall responses of glucose, insulin and GIP to the test meals. Student's paired *t* test was used for other comparisons. The correlation between the fasting and mean incremental response of the plasma glucose to the cooked flummery was assessed by the Spearman Rank Test.

Results

Fasting plasma glucose, insulin and GIP

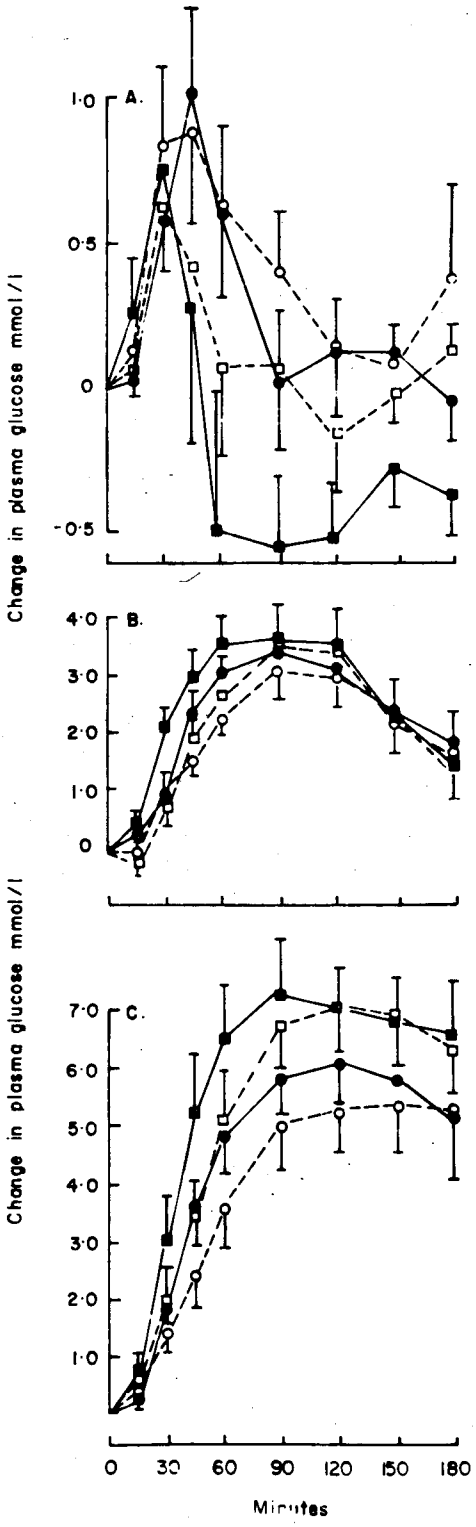
The mean fasting plasma glucose for the normal subjects was 4.9 mmol/l (range 4.7–5.2 for the four meals), for NIDD was 8.1 mmol/l (7.8–8.4), and for IDD was 11.3 mmol (10.7–11.7). Although there were significant differences between subject groups, there were no significant (two-way Anova) differences within any subject groups between different meals. The mean fasting insulin level for normal subjects was 5.0 mμ/l (range 4.6–5.5), and NIDD was 8.7 mμ/l (6.5–11.1). The mean fasting GIP level for normal subjects was 357 pg/ml (range 287–418), for NIDD was 526 pg/ml (467–600) and IDD was 798 pg/ml (739–907). Again, no consistent significant differences were found within any subject group between different meals.

Meal responses

*Plasma glucose (**Fig 1**).* The plasma glucose responses to whole beans and blended beans on toast are identical in all subject groups (two-way Anova).

In nondiabetics the response to the blended beans was greater than that for cooked flummery (two-way Anova, $p < 0.01$) with the latter glycemic response significantly less than the former between 90 and 120 min (Student's paired *t* test, $p < 0.05$). By contrast, the glycemic response to cooked flummery was significantly greater than that for blended beans in both diabetic groups (two-way Anova, NIDD $p < 0.05$, IDD $p < 0.01$). In both these groups there was a faster rise in the glucose levels after ingestion of the cooked flummery, compared with the beans meal (Student's paired *t* test: NIDD, 15 to 30 min, $p < 0.05$; IDD, 30 to 120 min, $p < 0.05$ to <0.01). Only in the IDD subjects was the peak glucose value for the cooked flummery significantly greater than for blended beans (Student's paired *t* test $p < 0.05$).

Although the overall glucose responses between the cooked and uncooked flummeries did not differ significantly in any of the subject groups (two-way Anova) there were significant differences at different time points in nondiabetic and NIDD. In the nondiabetic, the glycemic response to cooked flummery was significantly less than for uncooked flummery between 150 and 180 min (Student's paired *t* test, $p < 0.01$). In contrast for NIDD, the cooked flummery gave a significantly greater glycemic response than uncooked flummery between 30 and 45 min (Student's paired *t* test, $p < 0.05$). There were



no differences in the peak values between the two flummeries in any subject group.

There was a strong correlation (Spearman Rank, $\rho = 0.75$, $n = 28$, $p < 0.001$) between the fasting plasma glucose and the incremented response in plasma glucose to the cooked flummery when all subjects were pooled.

Insulin (Fig 2). No difference was observed between the insulin responses to whole and blended beans on toast in any subject group (two-way Anova).

In both subject groups, the overall insulin response to the cooked flummery was significantly greater than that for blended beans (two-way Anova, $p < 0.05$). The maximum peak level for the cooked flummery was significantly greater than for blended beans (paired t test, $p < 0.05$ for both groups). In the nondiabetics there was no overall significant difference in the insulin response to cooked and uncooked flummery (two-way Anova), while there was a significant difference in the peak values achieved (Student's t test, $p < 0.01$). In the NIDD, the uncooked flummery resulted in a significantly greater overall insulin response (two-way Anova, $p < 0.05$) than cooked. The peak insulin values on these two flummeries also differed significantly (paired t test, $p < 0.05$).

GIP (Fig 3). There was no difference between the GIP response to whole or blended beans.

In all subject groups the response to cooked flummery was significantly greater (two-way Anova, $p < 0.01$) than for blended beans. Again, in all groups there were significant differences between these two meals from 15 to 90 min (paired t test, p between <0.05 and <0.01). Likewise, the peak responses to the cooked flummery for all subject groups was significantly greater (paired t test, $p < 0.01$) than for blended beans.

FIG 1. The plasma glucose response to the beans and flummery meals. ●——● whole beans on toast, ○---○ blended beans on toast, ■——■ cooked flummery, □---□ uncooked flummery. (Mean ± SEM). *A*, nondiabetics, *B*, noninsulin dependent diabetics, *C*, insulin dependent diabetics. NB: Scale on ordinate different for diabetics in Figures 2 and 3.

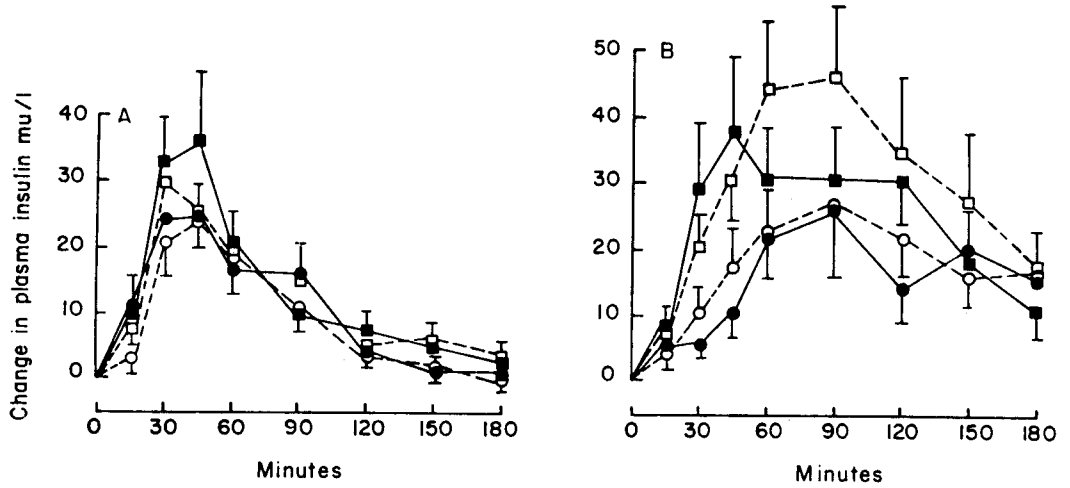


FIG 2. The insulin response to the beans and flummery meals. *A*, nondiabetics, *B*, noninsulin dependent diabetics. Symbols as in Figure 1.

In nondiabetics there was a trend to a greater GIP response after cooking compared with the uncooked flummery but this did not reach significance either overall (two-way Anova) or at individual time point or peak values (paired *t* test). By contrast, the overall response in NIDD was significantly enhanced by cooking (two-way Anova, $p < 0.01$). Again, for these subjects there was no difference between responses to cooked and uncooked flummery at any time point or in peak values. Likewise, the overall GIP response to cooked flummery was significantly greater than uncooked (two-way Anova, $p < 0.01$) in IDD. Here there were significant differences at various time points (Student's paired *t*

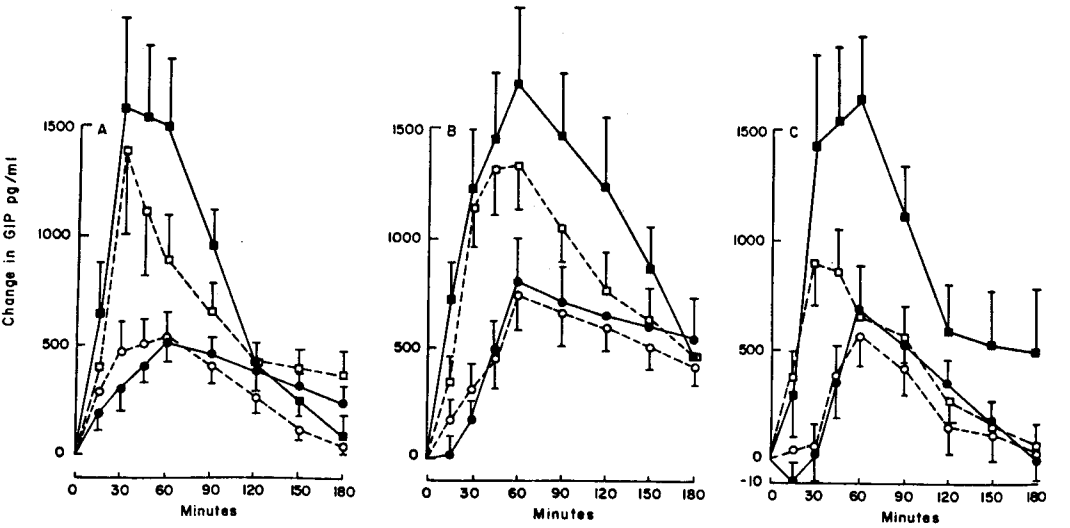


FIG 3. The GIP response to the beans and flummery meals. *A*, nondiabetics, *B*, noninsulin dependent diabetics, *C*, insulin dependent diabetics. Symbols as in Figure 1.

test, 15–90 min, $p < 0.01$) and between peak values (Student's paired t test $p < 0.01$).

Discussion

A range of leguminous vegetables, given as single food items, have been shown to give lower glycemic responses than an equivalent (by mass) load of glucose in nondiabetics (7). These were all nonisoenergetic comparisons and the relative effects of physical factors and other macronutrients were not fully considered. In a group of 12 diabetics (10 on insulin) a similar range of legumes were compared against a nonisoenergetic equal carbohydrate load derived from bread and cheese (10). Again, the legumes were reported to give a lower glycemic response. In addition, the meal comparisons did not appear to be truly paired and different groups of patients (presumably with differing levels of glucose intolerance) were included in the groups used for comparing different food items.

Reference meal

In order to dissect out the contribution of differing physical food factors in the meal response we have designed a reference meal—the uncooked flummery. This is composed principally of cornstarch, protein, and fat to match the macronutrient content of (and be isoenergetic with) the beans meal. The importance of this match is seen here where the cooked flummery gave a shorter glycemic response than beans in nondiabetics. This contrasts with the greater response to glucose alone reported in other studies (7, 10) highlighting the limitations of this as a reference meal. Further details of the macronutrient contribution to the glycemic response are the subject of another report.

Role of bean structures

In the current study, we have observed that blending of cooked beans, like cooked lentils (19), but unlike rice (2), has no effect on the glycemic or hormonal response to the bean meal.

In contrast, we did observe significant metabolic differences between the bean meal and the cooked flummery in all subject groups. The enhanced GIP secretion to the cooked flummery in all subjects suggests that the cornstarch is more rapidly digested and absorbed than the starch in legumes (11). This difference may result from the presence of legume fiber, from intrinsic differences between the two forms of starch, or from the presence of some factor in legumes inhibitory of carbohydrate digestion.

In this study for the first time, we have directly measured the fiber content of the beans under study and observed approximately 15.4 g of legume fiber compared with the 18.8 g calculated from published tables (13). Guar gum and pectin (both gelling fibers) taken with carbohydrate (15–25 g) in acute studies, reduce the postprandial glucose and insulin levels in nondiabetics (1) and diabetics (9) probably by delaying gastric emptying. The major sugar of the noncellulosic fiber in these beans is arabinose, indicating that it is not a galactomannan (guar gum) or pectin (20). Although we have shown that the major legume fiber is not a compound belonging to either of the above groups of gelling fibers, the chemical composition does not permit any conclusion about the physical properties.

In vivo studies (21) have shown that the starch in legumes is more slowly digested than cereal starch. The reason for this difference is uncertain, although these two starches are known to have physical differences (22).

Again, in all subject groups, cooking significantly affected the metabolic response to the flummery. This is consistent with earlier reports that cooking of cornstarch alone increases the insulin response in nondiabetics (23).

It is of interest that the glycemic and hormonal responses to the uncooked flummery is more similar to that of the cooked bean meal than to the cooked flummery. In addition, earlier work (19) has suggested that the rate of digestion of legume starch appears to be enhanced if the vegetable is ground before cooking. Thus, legume starch granules in the intact bean are protected from the hydrating effects of cooking. This protection may account for the differences between the susceptibility of this starch (as compared with cornstarch) to digestion and absorption in the human bowel.

Differences between nondiabetics and diabetics

The other important aspect of this study is the different effect of these physical factors on the glycemic responses of nondiabetics and diabetics. The response to beans was greater than for the cooked flummery in nondiabetics; the opposite was observed for diabetics (NIDD and IDD). The uncooked flummery gave a greater response than cooked flummery in nondiabetics; again, the opposite was observed for the diabetics. In addition, while these physical factors markedly influence (in relative terms) the glycemic response in nondiabetics, the influence while significant, was less marked for diabetics.

A possible explanation for the difference in plasma glucose response observed between subject groups is the difference in fasting plasma glucose. The strong correlation observed between the fasting plasma glucose and the incremental plasma glucose response to cooked flummery is consistent with the former influencing the amplitude of the latter. However, this relationship need not be causal, and apart from one previous study (10) where no such relationship was reported in a smaller number of diabetics alone, has not been seriously examined in the literature. The unfortunate clinical reality is that many diabetics commonly have fasting plasma glucose levels above the normal range despite all efforts to achieve optimal control. It therefore remains important to recognize that diabetics do behave differently than nondiabetics.

In NIDD, the effect of the physical factors on the insulin responses were less marked, or in one case, opposite (effect of cooking on flummery) to that seen in nondiabetics. This probably reflects the disordered β cell function in these subjects and, in turn, accounts for much of the difference in the glycemic responses between nondiabetics and diabetic groups.

By contrast, the different physical food factors had similar effects on the GIP response in all subjects. Thus, in common with several other studies (11, 24), we have observed a relatively normal pattern of GIP secretion in diabetics.

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