Indian J Physiol Pharmacol 1998; 42 (1) : 81–89

GLYCAEMIC AND INSULINAEMIC RESPONSES TO NATURAL FOODS, FROZEN FOODS AND THEIR LABORATORY EQUIVALENTS

W. KANAN, R. L. BIJLANI*, U. SACHDEVA, S. C. MAHAPATRA, P. SHAH AND M. G. KARMARKAR

*Departments of *Physiology, Endocrinology and Laboratory Medicine, and Food Science Laboratory, All India Institute of Medical Sciences, New Delhi – 110 029*

(Received on May 12, 1997)

Abstract : Glycaemic response to a food is determined by a large number of factors, of which composition is only one. The present study was designed to study the effect of composition and overnight refrigeration on the glycaemic response. The study involved determination of the glycaemic and insulinaemic response of healthy human volunteers to rice or potato, and to meals equivalent to these foods in terms of carbohydrate, protein, fat and fibre content, but made up of cornflour, casein, corn oil and cellulose. Further, each of these meals was served either freshly cooked, or after overnight storage in a refrigerator and rewarming. The natural foods led to a higher postprandial glycaemia than their respective equivalents, and the freshly cooked foods led to a higher glycaemic response than the refrigerated and rewarmed forms of the corresponding foods. No such consistent differences were observed in case of the insulinaemic responses.

The difference in the glycaemic response to foods and their laboratory equivalents may be due to the unique physical arrangement of nutrients within the food or due to specific chemical differences in terms of macro- or micro-nutrients, non-nutrients or anti-nutrients. The difference in the glycaemic response to freshly cooked and refrigerated foods may be due to the formation of resistant starch during cold storage.

Key words : glycaemic response, glycaemic index, dietary fibre, cellulose

INTRODUCTION

Glycaemic response to a food is now considered a valid and rational indicator of its suitability for inclusion in diabetic diets (1, 2). In addition to the macronutrient composition of a food (3), a large number of micronutrient (4), antinutrient (5) and non-nutrient components (6), and factors related to cooking, processing and storage of the food also affect the glycaemic response (7, 8). While the insulinaemic response to a food generally parallels the glycaemic response, it is not always so (9, 10). Hence it is better

*Corresponding Author

to determine both the glycaemic and insulinaemic responses to a food for a better assessment of its suitability for diabetic diets. In a previous study we found that the glycaemic responses to rice, potato, green gram and bread were consistently higher than those to corresponding laboratory equivalents having an identical carbohydrate, protein, fat and fibre composition (11). One factor which could have possibly contributed to those observations was the fact that the fibre used in the laboratory equivalents of natural foods was ispaghula husk, which is a predominantly water-soluble, viscous type of fibre. Water-soluble viscous fibre has a potent attenuating effect on the glycaemic response (3,12). The present study was designed to find how far our previous observations (11) were due to a water-soluble viscous fibre having been used in the laboratory-fabricated foods. Hence, in the present study, laboratory equivalents were prepared by incorporating a water-insoluble, nonviscous fibre, viz. cellulose. Further, there is a possibility of an increase in the resistant starch content of a food as a result of refrigeration (13, 14), which in turn could attenuate the glycaemic response. Hence we tested the natural foods as well as their laboratory equivalents under both conditions: served fresh, and served after overnight refrigeration.

METHODS

Subjects

The study was conducted on a pool of 9 normal, healthy human volunteers (8 male, 1 female). Their physical characteristics are given in Table I. Of these, 8 subjects participated in the rice (R) meal study and 5 in the potato (P) meal study. Four of the subjects were common to both studies.

TABLE I : Physical characteristics of subjects.

Variable	*Value (mean ± SD)*
Age (years)	30.1 ± 18.2
Weight (kg)	56.1 ± 6.6
Height (cm)	167.5 ± 10.3
Body mass index	20.4 ± 2.7
Systolic blood pressure (mg Hg)	112.0 ± 7.8
Diastolic blood pressure (mm Hg)	74.0 ± 6.9

Experimental design

Each volunteer underwant seven meal tolerance tests (MTT) as follows :

1. First oral glucose tolerance test (OGTT)
2. Second OGTT
3. White bread
4. Natural food, freshly cooked (FC)
5. Natural food, refrigerated and rewarmed (RR)
6. Laboratory equivalent (E), freshly cooked
7. Laboratory equivalent, refrigerated and rewarmed

The order of MTT No. 3–7 was randomised.

Meals

OGTT was performed using 75 g glucose, which was dissolved in 300 mL water. The white bread meal consisted of 96 g (50 g-

TABLE II : Composition of meals studied.

Meal	*Ingredient(s)*		*Per meal (g)*			
			Carbohydrate	*Protein*	*Fat*	*Fibre*
White bread	White bread	96 g	50	8.4	1.9	3.8
Rice	White Rice	64 g	50	4.3	0.3	5.0
	Salt	1.0 g				
Rice	Corn flour	50 g	50	4.3	0.3	5.0
equivalent	Casein	4.3 g				
	Corn oil	0.3 g				
	Cellulose	5.0 g				
	Salt	1.0 g				
Potato	Potato	220 g	50	3.5	0.2	8.5
	Salt	1.0 g				
Potato	Corn flour	50 g	50	3.5	0.2	8.5
equivalent	Casein	3.5 g				
	Corn oil	0.2 g				
	Cellulose	8.5 g				
	Salt	1.0 g				

carbohydrate portion) of white bread, which was served with 300 mL water. The natural food was a 50 g-carbohydrate portion of either cooked rice (n=8) or boiled potato (n=5) with 1 g salt. The laboratory equivalents were formulated using cornflour, casein, corn oil, cellulose and salt. The water used for cooking a meal and the water served with the meal together was 300 mL in case of each meal. The composition of meals is given in Table II.

The 'freshly cooked meal' was cooked on the morning of the MTT. The 'refrigerated and rewarmed' meal was cooked on the day before the MTT and kept in the refrigerator at about 10°C for 16–20 h. It was rewarmed in an oven on the morning of the MTT.

To prepare the laboratory equivalents, corn flour (Brown and Polson cornflour, Corn Products Company, Bombay) was added to 50 mL of preboiled water and stirred thoroughly. This mixture was then added to 100 mL of boiling water. Casein (SISCO Research Laboratories, Bombay), corn oil (Cornola, Ballarpur Industries, Chandrapur) and table salt were added to the preparation at this stage. The mixture was allowed to simmer at low heat for 2 min, stirring gently and continuously. Then it was removed from the hot plate and cellulose (Nutrition grade, CSIR Biochemicals Unit, New Delhi), which was mixed in 10 mL of preboiled water, was added. The meal was stirred thoroughly and allowed to cool to room temperature.

Meal tolerance tests

On the morning of the test, the volunteer reported after an overnight fast. After taking a fasting venous blood sample, the meal was provided. The meal was consumed at a rapid and steady pace. The mid-point between starting and finishing the meal was taken as zero time. Blood samples were drawn at 0.5, 1.0, 1.5, 2.0 and 3.0 h.

Estimations

All blood samples were analysed for plasma glucose concentration by the glucose oxidase method and for serum insulin by double antibody radioimmunoassay using a kit (RIAK 1, Bhaba Atomic Research Centre, Bombay).

Calculations

Areas under the 3-h glucose or insulin curves were calculated by using a programmable calculator (Casio PB 100F).

Statistical analysis

Responses to different meals were compared by analysis of variance (ANOVA). The points at which a significant difference could be expected on the basis of ANOVA were further evaluated by Student's 't' test for paired observations. Differences were considered significant at a level of $P < 0.05$.

Ethical considerations

The protocol of the study was approved by the Ethics Committee of the All India Institute of Medical Sciences. An informed written consent was obtained prior to enlisting a subject for the study.

RESULTS

The glycaemic and insulinaemic responses to various meals have been provided in Tables III and IV. The incremental glycaemic and insulinaemic responses to the various meals have been shown in Figs. 1 and 2.

The glycaemic response to RFC was significantly higher than that to REFC as well as RRR at several points in time as well as in terms of AUC-G. Other similarly consistent and significant differences in glycaemic responses were: REFC > RERR, PFC > PRR and PEFC > PERR. Other noteworthy significant differences ($P < 0.05$) in glycaemic responses were RRR > RERR at 0.5, 1 and 1.5 h, PFC > PEFC at 2 h (absolute) and at 2 and 3 h (incremental). No such consistent differences were observed in case of the insulinaemic responses. Thus the glycaemic response to freshly cooked meals was consistently higher than that to corresponding refrigerated and rewarmed meals. The glycaemic response to the natural food was higher than that to the corresponding laboratory equivalent in case of rice meals but not so clearly in case of potato meals.

DISCUSSION

The results of the present study are similar to those of our previous study in which we had found that the glycaemic responses to natural foods were higher than

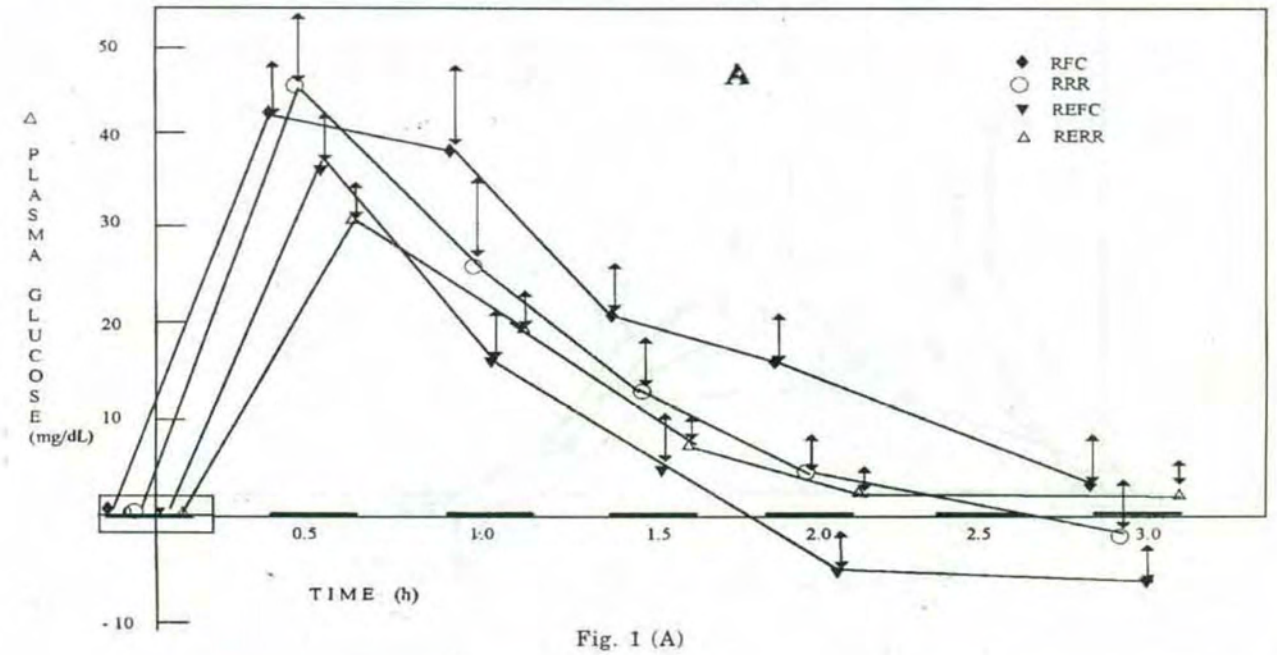

Fig. 1 (A)

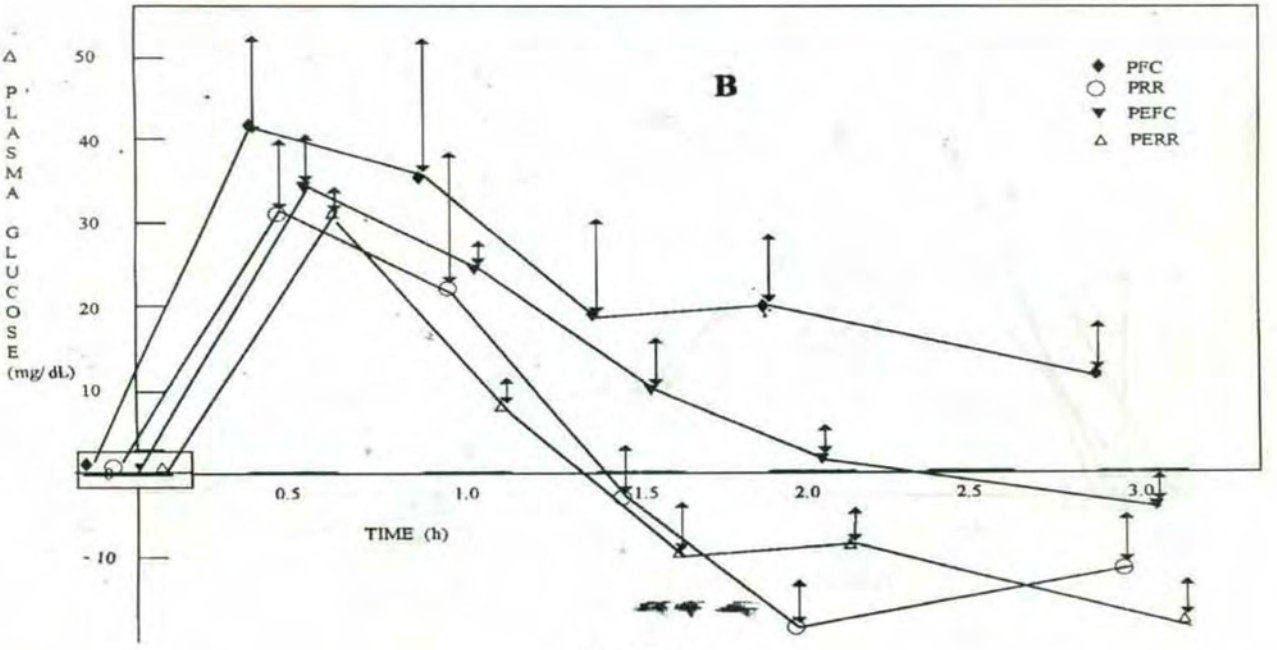

Fig. 1 (B)

Fig. : 1 Incremental glycaemic response to the meals administered. A. Rice meals and their equivalents. B. Potato meals and their equivalents. Points are mean values, with their standard errors represented by vertical bars. RFC, rice freshly cooked; RRR, rice refrigerated and rewarmed; REFC, rice equivalent freshly cooked; RERR, rice equivalent refrigerated and rewarmed; PFC potato freshly cooked; PRR, potato refrigerated and rewarmed; PEFC, potato equivalent freshly cooked; PERR, potato equivalent refrigerated and rewarmed.

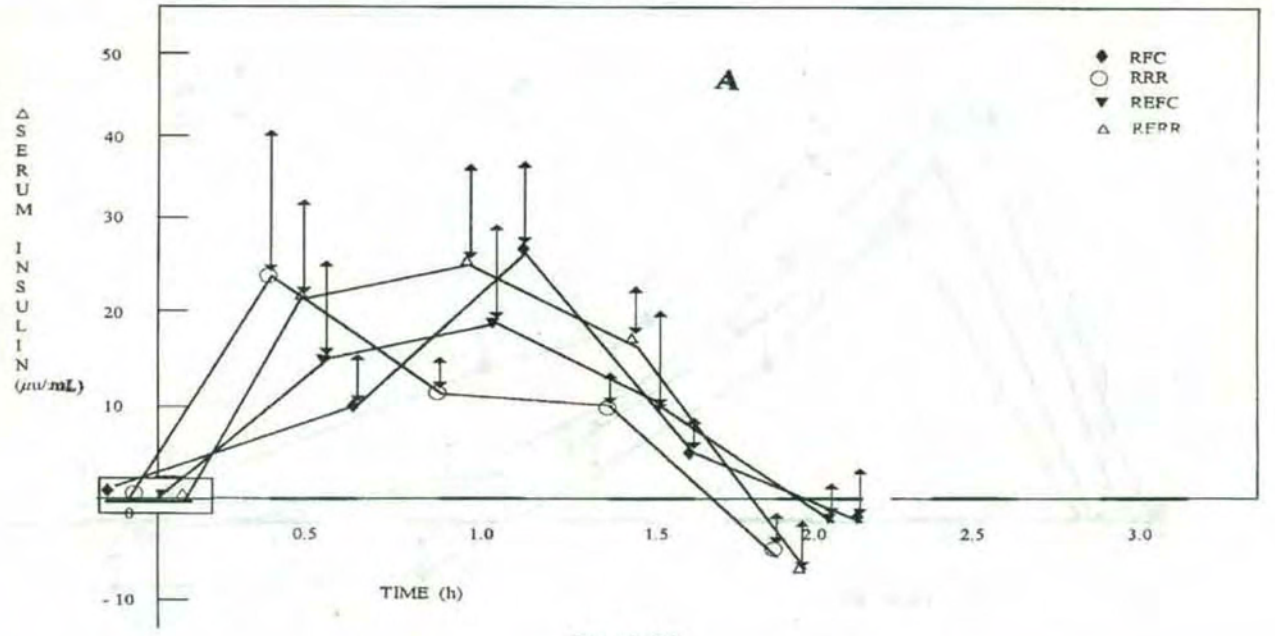

Fig. '2 (A)

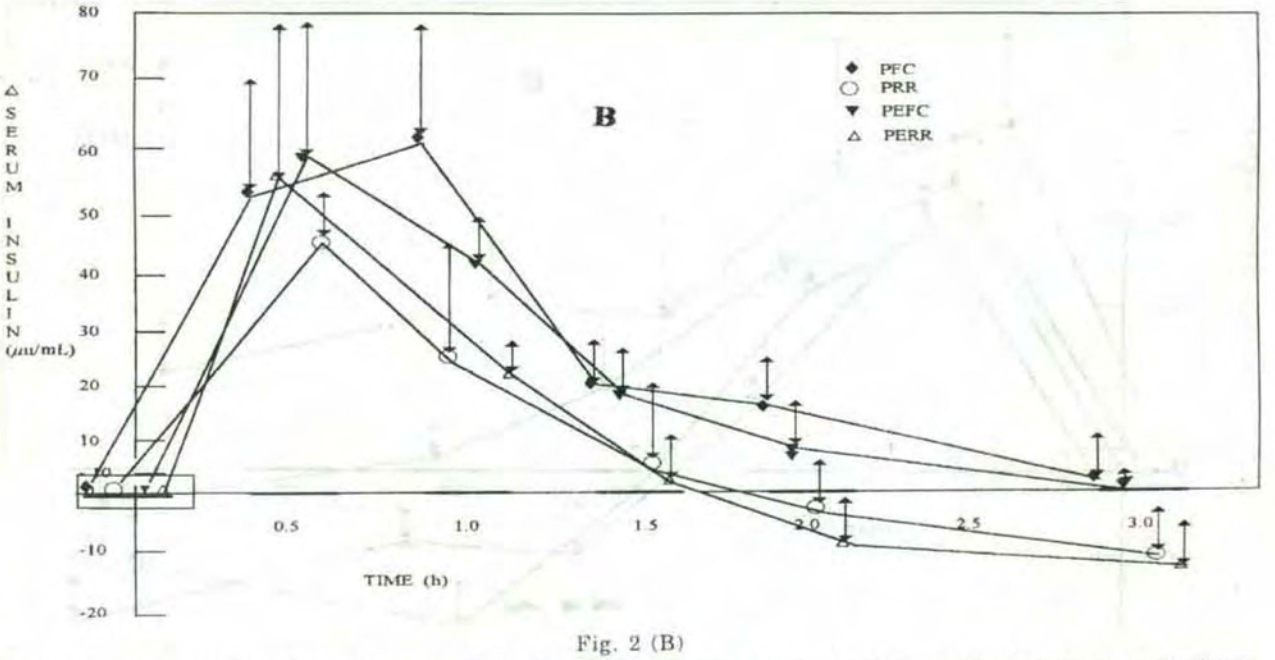

Fig. 2 (B)

Fig. : 2 Incremental insulinaemic response to the meals administered. A. Rice meals and their equivalents. B. Potato meals and their equivalents. Points are mean values, with their standard errors represented by vertical bars. RFC, rice freshly cooked; RRR, rice refrigerated and rewarmed; REFC, rice equivalent freshly cooked; RERR, rice equivalent refrigerated and rewarmed; PFC, potato freshly cooked; PRR, potato refrigerated and rewarmed; PEFC, potato equivalent freshly cooked; PERR, potato equivalent refrigerated and rewarmed.

TABLE III : Glycaemic response to the meals tested (Mean ± SEM).

Meal	*n*	*Plasma glucose (mg/dL)*						*(AUC–G) (mg/dL.h)*
		Fasting	*0.5 h*	*1.0 h*	*1.5 h*	*2.0 h*	*3.0 h*	
RFC	8	93.9 ±5.8	135.4 ± 6.9	131.2 ± 8.2	114.6 ± 3.6	110.5 ± 4.3	97.6 ± 4.2	344.7 ± 12.0
RRR	8	83.5 ±3.6	127.9 ± 7.1	110.6 ± 7.7	95.5 ± 5.6	88.6 ± 2.0	81.6 ± 2.6	295.4 ± 8.8
REFC	8	90.2 ±3.7	125.6 ± 5.5	104.2 ± 4.9	95.0 ± 4.9	86.1 ± 3.3	85.1 ± 4.1	291.6 ± 10.4
RERR	8	75.8 ±2.2	106.2 ± 4.4	95.0 ± 4.8	83.2 ± 2.7	79.5 ± 2.8	77.2 ± 3.4	259.1 ± 9.0
PFC	5	79.1 ±5.8	120.6 ± 10.0	113.8 ± 12.6	97.3 ± 5.2	98.8 ± 3.2	83.9 ± 2.5	300.0 ± 12.3
PRR	5	73.3 ±6.3	104.8 ± 6.0	75.4 ± 9.7	70.4 ± 6.7	57.1 ± 2.9	61.4 ± 3.7	217.1 ± 55.5
PEFC	5	86.5 ±1.7	121.0 ± 7.2	111.2 ± 2.7	95.6 ± 4.3	87.7 ± 3.9	84.9 ± 3.8	292.8 ± 9.4
PERR	5	88.1 ±5.2	122.4 ± 3.1	97.4 ± 2.9	79.0 ± 3.2	81.1 ± 4.2	73.3 ± 6.4	269.0 ± 10.2

For explanation of abbreviations, see text.

TABLE IV : Insulinaemic response to the meals tested (Mean±SEM).

Meal	*n*	*Plasma insulin (μU/mL)*						*(AUC–G) (μU/mL.h)*
		Fasting	*0.5 h*	*1.0 h*	*1.5 h*	*2.0 h*	*3.0 h*	
RFC	5	12.0 ±5.3	21.8 ± 8.4	29.0 ± 8.0	26.0 ± 9.9	10.6 ± 3.7	—	44.2 ± 9.2
RRR	5	14.6 ±5.0	36.6 ± 14.9	25.8 ± 4.7	24.2 ± 8.3	9.8 ± 2.8	—	47.7 ± 12.9
REFC	5	18.6 ±5.2	29.0 ± 12.9	37.2 ± 8.6	26.4 ± 10.3	17.4 ± 4.5	—	55.3 ± 15.1
RERR	5	20.2 ±5.0	41.2 ± 16.6	45.4 ± 13.9	37.0 ± 6.5	13.4 ± 4.9	—	70.1 ± 16.5
PFC	5	12.8 ±3.1	66.2 ± 18.7	74.8 ± 12.8	32.4 ± 5.0	30.0 ± 7.2	14.8 ± 3.7	119.8 ± 13.2
PRR	5	24.4 ±6.5	71.0 ± 5.5	49.6 ± 15.4	30.4 ± 14.3	22.4 ± 6.0	14.4 ± 2.4	105.8 ± 20.3
PEFC	5	12.8 ±1.3	72.8 ± 16.3	55.6 ± 5.3	31.2 ± 6.4	21.4 ± 3.7	14.0 ± 1.8	114.8 ± 21.2
PERR	5	20.0 ±4.8	75.0 ± 24.3	41.2 ± 7.5	21.2 ± 6.4	12.6 ± 3.5	7.8 ± 1.7	87.0 ± 18.0

In case of rice meals, insulin was measured only in 5 subjects in samples collected upto 2 h after ingestion.
For explanation of abbreviations, see text.

those to their laboratory equivalents having an identical macronutrient and fibre content (11). This is in spite of the fact that in the present study the fibre used was cellulose, while in the previous study it was ispaghula husk. Thus the reduction in glycaemic response of the laboratory equivalents in the previous study was not due to using a water-soluble viscous fibre. The difference in response between the natural food and its laboratory equivalent is much more marked in case of rice than in case of potato; this observation is also similar to that of our previous study. No other similar study is available for comparison. The phenomenon could be due to several reasons. The type of starch in the natural food may differ from that in the equivalent in its digestibility. Further, the unique way in which nutrients are organized in the natural food may make it more digestible, since physical form is known to affect glycaemic response (15). Finally, chemicals other than the major nutrients taken into consideration while preparing the laboratory equivalents may affect the glycaemic response. These chemicals may be micronutrients, non-nutrients or anti-nutrients.

The second aim of the study was to investigate the effect of overnight refrigeration on the glycaemic response. The results in this respect are clear and consistent for the meals studied. The freshly cooked meal has a significantly higher glycaemic response than a similar meal refrigerated overnight and rewarmed just before ingestion. Overnight storage at 5°C has been reported to increase the amylase-resistant starch of potato four-fold (14). A similar process may be taking place in rice and also in the corn starch used for preparing laboratory equivalent meals. The observation is also consistent with the folk belief in India that foods stored in the refrigerator are more likely to induce flatulence. Whether it is desirable to employ refrigeration for achieving a reduction in postprandial glycaemia in diabetic diets is difficult to say at this stage.

In short, the determinants of glycaemic response are complex and extend beyond composition. Besides several other factors, attention to the temperature and duration of storage is also important for getting reliable and reproducible data on glycaemic response to foods.

ACKNOWLEDGEMENTS

The present study was supported by a grant from the Indian Council of Medical Research (No. 9301860). The authors would like to thank Ms. Promila Kapoor and Mr. B. R. Arya for efficient technical assistance, Mr. Satish Sachdeva for typing the manuscript, and the volunteers for their cooperation.

REFERENCES

1. Jenkins DJA, Ghafari H, Wolever TMS, Taylor RH, Jenkins AL, Barker HM, Fielden H, Bowling AC. Relationship between rate of digestion of food and postprandial glycaemia. *Diabetologia* 1982; 22: 450–455.
2. Alberti KGMM, Hockaday TDR. Diabetes mellitus. In : Weatherall DJ, Ledingham JGG, Warell DA (Eds.). *Oxford Textbook of Medicine*, Volume 1, 2nd Edition. Oxford: Oxford University Press, 1987: 9: 67.
3. Siddhu A, Sud S, Bijlani RL, Karmarkar MG, Nayar U. Nutrient interaction in relation to glycaemic and insulinaemic response. *Indian J Physiol Pharmacol* 1992; 36: 21–28.

4. Thorburn AW, Brand JC, Truswell AS. Salt and glycaemic response. *Br Med J* 1986; 292: 1697–1699.

5. Yoon JH, Thompson LV, Jenkins DJA. The effect of phytic acid on *in vitro* rate of starch digestibility and blood glucose. *Am J Clin Nutr* 1983; 38: 835–842.

6. Leatherdale BA, Panesar RK, Singh G, Atkins TW, Bailey CJ, Bignell AHC. Improvement in glucose tolerance due to *Memordica charantia* (Karela). *Br Med J* 1981; 282: 1823–1824.

7. Jenkins DJA, Wolever TMS, Jenkins AL, Giordano C, Giudici S, Thompson LU, Kalmusky J, Josse RG, Wong GS. Low glycemic response to traditionally processed wheat and rye products: Bulgur and pumpernickel bread. *Am J Clin Nutr* 1986; 43: 516–520.

8. Holm J, Hagander B, Bjorck I, Eliasson AC, Lundquist I. The effect of various thermal processes on the glycaemic response to whole grain wheat products in humans and rats. *J Nutr* 1989; 119: 1631–1638.

9. Shively CA, Apgar JL, Tarka SM. Postprandial glucose and insulin responses to various snacks of equivalent carbohydrate content in normal subjects. *Am J Clin Nutr* 1986; 43: 335–342.

10. Shaheen SM, Fleming SE. High-fibre foods at breakfast : influence on plasma glucose and insulin responses to lunch. *Am J Clin Nutr* 1987; 46: 804–811.

11. Sud S, Siddhu A, Bijlani RL, Karmarkar MG. Nutrient composition is a poor determinant of the glycaemic response. *Br J Nutr* 1988; 59: 5–12.

12. Jenkins DJA, Wolever TMS, Leeds AR, Gassul MA, Wainsman P, Dilawari J, Goff DV, Metz GL, Alberti KGMM. Dietary fibre, fibre analogues and glucose tolerance : Importance of viscosity. *Br Med J* 1978; 1: 1392–1394.

13. Berry CS. Resistant starch; formation and measurement of starch that survives exhaustive digestion with amylolytic enzymes during the determination of dietary fibre. *J Cereal Sc* 1986; 4: 301–314.

14. Englyst HN, Cummings JH. Digestion of polysaccharide of potato in the small intestine of man. *Am J Clin Nutr* 1987; 44: 423–431.

15. Wong S, O'Dea K. Importance of physical form rather than viscosity in determining the rate of starch hydrolysis in legumes. *Am J Clin Nutr* 1983; 37: 66–70.