

## Glycaemic & insulinaemic responses in men at rest following sago meal

Hishamuddin Ahmad, Rabindarjeet Singh & Asok Kumar Ghosh

*School of Medical Sciences, Universiti Sains Malaysia, Kelantan, Malaysia*

Received February 7, 2006

**Background & objective:** Sago (*Metroxylum sagu*) is one of the main sources of native starch. In Malaysia sago dishes are commonly eaten with sugar. However, other societies use sago as a staple food item instead of rice or potato. The study was undertaken to investigate the effect of ingestion of different physical forms of sago supplementation on plasma glucose and plasma insulin responses, as compared to the white bread supplementation in man, during resting condition.

**Methods:** Twelve male subjects were given in random order with three different physical forms of a sago supplementation, *viz.*, sago porridge (SR), sago paste (SP), sago gel (SG) and white bread (WB) which was repeated on separate days, at least, 1 wk apart after an overnight fast. Venous blood samples were collected at baseline and at 15, 30, 45, 60, 90, 120, 150 and 180 min after the start of each meal and were analyzed for plasma levels of glucose and insulin.

**Results:** Plasma glucose reached peak at 45 min after supplementation of various sago meals. Plasma glucose area under the curve (AUC) for WB was significantly lower than SG but not significantly different from SR and SP. No significant difference was observed in plasma glucose AUC among the three sago meals. Plasma insulin AUC for SG was significantly higher than WB and SR. All three sago meals tested were not significantly different in their glycaemic responses. However, the insulin response was significantly lower for SR compared to SP and SG.

**Interpretation & conclusions:** The present findings suggest that any one of the three sago meals tested in this study may be used to elucidate the effect of sago starch ingestion on exercise performance in the heat. Sago paste and sago porridge may be used for supplementation before and during exercise, whereas, sago gel may be used after endurance exercise during recovery process.

**Key words** Glycaemic response - humans - insulinaemic response - sago gel - sago paste - sago porridge - white bread

Carbohydrate (CHO) supplementation before and/or during prolonged exercise can delay muscular fatigue and enhance work output<sup>1-3</sup>. This improvement in exercise performance and maintenance of power output has been suggested to be due to the maintenance of high

plasma glucose concentrations throughout exercise<sup>2-4</sup>. A high glycaemic index meal results in greater muscle glycogen storage than a low glycaemic index meal in overnight fasting individuals with normal glycogen concentration<sup>5</sup>. Sports scientists generally recommend

CHO-rich foods with low GI before prolonged exercise<sup>6-8</sup> which reduces the dependency on endogenous CHO at the onset of exercise and to maintain euglycaemia for a longer period during exercise<sup>9</sup>. Fat oxidation rates are higher during exercise after the low GI meals than after the high GI meals<sup>8</sup>. CHO-rich foods with moderate to high GI are recommended during exercise to promote muscle CHO uptake and utilization<sup>10</sup> and during the post-exercise recovery period to promote the restoration of muscle glycogen<sup>11,12</sup>.

Sago (*Metroxylon sagu*) is one of the main sources of native starch. In Malaysia sago dishes are commonly eaten with sugar. However, other societies use sago as a staple food item instead of rice or potato. The sago palms grow all over Southeast Asia, and are used as staple foods in places where there is insufficient rain to grow wet rice. In India, it is used as 'sabudana'. In Sarawak, Malaysia, sago is widely used to produce sago pearls and "tabaloi", a local biscuit delicacy. Sago pearls can be boiled, either alone or mixed with other foods, and consumed directly as a carbohydrate source. Sago is also widely used, together with rice, corn and potatoes, in the manufacture of noodles in Malaysia<sup>13</sup>.

However, data on plasma glucose and insulin responses after oral ingestion of any physical form of sago meals are scanty. Previous studies exhibited that some varieties of starches were better than other simple CHO such as glucose in maintaining higher CHO availability during exercise<sup>10,14,15</sup>. Hence, the present study was undertaken to investigate the glycaemic and insulinaemic responses of three different physical forms of a sago based CHO supplementation as compared to white bread meal at rest in humans.

### Material & Methods

**Subjects:** This study was performed in Sports Science Unit, School of Medical Sciences, Universiti Sains Malaysia, Kelantan, Malaysia during April 2004-March 2006. Twelve male subjects gave written consent to participate in this study. All the subjects were students from Universiti Sains Malaysia and used to do physical activities like jogging, playing recreational games at least twice a week. All the subjects were non-smoking and normoglycaemic (glycosylated haemoglobin, 4.8-5.9 and fasting blood sugar, <5.6 mmol/l)<sup>16</sup>. The sample size was calculated using PS Power and Sample Size Calculation version 2.1.30. The power of the study was set at 80 and 95 per cent confident interval. The calculated sample size was 12 subjects including the

drop out rate at 2 per cent. The study was approved by the Ethical and Research Committee, Universiti Sains Malaysia. The age, height, weight, body mass index and fasting glucose values were  $27.8 \pm 1.9$  yr,  $1.70 \pm 0.01$  m,  $63.5 \pm 2.1$  kg,  $21.9 \pm 0.7$  kg/m<sup>2</sup> and  $4.7 \pm 0.1$  mM/l (mean  $\pm$  SEM), respectively.

**Test foods preparation:** Sago starch in the form of sago pearls were procured from a local store. Proximate compositions of the sago pearls were determined using the AOAC official methods of analysis<sup>17</sup>. Three physical forms of sago meals, like sago porridge, sago paste and sago gel, have been prepared from these sago pearls. Specific sago meal supplemented each day was prepared fresh for oral ingestion. Similar artificial flavouring and natural sweetener have been used for preparation of these sago starch meals. From these preparations a portion providing 50 g of CHO (801-834 g) was consumed by each subject.

**Sago porridge (SR):** 60 g sago pearls were soaked in 790 ml distilled water and left to stand for 10 min. Thereafter the mixture was steam cooked for 25 min. Stirring of this mixture was done for about 2 min after 20 min of cooking. At the end of cooking, 7 ml artificial flavour (orange essence 19232, Sim Company Sdn. Bhd., Penang, Malaysia) and 0.8 g natural sweetener (SWETA, Stevian Biotechnology Corporation, Seremban, Malaysia) were added and left to cool to room temperature.

**Sago paste (SP):** 60 g sago pearls, were ground into powder and soaked in 390 ml distilled water for 10 min. The mixture was then steam cooked for 25 min. After 20 min, this mixture was stirred for about 2 min. After 25 min of cooking, the cooked sago was immediately transferred to blender jug containing 400 ml cool distilled water, artificial flavour and sweetener. This mixture was then blended at high speed for 3 min and left to cool to room temperature.

**Sago gel (SG):** 60 g sago pearls were ground into powder and soaked in 790 ml distilled water for 10 min. The mixture was then steam cooked for 25 min with stirring done after 20 min of cooking. At the end of cooking, artificial flavour and sweetener were added and left to cool to room temperature. Sago gel was a little thicker than the other two sago preparations.

**Reference food:** Commercially available white bread (WB) (Gardenia Bonanza, Gardenia Bakeries Sdn. Bhd., Kuala Lumpur, Malaysia) was used as the reference meal. The breads were purchased fresh on

each testing day. On test days involving the ingestion of WB, each subject was given 94 g of WB (providing 50 g of CHO) and 240 ml distilled water for ingestion. White bread was used instead of glucose as a reference food<sup>18,19</sup> because it was considered more palatable and was thought to correlate to insulin secretion better than glucose<sup>20,21</sup>.

**Experimental protocol:** Each subject undertook one supplementation trial of each sago meal and 3 supplementation trials of the reference meal. The reference meal supplementations were done at the beginning, middle and end of the series of tests, with the order of the sago meals supplementation randomized between the reference meals. Each supplementation trial was separated by at least one week. During the period of the study, the subjects were asked to conform to the same daily activities and usual self-selected regular diets between the experimental studies of each sago meal and reference food. The regular food intake of these subjects included a balanced diets comprising of rice, vegetables and either fish or chicken. After an overnight fast beginning at 2100 h, the subjects arrived at the laboratory and an indwelling cannula (22G, 1", Vasocan, B. Braun, Melsungen AG) was inserted into a superficial forearm vein for repeated blood sampling. The cannula was kept patent by flushing with 1.0 ml of heparinized saline (10 IU heparin sodium in 1 ml 0.9% NaCl, B. Braun, Malaysia). Subjects then entered the experiment room at 0800 h where they rested in a semi-supine position until the experiments began at 0900 h. Fasting blood samples (4 ml) were drawn and following this, subjects ingested one of the test meals. After oral ingestion, blood samples (4 ml) were collected at 15, 30, 45, 60, 90, 120, 150 and 180 min. All procedures were performed at a temperature of 25°C with relative humidity 60 per cent. After completion of each test, the subjects provided a written record of their overall preference for a specific test food.

**Blood glucose and insulin analysis:** From each blood sample 2 ml of was anti-coagulated with sodium fluoride oxalate for the analysis of glucose and 2 ml with lithium heparin for the analysis of insulin. These samples were then spun in a centrifuge at 1145 g for 10 min at 4°C (Rotina 46 RS, Hetteich Zentrifugen, Germany). The supernatant was stored at -80°C (ULT Freezer, Thermo Forma, USA) for later analysis of plasma glucose using the GOD-PAP method (Randox, UK) and chemiluminescent immunometric assay for the quantitative measurement of insulin (IMMULITE, DPC, USA). All specimens for a given subject

were analyzed in duplicate and the mean value was recorded.

**Calculation of the incremental area under the curve (AUC):** The positive incremental area under the plasma glucose and insulin response curve (AUC) for the 180 min test period was calculated using the method described previously<sup>18</sup>.

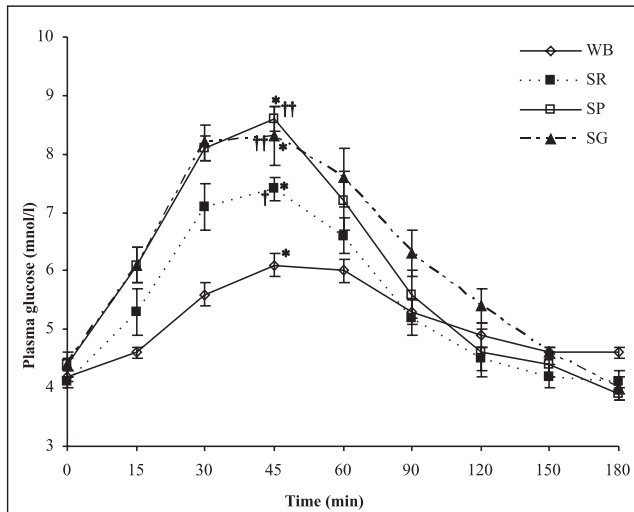
**Statistical analysis:** Two way repeated measure ANOVA (meal x time) followed by Tukey post-hoc analysis was applied to observe the significant difference at  $P < 0.05$  level in plasma glucose and plasma insulin responses for different sago meals treatment. One-way ANOVA was used to observe overall significant differences among the AUC for plasma glucose and insulin, peak plasma glucose and insulin responses. When the ANOVA result was significant, Tukey HSD post-hoc test was used for multiple comparisons. Subjects' preferences for a specific test food were analyzed using frequency table. Statistical treatments were done with SPSS 12.0.1 for Windows (SPSS Inc. Chicago, IL).

## Results

Proximate compositions of sago (dry) and the white bread used in this study are shown in the Table. The sago pearl contained 87.3 per cent CHO. There were no significant differences in the baseline plasma glucose concentrations in subject on different sago meals and WB. Plasma glucose concentrations significantly increased above their respective baseline values ( $P < 0.001$ ) after 45 min of ingestion of all the foods. At this time point, peak glucose (Mean  $\pm$  SEM) values were  $6.1 \pm 0.2$  mM/l for the WB,  $7.4 \pm 0.2$  mM/l for SR ( $P < 0.001$  vs WB),  $8.6 \pm 0.2$  mM/l for SP ( $P < 0.001$  vs WB) and  $8.3 \pm 0.5$  mM/l for SG ( $P < 0.001$  vs WB). The peak plasma glucose responses for all the sago meals were significantly higher ( $P < 0.001$ ) than that of the white bread. No significant difference existed among the peak plasma glucose responses of all the three sago meals (Fig. 1). Except for WB, plasma glucose concentrations returned to baseline at 150 min after each of the different sago foods. Plasma glucose AUC for WB ( $170 \pm 14$  mM/l at 180 min)

**Table.** Proximate composition (g/100g) of white bread (reference food) and sago pearls (average of 3 determinations)

Component	White bread	Sago pearls
Carbohydrates	57.19	87.3
Moisture	31.03	11.00
Protein	8.70	0.20
Fat	3.09	0.10
Ash	1.84	0.10
Crude fiber	2.15	0.20



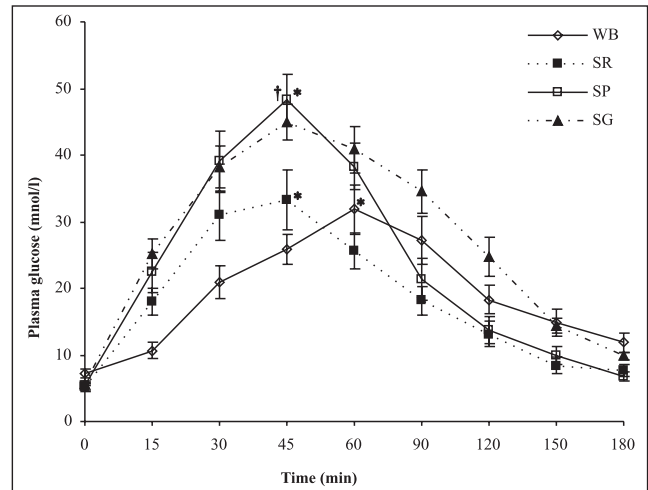
**Fig. 1.** Plasma glucose responses after supplementation of 50 g portions of the sago meals and white bread. Values are mean  $\pm$  SEM (n=12 subjects). SR, Sago porridge; SP, Sago paste; SG, Sago gel; WB, White bread.

\* $P < 0.001$  compared to respective baseline values

$P < 0.01$   $^{††} < 0.001$  compared to WB.

was significantly lower than SG ( $314 \pm 38$  mmol/l at 180 min,  $P < 0.01$ ) but not significantly different from SR ( $233 \pm 24$  mmol/l at 180 min) and SP ( $270 \pm 38$  mmol/l at 180 min). There was no significant difference in plasma glucose AUC between the three different sago foods.

The baseline plasma insulin concentrations of the test foods and reference food did not differ significantly. Like plasma glucose, plasma insulin reached peak at 45 min post-prandial for the all the different sago foods. But for the WB, the peak value reached at 60 min (Fig. 2). Comparing all the test foods, SP exhibited the highest peak plasma insulin response ( $48.3 \pm 3.8$   $\mu$ IU/ml) which was significantly higher than WB ( $31.9 \pm 3.7$   $\mu$ IU/ml,  $P = 0.001$ ) and SR ( $33.2 \pm 4.5$   $\mu$ IU/ml,  $P < 0.001$ ) but not from SG ( $44.9 \pm 2.7$   $\mu$ IU/ml). Plasma insulin concentrations for the different sago meals declined thereafter with SP showing a significant decline at 60 min ( $38.3 \pm 3.6$   $\mu$ IU/ml,  $P < 0.001$ ) while the decline for SR ( $25.6 \pm 2.8$   $\mu$ IU/ml) and SG ( $40.8 \pm 3.5$   $\mu$ IU/ml) was not significant. Plasma insulin AUC for SG ( $3920 \pm 348$   $\mu$ IU/ml at 180 min) was significantly higher than WB ( $2282 \pm 270$   $\mu$ IU/ml at 180 min,  $P < 0.001$ ) and SR ( $2235 \pm 195$   $\mu$ IU/ml at 180 min,  $P < 0.001$ ) but not significantly different than SP ( $3045 \pm 382$   $\mu$ IU/ml at 180 min). With regard to the preferred sago food for ingestion, 10 subjects (83.3%) preferred SP over SR and SG, on the basis of a post-test questionnaire.



**Fig. 2.** Plasma insulin responses after supplementation of 50 g portions of the sago meals and white bread. Values are mean  $\pm$  SEM (n=12 subjects). SR, Sago porridge; SP, Sago paste; SG, Sago gel; WB, White bread.

\* $P < 0.001$  compared to respective baseline values

$^{†} P < 0.01$  compared to WB, SR.

## Discussion

The major finding of this study was that all the three different physical forms of the sago meal elicited high plasma glucose responses. The sago paste ingestion elicited highest plasma glucose response, though not significantly, from those of sago gel and sago porridge ingestion. The overall plasma glucose response (AUC) of sago paste (SP) was lower than sago gel and higher than sago porridge. Wu and Williams<sup>8</sup> observed that foods eliciting low glycaemic response, resulted in a greater endurance capacity when ingested before exercise than after the ingestion of foods eliciting high glycaemic response. Foods eliciting low glycaemic response may result in a high rate of fat oxidation<sup>15,22</sup>. On the other hand, foods eliciting a high glycaemic response can increase muscle glycogen concentration as compared to low glycaemic response food<sup>8</sup> and hence may be used at the time of recovery after a prolonged exhaustive workout. It is postulated that SR may be used as a supplement prior to an endurance event, since plasma glucose AUC after SR ingestion was the lowest among the three test meals, though not significantly. On the other hand, SG can be used after a strenuous physical activity to replace the glycogen content of skeletal muscles. The greater fat oxidation and lower muscle glycogen utilization after a low glycaemic index meal may not always translate to a greater endurance capacity than after a high glycaemic index meal, as indicated by the inconsistency in the literature regarding the ergogenic effects of low or

medium glycaemic index meals over high glycaemic index meals<sup>8</sup>.

The negligible amounts of fiber, fat or protein in sago starch<sup>23</sup> might have also influenced the glycaemic responses to sago meals in this study. Gastric emptying and the rate of hydrolysis of starch polysaccharides have been shown to decrease by the presence of dietary fibers in meals<sup>24,25</sup>. However, the absence of natural dietary fibre or the removal of fibre in meals results in more rapid absorption of the carbohydrate and resulting in greater insulin responses<sup>26</sup>. The sago used in this study, contained a negligible amount of dietary fiber. Gastric emptying has also been shown to be influenced by the physical form of the meal. In gastric emptying physiology, liquid meals leave the stomach faster compared to semi-solid meals and solid meals. The sago meals consumed by human subjects in this study were in the form of a mixture of solids and liquids. Sago paste (SP) was more liquid like than the sago porridge (SR) and sago gel (SG).

The high glycaemic responses to the different forms of a sago meal observed in this study was in agreement with previous studies which showed that starch was better than simple carbohydrates such as glucose in maintaining higher carbohydrate availability<sup>14</sup>. However, the greater insulin responses following the ingestion of the different sago meals compared to WB may present a potential disadvantage to endurance exercise performance if these meals were to be ingested between 30 to 60 min before exercise. Instead, if these substrates supplemented after strenuous exercise (at recovery period), would be able to replenish the carbohydrate used during exercise. A high GI meal results in greater muscle glycogen storage than a low GI meal<sup>27</sup>.

Increased insulin secretion causes hypoglycaemia at the start of exercise and also reduces lipolysis which in turn may promote increased usage of muscle glycogen during exercise. In order to prevent such disturbances, nutritional strategies indicate that CHO sources that produce minimal glycaemic and insulinaemic responses be ingested before exercise<sup>5,28</sup>. In the present study, SR ingestion revealed minimum plasma insulin AUC, whereas, SP ingestion revealed an optimum or medium plasma insulin AUC. The debilitating effects of pre-exercise hyperglycaemia and hyperinsulinaemia may also be attenuated by undertaking a combination of both pre-exercise and during exercise CHO feedings. Wright *et al*<sup>29</sup> found that exercise performance was

enhanced using this feeding strategy compared to pre-exercise or during exercise feedings. Burke *et al*<sup>30</sup> suggested that pre-exercise CHO intake had little effect on metabolism or subsequent exercise performance if CHO feedings in appropriate amounts was undertaken during exercise. Several studies investigating the effect of the GI of pre-exercise meals have reported a higher rate of fat oxidation and consequently a lower CHO oxidation rate during exercise following a low GI meal in comparison to an isocaloric, nutrient-matched high GI meal<sup>6,22,27</sup>. A 15 per cent increase in muscle glycogen concentration was reported at the end of a 3 h postprandial period following the high GI breakfast; however, only a small non significant increase in muscle glycogen was reported following the low GI breakfast<sup>27</sup>.

The present study revealed that all the three sago meals tested have higher glycaemic and insulinaemic responses compared to WB and thus their ingestion may help improve prolonged exercise performance. However, the selection of CHO-rich foods based on their glycaemic and insulinaemic responses alone may be impractical since other factors influencing food selection such as palatability and portability of the food is also important since it may encourage or deter its consumption. On the basis of present findings, SP or SR could be used as a supplementation before and also during endurance exercise to improve the performance and SG during recovery after a strenuous endurance activity for replenishing the carbohydrates.

### Acknowledgment

Authors acknowledge the Universiti Sains Malaysia (Grant No.304/PPSP/6131315), for financial support, and thank Sports Science Unit Laboratory Staff (Nawawi, Jamaayah and Rozaid) for assistance in the experimental trials.

### References

1. Goodpaster BH, Costill DL, Fink WJ, Trappe TA, Jozsi AC, Starling RD, *et al*. The effects of pre-exercise starch ingestion on endurance performance. *Int J Sports Med* 1996; 17 : 366-72.
2. Burke LM, Hawley JA. Carbohydrate and exercise. *Curr Opin Clin Nutr Metab Care* 1999; 2 : 515-20.
3. Febbraio MA, Chiu A, Angus DJ, Arkinstall MJ, Hawley JA, Garnham AP. Pre-exercise carbohydrate ingestion, glucose kinetics and muscle glycogen use: effect of the glycemic index. *J Appl Physiol* 2000; 89 : 2220-6.
4. Anantaram R, Carmines, AA, Gaeser GA, Weltman A. Effects of carbohydrate ingestion before and during exercise on glucose kinetics and performance. *Int J Sports Med* 1995; 16 : 461-5.

5. Wee SL, Williams C, Tsintzas K, Boobis L. Ingestion of a high glycemic index meal increases muscle glycogen storage at rest but augments its utilization during subsequent exercise. *J Appl Physiol* 2005; *99* : 707-14.
6. DeMarco HM, Sucher KP, Cisar CJ, Butterfield GE. Pre-exercise carbohydrate meals: application of glycemic index. *Med Sci Sports Exerc* 1999; *31* : 164-70.
7. Kirwan JP, Cyr-Campbell D, Campbell WW, Scheiber J, Evans WJ. Effects of moderate and high glycemic index meals on metabolism and exercise performance. *Metabolism* 2001; *50* : 849-55.
8. Wu CL, Williams C. A low glycemic index meal before exercise improves endurance running capacity in men. *Int J Sports Nutr Exerc Metab* 2006; *16* : 510-27.
9. Guezennec CY. Oxidation rates, complex carbohydrates and exercise. Practical recommendations. *Sports Med* 1995; *19* : 365-72.
10. Guezennec CY, Satabin P, Duforez F, Koziet J, Antoine JM. The role of type and structure of complex carbohydrates response to physical exercise. *Int J Sports Med* 1993; *14* : 224-31.
11. Jozsi AC, Trappe TA, Starling RD, Goodpaster B, Trappe SW, Fink WJ, *et al.* The influence of starch structure on glycogen resynthesis and subsequent cycling performance. *Int J Sports Med* 1996; *17* : 373-8.
12. Burke LM. Nutritional needs for exercise in the heat. *Comp Biochem Physiol* 2001; *128* : 735-48.
13. Kueh Hong-Siong, Robert Elone, Tie Yiu-Liong, Ung Cin-Min, Jaman Hj. Osman. The feasibility of plantation production of sago (*Metroxylon sagu*) on an organic soil in Sarawak. In: Ng Thai-Tsiung, Tie Yiu-Liong, Kueh Hong-Siong, editors. *Proceedings of the fourth international sago symposium* (Kuching, Sarawak, August 6-9, 1990); 1991. p. 127-36.
14. Thomas DE, Brotherhood JR, Miller JB. Plasma glucose levels after prolonged strenuous exercise correlate inversely with glycemic response to meal consumed before exercise. *Int J Sports Nutr* 1994; *4* : 361-73.
15. Stevenson EJ, Williams C, Mash LE, Phillips B, Nute ML. Influence of high-carbohydrate mixed meals with different glycemic indexes on substrate utilization during subsequent exercise in women. *Am J Clin Nutr* 2006; *84* : 354-60.
16. Mettler S, Lamprecht-Rusca F, Stoffel-Kurt N, Wenk C, Colombani PC. The influence on subjects' training state on the glycemic index. *Euro J Clin Nutr* 2007; *61* : 19-24.
17. Association of Official Analytical Chemists. *Official methods of analysis*, 16<sup>th</sup> ed. VA: AOAC; 1995.
18. Wolever TMS, Jenkins DJA, Jenkins AL, Josse RG. The glycemic index: methodology and clinical implications. *Am J Clin Nutr* 1991; *54* : 846-54.
19. Foster-Powell K, Miller JB. International tables of glycemic index. *Am J Clin Nutr* 1995; *62* : 871S-93S.
20. Bornet FRJ, Costagliola D, Rizkalla SW, Blayo A, Fontvieille AM, Haardt M-J, *et al.* Insulinemic and glycemic indexes of six starch-rich foods taken alone and in a mixed meal by type 2 diabetics. *Am J Clin Nutr* 1987; *45* : 588-95.
21. Wolever TMS, Nuttall FQ, Lee R, Wong GS, Josse RG, Csima A, *et al.* Prediction of the relative blood glucose response of mixed meals using the white bread glycemic index. *Diabetes Care* 1985; *8* : 418-28.
22. Wu CL, Nicholas C, Williams C, Took A, Hardy L. The influence of high-carbohydrate meals with different glycemic indices on substrate utilization during subsequent exercise. *Br J Nutr* 2003; *90* : 1049-56.
23. Ahmad FB, Williams PA. Rheological properties of Sago starch. *J Agric Food Chem* 1998; *46* : 4060-5.
24. Wolever TMS. Relationship between dietary fiber content and composition in foods and the glycemic index. *Am J Clin Nutr* 1990; *51* : 72-5.
25. Salmerón J, Ascherio A, Rimm EB, Colditz GA, Spiegelman D, Jenkins DJ, *et al.* Dietary fiber, glycemic load and risk of NIDDM in men. *Diabetes Care* 1997; *20* : 545-50.
26. Benini L, Castellani G, Brighenti F, Heaton KW, Brentegani MT, Casiraghi MC, *et al.* Gastric emptying of a solid meal is accelerated by the removal of dietary fibre naturally present in food. *Gut* 1995; *36* : 825-30.
27. Wee SL, Williams C, Tsintzas K, Leslie B. Ingestion of a high-glycemic index meal increases muscle glycogen storage at rest but augments its utilization during subsequent exercise. *J Appl Physiol* 2005; *99* : 707-14.
28. Wee SL, Williams C, Gray S, Horabin J. Influence of high and low glycemic index pre-exercise meals on endurance running capacity. *Med Sci Sports Exerc* 1999; *31* : 393-9.
29. Wright DA, Sherman WM, Dernbach AR. Carbohydrate feedings before, during, or in combination improve cycling endurance performance. *J Appl Physiol* 1991; *71* : 1082-8.
30. Burke LM, Claassen A, Hawley JA, Noakes TD. Carbohydrate intake during prolonged cycling minimizes effect of glycemic index of preexercise meal. *J Appl Physiol* 1998; *85* : 2220-6.

Reprint requests: Dr Asok Kumar Ghosh, Associate Professor, Sports Science Unit, School of Medical Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Malaysia  
e-mail: asokghosh@kb.usm.my, naroo\_akg@yahoo.com