Glycemic and insulinemic responses to carbohydrate rich whole foods

Kasturi Sen Ray · Pooja Ratan Singhania

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Abstract Glycemic and insulinemic responses to food may depend on several intrinsic factors such as the type of sugar, molecular arrangement, size of starch granules, co-components in the whole food like moisture, fat, protein, fiber, as well as external factors like processing technique and total amount consumed. The postprandial glycemic response to equivalent quantities of test food and standard food is compared using Glycemic Index_{food} (GI_{food}). The incremental area under the curve for blood glucose and insulin at fasting, 30, 60, 90 and 120 min after consumption of different doses (50 and 100 g) of carbohydrate rich foods like rice and chapatti were compared with standard food, white bread. The GI_{food} value for 50 g of chapatti and rice was 44 and 11 respectively. The Insulinemic Index_{food} (II_{food}) values, calculated similarly, for 50 g portion of chapatti and rice were 39 and 6 respectively. Glycemic and insulinemic response showed a dose dependent increase from 50 to 100 g. Both glycemic and insulinemic impact of chapatti were found to be significantly higher than that of rice ($p < 0.05$). The GI_{food} and II_{food} values will facilitate qualitative and quantitative judgment about the selection of specific foods for effective metabolic control.

Keywords Whole food · Carbohydrate · Glycemic Index_{food} · Insulinemic Index_{food} · Dose response

Introduction

Carbohydrates (CHO) are classified functionally on the basis of postprandial glycemic effect, depending mainly on the rate of breakdown and absorption of carbohydrate in the intestine. Factors such as amylose to amylopectin ratio of the starch component, percent moisture present, other components like fiber, fat, proteins, processing method, individual gastric emptying time and total amount consumed may affect this postprandial glycemic effect to a large extent. To assess the quality of CHO rich products, Jenkins et al. (1981) developed the concept of “Glycemic Index” (GI). The index is expressed as the percentage increase in blood glucose, produced by specific amount (50 g) of available CHO in a test food as compared to the same amount of available CHO from a reference food such as glucose.

$$GI_{carb} = \frac{\text{IAUC in response to food containing 50g available carbohydrate}}{\text{IAUC in response to 50g glucose or bread}} \times 100$$

Therefore the GI classification is based on a food component (equi-carbohydrate basis) rather than food. In order to obtain equal amount of available CHO, the quantity of foods fed will vary tremendously depending on the concentration of CHO in the specific food. In practical situation food cannot be served according to its CHO content. In the same quantity of food, there are other macro and micronutrients present along with variable amount of moisture.

GI is an absolute value where the dose response effect is not perceived. Unless equal glycemic carbohydrate doses

K. S. Ray · P. R. Singhania
Department of Food Science and Nutrition,
P.G.S.R. (Home Science), SNTD Women's University,
Juhu,
Mumbai 400049, India

P. R. Singhania
e-mail: pisceanpooja@gmail.com

K. S. Ray (✉)
Tata Institute of Social Sciences (TISS),
Deonar,
Mumbai 400088, India
e-mail: kasturisenray@gmail.com

are involved, the GI fails to respond to the changes in the amounts of carbohydrate consumed (Monro 1999).

In order to account for the differences in glycemic response to the amount consumed, the concept of “Glycemic load” (GL) was introduced by Harvard School of Public health in 1997. Glycemic Load is calculated as the product of the glycemic index and the amount of carbohydrate in a serving.

$$\text{Glycemic Load} = \frac{\text{Glycemic Index} \times \text{Total Available Sugar}}{100}$$

But GL again is a mathematical expression and its practical use is still limited because analytically determined available carbohydrate and glycemic carbohydrate are not the same (Monro 2000).

Some foods with high GI may have a low GL. For example, watermelon has a high GI value (Foster-Powell et al. 2002) indicating that the type of sugar present in watermelon is hyperglycemic in nature. However, GL is

low due to its high moisture content. Hence, large amount of this fruit will have to be consumed in order to obtain the proposed high glycemic response in terms of 50 g of available CHO. Regular serving size of watermelon will not increase the postprandial glucose level very high due to its low CHO density.

Expression of carbohydrate quality of food for dietary management must be food based; intake responsive and sensitive to variation in composition of typical diets (Monro 2003). Considering the fact that the interplay of both type and amount of carbohydrates is responsible for the postprandial glycemic effect of specific CHO source, Monro (2003) has introduced the concept of GI_{food} , which compares glucose response to test food with standard food such as glucose or bread on equi-quantity basis (GI_{food}) rather than equi-carbohydrate basis (GI_{carb}). These values can act as a virtual food component responsive to changes in food intake in the same way as a nutrient (Monro 2002).

$$GI_{\text{food}} = \frac{\text{IAUC in response to a relevant food portion}}{\text{IAUC in response to equal weight of glucose or bread}} \times \text{Amount of Food [50/100]}$$

The GI_{food} value can be expressed in gram units and placed besides other nutrients in the food exchange list.

The insulin response to foods also differs with the composition whereby they may or may not be parallel to the glucose response (Holt et al. 1997). Therefore, Insulin Index_{food} (II_{food}) can also be determined in the same way as GI_{food} to categorize carbohydrate rich foods on the basis of equal quantities of foods that elicit similar insulin responses. Such an index will be of significance to the insulin resistant or insulin deficient patients for making appropriate food choices.

The present study aims to establish the GI_{food} and II_{food} value of different quantities of selected food which can be a useful tool in diet counseling in terms of food exchanges that elicit a similar glucose and insulin response.

Materials and methods

Clinically healthy adult subjects ($n=9$) of both sexes were enrolled on the basis of consent to adhere to the experimental requirements. Subjects on any medication were excluded. Written informed consent was taken from all the subjects. Ethics committee (Registered under section 25 of the Companies Act, 1956) approval was obtained.

Food selection Two main staple foods of India such as Rice (white, short grain, kolum variety) and *Chapati* (Indian

flatbread made from whole wheat flour, without fat) were selected for assessment. The food was prepared fresh every time in the morning on the day of the test using the same batch of raw ingredients following standardized procedure.

Experimental design After an overnight fast, subjects were fed 50 g or 100 g of the test foods and equal amount of white bread (Britannia, Daily Fresh) as a reference food on different days, to determine the exchange value of the food with bread. Subjects were given 10 min to complete the given test food portion with drinking water (250 ml) and asked to chew the food thoroughly.

Blood sampling and analysis Venous blood was used for blood glucose estimation using Glucometer (Sugar scan manufactured by HMD Biomedica Inc.) and Serum Insulin levels were estimated using Radio-immuno Assay (Feldman and Chapman 1973). The blood samples were analyzed in duplicates. Blood samples were taken at fasting state (0 min) and at 30, 60, 90, and 120 min intervals after the ingestion of reference food and test food. The subjects were restricted from performing any physical activity during 2 h of study period. The area under curve of each food and bread were calculated per subject. The net incremental area under curve is based on simple application of the trapezoid rule to all the blood glucose increments. Mean total glycemic and insulinoemic IAUC and the peak glycemic and insulin responses as compared to fasting value for test foods and standard food

were compared using Student's *t*-test for paired data. Results were considered as statistically significant at *p* value of <0.05 on two tailed testing.

Chemical analysis The selected foods were analyzed for

- Total, reducing sugar and starch (Lane and Eynon 1923)
- Moisture content—Vacuum oven method (Ranganna 1986)
- Protein—Macro-Kjeldhal method (Marrack 1970)
- Fat—Soxhlet method (Cohen 1971)

Each food sample was analyzed in triplicates.

Results and discussion

The Blood glucose and insulin response of the test foods were compared with equal quantity of standard food—White bread. Based on the glucose response to equiquantity portion of foods, the GI_{food} value was 11 for rice and 44 for chapatti, when bread response was taken as 50.

The peak blood glucose response was seen at 30 min for all the 50 g portions of test foods and returned to baseline within 2 h for bread and chapatti (Fig. 1a). The 30 min peak blood glucose value ($C_{\max}$ mmol/L) and total glycemic effect of Chapatti and bread was found to be significantly higher than that of Rice ($p < 0.05$). The postprandial glycemic response to cooked white rice returned to baseline level as early as 60 min compared to equal quantity of chapatti or bread (Fig. 1a). The time taken for post prandial blood sugar levels to come back to baseline was maximum for chapatti (120 min) followed by bread (115 min) and least for rice (47 min) indicating that total amount of starch present in cooked rice may get utilized faster as compared to chapatti or bread.

Several factors may contribute to the overall blood sugar response to food, such as moisture content, percentage of total solids, amylose to amylopectin ratios, the extent of processing, influence of other components of the food matrix or individual gastric emptying time, etc. (Pi-Sunyer 2002). This indicates that although high starch foods have been promoted for reducing glycemic and insulinemic responses, it is important to note that all starchy foods may not respond similarly and they may not be interchangeable (Lerer-Metzger et al. 1996).

In the present study, it was seen that the postprandial glycemic response of the food increases with an increase in the starch content of food as consumed on wet weight basis, which is similar for bread and chapatti and much lower for cooked rice (Table 1).

Chapatti and Bread have less moisture and more concentrated starch molecules which cause a greater total

Fig. 1 Mean Blood Glucose response curve (a) and total IAU glycemic effect (b) of test foods and bread ($n=9$), * ($p < 0.05$), ** ($p < 0.01$)

glycemic effect whereas rice with very high moisture content has lesser amounts of total starch (Table 1) and a lower total glycemic response as observed in the study (Fig. 1b). In specific amount of food when water content increases, total solid along with carbohydrate concentration decreases. Therefore high water content of the food acts as energy diluent and reduces the glycemic load thereby lowering the postprandial glycemic effect.

The rate of breakdown and release of sugar upon starch hydrolysis in the GI tract varies with the effect of processing on starch granule. In chapatti, the preparation of dough allows for sufficient hydration and swelling of starch granules. During roasting, the dry heat treatment causes dextrinization of starch. These dextrins are low-molecular-weight carbohydrate mixtures containing polymers of D-glucose units linked by $\alpha 1 \rightarrow 4$ or $\alpha 1 \rightarrow 6$ glycosidic bonds which are only second to glucose in causing a rapid increase in the blood sugars (Jones 1920).

The foods tested in the present study showed peak glucose response at 30 min, but for rice; a rapid fall was observed within 1 h of consumption (Fig. 1a). Gelatinization of the starch in presence of enough water allows faster action of alpha amylases. The granules in Rice starch (average size 5 μ m) are smaller and provide a greater surface area for

Table 1 Proximate composition of the test foods

Food product	Moisture	Protein (g%)	Fat (g%)	T.Solid (g%)	Total starch	
					Wet wt. (%)	Drywt. (%)
Bread, white	36.8±3.47	8.4±0.75	0.65±0.05	63.2	33.6±0.61	53.2
Chapatti, whole wheat flour	33.3±2.56	11.1±1.25	2.2±0.68	66.7	34.1±5.69	51.2
Rice, white, cooked	74.3±2.23	6.9±0.76	0.07±0.02	25.7	21.0±0.77	82

Mean ± SD for each sample ($n=3$)

absorption of water, swelling and subsequent enzyme action (Kulp and Ponte 2000). Hence earlier drop in blood sugar level may take place due to possible rapid utilization of smaller amount of starch present in cooked rice.

Starch granules in wheat are arranged more compactly and are larger in size {bimodal size distribution of 25–40 (large lenticular) 5–10 μm (small spherical)} (Li 1999), which causes limited contact with the hydrolytic enzymes. Therefore, lower moisture content, higher total starch and slower action of amylase enzyme due to compact granules of starch in chapatti may be responsible for higher and sustained glycemic response resulting in larger area under the curve.

Proportion of amylopectin:amylose is another factor that affects the postprandial glycemic effect. Amylopectin has a branched structure that makes it more readily digestible than linear chain amylose starch (Van Amelsvoort and Westrate 1992). Rice has relatively greater proportion of amylopectin:amylose (4.4:1) compared to chapatti (3:1), responsible for faster absorption and utilization of the starch. The greater proportion of amylose units in chapatti (25%) compared to rice (18.5%) (Kearsley and Sicard 1989) may be another factor for slower utilization of blood sugar during 2 h post prandial period.

Fig. 2 Dose dependent glycemic response to test foods and bread ($n=9$)

Glycemic response from 50 to 100 g was found to be much higher for chapatti at both 30 and 60 min sample than equal amount of rice. With higher doses (100 g) of bread and chapatti, the blood glucose values did not return to baseline levels even at the end of 120 min (Fig. 2). This provides clear evidence of the fact that even for foods classified as high (e.g. White Rice, potato), medium (whole wheat products) or low GI (most fruits, legumes), the ultimate quantity consumed needs to be regulated. This also emphasizes that GI_{food} is dose responsive which has practical importance in blood glucose management.

Fig. 3 Mean serum insulin response curve (a) and total IAUC insulinemic effect (b) of test foods and bread ($n=9$), $^*(p<0.05)$, $^{**}(p<0.01)$

Boiled white Rice, when consumed in larger amounts (100 g), did show a relative increase as compared to 50 g portion, however, the total glycemic effect continued to be significantly lower than chapatti ($p<0.01$). The total glycemic response to 100 g chapatti was found to be even higher than that of standard- bread (Fig. 1b).

Since both, the type and amount of the carbohydrate present is reflected in the GI_{food} value, it can be used to express food exchanges wherein required quantum of foods with similar glucose responses can be substituted for each other.

Insulin response

The glucose and insulin concentrations in post prandial state influence metabolic control hence it is important to study their independent effects with different carbohydrate containing foods. The insulin response to equal quantities of test foods was compared with that of bread upto 2 h.

The peak insulin response was attained at 30 min for all foods and remained above baseline even after 120 min for chapatti whereas with Rice; the insulin levels dropped to near baseline by the end of 1 h itself producing a very flat curve (Fig. 3a). The 30 min (C_{max} mmol/L) and 60 min blood insulin response to rice was significantly lower than that of equal quantity of chapatti and bread ($p<0.05$). The duration of postprandial insulin level to come back to fasting level was about 66 min with rice, however for chapatti and bread longer time was required for insulin levels to reach baseline (>120 min). Insulin secretion in response to blood glucose levels occurs in larger quantities (to initiate negative feedback mechanism) and requires longer time to return to fasting levels.

Total insulinemic effect of 50 g chapatti is significantly higher ($p<0.01$) than that of equal quantity of rice (Fig. 3b). The total insulinemic effect of 100 g portion for Rice and Chapatti was found to be almost twice that of 50 g (Fig. 3b). Clearly, the 2 h postprandial IAUC for insulin response of 100 g chapatti was also significantly higher than that of rice ($p<0.01$). The observed high insulinergic effect of chapatti can be attributed to its high glycemic response and higher protein content compared to rice (Table 1) as amino acids in protein potentiate glucose-induced insulin secretion (Rabinowitz et al. 1966).

Higher insulinemic effect of chapatti may be a concern in insulin deficient or insulin resistant individuals who cannot cope with the increased demand for insulin which causes stress on pancreatic beta cells. This stark difference observed between insulin responses of Rice versus Chapatti indicates that Rice may be a better food for insulin resistant or insulin deficient patients.

Conclusion

The Glycemic Index can predict responses when equi-carbohydrate comparisons are made and GL may help to differentiate acute impact of varying amounts of carbohydrate but not food. GI_{food} value can facilitate both quality and quantity based selection of whole foods.

Whole wheat Chapatti with its high density of dextrinized starch (fresh weight basis) showed high and sustained postprandial blood glucose response whereas the moisture rich gelatinized molecules of starch in cooked white rice produced a very low postprandial glycemic effect.

It is interesting to note that both, rice and chapatti, belonging to the same food group (cereals) considered as carbohydrate rich foods differ in their impact on blood sugars to such a large extent justifying the need to classify foods based on the form and quantities as consumed by individuals.

The insulin responses were found to follow the same trend as the glycemic response for both rice and chapatti with varying doses as well. However, the insulinergic effect of chapatti was very high while rice produced a small and flattened insulin response. The lower insulin response can help to improve long term metabolic control in the insulin resistant or insulin deficient patients.

GI classifies foods on equi-carbohydrate basis, wherein Rice ($GI=72$) (Foster-Powell et al. 2002) is classified as high glycemic index food and chapatti ($GI=45.1$) (Radhika et al. 2010) is considered as low GI food whereas GI_{Food} values for whole food comparisons on equi-quantity basis (50 g), is found to be much lower for Rice ($GI_{\text{Food}}/50 \text{ g}=11$) as compared to wheat chapatti ($GI_{\text{Food}}/50 \text{ g}=44$). Thus, GI_{food} value (expressed in gram units) can be useful for consumer friendly food labeling and practical nutrition counseling.

References

- Cohen EH (1971) Rapid technique for solvent removal in the determination of fat. *J Assoc Off Anal Chem* 54:212–214
- Feldman JM, Chapman BA (1973) Radioimmunoassay of Insulin in Serum and Plasma. *Clin Chem* 19:1250–1254
- Foster-Powell K, Holt Susanna HA, Brand-Miller JC (2002) International table of glycemic index and glycemic load values: 2002. *Am J Clin Nutr* 76(1):5–56
- Holt Susanne HA, Brand Miller JC, Petcoz P (1997) An Insulin Index of foods: the insulin demands generated by 1000 kJ portions of common foods. *Am J Clin Nutr* 66:1264–76
- Jenkins DJ, Wolever TM, Taylor RH, Barker H, Fielden H, Baldwin JM, Bowling AC, Newman HC, Jenkins AL, Goff DV (1981) Glycemic index of foods: a physiological basis for carbohydrate exchange. *Am J Clin Nutr* 34(3):362–6
- Jones MR (1920) Studies on carbohydrate metabolism in rabbits. II. Effect of carbohydrate feeding on blood sugar. *J Biol Chem* 43 (2):507–519

- Kearsley MW, Sicard PJ (1989) The chemistry of starches and sugars present in food. In: Dobbing J (ed) *Dietary starches and sugars in man: A comparison*. Springer Verlag, Berlin, p 4
- Kulp K, Ponte JG Jr (2000) *Handbook of cereal science and technology*, vol 99, 2nd edn. Marcel Dekker, Inc, New York, p 389
- Lane JH, Eynon L (1923) Determination of reducing sugars by means of Fehling's solution with methylene blue as internal indicator. *J Soc Chem Indust* 42:32T–37T
- Lerer-Metzger M, Rizkalla SW, Luo J, Champ M, Kabir M, Bruzzo F, Bornet F, Slama G (1996) Effect of long-term low-glycaemic index starchy food on plasma glucose and lipid concentrations and adipose tissue cellularity in normal and diabetic rats. *Br J Nutr* 75:723–732
- Li BW (1999) Determination of complex carbohydrate fractions in foods In: *Complex carbohydrates in foods*. Susan Sungsoo Cho, Leon Prosky, Mark Dreher (ed). Marcel Dekker, Inc., New York, Basel p 150–151
- Marrack D (1970) Improved equipment for macro Kjeldahl nitrogen assay in human metabolic balance studies. *Lab Pract* 19(3):291–2
- Monro JA (1999) Available carbohydrate data and glycemic index combined in new data sets for managing glycaemia and diabetes. *J Food Comp Anal* 12:71–82
- Monro JA (2000) Evidence-based food choice: the need for new measures of food effects. *Trends Food Sci Technol* 11:136–144
- Monro JA (2002) Glycemic glucose equivalent: combining carbohydrate content, quantity and glycemic index of foods for precision in glycemia management. *Asia Pac J Clin Nutr* 11:217–225
- Monro JA (2003) Redefining the glycemic index for dietary management of postprandial glycemia. *J Nutr* 133:4256–4258
- Pi-Sunyer FX (2002) Glycemic index and disease. *Am J Clin Nutr* (suppl) 76:290S–298S
- Rabinowitz D, Merimee TJ, Maffezzoli R, Burgess JA (1966) Patterns of hormonal release after glucose, protein and glucose plus protein. *Lancet* 2:454–6
- Radhika G, Sumathi C, Ganesan A, Sudha V, Jeya Kumar Henry C, Mohan V (2010) Glycaemic index of Indian flatbreads (rotis) prepared using whole wheat flour and 'atta mix'-added whole wheat flour. *Br J Nutr* 103(11):1642–7
- Ranganna S (1986) Proximate composition. In: *Handbook of analysis and quality control for fruit and vegetable products*, 9th edn. Tata McGraw Hill Publishing Company Ltd, New Delhi, p 3, 5, 12–15
- Van Amelsvoort JM, Westrate JA (1992) Amylose- amylopectin ratio in a meal affects postprandial variables in male volunteers. *Am J Clin Nutr* 55:712–718