Food related factors that affect the glycaemic response and glycaemic index of foods

Sagarika Ekanayake

Abstract

Common modifiable risk factors such as unhealthy diet, physical inactivity and tobacco use associated with urbanization and lifestyle changes and an aging population, give rise to the intermediate risk factors such as overweight/obesity, hyperglycaemia, hypertension and hyperlipidaemia the stepping stones to the main chronic non communicable diseases (NCDs) such as heart disease, stroke, cancer, diabetes etc. Unhealthy dietary food habits especially increased intake of highly refined carbohydrates is identified as one major factor for the increase in nutrition related non communicable diseases (NCDs) in Sri Lanka. In this context glycaemic index (GI) of foods is important as this reflects how food carbohydrates affect the glycaemic response and thus energy intake and as GI can be used to select food ingredients, foods for consumption and also healthy food production.

Analysis of different starchy foods commonly consumed by Sri Lankans clearly indicated that raw red or white rice or red or white (samurdhi) basmati elicited high GI. Parboiling decreased the GI. Mixed rice meal contribute to lower the GI decreased. The same observation was seen with bread where a mixed meal produced a lower GI. Hoppers, string hoppers and pittu when made with rice or wheat flour and consumed as a mixed meal produced high GIs. However, when millet flour was introduced to pittu the GI decreased to medium. Roti irrespective of flour variety used produced a low GI. Boiled legumes, Dioscorea alata (purple) tubers and green leafy porridges produced low GI due to varied reasons.

When considering the GIs obtained for different foods, the dietary components, processing method and particle size of flour used in food preparation were identified as major factors contributing to the different GIs. Food or meal components; i.e dietary fibre, moisture and protein contents affected the glycemic response. The effect of increased dietary fibre and protein was responsible for the lower GI in mixed meals and legumes. The increased moisture in green leafy porridges contributed to decrease the GI. Wet processing (boiling) compared to dry processing (roasting) increased GI. This was clearly demonstrated by the high GI in pittu and string-hoppers which were wet processed and low GI in roti. Another factor that contributes to high GI was the particle size of the flour used in food preparations. This was seen when the GI of foods made with flour produced with different particle sizes elicited different GIs. Higher the particle size lower was GI. Extrusion also contributed to increase the GI of foods. However, the contribution of each of above factors to GI in each food would be different and will depend on the accompaniments added, the processing technique the food is subjected to and the properties of starch granular structure as well.
Thus when selecting food, preparing meals or in industrial food production careful selection of foods or ingredients and combination of high GI foods with medium or low GI foods, controlling the processing and increasing the particle size could be used to control the carbohydrate intake and hence the glycaemic response which will prevent/control insulin resistance and associated complications leading to NCDs.

Keywords: Food, glycaemic index, glycaemic response, dietary fibre, processing, particle size
Introduction

Common modifiable risk factors such as unhealthy diet, physical inactivity and tobacco use associated with urbanization and lifestyle changes and an aging population, give rise to the intermediate risk factors such as overweight/obesity, hyperglycaemia, hypertension and hyperlipidaemia the stepping stones to the main chronic non communicable diseases (NCDs) such as heart disease, stroke, cancer, diabetes etc. worldwide. Unhealthy dietary food habits especially increased intake of highly refined carbohydrates is identified as one major factor for the increase in nutrition related non communicable diseases (NCDs) in Sri Lanka.

In this context glycaemic index (GI) which ranks starchy foods according to their potential to raise the blood glucose levels is important as this reflects how the food carbohydrates affect the glycaemic response. GI concept is applied to foods providing 15g-20g or more of glycaemic carbohydrates per portion and is determined by consuming food portions containing 50 g of digestible carbohydrates. Thus GI reflects the glycaemic response of different foods to the same amount of carbohydrate; thus the quality of the carbohydrates in that particular food. Depending on the blood glucose raising potential, carbohydrates rich foods are classified as low (GI≤55), medium (56 ≥GI≤69) or high (GI≥70) GI foods. GI values are also used to calculate the glycaemic load (GL; quantity) of an edible portion of starchy food in a diet. GL is useful as sometimes the actual carbohydrate load from a normal portion is not similar to a 50g digestible carbohydrate containing portion. The actual blood glucose levels are determined by the GI of the carbohydrate (quality) & quantity (GL) of the carbohydrate in edible portion.

Low GI foods are digested slowly and release glucose gradually into blood which facilitate higher extraction of carbohydrates from liver & periphery and gives rise to low glucose peaks which in turn demands a low insulin dose compared to high GI foods thus decrease the incidence of insulin resistance and development of intermediate risk factors such as obesity, hypertension, the key factors responsible for development of above mentioned nutrition related NCDs. Consumption of low GI /GL diets has shown to decrease obesity, lower the risk of diabetes type 2, reduce insulin resistance and risk of coronary heart diseases and certain cancers.

Glycaemic indices of Sri Lankan foods

Analysis of different rice clearly indicated that raw rice elicited high GI (white [81] or red [80]). Red or white (samurdhi Sri Lankan variety) basmati and Samba variety elicited high [both 73] and medium GI [66] respectively. A parboiled Nadu variety had the lowest GI [40] indicating the suitability of parboiled rice in the dietary regime of individuals with chronic NCDs. When a red raw rice was given with other accompaniments (egg, green leafy vegetable, lentil curry, gravy) the GI decreased by 39% (low GI = 47). GL for a normal portion size of red basmati was lower
when compared to the white basmati variety (>37) studied due to high fibre in red variety. Rice mixed meal had the most desirable GL [16] indicating the suitability of a mixed meal in controlling the glycaemic response (Figure 1). When the GI and insulin index of red rice mixed meal were determined in diabetic individuals, higher values (64; medium GI) than obtained with healthy individuals were observed but indicating good glycaemic control.

![Figure 1. Glycaemic responses of red raw rice only and red raw rice mixed meal](image)

Bread (white, brown) consumed without any accompaniments had high GI [77 and 76] and high GL. However, the actual portion size that a person could consume contained a less carbohydrate load (GL= 16). Brown bread eaten alone elicited a high GI which when given with a dhal curry produced a medium GI [61] causing the GI to decrease. Though the GL was high in all three varieties, the metabolic response (lower peak eliciting lower insulin response) to the same carbohydrate load was better in the mixed meal as seen with rice.

GI [90] and GL [45] of hoppers were high and the portion size was considered not adequate by the participants. Thus the GL of hoppers would be much higher and is not a suitable food for daily consumption as this would induce a high insulin response. Roti, irrespective of the flour used (wheat, rice, millet) in the preparation elicited low GI [<55]. Among different roti, millet roti elicited the lowest GL due to high DF which decreased the digestible carbohydrate in a portion and induced satiety. Irrespective of flour (rice or wheat) used in preparation and when given with as many accompaniments as with red raw rice meal, string hoppers elicited a high GI [79 and 72] and high GL which were similar to that of brown bread. Compared to string hoppers, rice mixed meal where the GL as well as the glucose peaking after the meal was lower produce a better metabolic response.

Pittu when prepared using wheat or rice flour elicited high GI [75 and 76] and high GL (>38) even for a normal portion. When millet was used in the preparation, GI [64] and the GL [edible portion < 20] both decreased due to the high DF which makes the normal edible portion smaller.
by inducing satiety and decreasing digestible carbohydrate. Ingestion of millet *pittu* gives a better glycaemic profile with a lower peaking. Addition of other accompaniments (curries) may lead to further lowering the GL.

Among the many tubers studied *Diascorea alata* (purple), consumed as a traditional breakfast with coconut scrapings elicited low GI [48] and contained more protein (9%) and polyphenols in contrast to manioc which gave a high GI [86]. In contrast to popular belief, jack fruit and breadfruit eaten with coconut as a meal elicited lower GI [<55]. Thus addition of starchy fruit vegetables as accompaniments in a meal will not contribute to a higher glycaemic response and is suitable in a diabetic meal.

Boiled legumes, chickpea, cowpea and green gram when consumed as breakfast had low GI [<55] and constituted a low GL [<10]. Incremental increase in blood glucose was low leading to lower insulin demand. The incorporation of green gram when making milk rice decreased the GI [<70] when compared to milk rice made without green gram. Porridge made with different green leaves elicited a low GI [<55] and low or medium GL (<19] and good satiety thus proving the health benefits of these in dietary management. Further studies with diabetics have shown that *Scoparia dulcis* leaves incorporated porridge to be superior in controlling diabetic parameters and led to produce a marketable product.

**Factors affecting GI of foods**

**Components in food/meal**

The presence of other food or dietary components in a meal can affect the glycaemic response. When considering raw rice the GI of different varieties was not affected as the dietary fibre in whole grain itself is not adequate to cause an effect on GI thus all rice eliciting high or medium GI. Since parboiled rice had high dietary fiber (14%) due to the processing (retrograded starch) it is subjected, the GI was low.

Likewise, when rice or bread is consumed as a meal the dietary fibre and different sources of starch in different components contributes to lower the GI. Increased dietary fibre (DF) content had shown to reduce the GI of Sri Lankan rice mixed meal. Dietary fibre was also causative in lowering the GI of *pittu* made with millet flour and to a certain extent in legumes. Dietary fiber by delaying gastric emptying and absorption of carbohydrates and also by increasing satiety contributes to decrease the GI.

Generally, the dietary fibre content in Sri Lankan foods has shown to be negatively correlated with GI indicating if the diet is properly formulated we might be able to add adequate fibre to have beneficial effects. The correlation was more significant with IDF than with SDF indicating
that the soluble dietary fibre in our meals to be less. Studies had further shown the benefits of both the increased quantity and sources of fibre in rice meals.

The impact of protein content in a meal on GI was not apparent when food groups with low protein, such as green leafy porridges, manioc and rice only were considered. Nevertheless, in high protein foods/meals such as legumes, mixed rice meal or green gram milk rice whose protein content was high had a GI lowering effect. The reason could be that 25g protein/50g digestible carbohydrate portion is required to cause a significant effect on the GI. Thus increased consumption and incorporation of legumes/legume flour in food production should be encouraged as a healthy option.

Though it is reported that fat in a food/meal contributes to decrease the GI when the total fat content in Sri Lankan foods or meals were considered no such correlation was observed. This is an indication that the fat content in a Sri Lankan diet is not adequate to make an impact on the carbohydrate digestion and absorption and hence the GI. This clearly indicates that major source of energy is carbohydrates and therefore to reduce the incidence of NCDs more attention needs to be paid to the carbohydrates in our diet.

The moisture in a food is a major factor that determines the portion size thus the glycaemic load. Higher the moisture the lower will be the portion size. This was seen with different cooked rice varieties where the moisture increased in order of white basmati < nadu < samba and a 50g carbohydrate containing portion size increased as 150g > 200g > 225g. The participants found the portion not adequate for white basmati which had the lowest moisture but nadu and samba portion sizes were considered adequate. Thus the moisture in a food will also be a major factor in determining the glycaemic load and hence the glycaemic response. The high water (> 80%) content in green leafy porridges contributed to the low GI.

Above observations clearly indicated the importance of addition of other accompaniments to the carbohydrate staple as these would contribute to lowering of the GI by virtue of reducing the portion size of starchy staple and addition of other nutrients which helps in reducing GI.

**Processing method**

In addition to other components such as mentioned above, the processing method is also important in determining the GI of a food. Wet processed foods such as pittu (steaming), rice, string-hoppers, manioc tends to have a higher GI compared to dry processed food such as roti, if any other factor does not contribute to lower the GI. The high GI of wet processed foods is due to increased disintegration of the starch granule and gelatinization of the starch due to high temperature and presence of water. This was apparent when the starch granules of raw wheat flour and roti and pittu made with wheat flour were compared (Figure 2). A clear correlation
between starch granule destruction and GI was observed. Thus excessively wet processed foods may lead to higher glycaemic responses.

![Figure 2](image)

Figure 2. Iodine stained starch granules (a) wheat flour (b) wheat *pittu* flour [GI 75] (c) wheat *roti* flour [GI 54] made using the same composition (10 x 10)

However, though wet processed, legumes and *Diascorea alata* tubers were exceptions to the above as these elicited low GI [<55]. On examination of flour (starch) microscopically it was observed that the starch granules were protein/cell enclosed. This delays the digestion of starch leading to a lower GI. Thus the effects due to wet processing of the starchy staple can be overcome to a certain extent by addition of foods rich in dietary fiber and protein as seen in the case of rice only and mixed rice meal. However, if the processing is excessive as in string-hoppers this may not be possible and it would be advisable to consume these foods less frequently.

**Particle Size**

Particle size of flour used in food preparation was another factor that was identified as affecting the GI. This was illustrated when two flour samples of millet, one made using the traditional stone grinder and the other produced with an industrial mill were used in food preparation. The composition of *roti* and *pittu* was the same except for the milling method of flour.

![Figure 3](image)

Figure 3. Blood glucose response of *roti* and *pittu* made with differently milled millet flour
A significant reduction in GI (p < 0.05) was observed when stone ground flour was used in both roti (44 against 59 of roti made with industrially milled flour) and pittu (67 against 79 of pittu made with industrially milled flour) preparation (Figure 3). This was due to the different particle size distribution observed in the two flours where the stone ground flour had a higher particle size distribution (0.1mm or larger = 30%, 0.05mm = 35%, smaller than 0.05mm = 35%) compared to industrially milled flour (0.1mm or larger = 23%, 0.05mm = 30%, smaller than 0.05mm = 47%).

A similar observation was made when a herbal porridge (rice, Scoparia dulcis leaves, coconut scrapings) was commercially produced. When the rice portion was introduced as flour the GI of the product was high (>90). When only a portion of rice was extruded and the other portion was introduced as cooked whole grain into the porridge a significant decline in GI was observed in both normal (58) and diabetic individuals (61) with the decline in blood glucose peak being more significant in diabetics and the only difference in the porridges was rice particle size.

Conclusion & recommendations

It is important to create more awareness and knowledge among sedentary workers susceptible to develop obesity and related complications, regarding the intake of only adequate portion size of the staple carbohydrate in a meal in order to control the energy intake. Also when selecting, purchasing food to opt for healthier options and include a variety of nutritionally balanced accompaniments to the starchy staple. This includes using less refined cereal grains or flour made with whole grains or legume flour in food preparation instead of refined flour. It would be preferable if flour can be milled or ground at household level so that the particle size could be controlled. Public should be educated on the importance of higher intake of energy-dilute foods (i.e. vegetables and fruits) and foods high in dietary fiber (i.e. wholegrain cereals) as these contributes to a reduced calorie density and increase micronutrient and phyto-nutrient intake and contributes to increase K⁺ intake. As processed ready to cook foods are likely to be a substantial part of the diet in the future, it is necessary to encourage food producers to include novel and new food ingredients in foods to reduce the GI of foods. Advocate the producers of cereal or millet flours to produce flours of higher particle size (adjusting the mesh sizes of industrial mills) and decrease starch availability (roasting of the ground flour before packaging).

Many factors inherent to starchy foods and the processing the foods are subjected to contributes to the glycaemic response and hence the GI of a food. Thus when selecting food, preparing meals or in industrial food production careful selection of foods and combination of high GI foods with medium or low GI foods, controlling the processing and increasing particle size could be used to control the carbohydrate intake and hence the glycaemic response.
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• **Author’s biography (200 words)**

Prof Sagarika Ekanayake B Sc (Hons), M Phil, Ph D, C Chem, F I Chem C is currently attached to the Department of Biochemistry, Faculty of Medical Sciences, University of Sri Jayewardenepura. An academic and a researcher with over 22 years experience and a visiting lecturer in many state and private sector universities and higher education institutes in Sri Lanka and is listed under Marquis’s Who’s Who in the World 2014. Produced many postgraduates during the last 09 years and published over 50 research articles in international and national peer reviewed journals and over 115 abstracts on topics related to Food Chemistry, Applied Nutrition, Bioactivity studies and Clinical Biochemistry. Research has been honored with Dr C L De Silva gold medal (Institute of Chemistry, Ceylon; 2013), many presidential awards for research publications, awards for best presentations at many national and international scientific fora, Young Scientist Forum Research excellence award (2009) and awards for research supervision (2009, 2010).

• **Author’s postal and email address**

Department of Biochemistry  
Faculty of Medical Sciences  
University of Sri Jayewardenepura  
Nugegoda  
Sri Lanka  
sagarikae@hotmail.com