Effect of Processing on Blood Glucose and Insulin Responses to Starch in Legumes

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Postprandial glycemic and insulinemic responses to variously processed red kidney beans were evaluated in normal subjects. The dried seeds were (a) boiled; (b) autoclaved; (c) boiled, freeze-dried, and milled to obtain a precooked flour (PCF) rich in cell-enclosed starch; or (d) milled, steam-cooked, and freeze-dried to yield a flour containing free starch (FSF). All bean products elicited lower metabolic responses than white wheat bread, used as a reference. Judged from the glycemic and insulinemic indices and the postprandial peak concentrations, autoclaved beans, PCF, and FSF had a more "rapid" behavior than the boiled seeds. Responses to autoclaved beans and PCF were intermediate between boiled beans and the FSF. The insulinemic indices of a lentil PCF and white bread were similar, indicating that different legumes may have different susceptibilities to processing. It is concluded that both the cellular and the cotyledon tissue structures are important determinants of the metabolic responses to legumes.

INTRODUCTION

Glycemic and hormonal responses following ingestion of dried legumes are generally low. In fact, legumes evoke lower metabolic responses than most common starchy foods (Jenkins et al., 1980; Traianedes and O'Dea, 1986; Brand et al., 1990). These characteristics have promoted the use of pulses for the dietary management of diabetic patients (Jenkins et al., 1983) and may be a protective factor against development of hyperlipidemia and cardiovascular disease (Thorburn et al., 1987; Brand et al., 1990). The well-documented "slow carbohydrate" nature of starch in legumes appears to be due to various factors. Their relatively high content of dietary fiber has been suggested to delay both gastric emptying and absorption of digestion products at the intestinal level (Torsdottir et al., 1984). However, in spite of some discrepant observations (O'Dea and Wong, 1983), the low rate of starch digestion is generally considered the most important determinant of the low glucose and insulin responses to legumes (Jenkins et al., 1982; Crapo, 1985; Brand et al., 1990).

The low rate of amylolysis in pulses has been suggested to result from the intrinsic slow-digestion characteristics of the starch constituents (Jenkins et al., 1982; Socorro et al., 1989), as well as interactions of the amylolytic enzymes and/or the starch substrate with both dietary fiber and the so-called "antinutrients", such as polyphenols, phytic acid, lectins, and α-amylase inhibitors of protein nature (Wong et al., 1985; Wolever et al., 1987; Socorro et al., 1989; Fish and Thompson, 1991). Another important factor is the thick and mechanically resistant nature of the cotyledon cell walls, which constitutes a physical barrier, preventing complete swelling of starch granules during gelatinization and also restricting their interaction with digestive enzymes (Würsch et al., 1986; Tovar et al., 1991).

The long time required for the preparation of legumes is a major drawback for a more generalized consumption of pulses in affluent societies. Although industrially processed pulses could constitute an appropriate alternative, some studies have suggested that the slow features of boiled legumes are susceptible to extensive processing. For instance, increased rate of digestion and in vivo responses were observed after canning (Traianedes and O'Dea, 1986; Wolever et al., 1987) or powdering (Jenkins et al., 1982; Wong et al., 1985; Golay et al., 1986) different legumes.

Alternative ways to process legumes into slowly digested products have been explored. Starch in instant flakes prepared from white beans is slowly digested and elicits a low glycemic response (Tappy et al., 1986; Würsch et al., 1988; Schweizer et al., 1990). Furthermore, the preparation of precooked legume flours that maintain the integrity of cotyledon cell walls and exhibit low starch digestion rates was reported recently (Tovar et al., 1990a,b; 1991). The "slow" features of both types of preparations are due mainly to the presence of cell-enclosed starch. The purpose of the present study was to investigate the metabolic response in normal subjects to precooked cell-containing flours from red beans and lentils (Tovar et al., 1990a,b), compared with boiled or autoclaved red kidney beans. The importance of retaining cell wall integrity was evaluated by including a red bean preparation devoid of cellular structures.

MATERIALS AND METHODS

Legume Seeds. Dried red kidney beans (*Phaseolus vulgaris* L.) and green coat lentils (*Lens culinaris* Medik) were obtained from the local market.

Processing of Legumes. Experiments were carried out with (a) whole boiled beans; (b) whole autoclaved beans; (c) precooked flours containing cell-enclosed starch (PCF) from beans and lentils; and (d) a red bean preparation containing free starch (FSF).

The whole bean preparations were obtained after soaking the seeds in twice their weight of water for 20 min. The soaked seeds were drained and cooked either by boiling for 70 min in water, employing a constant seed to water ratio of 1:3 (w/v), or by autoclaving (20 min at 1.05 kg/cm^2, 121 °C). These procedures rendered cooked (soft) seeds (Tovar et al., 1990b). Finally, the seeds were drained and either served directly (boiled beans) or kept at 4 °C overnight, warmed up to 40–50 °C in a microwave oven, and served (autoclaved beans). The microwave step simulated the additional heat treatment performed before consumption of canned beans.

Red bean and lentil PCFs were prepared according to Tovar et al. (1990a,b): seeds boiled for 70 min, along with cooking water,

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Table I. Composition of the Test Meals

test meal	test product,[a] g	total meal,[b] g	water,[c] g	starch,[d] g	protein, g	fat,[e] g	dietary fiber, g	energy, kJ
red beans								
boiled	252	305	280	30	19.6	2.7[f]	17.0	932
autoclaved	273	317	280	30	19.6	2.7[f]	nd	932
PCF porridge	83	285	330	30	19.0	2.6[f]	16.8	928
FSF cakes	264	264	310	30	19.0	2.6[f]	nd	928
lentils								
PCF porridge	70	242	310	30	17.6	2.4[f]	11.1	887
wheat								
bread	70	138[g]	390	30	19.0[g]	3.0[g]	1.4	933

[a] Fresh basis. [b] Test product weight plus water necessary for serving. [c] Sum of water and coffee/tea drank during the meal. [d] Potentially available starch. [e] From the Swedish food composition tables (SLV, 1986). [f] Fat in the test product plus added butter. [g] Bread plus boiled ham contribution.

were freeze-dried and ground to pass a 1-mm screen in a Cyclotec 1093 mill (Tecator AB, Höganäs). The resulting flour was kept in a dessiccator until used. The PCFs were tested as a porridge, after addition of water (40–50 °C, 2:5 w/w). The FSF was prepared after dry milling of raw red beans (Tovar et al., 1991). The flour was suspended in water (1:6, w/v) and heated for 70 min with steam at 96 °C, freeze-dried, and milled to pass 1-mm screen. Before inclusion into test meals, this powdered material was mixed with water (1:3, w/w), formed to a cake, extended on a Teflon frying-pan, and heated moderately for 5 min.

Texture Evaluation. The texture of boiled and autoclaved seeds, as served in the test meals, was evaluated by determining the puncture peak force (Tovar et al., 1990b). An Instron 4301 equipment with a conical puncture probe (6.6-mm largest diameter, 1.1-mm tip diameter, 8.8-mm height) was used at a speed of 30 mm/min. Fifty single seeds were tested from each legume preparation.

White Bread Reference. A white wheat bread was baked in a home baking machine (Panasonic SD-BT 2P, Matushiba Electric Trading, Osaka, Japan) using the following ingredients (Granfeldt and Björck, 1991): commercial white wheat flour (300 g), water (200 g), salt (3 g), dry yeast (3 g), and monoglycerides from soybean and palm oil (1:1 w/w, consisting mainly of C-18 fatty acids) (1.5 g). The dough was mixed, kneaded, fermented in four steps, and baked in the machine. After baking, the bread was allowed to cool to room temperature and the crust was removed. The bread crumb was then sliced and frozen. The bread slices were thawed at room temperature before ingestion.

Starch Determination. Analysis of "potentially available starch" content, i.e. starch susceptible to digestion by Termamyl and amyloglucosidase, was performed in thoroughly homogenized samples (Tovar et al., 1990b), by the enzymic–colorimetric method of Holm et al. (1986). This procedure measures free and cell-enclosed starch fractions in leguminous materials, but does not include enzyme-resistant retrograded amylose (Tovar et al., 1990b; 1991).

Total in vitro indigestible starch and retrograded amylose (previously designated resistant starch) were measured according to Björck et al. (1986) in dietary fiber residues prepared as described below. All products were analyzed in the ready-to-eat form.

Dietary Fiber and Protein Content. Total dietary fiber was analyzed by the enzymic–gravimetric method of Asp et al. (1983). Crude protein (N × 6.25) was evaluated by the Kjeldhal method.

Evaluation of Postprandial Glucose and Insulin Responses. Ten healthy subjects (four men, six women) with an average age of 36 ± 2.5 years took part in the study. Their body mass indices were normal, mean of 22.4 ± 0.9 kg/m^2, and all had normal glucose tolerance.

Six different test meals were taken in a randomized order at breakfast after overnight fast on separate mornings approximately 1 week apart. The meals were given between 8 and 8:30 a.m. and were eaten over 15 min. Zero time was taken at the time eating commenced. Fingerprick blood samples were taken using mini lancets (Clean Chemical Sweden AB, Borlänge, Sweden) at −5, 30, 45, 70, 95, 120, and 180 min. Capillary blood was collected and analyzed for glucose with a glucose oxidase/peroxidase reagent. Serum insulin was evaluated in the samples taken at −5, 30, 45, 95, and 120 min by employing an enzyme-linked immunoassay kit (Boehringer Mannheim, Germany). The glycemic index (GI) was calculated from the 2-h incremental glucose area (Jenkins et al., 1984) with white wheat bread used as reference (GI = 100). For comparative purposes, GIs were also calculated with the 95- and 70-min areas (Granfeldt and Björck, 1991; Granfeldt et al., 1991). Areas under the glucose response curves were evaluated geometrically. Concentration values below base line were considered equivalent to 0. The insulinemic index (II) was calculated in a similar way from the 2-h insulin response curves (Bornet et al., 1987).

The study was approved by the Research Ethics Committee of the Medical Faculty of the University of Lund.

Test Meals. The potentially available starch content of the products tested was ("as eaten" basis): boiled beans, 11.9%; autoclaved beans, 11.0%; bean PCF porridge (see next paragraph), 10.4%; FSF cakes, 11.4%; lentil PCF porridge (see next paragraph), 12.6%; wheat bread, 43.1%. Their total in vitro indigestible starch content, i.e. total starch remaining in the dietary fiber residues, were as follows: boiled beans, 0.9% (2.8% dry matter basis, dmb); autoclaved beans, 1.0% (2.9% dmb); bean PCF porridge, 1.1% (3.9% dmb); FSF cakes, 1.5% (4.2% dmb); lentil PCF porridge, 1.2% (3.9% dmb); wheat bread, 0.6% (0.9% dmb). Most of the products had similar "retrograded amylose" contents (0.7–0.9% fresh basis), with extreme values recorded for the bean FSF cakes (1.2%) and the reference bread (0.4%).

The composition of test meals made from the various products is shown in Table I. The test meals consisted essentially of either the legume sample or the reference bread, all providing 30 g of potentially available starch and containing similar amounts of fat (adjusted with butter) and protein. The protein content of the bread meal was balanced by addition of boiled ham. In order to equalize the water content of the meals, cooked whole beans were mixed with warm water (40–50 °C) shortly before consumption. PCFs were consumed as a porridge after mixing with warm water (40–50 °C, 2:5 w/w) 5 min before serving. The legume meals were seasoned with salt (0.5 g) and slightly spiced. For the final adjustment of the total fluid volume of the test meals (480 g), all breakfasts were taken with measured portions of plain coffee or tea and water (between 280 and 390 mL).

The main reason for choosing 30-g starch meals, instead of the commonly used 50 g, was the bulkiness of some of the test products, particularly the bean and lentil PCF porridges. Preliminary trials indicated that portions of these materials containing 50 g of starch were not realistic for consumption at breakfast.

Satiety Score. The numerical satiety score of the test meals was estimated according to Haber et al. (1977). At the different blood sampling times the volunteers were requested to rank their satiety/hunger status on a scoring system graded from −10 (extreme hunger) and +10 (representing extreme satiety).

Statistical Evaluation. Results are expressed as means ± SEM. Significant differences ($p < 0.05$) were evaluated by the Wilcoxon test for paired observations using the SPSS/PC+ program, each person being his/her own control. Means from the textural measurements were compared using Student's t test.

RESULTS

Texture of Cooked Seeds. There was no significant difference in the texture of whole boiled red kidney beans

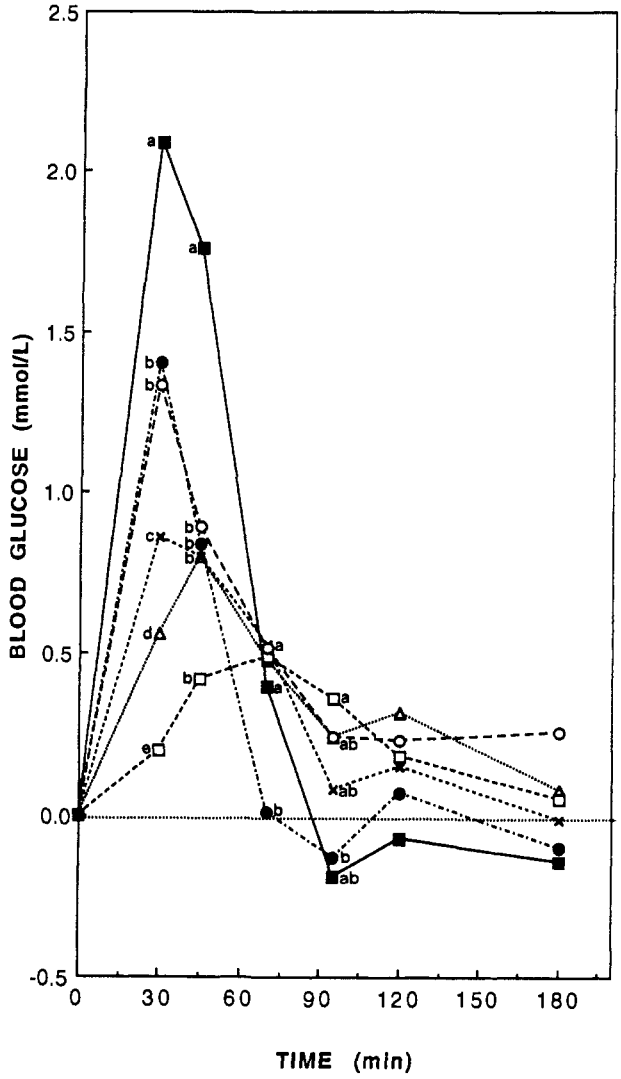

Figure 1. Mean incremental blood glucose responses obtained after ingestion of boiled red beans (□), autoclaved red beans (△), red bean PCF porridge (×), red bean FSF cakes (○), lentil PCF porridge (●), White wheat bread (■). For each time, means with different letters are significantly different ($p < 0.05$).

and autoclaved seeds. Instron hardness values were 0.114 ± 0.006 and 0.101 ± 0.005 kg for the boiled and autoclaved samples, respectively.

Postprandial Glycemic and Insulinemic Responses. Figure 1 presents the mean glycemic response to the various test meals. All the leguminous samples elicited lower responses than the wheat bread reference during the first 45 min. Most legume-based meals showed a rather slow postpeak decline. Thirty-minute values indicated clear differences between the various red bean products, boiled beans showing the lowest plasma glucose concentration rise, followed in increasing order by autoclaved seeds, PCF porridge, and FSF cakes. The lentil PCF 30-min value was similar to that of bean FSF. No major differences were observed between the meals during the late phase of the curve (95–120 min), although values for the bread and lentil PCF meals showed a sharp postpeak decrease and a tendency to drop below fasting level.

In Table II, the postprandial glycemic responses are characterized by various parameters. Boiled beans showed a lower peak value and later peaking time than most other legume preparations. Some differences were also noted between the remaining legume products. A relatively late peaking time was recorded for the autoclaved beans, whereas the bean FSF cakes and lentil PCF porridge showed the highest peak values. Blood glucose values below fasting levels were obtained at 180 min after the lentil PCF porridge and white bread meals.

The GIs of boiled and autoclaved whole seeds were similar (Table II). However, contrasting with the values calculated with the 120 min areas, GIs based on 70 min indicated significantly greater responses to the bean PCF porridge, bean FSF cakes, and lentil PCF porridge meals than to whole red beans. Ninety-five-minute GI values did not differ from the 120-min ones (results not shown).

The mean insulinemic responses, shown in Figure 2, revealed similar tendencies as the blood glucose responses, although the curve after the lentil PCF porridge meal deviated clearly from the other legume samples and approached that observed after the bread meal. The calculations in Table II show that boiled beans promoted the lowest postprandial insulin rise, followed by an intermediate group comprising the other red bean preparations. Lentil PCF porridge and bread meals constituted a high response-eliciting group.

The hydrolysis indices of the test meals were measured recently in a chewing/dialysis digestion system (Granfeldt et al., 1992). Data from that study are included in Table II. Starch digestion products from boiled bean starch appeared in the dialyzate at a remarkably low rate. Increased in vitro digestibility rates were observed for the autoclaved beans and bean PCF. The FSF cakes and the lentil PCF porridge gave higher in vitro hydrolysis indices than whole beans, although significantly lower than the bread reference.

Satiety Score of the Test Meals. All test meals exerted similar satiating effects during the early postprandial phase (data not shown). However, significant differences were recorded after 120 and 180 min, when the satiety scores for the lentil PCF porridge (120 min = −0.2, 180 min = −3.7) and the wheat bread (120 min = −1.0, 180 min = −3.9) were lower than for the red bean meals (average values: 120 min = 1.1, 180 min = −1.1).

DISCUSSION

The glycemic and insulinemic responses to the leguminous meals tested were lower than to white wheat bread. This is in accordance with the well-known "slow" properties of starch in legumes (Jenkins et al., 1980; Brand et al., 1990).

As judged from all the evaluated parameters, boiled beans elicited notably low postprandial metabolic responses. The 120-min GI of the boiled bean meal (44%) is within the range of values reported for common beans (*Phaseolus vulgaris* L.) (Jenkins et all, 1984). The comparability of GI measured with small starch loads, such as the 30 g employed in this study, and those obtained with standard 50-g portions has been established (Jenkins et al., 1981; Brand et al., 1990).

Industrially processed pulses may provide a way of extending uses for legumes, but convenient products should keep, as much as possible, the "slow" carbohydrate features of conventionally cooked seeds. Present observations make it clear that processing has negative effects on these beneficial properties.

Compared to boiling, all other processes applied to red beans resulted in increased responses. Autoclaved seeds, for instance, promoted higher glucose and insulin responses at 30 min (Figure 1) and showed significantly higher peak insulin concentration and insulinemic index (Table II). Autoclaving is part of the industrial processing (canning) of legumes. The detrimental effect of canning on glucose and insulin responses to different legume species has been

Table II. Fasting Values and Postprandial Glucose and Insulin Characteristics[a]

	red kidney beans				lentils	wheat
	boiled seeds	autoclaved seeds	PCF porridge	FSF cakes	PCF porridge	white bread
plasma glucose response						
fasting concn, mmol/L	4.4^{b} (0.1)	4.4^{b} (0.1)	4.4^{b} (0.3)	4.4^{b} (0.1)	4.5^{b} (0.1)	4.4^{b} (0.1)
peak above fasting value, mmol/L	0.7^{b} (0.1)	1.0^{b} (0.1)	1.0^{b} (0.1)	1.4^{c} (0.2)	1.5^{c} (0.1)	2.3^{d} (0.2)
peaking time, min	64.5^{b} (7.3)	49.5^{b,c} (4.9)	38.5^{c,d} (4.2)	33.0^{d} (2.0)	34.5^{d} (2.3)	36.0^{d} (2.5)
glycemic index (70 min), %	32.7^{b} (4.6)	41.9^{b} (4.8)	51.0^{c} (7.6)	63.1^{c} (9.9)	60.2^{c} (6.4)	100.0^{d}
glycemic index (120 min), %	43.7^{b} (8.4)	57.9^{b,c} (7.8)	61.8^{c} (8.8)	76.2^{c} (12.5)	62.8^{b,c} (8.8)	100.0^{d}
plasma insulin response						
fasting concn, pmol/L	57.0^{b} (6.6)	47.0^{b} (4.4)	50.0^{b} (4.7)	55.0^{b} (6.6)	53.0^{b} (4.4)	53.0^{b} (6.0)
peak above fasting value, pmol/L	50.0^{b} (9.9)	120.0^{c} (30.0)	110.0^{c} (20.0)	130.0^{c} (30.0)	240.0^{d} (30.0)	270.0^{d} (40.0)
insulinemic index, %	33.5^{b} (7.4)	50.8^{c} (8.2)	51.7^{c} (6.1)	51.1^{b,c} (10.3)	89.3^{d} (9.6)	100.0^{d}
hydrolysis index,[e] %	21^{a} (2)	38^{b} (3)	38^{b} (2)	77^{c} (3)	63^{c} (4)	100^{d}

[a] Values are means of 10 individuals. SEM is indicated in parentheses. Means within one row not sharing common superscript letters (b–d) are significantly different ($p < 0.05$). [e] In vitro starch hydrolysis index measured in a chewing/dialysis system. Values are referred to wheat bread. Taken from Granfeldt et al. (1992).

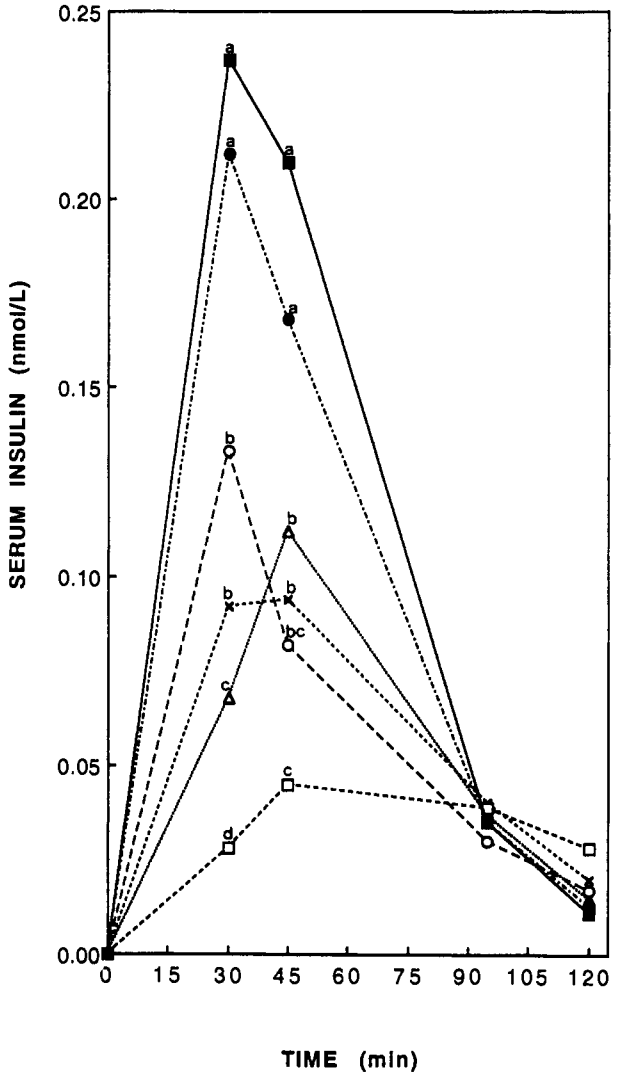

Figure 2. Mean incremental serum insulin responses obtained after ingestion of boiled red beans (□), autoclaved red beans (△), red bean PCF porridge (×), red bean FSF cakes (○), lentil PCF porridge (●), white wheat bread (■). For each time, means with different letters are significantly different ($p < 0.05$).

observed previously in normal subjects (Traianedes and O'Dea, 1986) and in non-insulin-dependent diabetics (Wolever et al., 1987), although no clear explanation for the phenomenon has been found. However, process-related changes in the physical accessibility of starch to amylolytic enzymes seem to be of importance for the increase in metabolic responses.

Although the comparison of textural properties showed no evident difference in hardness between boiled and autoclaved beans, more extensive changes in cell wall integrity may be expected in the pressure-cooked seeds, and this could result in increased accessibility of the starch. Autoclaving might, for instance, facilitate alteration of protein/fiber associations, which seem to be important for the resistance to amylolysis of cell-containing legume preparations (Tovar et al., 1991). Increased leaching of phytate and other heat-stable antinutrients from the pressure-cooked beans might also lead to differences in the rate of digestion/absorption (Wolever et al., 1987). Protein α-amylase inhibitors and lectins are almost completely inactivated after relatively short conventional boiling of the seeds (Jaffé, 1980; Würsch et al., 1986; Almeida et al., 1991); thus, differential inactivation of these antiamylolytic factors can be ruled out.

We recently measured the in vitro hydrolysis index of the samples studied here (Granfeldt et al., 1992), using a chewing/dialysis procedure that takes into account both the influence of the physical form of the food and viscosity effects. These data, included in Table II, are in good agreement with the glycemic responses, since boiled beans had the lowest hydrolysis index whereas the preparation containing free starch (FSF) appeared more efficiently digested than those products retaining cell-enclosed starch (boiled, autoclaved and PCF). Therefore, the increased metabolic responses elicited by processed beans seem to be a consequence mainly of increased rates of digestion.

The preparation of PCF disrupts cotyledon structure but preserves, to a large extent, the integrity of cell walls (Tovar et al., 1990a,b; 1991). Both the in vitro hydrolysis index and the metabolic responses to the red bean PCF were higher than to whole cooked seeds (Figure 1, Table II), suggesting a role for the seed tissue architecture in the slow feature of intact beans. Relatively large particles remain after chewing whole beans, which may result in slow starch break down compared with the PCF porridge (Crapo, 1985). Differences in the rate of gastric emptying might also contribute to variable in vivo responses (Torsdottir et al., 1984). The porridge meal, being more fluid than the whole seed-based ones, could have emptied more rapidly from the stomach, reaching the small intestine earlier.

No major difference was observed between 95-min-based GI values (data not shown) and those calculated after 120 min. However, comparison of 70-min-based GIs indicated that the responses to bean PCF, FSF, and lentil PCF were similar, but significantly higher than those observed with intact cooked seeds (Table II). Such a clear difference

could not be established with the 120-min GI values. This is in agreement with our recent observations that the use of 120-min areas may mask differences in glycemic responses to pasta products (Granfeldt and Björck, 1991; Granfeldt et al., 1991). This point emphasizes the importance of appropriate selection of the postprandial period length when evaluating metabolic responses to slow carbohydrate foods in subjects with normal glucose tolerance.

Some differences in behavior between bean PCF porridge and FSF cakes are noteworthy. In addition to the evident difference in hydrolysis index (Table II), both 30-min (Figure 1) and peak glucose values (Table II) for the FSF meal were larger than for the PCF product. Furthermore, in spite of the overall statistical similarity in GIs, most of the volunteers (7 out 10) ranked GI for FSF greater than for PCF, irrespective of the postprandial period selected for calculation. These results confirm that the preservation of cell wall structures enclosing starch contributes to the low postprandial responses to beans processed in this way. In this respect, PCF seems to be similar to the instant flakes prepared by cooking and drum-drying white common beans, which are also rich in cell-enclosed starch, slowly digested in vitro, and elicit moderate postprandial responses (Tappy et al., 1986; Golay et al., 1986; Schweizer et al., 1990). However, the glycemic response to such processed beans has not been characterized in terms of GI (Golay et al., 1986; Schweizer et al., 1990), which hampers direct comparison with our materials.

Nevertheless, it is clear that even if being slower than FSF and white bread, the PCF lost an important part of the remarkably slow feature of whole red beans. No conclusion on the relative "slow"-preserving efficiency of the PCF- and the flake-type of processing can be drawn at present, since the metabolic responses to bean flakes and the original seeds have not been compared (Golay et al., 1986; Tappy et al., 1986; Würsch et al., 1988; Schweizer et al., 1990).

Among the legume samples studied, the PCF from lentils promoted the highest metabolic responses. This is in accordance with the previously reported α-amylolysis rates of these products (Tovar et al., 1990b; 1991) and their hydrolysis indices (Table II). Susceptibility of cell-enclosed starch in lentil PCF to hydrolysis by amylases suggested that cell walls in this preparation are less resistant than those in similarly processed beans (Tovar et al., 1990b), which may also contribute to a more rapid digestion in vivo and concomitantly higher blood responses. Boiled red lentils have a remarkably lower GI (43%) (Jenkins et al., 1984) than the one calculated here for the PCF (63%, Table II). In addition, the lentil flour resembled the reference bread with regard to insulinemic response and tendency to negative values in the late phase of the glucose curve. These considerations suggest that the "lente carbohydrate" properties of lentils are more sensitive to processing than those of common beans, although definite conclusions cannot be drawn without direct comparison of boiled lentils and the corresponding PCF preparation.

Contrasting with the lentil PCF product and the reference bread, the postprandial glycemia with all red bean-based meals consistently remained above fasting levels (Figure 1). Meals resulting in a rebound fall in plasma glucose are likely to promote hunger more promptly than those allowing sustained positive postprandial glycemic values (Haber et al., 1977; Leathwood and Pollet, 1988). This may explain the similar satieting effect of the various red bean products and the lower satiety scores registered for the lentil and bread meals during the late phase of the experimental period.

In conclusion, the present study confirms the deleterious effect of processing on the metabolic responses to legumes. This may be attributed in part to thermal/mechanical alteration of the botanical structure of the seeds and also to the release of physically inaccessible starch by mechanical disruption of cell walls. The moderate glycemic and insulinemic indices of extensively processed red beans stress the importance of other factors, such as intrinsic characteristics of legume starches, presence of thermostable antinutrients, and the quality and quantity of dietary fiber (Crapo, 1985; Wong et al., 1985; Tovar et al., 1991), for the overall metabolic features of pulses. The relatively rapid behavior of powdered lentils indicates that metabolic responses to processed legumes may be rather variable.

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