GLUCOSE AND INSULIN RESPONSES AT REST FOLLOWING THE INGESTION OF DIFFERENT PHYSICAL FORMS OF A SAGO MEAL

This study was undertaken to determine the effect of different physical forms of a similar sago starch meal on postprandial glycemia and insulinemia in normal subjects compared with white bread (WB). Twelve subjects consumed in random order, sago porridge (SR), sago paste (SP), sago gel (SG) and WB which was repeated on separate days at least 1 week apart after an overnight fast. Venous blood samples were analyzed for glucose and insulin concentrations, respectively, at baseline and at 15, 30, 45, 60, 90, 120, 150 and 180 minutes after the start of each meal. There were no significant differences in the baseline plasma glucose concentrations (WB = 4.2, SR = 4.1, SP = 4.4, SG = 4.4, p=0.271). Peak plasma glucose was reached at 45 minutes for all treatments and the incremental peak values were 6.1±0.2 mmol/L for the WB, 7.4±0.2 mmol/L for SR (p=0.002 vs WB), 8.6±0.2 mmol/L for SP (p<0.001 vs WB) and 8.3±0.5 mmol/L for SG (p<0.001 vs WB). Plasma glucose AUC for WB (170±14 mmol/L•180 min) was significantly lower than SG (314±38 mmol/L•180 min, p=0.008) but not significantly different from SR (233±24 mmol/L•180 min) and SP (270±38 mmol/L•180 min). However there was no significant difference in plasma glucose AUC between the three sago starch meals (p=0.255). Plasma insulin AUC for SG (3920±348 μIU/mL•180 min) was significantly higher than WB (2282±270 μIU/mL•180 min, p=0.003) and SR (2235±195 μIU/mL•180 min, p=0.002). This study demonstrated that all three sago meals were not significantly different in their glycemic responses. However the insulin response was significantly lower for SR compared to SP and SG.

Key words: glycemic response, insulinemic response, sago starch meals,

INTRODUCTION

Glycogen depletion and hypoglycemia have been associated with fatigue and the decrement of performance during prolonged exercise (Coulston et al., 1987; Romieu et al., 1988; Kleiner, 1997; Tsintzas & Williams, 1998). On the other hand, when carbohydrate (CHO) is consumed before and/or during prolonged exercise, fatigue is delayed and work output is enhanced (Coyle et al., 1983, 1986; Coggan & Coyle, 1987). The improvement in exercise performance has been suggested to be related to the prevention of hypoglycemia and maintenance of high rates of CHO oxidation during the latter stages of such an exercise (Coggan & Coyle, 1987; Wright et al., 1991; Costill & Hargreaves, 1992; Goodpaster et al., 1995; Burke & Hawley, 1999).

Glycemic and insulinemic responses to the ingestion of CHOs from different sources are not equal and thus have different effects on exercise metabolism and performance. Carbohydrates that produce rapid increases in blood glucose and a concomitant increase in insulin secretion at the onset of exercise, might impair performance due to hypoglycemia (Foster et al., 1979; Koivisto et al., 1981; Decombaz et al., 1985; Hargreaves et al., 1985, 1987; Chryssanthopoulus et al., 1994;); increased CHO oxidation (Hargreaves et al., 1985; Gleeson et al., 1986) and suppression of fat metabolism (Foster et al., 1979; Koivisto et al., 1981; Gleeson et al., 1986). These adverse effects on exercise performance may be alleviated by choosing CHO sources that produce a minimal glycemic and insulinemic responses (Decombaz et al., 1985; Hargreaves et al., 1985, 1987; Guezennec et al., 1989). During prolonged exercise, the metabolic disturbances arising from hyperglycemia and hyperinsulinemia following CHO ingestion are averted because elevations in catecholamines and growth hormone during exercise depress insulin release from the pancreas (Coleman, 2003).

In order to avoid confusion over the differences in the glycemic and insulinemic responses accompanying the ingestion of different CHO foods, the use of glycemic index (GI) has been recommended to aid in planning nutritional strategies for enhancing endurance exercise performance. The GI concept was introduced by Jenkins et al. (1981) as a means to rank different sources of CHO and foods rich in CHO according to their actual postprandial glycemic response relative to a reference food which is either glucose or white bread. The rate of digestion and absorption are based on the GI ranking of a particular food. Accordingly, CHO-rich foods with low GI are digested and absorbed slowly and lead to a low glycemic response. On the other hand, CHO-rich foods with high GI are rapidly digested and absorbed and show a high glycemic response

The GI is now widely recommended as a reference guide for the selection of an ideal CHO supplement to combat the debilitating effects of fatigue on endurance exercise performance. Sports nutritionists have recommended that athletes consume CHO-rich foods with low GI before prolonged exercise (Thomas et al., 1991; DeMarco et al, 1999; Kirwan et al., 2001). This practice has been shown to reduce the dependency on endogenous CHO at the onset of exercise and to maintain euglycemia for a longer period during exercise by relying more on lipid utilization (Guezennec, 1995). CHO-rich foods with moderate to high GI are recommended during exercise to promote muscle CHO uptake and utilization (Guezennec et al., 1993) and during the

post-exercise recovery period to promote the restoration of muscle glycogen (Burke et al., 1993; Jozsi et al., 1996).

To help athletes meet these recommendations, GI values for more than 750 types of foods have been published (Foster-Powell et al., 2002). However from the Malaysian perspective, there is no data available for sago which is the main source of native starch. In light of the results of previous studies which show that some starches are better than other simple CHO such as glucose in maintaining higher CHO availability during exercise (Thomas et al., 1991; Guezennec et al., 1993; Thomas et al., 1994) the present study was undertaken to ascertain the glycemic and insulinemic responses of three different models of a sago based CHO supplement. This study has been designed with a view of using one of these three sago meals as a CHO supplement for endurance exercise performed in the heat.

METHODOLOGY

Subjects

12 healthy male subjects gave written informed consent to participate in this study which was approved by the Ethical and Research Committee, Universiti Sains Malaysia. Their age, height, weight, body mass index and fasting glucose values were 27.8 ± 1.9 years, 1.70 ± 0.01 m, 63.5 ± 2.1 kg, 21.9 ± 0.7 kg/m^2 and 4.7 ± 0.1 mmol/L (mean ±SEM) respectively.

Test foods

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 (Association of Official Analytical Chemists, 1995). These sago pearls were tested in three forms and prepared fresh on each testing day: Unless otherwise stated, the preparation of these sago starch meals used similar artificial flavoring and natural sweetener. From these preparations a portion providing 50g of CHO (801-834 g) were consumed by each subject.

1) Sago porridge (SR)
60 g sago pearls were soaked in 790 mL distilled water and left to stand for 10 minutes. Thereafter the mixture was steam cooked for 25 minutes. Stirring of this mixture was done for ~2 minutes after 20 minutes of cooking. At the end of 25 minutes of cooking time, 7 mL artificial flavor (orange essence 19232, Sim Company Sdn. Bhd., Penang) and 0.8 g natural sweetener (SWETA, Stevian Biotechnology Corporation, Seremban) was added and stirred for ~2 minutes for homogenization and then left to cool to room temperature.

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

3) Sago gel (SG)
60 g sago pearls were ground into powder and soaked in 790 mL distilled water for 10 minutes. The mixture was then steam cooked for 25 minutes with stirring done after 20 minutes of cooking. At the end of 25 minutes of cooking time, artificial flavor and sweetener was added and stirred for ~2 minutes for homogenization and then left to cool to room temperature.

Reference food

Commercially available white bread (WB) [Gardenia Bonanza, Gardenia Bakeries (KL) Sdn. Bhd.] 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 50g of CHO) and 240 mL distilled water for ingestion.

Experimental protocol

Each subject undertook one trial of each test meal and 3 trials of the reference meal. The reference meal trials were done at the beginning, middle and end of the series of tests, with the order of the test meals randomized between the reference meals. Each 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 typical self-selected diets between test periods. After an overnight fast beginning at 9.00 pm, 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 8:00 am where they rested in a semi-supine position until the experiments began at 9:00 am. Fasting blood samples (4 mL) were then drawn and following this, subjects ingested one of the test meals or WB within ~15 minutes. Further blood samples (4 mL) were collected at 15, 30, 45 60, 90, 120, 150 and 180 min after the subjects began to eat. All procedures were performed in the experimental room under the same conditions (temperature: ~25°C; relative humidity: ~60%). Each subject again visited the laboratory one week after the completion of their experimental trials to sample all the test foods again and later provide 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 4000 revolutions/min for 10 minutes at 4°C (Rotina 46 RS, Hetteich Zentrifugen, Germany). The supernatant was then 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.

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-minute test period was calculated using the method described previously (Wolever et al., 1991).

Statistical analysis

Plasma glucose and plasma insulin were analyzed using separate two-way (meal x time) repeated-measures analysis of variance (ANOVA) to determine if there were significant differences across the different treatment conditions. When appropriate, student's paired t-Test was used to compare the differences between trials at individual time points. Separate one-way ANOVA was used to test for overall significant differences among the means for plasma glucose and insulin treatment means for AUC, peak and individual time points. When the ANOVA result was significant, Tukey HSD post-hoc test was used for multiple comparisons. Metabolic data are reported as mean ± standard error of the mean (SEM) and significance was defined as $P<0.05$. Subjects' preference for a specific test food was analyzed using frequency table. Statistical analyzes 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 Table 1. The plasma glucose responses to the test and reference foods and the plasma glucose incremental AUC values are shown in Figure 1 and Figure 2, respectively. There were no significant differences in the baseline plasma glucose concentrations ($p=0.271$). Forty-five minutes after the ingestion of all the foods, plasma glucose concentrations were significantly increased above their respective fasting values ($p<0.001$) At this time point, peak glucose values were 6.1±0.2 mmol/L for the WB, 7.4±0.2 mmol/L for SR ($p=0.002$ vs WB), 8.6±0.2 mmol/L for SP ($p<0.001$ vs WB) and 8.3±0.5 mmol/L for SG ($p<0.001$ vs WB). Except for WB, plasma glucose concentrations returned to baseline at 150 min after each of the different sago foods ($p<0.05$). Plasma glucose AUC for WB (170±14 mmol/L•180 min) was significantly lower than SG (314±38 mmol/L•180 min, $P=0.008$) but not significantly different from SR (233±24 mmol/L•180 min, $P=0.459$) and SP (270±38 mmol/L•180 min, $p=0.107$). However there was no significant difference in plasma glucose AUC between the three different sago foods ($P=0.255$).

Plasma insulin responses to the test and reference foods and plasma insulin incremental AUC values are displayed in Figures 3 and 4 respectively. The baseline plasma insulin concentrations were not significantly different ($p=0.064$). Peak plasma insulin was reached at 45 minutes postprandial for the all the different sago foods and at 60 minutes for WB. Comparing all the test foods, SP had the highest peak plasma insulin value (48.3±3.8 μIU/mL) which was significantly higher than WB (31.9±3.7 μIU/mL, $p=0.008$) and SR (33.2±4.5 μIU/mL, $p=0.003$) but not significantly different from SG (44.9±2.7 μIU/mL, $p=3.0$). Plasma insulin concentrations for the different sago meals declined thereafter with SP showing a significant decline at 60 min (38.3±3.6 μIU/mL, $p=0.007$) while the decline for SR (25.6±2.8 μIU/mL) and SG

(40.8±3.5 μIU/mL) was not significantly different ($p>0.05$). Plasma insulin AUC for SG (3920±348 μIU/mL•180 min) was significantly higher than WB (2282±270 μIU/mL•180 min, $p=0.003$) and SR (2235±195 μIU/mL•180 min, $p=0.002$) but not significantly different than SP (3045±382 μIU/mL•180 min, $p=0.199$).

With regard to the preferred sago food for ingestion, 10 subjects (83.3%) nominated SP as the preferred choice over SR and SG.

Table 1
Proximate composition of white bread (reference food) and sago pearls (average of 3 determinations)

Component	White bread	Sago pearls
Portion (g)	100.00	100.00
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

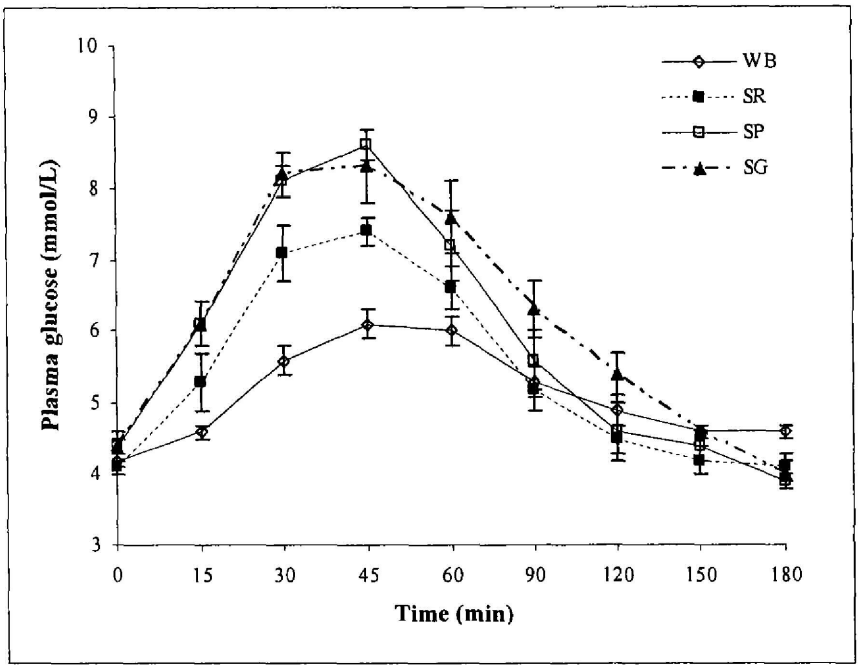

Fig.1 Plasma glucose responses to 50 g portions of the sago meals and WB. Values are mean ± SEM (n =12 subjects). SR = Sago porridge, SP = Sago paste, SG = Sago gel, WB = White bread

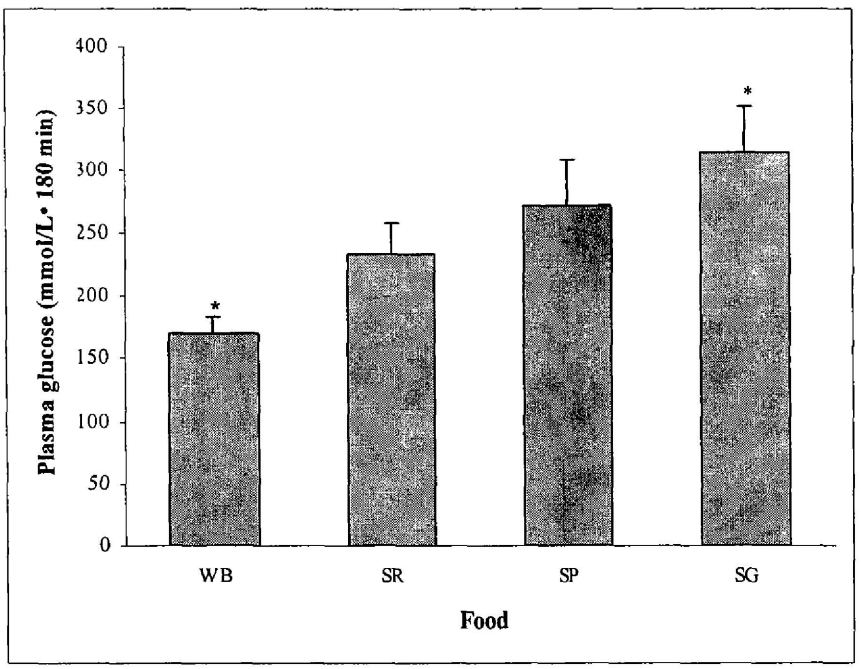

Fig.2 Plasma glucose AUC following the ingestion of white bread and the different sago meals. Values are mean ± SEM (n =12 subjects)
* Significantly different, p= 0.008. SR = Sago porridge, SP = Sago paste, SG = Sago gel, WB = White bread

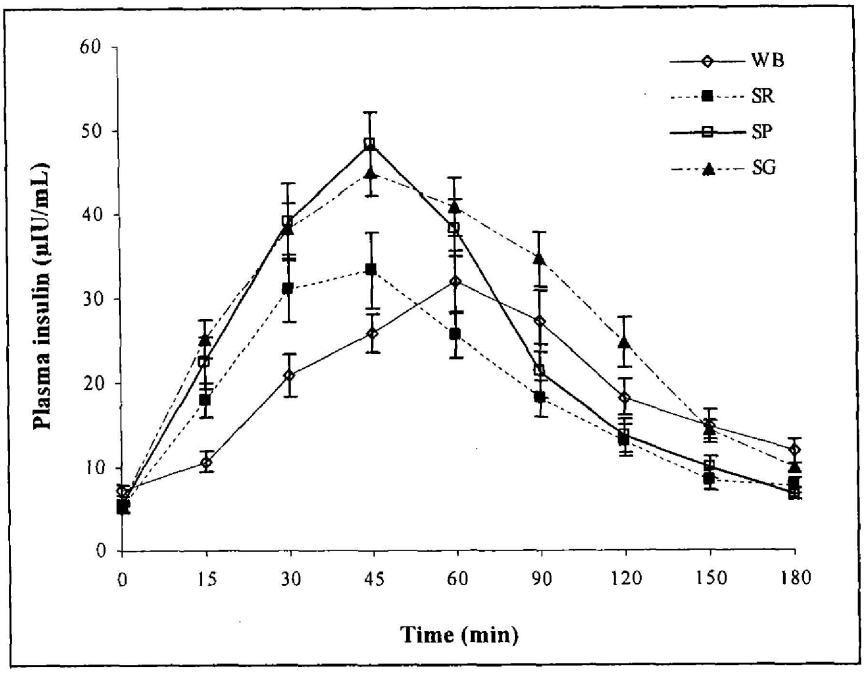

Fig.3 Plasma insulin responses to 50 g portions of the sago foods and WB. Values are mean ± SEM (n=12 subjects). SR = Sago porridge, SP = Sago paste, SG = Sago gel, WB = White bread

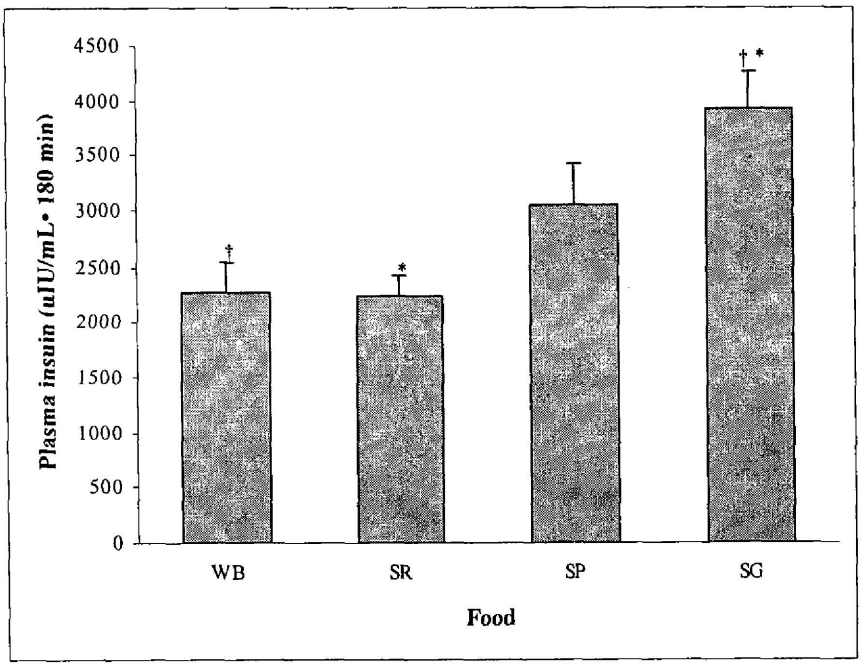

Fig.4 Plasma insulin AUC following the ingestion of white bread and the different sago based CHO supplements. Data are mean ± SEM (n=12 subjects). † Significantly different, p=0.003, * Significantly different, p=0.002. SR = Sago porridge, SP = Sago paste, SG = Sago gel, WB =White bread

DISCUSSION

The major finding of this study was that all three different physical forms of the sago meal elicited high glycemic responses as evident from the plasma glucose incremental AUC values. The glycemic response was highest for SG, followed by SP and SR. However, the differences in glycemic response to the different sago meals were not significant. With the exception of SG which had significantly higher glycemic response than WB, the glycemic responses of both SR and SP were not significantly different from WB. With regard to the insulin response, the result of this study showed that this response basically matches the glycemic response to the various meals tested. However, it is interesting to note that although the glycemic response to SR was comparable to that of SG; its overall insulin response was significantly lower than that for SG. Since the composition of these two sago meals was similar, this difference in insulin response may be attributed to their different physical forms which in turn may have influence the rate of digestion and absorption of these meals.

Differences in glycemic responses to the ingestion of various sources of starches has been shown to be influenced by the ratio of amylose to amylopectin in a given starch (Thomas et al., 1991; Guezennec et al., 1993; Thomas et al, 1994), the degree of processing and cooking of the starch (Jenkins et. al, 1983; Febbraio et. al, 2000), the physical form of the starch (O'Dea et al., 1980; Jenkins et al., 1984) and the fiber or protein content of the starch meal (Thorne et al., 1983). Similarly the high glycemic responses to the different sago meals in this study may have been attributed to these factors.

In terms of the nature of the sago starch, although it was not elucidated in this study, it has been previously suggested that sago native to South East Asia contain 27% amylose (Ahmad & Williams, 1998). Raw starches containing higher amounts of amylose are metabolized more slowly than those containing more amylopectin (Guezennec et al., 1993) and thus may evoke a slower rise in resting blood glucose than amylopectin (Snow & O'Dea, 1981; Wong & O'Dea, 1983; Goddard et al., 1984). However, cooking of starches in water (gelatinization), as was done in this study, increases the digestibility of starches due to the rupture and the disintegration of the starch structure (Collings et al., 1981; Snow & O'Dea, 1981). Furthermore, studies have also shown that glucose and insulin responses in vivo are significantly greater after ingestion of cooked compared with raw starches (Collings et al., 1981; Vaaler et al., 1984).

The structure of the ingested meal is also a factor affecting postprandial glycemic responses. O'Dea et al. (1980), in a study comparing glycemic responses to whole and ground rice, found no significant difference between whole white and brown rice but when these rice was ground to flour, the glycemic responses of both were significantly higher. According to these researchers, decreasing the particle size by grinding greatly increases the surface area and results in a much more rapid digestion and absorption of the rice that in turn produced the higher glycemic response. They concluded that the physical form of the rice was of particular importance in determining the postprandial glucose and insulin responses to rice. Under similar circumstance, the grinding of sago pearls to approximately 600 μm for use in the preparation of SP and SG might have also affected the glycemic responses.

The negligible amounts of fiber, fat or protein in sago starch (Ahmad & Williams, 1998) may have also influenced the glycemic responses to sago meals in this study. Gastric emptying and the rate of hydrolysis of starchy polysaccharides have been shown to decrease by the presence or mixing of dietary fibers in meals or meals (Salmerón et al., 1997; Wolever, 1990). However the absence of natural dietary fiber or the removal of fiber in meals results in more rapid absorption of the carbohydrate and resulting in greater insulin responses (Benini et al., 1995; Haber et al., 1997). 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. Liquids empty faster than solids because no grinding is required. The sago meals which were consumed in the form of a mixture of solids and liquids (SR); semi-liquid (SP); and solids (SG) would probably be the underlying reason for the differences in the glycemic responses.

The high glycemic responses to the different forms of a sago meal in this study is in agreement with previous studies which show that some starches were better than simpler carbohydrates such as glucose in maintaining higher carbohydrate availability (Thomas et al., 1991; Guezennec et al., 1993; Thomas et al., 1994). 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. Increased insulin secretion causes hypoglycemia 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 dictate that CHO sources that produce minimal glycemic and insulinemic responses be ingested before exercise (Decombaz et al., 1985, Guezennec et al., 1989; Hargreaves et al., 1985; Hargreaves et al., 1987). The debilitating effects of pre-exercise hyperglycemia and hyperinsulinemia may also be attenuated by undertaking a combination of both pre-exercise and during exercise CHO feedings. Wright et al, (1991) found that exercise performance was enhanced using this feeding strategy compared to pre-exercise or during exercise feedings. Similarly, Burke et al., (1998), suggested that pre-exercise CHO intake has little effect on metabolism or subsequent exercise performance if CHO feedings in appropriate amounts is undertaken during exercise.

The present study suggests that all the three sago meals tested have high glycemic and insulinemic responses compared to WB and thus their ingestion may help improve prolonged exercise performance. However, the selection of CHO-rich foods based on their glycemic and insulinemic 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. This issue was clarified in this study by asking the subjects to again visit the laboratory one week after the completion of their experimental trials to sample all the test foods. Upon completion of this sampling session, they were asked to provide in writing their overall preference for one of the three test foods. In agreement with the notion that food factors may influence food selection, the result of the test foods sampling session showed that most of the subjects (83%) had an overall liking to SP over SR and SG.

In conclusion, the present data suggests that any one of the three sago meals tested in this study may be used in a subsequent study to elucidate the effect of sago starch ingestion on exercise performance in the heat. However, we proposed to use a specific

test food that is SP in this later study in view of the subjects overall preference for it (10 out of 12 or 83%) and also due to its pattern of decline in glycemic and insulinemic responses which was more rapid after 45 min postprandial compared to SR and SG.

ACKNOWLEDGEMENTS

We would like to thank Universiti Sains Malaysia for the short term grant (304/PPSP/6131315) and Sports Scince Unit Laboratory Staff (Nawawi, Jamaayah and Rozaid) for their expert help in the experimental trials.

REFERENCES

Ahmad, F.B. and Williams, P.A.(1998). Rheological of Sago Starch. *Journal of Agriculture and Food Chemistry*, 46:4060-4065

Benini, L., Castellani, G., Brighenti, F., Heaton, K.W., Brentegani, M.T., Casiraghi, M.C., Sembenini, C., Pellegrini, N., Fioretta, A. and Minniti, G. (1995). Gastric emptying of a solid meal is accelerated by the removal of dietary fibre naturally present in food. *Gut*, 36:825-30

Burke LM, Collier GR, Hargreaves M. (1993). Muscle glycogen storage after prolonged exercise: effect of the glycemic index of carbohydrate feedings. *J. Appl. Physiol.*, 75:1019-1023

Burke, L.M., Classen, A., Hawley, J.A. and Noakes, T.D. (1998). Carbohydrate intake during prolonged cycling minimizes effect of glycemic index of pre-exercise meal. *Journal of Applied Physiology*, 85: 2220-2226

Burke, L.M. and Hawley, J.A. (1999). Carbohydrate and exercise. *Current Opinions in Clinical Nutrition Metabolism and Care*, 2 (6):515-20 (5)

Chryssanthopoulus, C., Hennessy, L.C.M. and Williams, C. (1994). The influence of pre-exercise glucose ingestion on endurance running capacity. *British Journal of Sports Medicine*, 28:105-109

Coggan, A.R., and Coyle, E.F. (1987). Reversal of fatigue during prolonged exercise by carbohydrate infusion or ingestion. *Journal of Applied Physiology*, 63:2388-2395

Coleman, E. (2003). *Eating for endurance.* 4th ed. CO: Bull Publishing Company

Collings, P. Williams, C. and MacDonald, I. (1981). Effect of cooking on serum glucose and insulin responses to starch. *British Medical Journal*, 282:1032-1033

Costill, D.L. & Hargreaves, M. (1992). Carbohydrate nutrition and fatigue. *Sports Medicine*, 13 (2):86-92 (4)

Coulston, A.M., Hollenbeck, C.B., Swislocki, A.L.M., Chen, Y-ID, Reaven, G.M (1987). Deleterious metabolic effects of high-carbohydrate, sucrose-containing diets in patients with non-insulin-dependent diabetes mellitus. *American Journal of Medicine,* 82:213–20

Coyle, E.F., Hagberg, J.M., Hurley, B.F., Martin, W.H., Ehsani, A.A. and Holloszy, J.O. (1983). Carbohydrate feeding during prolonged strenuous exercise can delay fatigue. *Journal of Applied Physiology*, 55: 230-235

Coyle, E.F., Coggan, A.R., Hemmert, M.K. and Ivy, J.L. (1986). Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *Journal of Applied Physiology*, 61:165-172

Decombaz, J., Sartori, J.D., Arnaud, M.J., Thelin, A.L., Schurch and Howald, H. (1985). Oxidation and metabolic effects of fructose or glucose ingested before exercise. *International Journal of Sports Medicine*, 6:282-286

DeMarco, H.M., Sucher, K.P., Cisar, C.J. & Butterfield, G.E. (1999). Pre-exercise carbohydrate meals: application of glycaemic index. *Med. Sci. Sports Exerc.*, 31:164-170.

Febbraio, M.A., Keenan, J., Angus, D.J., Campbell, S.E. and Garnham, A.P. (2000). Pre-exercise carbohydrate ingestion, glucose kinetics and muscle glycogen use; effect of the glycemic index. *Journal of Applied Physiology*, 89:1845-1851

Foster, C., Costill, L. and Fink, W.J. (1979). Effects of pre-exercise feedings on endurance performance. *Medicine and Science in Sports*, 11:1-5

Foster-Powell, K., Holt, S.H.A. & Brand-Miller, J.C.(2002). International table of glycemic index and glycemic load values. *Am. J. Clin. Nutr.*, 76:5-56

Gleeson, M., Maughan, R.J. and Greenhaff, P.L. (1986). Comparison of the effects of pre-exercise feeding of glucose, glycerol and placebo on endurance and fuel homeostasis in man. *European Journal of Applied Physiology*, 55:645-653

Goddard, M.S., Young, G. and Marcus, R. (1984). The effect of amylose content on insulin and glucose responses to ingested rice. *American Journal of Clinical Nutrition*, 39:388-392

Goodpaster, B.H., Costill, D.L., Fink, W.J., Trappe, T.A., Jozsi, A.C., Starling, R.D. and Trappe, S.W. (1995). The effects of pre-exercise starch ingestion on endurance performance. *International Journal of Sports Medicine*, 17, 366-372

Guezennec, C.Y. (1995). Oxidation rate, complex carbohydrates and exercise. *Sports Med.*, 19:365-372

Guezennec, C.Y., Satabin, P., Duforez, F., Koziet, J. and Antoine, J.M. (1993). The role of type and structure of complex carbohydrates response to physical exercise. *International Journal of Sports Nutrition*, 14:224-231

Guezennec, C.Y., Satabin, P., Duforez, F., Merion, D., Peronnet, F. and Koziet, J. (1989). Oxidation of corn starch, glucose and fructose ingested before exercise. *Medicine and Science in Sports and Exercise*, 21: 45-50

Haber, G,B,, Heaton, K.W. and Murphy, D. (1977). Depletion and disruption of dietary fibre. Effects of satiety, plasma glucose and serum insulin. *Lancet*, 1:679-82

Hargreaves, M., Costil, D.L., Fink, W.J., King, D.S. and Fielding, R.A. (1987). Effect of pre-exercise carbohydrate feedings on endurance cycling performance. *Medicine and Science in Sports and Exercise*, 19:33-36

Hargreaves, M., Costill, D.L., Katz, A. and Fink, W.J. (1985). Effects of fructose ingestion on muscle glycogen usage during exercise. *Medicine and Science in Sports and Exercise*, 17:360-363

Jenkins, D.J.A., Wolever, T.M.S, Jenkins, A.L., Josse, R.G. and Wong G.S. (1984). The glycaemic response to carbohydrate meals. *Lancet*,18:388-391

Jenkins, D.J.A., Wolever, T.M.S., Jenkins, A.L., Lee, R., Wong, G.S. and Joose, R.G. (1983). Glycemic response to wheat products: reduced response to pasta but no effects of fiber. *Diabetes Care*, 6:155-9

Jenkins, D.J.A., Wolever, T.M.S., Taylor, R.H., Barker, H., Fielden, H., Baldwin, J.M., Bowling, A.C., Newman, H.C., Jenkins, A.L. & Goff, D.V. (1981). Glycemic index of foods: a physiological basis for carbohydrate exchange. *Am. J. Clin. Nutr.*, 35:362-366

Jozsi, A.C., Trappe, T.A., Starling, R.D., Goodpaster, B., Trappe, S.W., Fink, W.J. & Costill, D.L. (1996). The influence of starch structure on glycogen resynthesis and subsequent cycling performance. *Int. J. Sports Med.*, 17:373-378

Kirwan, J.P., Cyr-Campbell, D., Campbell, W.W., Scheiber, J. & Evans, W.J. (2001). Effects of moderate and high glycemic index meals on metabolism and exercise performance. *Metabolism*, 50:849-55.

Kleiner, S.M. (1997). Nutrition for muscle builders. *Physician and Sports Medicine*, 25: 146 -146.

Koivisto, V., Karonen, S.L. and Nikkila, E.A. (1981). Carbohydrate ingestion before exercide: comparison of glucose, fructose and sweet placebo. *Journal of Applied Physiology*, 51:783-787

O'Dea , K. Nestel, P.J. and Antonoff, L. (1980). Physical factors influencing postprandial glucose and insulin responses to starch. *American Journal of Clinical Nutrition*, 33:760-765

Romieu, I., Willett, W.C., Stampfer, M.J., Colditz, G.A., Sampson, L., Rosner, B., Hennekens, C.H. and Speizer, F.E. (1988). Energy intake and other determinants of relative weight. *American Journal of Clinical Nutrition*, 47, 406-412

Salmerón, J., Ascherio, A., Rimm, E.B., Colditz, G.A., Spiegelman, D., Jenkins, D.J., Stampfer, M.J., Wing, A.L. and Willet, W.C. (1997). Dietary fiber, glycemic load and risk of NIDDM in men. *Diabetes Care*, 20:545-550

Snow, P. and O'Dea, K. (1981). Factors affecting the rate of hydrolysis of starch in meal. *American Journal of Clinical Nutrition*, 34:2721-2727

Thomas, D.E., Brotherhood, J.R. and Brand, J.C. (1991). Carbohydrate feeding before exercise; effect of the glycemic index. *International Journal of Sports Medicine*, 12:180-186

Thomas, D.E., Brotherhood, J.R. and Miller, J.B. (1994). Plasma glucose levels after prolonged strenuous exercise correlate inversely with glycemic response to meal consumed before exercise. *International Journal of Sports Nutrition*, 4:361- 373

Thorne, M.J. Thompson, L.U. and Jenkins, D.J.A. (1983). Factors affecting starch digestibility and the glycemic response with special reference to legumes. *American Journal of Clinical Nutrition*, 38:4281-488

Tsintzas, K. and Williams, C. (1998). Human muscle glycogen metabolism during exercise: effect of carbohydrate supplementation. *Sports Medicine*, 25: 7 - 23.

Vaaler, S., Hanssen, K.F. and Aagenoes, O. (1984). The effect of cooking upon the blood glucose response to ingested carrots and potatoes. *Diabetes Care*: 221-223

Wolever, T.M.S. (1990). Relationship between dietary fiber content and composition in foods and their glycemic index. *American Journal of Clinical Nutrition*, 50:72-75

Wolever, T.M.S., Jenkins, D.J.A., Jenkins, A.L. and Josse, R.G. (1991). The glycemic index: methodology and clinical implications. *American Journal of Clinical Nutrition*, 54: 846-854

Wong, S. and and O'Dea, K. (1983). Importance of physical form rather than viscosity in determining the rate of starch hydrolysis in legumes. *American Journal of Clinical Nutrition*, 37: 66-70

Wright, D.A., Sherman, W.M. and Dernbach, A.R. (1991). Carbohydrate feedings before, during, or in combination improves cycling performance. Journal of Applied Physiology, 71:082-1088.