

**A study of Hassawi rice (*Oryza sativa* L.) in terms of its carbohydrate hydrolysis *in vitro* and glycaemic and insulinaemic indices *in vivo***

M Q AL-MSSALLEM MSc<sup>1</sup>, S M HAMPTON PhD<sup>2</sup>, G S FROST PhD<sup>3</sup> and J E BROWN PhD<sup>1</sup>

<sup>1</sup>*Division of Nutritional Sciences and* <sup>2</sup>*Division of Biochemical Sciences, Faculty of Health and Medical Sciences, University of Surrey, Guildford, GU2 7XH, UK;* <sup>2</sup>*Nutrition and Dietetic Research Group, Department of Investigative Medicine, Division of Integrative Science, Imperial College of Science Technology and Medicine, University of London, W12 0HS, UK*

Corresponding author: J E Brown, PhD, Division of Nutritional Sciences, Faculty of Health and Medical Sciences, University of Surrey, Guildford, GU2 7XH, UK. Tel: +44 (0) 1483 686409 Fax: +44 (0) 1483 686401

Running title: Properties of Hassawi rice *in vitro* and *in vivo*

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## **Abstract**

**Background/Objectives:** A high prevalence of Type 2 diabetes exists in Saudi Arabia. Epidemiological evidence suggests that low glycaemic index (GI) diets reduce diabetes risk. Yet, little is known about the GI of traditional Saudi Arabian staples such as Hassawi rice (HR). HR was evaluated in terms of its GI and insulinaemic indices (II). Comparisons were made *in vitro* assessing glucose released enzymatically. A long grain rice variety available in both the UK and Saudi was studied as a comparison.

**Subjects/Methods:** For GI and II measurements, HR, Uncle Ben's rice (UBR) and a standard glucose solution were consumed by healthy subjects (n=13) on 7 randomised occasions. Capillary bloods were collected at specific times over 2 h after food intake. FAO/WHO protocols were employed to determine GI and II. For the *in vitro* studies, cooked rice was incubated with hydrolytic enzymes under standardised conditions. Samples were taken at t=20 & t=120 min and rapidly available glucose (RAG) and slowly available glucose (SAG) were computed.

**Results:** Values of RAG and SAG were lower for HR compared to their respective values for UBR ( $p<0.001$  &  $p=0.011$ , respectively). However, no significant difference was observed for GI ( $p>0.05$ ) despite a lower insulin response noted for HR ( $p=0.007$ ).

**Conclusions:** HR had a similar GI to UBR although a lower insulin response was evident. RAG and SAG values were different for the two rice varieties despite similar GI values. These differences may be important in terms of their metabolic impact and outcome on diabetes.

**Keywords:** glycaemic index, insulin, *Oryza sativa*, diabetes mellitus

## Introduction

The prevalence of diabetes mellitus (DM) is increasing at an alarming rate across much of the developed world (Wild *et al.*, 2004). In Saudi Arabia, in particular, the prevalence of DM has increased dramatically (El-Hazmi *et al.*, 1989; 1998). Within the last 20 years the prevalence of DM in Saudi adults has increased 6-fold (Fatani *et al.*, 1987; Al-Nozha *et al.*, 2004). Several factors are considered important. These include age, gender, obesity, socioeconomic status, genetic susceptibility and life style. In Saudi Arabia, one of the main reasons for the increase in DM may be due to a major change in habitual eating patterns, including modifications in the quality and quantity of dietary carbohydrates and their resultant impact on obesity (Musaiger, 1987). Indeed, daily intakes of finely milled cereal and grain products have increased over recent years (Alissa *et al.*, 2005) and there has been a concomitant reduction in the consumption of some healthy traditional starchy foods such as Hareece (pearl barley cooked with meat) and Kabsa which is a main dish prepared largely from rice (either white rice or the reddish brown rice variety known as Hassawi rice (HR) (Al-Mssallem, 1999)).

Rice (*Oryza sativa*) is one of the most important cereal food crops in the world (Wang and Li, 2005). In Saudi Arabia, rice is a staple carbohydrate (CHO) source (Al-Mssallem, 1999) with imported (e.g. long grain white rice such as Uncle Ben's rice) and locally grown (HR) varieties available. This latter type of rice is grown in the Al-Hassa oasis in Eastern Saudi Arabia (Al-Bahrany, 2002) and consumed traditionally (by 5 % of the Saudis). HR by tradition is consumed in a main dish (Kabsa) with cooked vegetables and meat (e.g. lamb). Traditionally, HR has been considered, with good reason, to have a better nutritional quality and to be healthier for women in the postpartum period compared to white

rice (Al-Mssallem, 1999). HR is lower in its total CHO content (CATM, 1985) and higher in total protein (Al-Mssallem & Al-Mssallem 1997; Al-Mssallem, 1999) compared to white long grain rice. Furthermore, levels of ash, proximate fat and fibre are higher in HR (CATM, 1985; Al-Bahrany, 2002).

Both the macro- and micro-nutrient content of foods can have a major impact upon health (Leena *et al.*, 2004). This is particularly applicable to the CHO present which can impact on both plasma glucose and insulin levels. Indeed, a strong positive association exists between the glycaemic index (GI, a measure of the impact a food makes on postprandial glucose levels) of foods and the risk of Type 2 diabetes (Schulze *et al.*, 2004; Salmeron *et al.*, 1997), which supports the idea of the importance of the quality of dietary CHO in delaying the onset or preventing Type 2 diabetes (Schulze *et al.*, 2004). There is also a positive link between high GI and low cereal fibre content and increased risk of diabetes and it has been suggested that minimally refined grains should be consumed to reduce the incidence of Type 2 diabetes (Salmeron *et al.*, 1997). As such, high GI foods may alter the risk of Type 2 diabetes owing to the production of higher postprandial blood glucose concentrations and a greater insulin demand compared to low GI foods (Kalergis *et al.*, 2005; Frost & Dornhorst, 2000).

CHO digestion and the subsequent release of glucose (available for absorption) can be assessed *in vitro*. Indeed in 1992, Englyst developed an *in vitro* technique of dietary CHO digestion and created two terms related to glucose release from CHOs (Englyst *et al.*, 1992). These terms were slowly available glucose (SAG) and rapidly available glucose (RAG). RAG is defined as the amount of glucose made available for absorption from a food during the first 20 minutes ( $G_{20}$ ) of the *in vitro* incubation. It in effect relates to glucose

released from readily digestible starch (RDS) and glucose released from the food in the form of the glucose monomer or glucose released from sucrose. SAG is defined as the amount of glucose released for absorption from a food between the 20 minute time point of the incubation ( $G_{20}$ ) and the 120 minute time point ( $G_{120}$ ). It is in effect the glucose released from a food from slowly digestible starch (SDS) and any further glucose released from the food in the form of the glucose monomer or glucose released from sucrose. Together these terms can help provide information on how a food may perform *in vivo*.

There is evidence that RAG can predict glycaemic response *in vivo* (Englyst *et al.*, 1999) but at present there is little information on RAG and SAG values of rice varieties. This is in contrast to a large amount of information on the GI of rice varieties which have been shown to vary from 37 (Bangladeshi rice; Foster-Powell *et al.*, 2002) to 109 (Jasmine rice; Brand-Miller *et al.*, 2007). Some data is also available on the insulinaemic indices (II) of rice but it is noteworthy that these are far less numerous than those for GI. Furthermore, although there is some consensus between GI and II values for some rice varieties (e.g. 88 (GI) and 89 (II) for waxy rice; Brand-Miller *et al.*, 1992) this is not the case for all (e.g. 64 (GI) and 40 (II) for Doongara white rice; Brand-Miller *et al.*, 1992).

We consider that a greater understanding of the effects of traditional Saudi Arabian foods on blood glucose and insulin levels may help lead to more effective lifestyle prevention strategies for Type 2 diabetes. In this respect our hypothesis is that a traditional Saudi Arabian food, namely HR, will produce a lower GI and II compared to a commonly consumed Western variety of rice (Uncle Ben's, UBR) and that RAG and SAG values will be helpful in predicting the GI. The objectives of the study are 1) to investigate and compare the RAG, SAG and chemical composition of HR and UBR and 2) to measure and

compare the GI and II of the two rice varieties. In order to do this RAG and SAG were measured using the *in vitro* carbohydrate hydrolysis method Englyst *et al.* (2000). Standard protocols (AOAC, 1995) were used to measure food chemical composition. GI and II were measured using FAO/WHO (1998) standard procedures.

## **Methods**

### *In vitro study*

#### *Preparation of samples*

Two types of rice were selected for the study, HR (Al-Hassa, Saudi Arabia) and long grain white parboiled UBR (Masterfoods, Belgium). UBR was chosen because it is one of the most commonly available rice varieties around the world and it is also consumed in Saudi Arabia. HR and UBR were cooked in their traditional ways in distilled water for 45 and 17 min, respectively. The ratio of rice to water used was 1:2. The water was heated to boiling point in a saucepan, the specified amount of rice was added and the lid applied. When the contents reached boiling point the heat was reduced to a simmer. All the water was absorbed during the cooking process.

For the *in vitro* analysis each sample was ground to the same consistency using a mincer and mortar and pestle and then used for RAG and SAG measurement. The chemical composition for Hassawi rice and Uncle Ben's rice (fat, protein, ash, non-starch polysaccharides (NSP) and amylose) were determined using standard methods (AOAC, 1995).

### *Measurement of RAG, SAG and TS*

The *in vitro* procedure used to determine RAG, SAG and TS (total starch) was an enzymatic hydrolysis of the food CHO employing the method of Englyst *et al.* (2000). For this measurement, portions of the rice (3 g) were weighed into 50 ml centrifuge tubes (Corning, NY, USA) to the nearest  $\pm 1$  mg and incubated with a mixture of hydrolytic enzymes (amyloglucosidase from Englyst Carbohydrate Services Ltd. (Southampton, UK), amylase (heat-stable) and pancreatin from Sigma Chemical Co. Ltd., Poole, UK) under controlled conditions of temperature (37 °C) and pH (pH 5.2). Viscosity was standardised using guar gum in the incubation mixture as indicated in the Englyst method (Englyst *et al.* (2000). Sub-samples were collected from the incubation mixture at specific time points (20 and 120 min) and measured for glucose content and these values were then used to calculate the RAG and SAG values, respectively.

The calculations were as follows:

$$\text{RAG (g)} = G_{20}$$

$$\text{SAG (g)} = G_{120} - G_{20}$$

Further treatment and incubations were performed to disperse any remaining starch present in the samples in order to determine the total glucose (TG) released which was then used to calculate the TS. The glucose present in each of the different samples was determined colorimetrically using Glucose Oxidase/Peroxidase Reagent (Sigma Chemical Co. Ltd.).

Two reference samples, namely potato starch (Sigma Chemical Co. Ltd.) and Corn flakes® (Kellogg's, UK) were included in every batch analysed and the inter-assay CVs were

calculated to be less than 10 % for reference 1 (Potato starch) and 5 % for reference 2 (Cornflakes).

### *In vivo study*

#### *Subjects*

A randomised crossover design carried out in accordance with the FAO/WHO guidelines (FAO/WHO, 1998) was used for GI testing. The study design received ethical approval from the University of Surrey Ethics Committee (EC/2004/37/SBMS) and 13 healthy volunteers were recruited from the postgraduate student and staff population at the University of Surrey by the distribution of both e-mails and posters. All volunteers gave informed written consent. The 13 individuals recruited were 6 men and 7 women, mean age 30.0 years (SEM 1.74 years; range 25 – 42 y). Weight, height, fasting blood glucose and blood pressure were measured at baseline.

#### *Test foods*

HR and UBR were cooked in a kitchen at the Clinical Investigation Unit (University of Surrey) as described above. A cooked portion of 120 g of Hassawi rice or 83 g of Uncle Ben's rice (which both contained 25 g of available CHO) were served to subjects with 250 ml of water. Each rice variety was tested twice. On three other separate occasions 250 ml of water containing 25 g glucose (Fisher Scientific, Loughborough, UK) was given. The day on which the subjects received either a rice variety or standard glucose was randomised. Subjects were asked to eat the rice and consume the drink within a 10 min time period.



### *Study protocol*

On the day prior to GI and II testing participants were asked to restrict their consumption of alcoholic and caffeinated beverages. They were also requested to limit their involvement in intense physical activity and to consume the same kind of meal prior to each test day to reduce variability in the response to the foods.

Subjects arrived at the Clinical Investigation Unit at the University of Surrey at 0830 h on each study day after an overnight fast (10 -12 h). They were asked to sit quietly for 10 mins and then requested to take the first capillary blood sample (fasting sample). Subjects were then requested to eat the rice with water or the glucose standard drink within a 10 min time period. Blood samples were taken by finger pricks using preset lancets (Accu-chek Softclix Pro., Brighton, UK) at fasting and at 15, 30, 45, 60, 90 and 120 minutes after consuming the HR, UBR or standard glucose solution. Individual time sheets were used to record sampling times and subjects were requested to remain within the CIU for the duration of sampling and to keep their physical activity to a minimum. Blood samples were collected into 300  $\mu$ L plastic microvette tubes (Sarstedt Ltd., Leicester, UK) coated with fluoride oxalate and were immediately centrifuged at  $3000 \times g$  for 10 min at 4 °C. The resultant plasma was transferred into separate 300  $\mu$ L plastic plain microvette tubes (Sarstedt Ltd.). The tubes were then frozen and kept at -20 °C until analysis (within 4 weeks).

At the end of the test duration subjects were provided with a light breakfast were allowed to leave the CIU and to continue with their day.

### *Glucose measurement*

An automatic analyser (YSI 2300 STAT plus, Yellow Springs, Analytical Technologies, YSI Ltd., Fleet, UK) was used to determine plasma glucose concentrations. Twenty four samples were analysed in each run along with three quality control (QC) samples. The intra- and inter-assay coefficient of variation of the QCs was less than 1 % and 5 %, respectively.

The incremental area under the glucose curve (iAUC) for the reference glucose drink, HR and UBR was calculated according to the recommended method by WHO (FAO/WHO, 1998). The GI values of HR and UBR for each subject were calculated as follows:

$$\text{GI of HR} = \text{iAUC for HR} / \text{iAUC for reference} \times 100;$$

$$\text{GI of UBR} = \text{iAUC for UBR} / \text{iAUC for reference} \times 100.$$

The GI value of HR and UBR was calculated as the average value obtained for 10 subjects.

### *Insulin analysis*

An enzyme linked immunosorbant assay (ELISA) was employed for measuring plasma insulin concentrations (MLT, Cardiff, UK). Samples were thawed at room temperature and then centrifuged at 3000 x *g* for 5 min to remove insoluble debris. The QCs, standards (Invitron Ltd., Monmouth, UK) and samples were incubated with the labelled antibody solution (Invitron Ltd.) at 37 °C for 2 h and unbound labelled antibodies were removed using the wash buffer (Invitron Ltd.) according to the manufacturer's instructions. The insulin was then measured using the micro-titre plate luminometer (Luminescent plate reader Centro LB 960). All readings obtained from the luminometer were multiplied by 6 to convert the units (mU/l) into pmol/l. Two QCs (one low and one high) were used and their intra-assay

CVs were 4 % and 5 % respectively, and the inter-assay CVs were 10 % and 12 %, respectively.

### *Statistical analyses*

Results were checked for normality using the Kolmogorov-Smirnov test (K-S test) and expressed as a means  $\pm$  one standard error of the mean (SEM). For the human study, a two factor (treatment and time) repeated measures ANOVA was used to analyse differences in the means of the glucose and insulin levels within the two types of rice and standard glucose. In addition, a single factor repeated measures analysis of variance ANOVA was used to analyse differences in the iAUC for glucose and insulin (SPSS 16.0 for Windows; Copyright © 2009 SPSS Inc.). If a significant interaction was obtained following ANOVA, a Bonferroni step-wise *post hoc* test was performed to determine the location of the variance. Differences in RAG, SAG and macronutrient levels between HR and UBR were evaluated by paired *t*-test. All data were examined using a two-tailed approach with a level of  $p < 0.05$  being considered as significant.

## **Results**

### *Compositional analysis*

Compositional data for HR and UBR is presented in Table 1. The proximate content of CHO in HR was significantly lower than that found in UBR ( $p < 0.001$ ), however; fat ( $p < 0.001$ ), protein ( $p < 0.001$ ), amylose ( $p = 0.003$ ), ash and NSP ( $p < 0.001$ ) were significantly higher.

### *In vitro measurement of RAG, SAG and TS*

The RAG, SAG and TS values are presented in Figure 1. RAG values were significantly lower for HR compared to UBR ( $16.70 \pm 0.58$  vs.  $21.10 \pm 0.28$  g, respectively;  $p < 0.001$ ,  $t = 8.44$ ,  $n = 6$ ). SAG values were significantly lower for HR compared to UBR ( $5.80 \pm 0.28$  vs.  $9.65 \pm 0.91$  g, respectively;  $p = 0.011$ ,  $t = 3.95$ ,  $n = 6$ ). The TS value for HR ( $21.52 \pm 0.55$  g) was significantly lower ( $p < 0.01$ ) than the corresponding value for UBR ( $31.07 \pm 0.50$  g).

### *In vivo determination of GI and II*

The subjects' characteristics are displayed in Table 2. They had an average age of 30 years and were modestly overweight according to the average body mass index (BMI) score but had normal blood pressure and fasting blood glucose levels.

The incremental area under the curve (iAUC) for glucose was calculated for the reference (glucose drink), HR and UBR (Figure 2). The iAUC for the reference was significantly higher ( $p < 0.01$ ) than the iAUC for HR and UBR. However, no difference was observed for this iAUC for glucose between the rice varieties. Furthermore, no difference was observed between the GI of HR and UBR which were calculated to be  $59 \pm 5$  and  $54 \pm 7$ , respectively.

The iAUC for insulin response was also calculated for the reference and two rice varieties (Figure 3). The II for HR ( $56 \pm 10$ ) was significantly lower than that observed for UBR ( $78 \pm 17$ ;  $p = 0.007$ ) and reference glucose ( $p = 0.005$ ).

## Discussion

In this study we evaluated the nutritional composition of HR and studied some metabolically relevant parameters related to its CHO content *in vitro* and *in vivo* which may be important in terms of diabetes prevention and treatment. The total CHO content of HR was approximately 20 % lower than that found in the previous literature while the NSP content was approximately double literature values (Al-Bahrany, 2002). Nevertheless, protein, fat and ash contents were essentially the same as previously reported (Al-Bahrany, 2002; Al-Mssallem & Al-Mssallem, 1997). It is well known that macro-nutrient composition is affected by a number of factors including soil type and climate and we consider that these differences in HR chemical composition are within the expected limits of variation.

HR had the lowest RAG, SAG and TS values of the two rice varieties measured. The difference compared to UBR was significant ( $p < 0.01$ ) for all these three measurements. As far as the authors are aware there is no information available on the RAG and SAG of different rice varieties although there are data on rapidly digestible starch (RDS) and slowly digestible starch (SDS) of rice varieties reported by Patindol *et al.* (2010). This group used a similar but modified version of the Englyst *in vitro* hydrolysis method (Englyst *et al.*, 1992) and analysed 16 different rice cultivars for RDS and SDS. Their results were presented in terms of cooked rice dry weight, but it is possible to convert our data, using moisture content information, and in doing so we find that their results are in accordance with our own results, in particular, for UBR. In addition, RAG and SAG data are available for a reasonably large number of different CHO-rich foods (Englyst *et al.*, 1996) and this reveals that our data are in good agreement in terms of food RAG values which range from 16 to 26 g/100 g and food SAG values which range from 4 to 10 g/100 g.

HR in this study had a medium GI ( $59 \pm 5$ ) and UBR had a low GI ( $54 \pm 7$ ). The GI categorization was proposed by Wolever *et al.* (1991) and within this classification medium GI foods are those with an index of between 55 and 70 (using glucose as a standard reference) while low GI foods have a value of less than 55. Nevertheless, there was no significant difference in GI between the two rice varieties and the value observed in this study for UBR is in good agreement with the results of Foster-Powell *et al.* (2002) who recorded a value of 50. We hypothesised, however, that UBR would have a higher GI than the traditionally used Saudi HR. Indeed a higher RAG was demonstrated for UBR *versus* HR and as RAG has been shown to be positively correlated to GI we anticipated a higher GI for UBR. Nevertheless, it is evident that the CHO content of the two rice varieties differs significantly and HR has a much lower CHO value. Thus if we normalise the RAG values in terms of CHO content we observe that there is no difference in the RAG percentage. This may thus in part help explain the similarity in GI values.

The slightly lower GI for UBR *versus* HR could be because UBR is parboiled as this can affect the digestibility of the rice starch. Interestingly, however, the influence of parboiling on lowering rice GI is conflicting. Indeed, a GI reduction was observed by Wolever *et al.* (1986) but this was not supported by the work of Larsen *et al.* (1996) who showed no effect of parboiling. A later study by Larsen *et al.* (2000), however, showed that a significant GI reduction could be produced by severely pressure parboiling rice but no significant effect was observed using the traditional parboiling process. Nevertheless, the aim of this study was not to compare a parboiled rice with a non-parboiled rice. Instead, the UBR was used as a valid comparison as it is one of the most commonly available rice varieties in the world and is available in the UK and Saudi Arabia.

The higher than expected GI for HR may be due to the fact that it was cooked for longer (45 *versus* 17 min). Longer cooking times may result in a greater gelatinisation of the starch and help increase the glycaemic response. Indeed, this effect of increased cooking time on GI elevation has been put forward by Ranawana *et al.* (2009) and can be supported by data from Panlasigui *et al.* (1991). It is well known that amylose and amylopectin content can also impact upon the GI. Indeed, high amylose rice varieties (~28 %, w/w) produce a lower GI and a lower II (Miller *et al.*, 1992). In this study the amylose content was in the normal range for both HR (17.5 %) and UBR (12.7 %) and this did not seem to impact upon the GI to any observable extent. Indeed, if higher amylose contributed to lowering the GI we would expect that HR would have the lower GI. Nevertheless, parboiling may have reduced the amylose density of UBR and thus lower the GI obtained for this rice.

Other macronutrients, namely levels of fat and protein, were different between the two rice varieties and these components have been shown to influence GI. Protein can reduce GI but the amount of protein required needs to be very high (50 g/ meal; Wolever *et al.*, 1987). Protein can also enhance the plasma insulin response via the insulinogenic amino acids but the difference in protein content between the two rice varieties, though significant, is considered too small to be able to mediate this effect. Fat can also affect GI by delaying gastric emptying. However, once again the difference in the amount of fat between the two rice varieties is considered too small to have any real impact on GI (Wolever *et al.*, 1991).

Although there was no significant difference between the GI of HR and UBR, the GL of HR was significantly lower ( $p < 0.001$ ) than UBR in terms of a similar serving size (Table 1). This reduced level could be explained by the lower total CHO content of HR in conjunction with the amount of *available* CHO which was lower than that present in UBR. Energy density

was also lower for HR compared to that found in UBR (4.5 and 5.8 KJ/g, respectively, ( $p < 0.001$ )). All these characteristics of HR may be important, suggesting that HR will have a lower glycaemic and insulinaemic *impact* than an equivalent cooked weight of UBR.

It could be argued that the different portion sizes may have influenced the outcome of the study. Indeed, the portion sizes were 120 and 83 g for HR and UBR, respectively. However, when taking the drinking water into account the difference in mass between the two meals was only approximately 10 %. As such we consider that this difference to be comparatively small. It is also noteworthy that a fundamental feature of the GI testing procedure is to ensure that the available CHO content is the same for the foods tested (either 25 g or 50 g). As such the GI testing was carried out in accordance with this procedure.

It has been observed that a lower risk of developing diabetes is associated with a higher consumption of low GL diets (Salmeron *et al.*, 1997). Similarly, the II of HR was significantly lower than UBR ( $p = 0.007$ ) and this finding could be due to the higher content of NSP in HR ( $p < 0.001$ , Table 1) compared with UBR. It is evident that NSP-rich foods may play a role in the reduced insulinaemic response (Stevenson *et al.*, 2008; Jenkins *et al.*, 2000) and their beneficial effect in reducing the risk of developing diabetes has been extensively studied in large cohort epidemiological studies. Indeed, many studies have shown a significant association between dietary NSP and reduced risk of diabetes (Schulze *et al.*, 2004; Salmeron *et al.*, 1997; Meyer *et al.*, 2000; Stevens *et al.*, 2002). Nevertheless although HR contains more than twice the level of NSP than UBR the NSP content is less than 1g/150 g and thus probably contributes little to this difference in insulin secretion.

We are aware that there are some limitations to this study. Clearly, this was an assessment of only two varieties of rice and as such it is quite a small study. However, the results



provide useful information on a variety of rice which has not been reported previously. It is unfortunate that there are no RAG and SAG data on rice with which to compare our findings. Nevertheless, this study helps build the collection of data on RAG and SAG to help evaluate their usefulness in terms of metabolic impact.

It is important to consider both GI and II in the dietary management of diabetes as some foods with a low GI have a high II. Several studies have included measures of II because of the clear role of insulin in glucose homeostasis. Furthermore, an association between a large insulin demand and a high GI food has been proposed in the aetiology of diabetes (Salmeron *et al.*, 1997; Wolever, 2000; Englyst *et al.*, 2003). Incorporating the use of both GI and II values should be considered in planning the optimal dietary CHO for people with diabetes. Furthermore, as HR has a smaller II it may be useful to include this rice variety. However, further research, particularly long term studies, may be required to ascertain the clear benefits of HR.

In conclusion, our hypothesis was that a traditional Saudi Arabian food, namely HR, would produce a lower GI and II compared to a commonly consumed Western variety of rice (UBR) and that RAG and SAG values would be helpful in predicting the GI. We observed a lower II for HR and so we can partially accept our hypothesis. Nevertheless there was no difference in GI between HR and UBR despite clear differences in RAG and SAG. Nevertheless, the lower GL and insulinaemic response possessed by HR suggest that this type of rice may have benefits on postprandial glycaemic and insulinaemic levels and may have a role to play in the management and prevention of Type 2 diabetes.

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## **Conflict of interest**

The authors declare no conflict of interest.

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**Table 1.** Nutritional composition, glycaemic index, insulinaemic index and glycaemic load values for the Hassawi rice and Uncle Ben's rice per serving size (150 g).

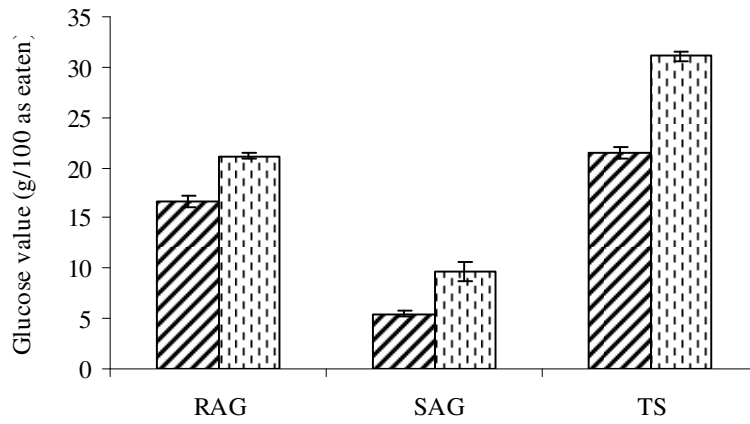
	Hassawi rice	Uncle Ben's rice	Significance	t-value & n
Energy (KJ)	683.0 ± 15.7	873.0 ± 11.8	***	t=-11.46, n=3
Energy density (KJ/g)	4.55 ± 0.10	5.82 ± 0.07	***	t= -11.46, n=3
Fat (g)	1.15 ± 0.01	0.36 ± 0.01	***	t=73.5, n=3
Protein (g)	5.58 ± 0.02	4.31 ± 0.02	***	t=42.8, n=3
Starch (g)	32.66 ± 0.90	46.73 ± 0.72	*	t=-14.97, n=3
Available CHO (g)	31.38 ± 0.92	45.21 ± 0.66	***	t=-13.31, n=3
Amylose (g)	26.31 ± 0.22	19.27 ± 0.31	**	t=18.03, n=3
NSP (g)	0.91 ± 0.01	0.38 ± 0.01	***	t=53.0, n=3
Ash (g)	0.67 ± 0.01	0.37 ± 0.01	***	t=54.76, n=3
GI	59 ± 5	54 ± 7	NS	t=0.88, n=10
II	56 ± 10	78 ± 17	**	t= -1.78, n=10
GL	18.51± 0.54	24.41 ± 0.35	***	t=-9.87, n=10

Results expressed as mean ± SEM. CHO, carbohydrate; NSP, non-starch polysaccharide; II, insulinaemic index; GI, glycaemic index; GL, glycaemic load. Moisture content contributed to 62.5 % of cooked Hassawi rice and 64.6 % of cooked Uncle Ben's rice. Statistical evaluation by paired t-test; \*\*\* = p<0.001, \*\* = 0.001<p<0.01, \* = 0.01<p<0.05

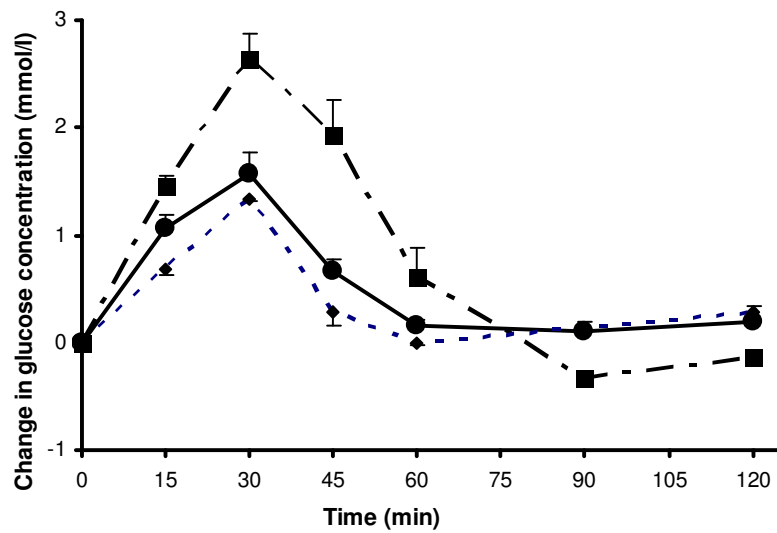
**Table 2.** Descriptive characteristics of study participants at baseline

<b>Measurement</b>	<b>Values</b>
Age (years)	30.0 ± 1.7
Weight (kg)	75.6 ± 4.0
Height (m)	1.71 ± 0.02
BMI (kg/m <sup>2</sup> )	25.6 ± 1.0
Diastolic blood pressure (mm Hg)	74.1 ± 2.3
Systolic blood pressure (mm Hg)	116.3 ± 2.9
Fasting blood glucose (mmol/l)	5.0 ± 0.1

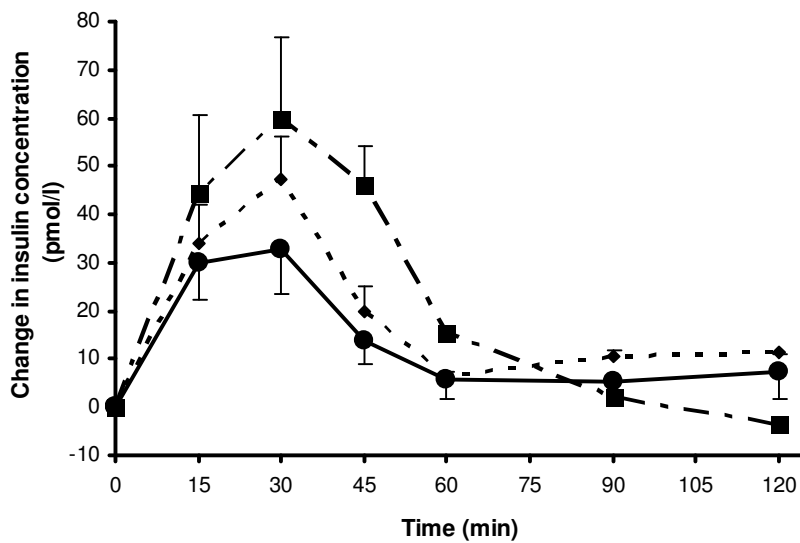
Results presented as Mean ± SEM (n=13). BMI, body mass index (calculated as weight (kg)/height<sup>2</sup> (m)).



**Figure 1.** Rapidly available glucose (RAG), slowly available glucose (SAG) and total starch (TS) values for Hassawi rice and Uncle Ben's rice. Results presented as g/100 g as consumed (Mean  $\pm$  SEM). RAG, SAG and TS measured using the enzymatic hydrolysis method of Englyst *et al.* (2000). Statistical evaluation by paired *t*-test; \*\*\* =  $p < 0.001$ , \*\* =  $0.001 < p < 0.01$ , \* =  $0.01 < p < 0.05$



**Figure 2.** Plasma glucose responses over 2 h following consumption of reference glucose, Hassawi rice and Uncle Ben's rice. Results presented as Mean  $\pm$  SEM. ■ = glucose drink; ♦ = Uncle Ben's rice; • = Hassawi rice. GI was measured using FAO/WHO (1998) standard procedures. A two factor (treatment and time) repeated measures ANOVA was used to analyse differences in the means of the glucose levels within the two types of rice and standard glucose consumed. No significant differences were observed.



**Figure 3.** Plasma insulin responses over 2 h following consumption of reference glucose, Hassawi Rice and Uncle Ben's rice. Results expressed as Mean  $\pm$  SEM. ■ = glucose drink; ♦ = Uncle Ben's rice; • = Hassawi rice. It was measured using FAO/WHO (1998) standard procedures. A two factor (treatment and time) repeated measures ANOVA was used to analyse differences in the means of the insulin levels within the two types of rice and standard glucose consumed. No significant differences were observed.