

## Nutrient composition is a poor determinant of the glycaemic response

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1. The glycaemic response of healthy males to potato, bread, rice and green gram (*Phaseolus aureus* Roxb.) was compared with that to meals equivalent to these foods in terms of carbohydrate, protein, fat and fibre content, but made up of maize flour, casein, maize oil and ispaghula husk.
2. Natural foods led to a higher postprandial glycaemia than their respective equivalents, but the difference was significant only in the case of potato at 0.5 h ( $P < 0.05$ ).
3. The insulin response, studied only in the case of rice and green gram, followed a trend similar to the glycaemic response but the differences between natural foods and equivalents were even more marked.
4. A food is more than the sum of its major nutrients. Several poorly understood factors may contribute to the glycaemic response to a food. In addition to the quantity of nutrients, the response may be the result of the specific type of nutrients, non-nutrient chemicals and anti-nutrients composing the food, and their unique physical arrangement within the food.

Reduction of postprandial glycaemia is now considered a desirable goal for the prevention and treatment of diabetes (Jovanovic *et al.* 1985), and about a dozen experimental approaches have been successful in achieving it (Read & Welch, 1985). The simplest of these approaches is to emphasize foods with a low glycaemic index (GI) (Jenkins *et al.* 1981, 1984) in the diet. Recent literature suggests that besides carbohydrate, other nutrients present in a food, i.e. protein, fat and fibre, may influence its GI (Jenkins *et al.* 1981, 1984; Jarjis *et al.* 1984; Hagander *et al.* 1984; Read & Welch, 1985). This raises the interesting possibility that if the precise interaction among nutrients in this respect is understood, it may be possible to predict the GI of a food from its composition. With this possibility in mind, we studied the glycaemic response to various isoenergetic and isocarbohydrate combinations of carbohydrate, protein, fat and fibre (Sahi *et al.* 1984, 1985*a, b, c*; Siddhu *et al.* 1986). These studies have not revealed a consistent or precise-enough interaction among nutrients to allow prediction of GI of foods from their nutrient composition. In order to make sure that this conclusion is justified, we approached the issue from a different angle. If GI cannot be predicted from nutrient composition, it follows that the glycaemic response to two different combinations of identical nutrient composition will not necessarily be the same. This deduction was tested by comparing the glycaemic response to a few natural foods with that to equivalent nutrient combinations using maize flour, casein, maize oil and ispaghula husk. It was found that the glycaemic response to natural foods was generally higher than that to the corresponding equivalent combinations. Thus the approach adopted in the present study has also confirmed the previous conclusion that nutrient composition is a poor predictor of glycaemic response.

### METHODS

The study was performed in two stages.

Table 1. *Composition of the experimental meals*

Meal	Maize flour (g)	Casein (g)	Maize oil (g)	Ispaghula husk (dry wt, g)	Table salt (g)	Water (ml)	Energy (kJ)
Stage 1							
Glucose, 50 g	—	—	—	—	—	200	840
Potato, with skin, 242 g	—	—	—	—	2	200	840
Potato equivalent	46.6	3.3	0.2	8.5	2	200	840
White bread, 77 g	—	—	—	—	—	200	840
White bread equivalent	40.0	6.7	0.6	2.1	2	200	840
Glucose, 50 g	—	—	—	—	—	200	840
Stage 2							
Glucose, 50 g	—	—	—	—	—	200	840
Green gram*, whole, 60 g	—	—	—	—	2	200	840
Green gram equivalent	34.0	14.4	0.8	9.6	2	200	840
Rice, milled, 58 g	—	—	—	—	2	200	840
Rice equivalent	45.0	4.0	0.3	5.0	2	200	840
Glucose, 50 g	—	—	—	—	—	200	840

\* *Phaseolus aureus* Roxb.*Stage 1*

Six healthy male volunteers (age 20–23 years, weight 50–66 kg, height 1.66–1.77 m) participated in the study. They were studied after an overnight fast on six mornings at weekly intervals. After a fasting venous blood sample had been drawn, they were administered one of the six isoenergetic 'meals' shown in Table 1 in different sequences in accordance with a Latin square design. As seen in Table 1, two of the 'meals' were 50 g glucose (G). The potato (P) and potato equivalent (PE) meals provided identical amounts of carbohydrate, protein, fat and fibre; and the same was true of bread (B) and bread equivalent (BE). The composition of PE and BE was decided on the basis of the published food values of potato (Gopalan *et al.* 1971; Kamath & Belavady, 1980) and white bread (US Department of Agriculture, 1971; Southgate *et al.* 1976). Potato was boiled on the evening before the test and stored overnight (for about 14 h) in a refrigerator at 10–12°. On the morning of the test, the potato was reheated by keeping it in an oven at 40° for 15 min. Bread was purchased about 16 h before the test, and was stored and served at room temperature. PE and BE were prepared by stirring the proper quantity of maize flour (Brown & Polson Cornflour, Corn Products Co., Bombay, India) in 50 ml tap water. The mixture was added gradually to 100 ml boiling water. Casein (SISCO Research Laboratories, Bombay, India), maize oil (Cornola, Ballarpur Industries, Chandrapur, India) and table salt were also added to the preparation at this stage. The mixture was allowed to simmer for 2 min, then removed from the hot plate and ispaghula husk (Sidhpur Sat Isabgol Factory, Sidhpur, India) was added. The meal was stirred thoroughly and allowed to cool to room temperature. It was stored under refrigeration at 10–12° until required, which generally meant storage for about 20 h. On the morning of the test the meal was reheated by keeping it in an oven at 40° for 15 min. The meal was served with 50 ml drinking water.

Each meal was consumed within 10 min. Starting with the time when the ingestion was begun, venous blood samples were drawn at 0.5, 1.0, 1.5 and 2.0 h. All blood samples were analysed for glucose concentration by the *o*-toluidine method.

### Stage 2

The experimental design was the same as that of Stage 1, but the foods studied were rice (R) and green gram (*Phaseolus aureus* Roxb., GG), and the insulin response was monitored as well as the glycaemic response.

The volunteers were six healthy young males (age 20–23 years, weight 50–63 kg, height 1.60–1.76 m). Three of the volunteers were the same as in Stage 1. The composition of the meals administered is shown in Table 1. The composition of R and GG equivalents (RE and GGE respectively) was decided on the basis of the published food values of rice and green gram (Gopalan *et al.* 1971; Kamath & Belavady, 1980). R and GG were boiled on the evening before the test, and stored and served like P in Stage 1. RE and GGE were also prepared, stored and served as described previously for similar meals. Venous blood samples, drawn at 0, 0.5, 1.0, 1.5 and 2.0 h relative to ingestion of meals, were analysed for glucose concentration by the *o*-toluidine method, and for insulin concentration by radioimmunoassay.

### Statistical analysis

Glucose and insulin levels at 0.5, 1.0, 1.5 and 2.0 h, and areas under the 2 h glucose curves (AUC-G) and insulin curves (AUC-I) following different meals were compared by analysis of variance (ANOVA). The points at which a significant difference between meals could be expected on the basis of ANOVA analysis were subjected to Newman-Keuls' multiple range test (Armitage, 1971). Differences between P and PE, B and BE, R and RE, and those between GG and GGE were evaluated by Student's *t* test for paired observations in addition to the multiple range test. Differences were considered significant at a level of  $P < 0.05$ .

### Ethical considerations

The experimental protocol of the study had the previous approval of the Ethics Committee of All India Institute of Medical Sciences. The participation was on a strictly voluntary basis, and the subjects knew that they could withdraw from the study at any stage. Every volunteer gave his informed written consent before being admitted to the study.

## RESULTS

Since the 50 g glucose tolerance test was done twice on each subject, the mean of the two readings has been used for presentation of results. The plasma glucose levels following different meals are shown in Fig. 1, insulin levels in Fig. 2, and AUC-G and AUC-I in Fig. 3.

### Glycaemic response

Natural foods gave a higher postprandial glycaemic response than their respective equivalents, but the difference was significant only in the case of potato. At 0.5 h, the mean plasma glucose level on P was 1257 (SE 39) mg/l, while that on PE was 1047 (SE 66) mg/l ( $P < 0.05$ ). Paired comparison of B and BE also revealed an almost significant difference in the glycaemic response at 0.5 h ( $t$  2.46). The glycaemic response to B was the most similar to that to G, the two being statistically indistinguishable with respect to every variable studied. The plasma glucose levels on PE and BE at 0.5 h were significantly lower than on G ( $P < 0.05$ ).

AUC-G for P, PE and BE were also significantly lower than that for G ( $P < 0.05$ ). In the case of R and GG, an approximate correspondence was seen between natural foods and their equivalents. R gave a higher glycaemic response than GG; correspondingly, RE gave a higher glycaemic response than GGE. The results indicate that the meals administered may be broadly divided into two groups: rapid-release carbohydrate (G, B, P and R) and slow-release carbohydrate (GG, PE, BE, RE and GGE).

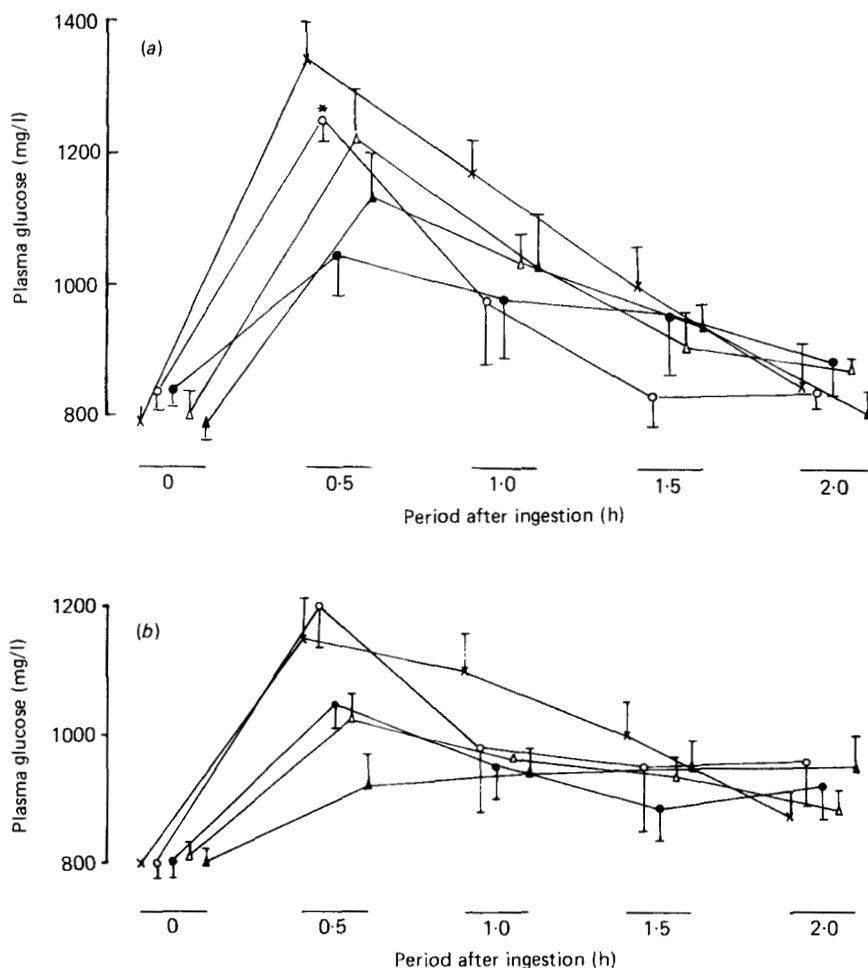


Fig. 1. Plasma glucose response to the meals administered. (a) Potato (○—○), bread (△—△) and their equivalents (●—●, ▲—▲ respectively). (b) Rice (○—○), green gram (*Phaseolus aureus* Roxb.) (△—△) and their equivalents (●—●, ▲—▲ respectively), glucose (×—×). Points are mean values, with their standard errors represented by vertical bars. For details of meals and procedures, see Table 1 and pp. 6-7.

#### Insulin response

The insulin response (Fig. 2) followed a trend similar to the glycaemic response but the differences between natural foods and their equivalents were even more marked. The insulin levels at 0.5 h after the 'meal' as well as AUC-I were significantly higher in response to G and R compared with RE, GG and GGE ( $P < 0.05$ ). Further, paired comparison of foods and their corresponding equivalents revealed significant differences between R and RE at 0.5, 1.0, 1.5 and 2.0 h, and in AUC-I, and between GG and GGE at 1 h ( $P < 0.05$ ). Logarithmic or square root transformation of insulin levels additionally revealed that AUC-I in response to GG was significantly higher than that in response to GE.

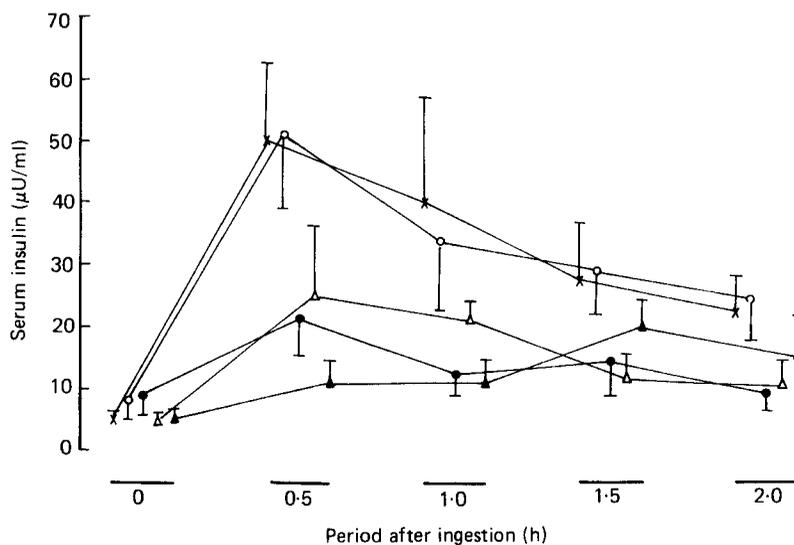


Fig. 2. Serum insulin response to rice (○—○), green gram (*Phaseolus aureus* Roxb.) (△—△) and their equivalents (●—●, ▲—▲ respectively), glucose (×—×). Points are mean values, with their standard errors represented by vertical bars. For details of meals and procedures, see Table 1 and pp. 6–7.

#### DISCUSSION

The glycaemic responses to natural foods and those to meals of equivalent nutrient composition may be compared from several angles. From a cursory look at Figs. 1 and 2, it is apparent that the glycaemic and insulin response to a natural food was higher than that to its equivalent. Statistical analysis revealed a significant difference between the glycaemic response to P and PE at 0.5 h. Also at 0.5 h, both PE and BE gave glucose levels significantly lower than G, but neither P nor B did so. Insulin response showed the same trend as the glycaemic response. Tappy *et al.* (1986) reported that addition of protein and fibre to potato to make it 'equivalent' to beans did not result in a glycaemic response comparable to beans. In short, the present study, as well as that of Tappy *et al.* (1986), show that a food is more than the sum of its nutrients.

Several factors may contribute to making the glycaemic response to a food different from that to its equivalent as designed in the present study. Although P, B, R and GG, as well as maize flour (used in equivalents) all contain carbohydrate in the form of starch, different types of starch may evoke different glycaemic responses (Crapo *et al.* 1980; Thorne *et al.* 1983; Goddard *et al.* 1984; Pikaar *et al.* 1985). The same argument holds good for the protein, fat and fibre components of natural foods and their respective equivalents. The varying effect of different types of fibre on glycaemic response is well established (Jenkins *et al.* 1978; Vaaler *et al.* 1980). The fibre used in the food equivalents, i.e. ispaghula, has been reported to reduce postprandial glycaemia following mixed meals (Sartor *et al.* 1981; Florholmen *et al.* 1982), and may be a major mechanism underlying our observations. Another factor which may contribute to the difference in glycaemic response to natural foods and their equivalents may be the unique way in which nutrients are organized in a food in contrast to the loose association present in equivalents. The importance of these considerations is suggested by the effect of physical form (Wong & O'Dea, 1983), chewing (Read *et al.* 1986), cooking (Collings *et al.* 1981) and processing (Brand *et al.* 1985) on glycaemic response. Further, most of the meals (except B) were stored at low temperature.

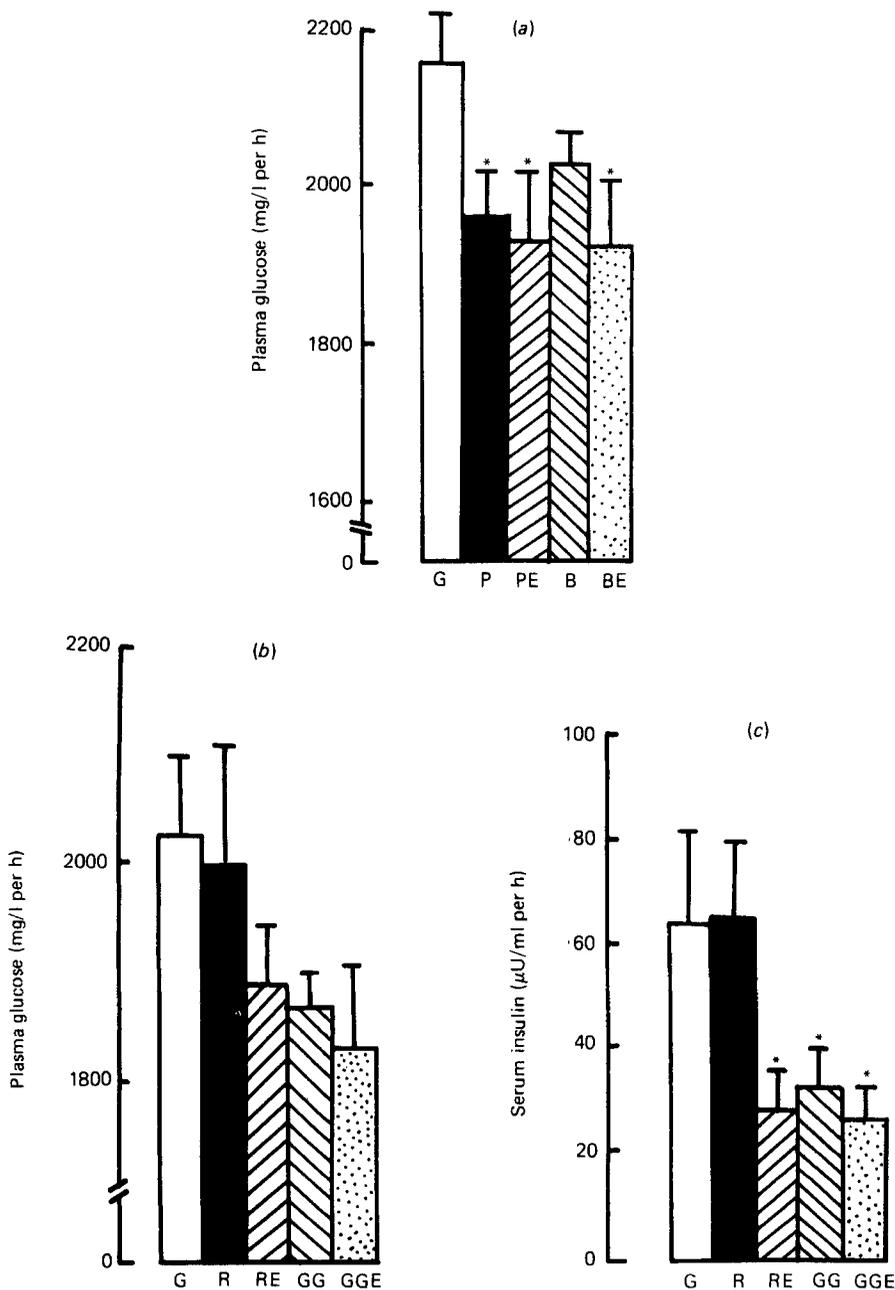


Fig. 3. Areas under the 2 h glucose and insulin curves in response to the meals administered. (a) Potato (P), bread (B) and their equivalents (PE, BE respectively). Mean values were significantly different from those for the glucose (G) meal:  $*P < 0.05$ . (b), (c) Rice (R), green gram (*Phaseolus aureus* Roxb.; GG) and their equivalents (RE, GGE respectively). Mean insulin values were significantly different from those for the glucose (G) and the R meals:  $*P < 0.05$ . Values are means, with their standard errors represented by vertical bars. For details of meals and procedures, see Table 1 and pp. 6-7.

Overnight storage at 5° has been reported to increase the amylase-resistant starch content of potato from 30 to 120 g/kg starch (Englyst & Cummings, 1987). Since relevant information on R, GG and maize starch is not available, it is difficult to say to what extent cold storage of meals might have influenced the results of the present study. Finally, chemicals other than the major nutrients taken into consideration in the present study, and some obscure host factors, may affect the glycaemic response (Jain *et al.* 1973; Mertz *et al.* 1974; Leatherdale *et al.* 1981; Rao, 1983; Yoon *et al.* 1983; Thompson *et al.* 1984).

It may be argued that the lower glycaemic response of equivalents is due to their lower digestibility. Since we did not measure breath-hydrogen, this possibility cannot be dismissed. However, since the AUC-G for P and PE, B and BE, R and RE, and GG and GGE were not significantly different, it seems that the difference is mainly in the pattern of the glycaemic response rather than the total quantity of glucose absorbed.

The great similarity between the glycaemic responses to G and B has been observed previously, and prompted Jenkins and his colleagues to propose B instead of G as a reference for calculation of GI (Jenkins *et al.* 1984).

It is noteworthy that a blunted glycaemic response similar to that of legumes, was also given by all the fabricated meals irrespective of composition. Hence the different responses to cereals and pulses do not seem to stem from differences in their composition in terms of major nutrients. Further, since a loosely-assembled mixture of carbohydrate, protein, fat and fibre behaves more like a legume than other natural foods, it may be pertinent to look for factors which accelerate nutrient release from cereals and from P.

Among nutrients, it is primarily carbohydrate which contributes to the glycaemic response, and also evokes the insulin response (Flatt & Bailey, 1984). Our studies indicate that in order to understand the pattern of these responses, we will have to look beyond the nutrient composition. The pattern of the responses may be partly the result of the specific type of constituent nutrients and their unique arrangement, conferring characteristic physico-chemical properties on the natural products. In addition, nutrients, non-nutrients and anti-nutrients, present in small amounts may also contribute to the spectrum of glycaemic responses to foods. Until we understand all these additional factors, there is no short-cut to determining the GI of individual foods and recipes if we want to use low GI as the scientific basis of a prudent diet for the prevention and treatment of diabetes.

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