Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: http://www.tandfonline.com/loi/bfsn20

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To cite this article: Bhupinder Kaur, Viren Ranawana & Jeyakumar Henry (2016) The Glycemic Index of Rice and Rice Products: A Review, and Table of GI Values, Critical Reviews in Food Science and Nutrition, 56:2, 215-236, DOI: 10.1080/10408398.2012.717976

To link to this article: http://dx.doi.org/10.1080/10408398.2012.717976

Critical Reviews in Food Science and Nutrition, 56:215–236 (2016)

ISSN: 1040-8398 / 1549-7852 online
DOI: 10.1080/10408398.2012.717976

The Glycemic Index of Rice and Rice Products: A Review, and Table of GI Values

BHUPINDER KAUR, VIREN RANAWANA, and JEYAKUMAR HENRY

Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences, Singapore

Rice is the principle staple and energy source for nearly half the world's population and therefore has significant nutrition and health implications. Rice is generally considered a high glycemic index (GI) food, however, this depends on varietal, compositional, processing, and accompaniment factors. Being a major contributor to the glycemic load in rice eating populations, there is increasing concern that the rising prevalence of insulin resistance is as a result of the consumption of large amounts of rice. Devising ways and means of reducing the glycemic impact of rice is therefore imperative. This review gathers studies examining the GI of rice and rice products and provides a critical overview of the current state of the art. A table collating published GI values for rice and rice products is also included.

Keywords Rice, rice products, glycemic index, glycemic response, diabetes

INTRODUCTION

The increasing prevalence of diabetes and related chronic diseases in recent times has prompted greater research attention into ways and means of curbing their further escalation. Dietary intervention methods which are the cornerstone of diabetes prevention and management are primarily aimed at maintaining a low and stable postprandial blood glucose concentration (Jenkins et al., 1984). The glycemic index (GI) which is based on the glycemic response is a well-established indicator of the blood glucose raising potential of a carbohydrate food. Studies show that regular consumption of high-GI diets is associated with an increased risk for type 2 diabetes mellitus (Salmeron et al., 1997a, 1997b). There is evidence to suggest that low-GI diets reduce the incidence of diabetes (Bjorck et al., 1994; Augustin et al., 2002), hyperlipidemia (Jenkins et al., 1987b), and cardiovascular disease (Ludwig et al., 1999; Ludwig, 2002; Ma et al., 2005; Murakami et al., 2006; Larsen et al., 2010;). Although simple carbohydrates such as glucose and maltose have been historically regarded as the greater inducers of hyperglycemia, recent data conclusively shows that complex carbohydrates, including starches, are able to produce equal or even larger blood glucose excursions (Kalergis et al., 1998).

Rice (*Oryza sativa* L.) is the most widely eaten staple in the world with global consumption levels more than tripling from 156 million tons to 456 million tons between 1960 and 2010 (Figure 1) (IRRI, 2010). It is the main energy source for a large segment of the population; around 3 billion depend on rice for 35–59% of their caloric intake (Meng et al., 2005). Asia has the highest consumption of rice with intake exceeding 100 kg per capita in many countries (IRRI, 2010). Whilst polished white rice is the most widely consumed form, unmilled brown rice is regularly eaten in some cultures.

White rice elicits a relatively large glycemic response and is thus associated with exacerbating impaired glucose tolerance (Sun et al., 2010). It contributes a large glycemic load (GL) to the diets of those in countries where it is the main staple due to both the large quantity eaten and its greater GI. These countries incidentally are also where diabetes rates are markedly increasing (Chan et al., 2009; Shaw et al., 2010). Therefore, devising ways and means of reducing the glycemic response of rice is imperative to reduce the risk of developing the metabolic syndrome. A good understanding of all the factors affecting the GI of rice is essential to achieve this. Although a considerable number of studies have focused on the GI of rice and factors affecting it a systematic review of the state-of-the-art has not been carried out. The objective of

Address correspondence to Prof. Jeyakumar Henry, Clinical Nutrition Research Centre, Singapore Institute for Clinical Sciences, 30 Medical Drive, Singapore 117609. E-mail: jeya_henry@sics.astar.edu.sg

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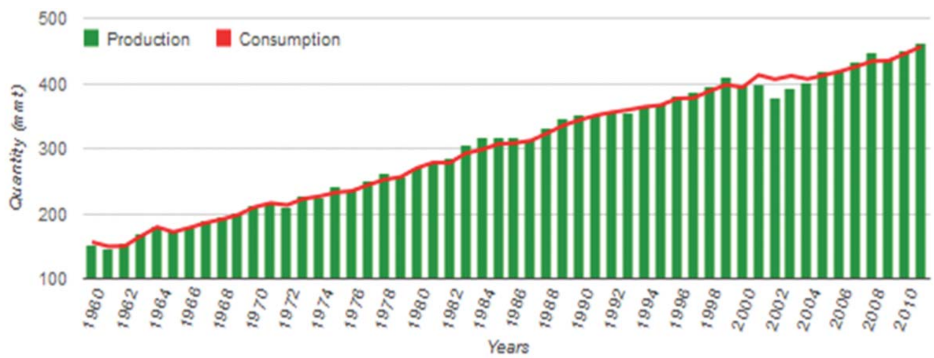

Figure 1 World production and consumption of domestic milled rice (1980–1982). (Source: IRRI, 2010, http://ricestat.irri.org/vis/wrs_quickCharts.php).

this article, therefore, was to review the literature surrounding the GI of rice and factors affecting it.

REVIEW

Composition of Rice

China, India, and Indonesia are believed to be where rice was first cultivated, and thus the origin of the three varieties of rice—*japonica, javanica*, and *indica* (Juliano, 1993). *Japonica* grains are short, roundish grains which do not shatter easily and contain 0–20% amylose. *Javanica* grains (long grain), which are long, broad, and thick, contains 0–25% amylose and tend to remain intact after cooking. *Indica* grains may be short or long and are slender and somewhat flat, and contains a higher amylose content (23–31%).

White rice is produced from the polishing of brown rice. Polishing removes the pericarp, seed-coat, testa, aleurone layer, and embryo which results in the loss of fat, protein, crude, and neutral detergent fiber, ash, vitamins, and polyphenols whilst increasing starch content (Shobana et al., 2011). Due to the removal of the bran layer, white rice has a lower total dietary fiber content (0.7–2%) than brown rice (3–4%) (Juliano and Bechtel, 1985). The energy content of brown rice is slightly higher than white rice due to lipids in the bran (Juliano, 2003).

Starch is the predominant macronutrient in milled rice. The rice starch granule is composed of 99% α-glucans which consists of two distinct glucose polymers, amylose, and amylopectin (Takeda et al., 1993). Amylose is an essentially linear molecule of α-(1→4)-linked D-glucopyranosyl units with a few branches. Amylopectin has a larger molecular weight and a highly branched structure consisting of straight chains of D-glucopyranosyl units linked by α-(1→4) bonds to which branched chains attach via α-(1→6) bonds (Hizukuri, 1986). Rice amylose has 2–4 chains with an average DP_n of 900 and a ß-amylolysis limit of 73–87%, whilst rice amylopectins have ß-amylolysis limits of 56 to 59%, chain lengths of 19 to 22 glucose units, and a DP_n of 5000 to 15000 glucose units (Hizukuri et al., 1983).

The Health Impact of Rice

Recent studies suggest that the high consumption of rice accelerates the development of diabetes (Hu et al, 2012). A high dietary glycemic load (predominantly from rice) has been associated with increased risk of type 2 diabetes in Chinese, Japanese (Murakami et al., 2006; Villegas et al., 2007; Nanri et al., 2008) and Indian (Mohan et al., 2009) populations. White rice is considered a high GL food (of about 23) (Foster-Powell et al., 2002). However, this depends on the quantity of rice consumed, and it is not a high GL food when consumed at levels typically found in Western diets compared to Asian diets.

Frequent consumption of high GI and GL meals over time is associated with insulin resistance, β-cell dysfunction, dyslipidemia, obesity, breast cancer, endothelial dysfunction, cardiovascular disease, and a reduction in cognitive functions (Liu et al., 2000; Ludwig, 2002; Ingwersen et al., 2007; Sieri et al., 2007; Venn and Green, 2007; Nakashima et al., 2010). The relationship between rice consumption and diabetes is equivocal (Hodge et al., 2004; Villegas et al., 2007; Nanri et al., 2010; Sun et al., 2010). A recent meta-analysis by Hu et al. (2012) found a significant relationship between white rice consumption and the risk of type 2 diabetes. The authors concluded that the association was stronger for Asian (Chinese and Japanese) populations than their Western counterparts which is probably due to the larger quantities eaten by the former group. Intervention studies also show a relationship between rice consumption and diabetes. A study in Japan found that the provision of white bread compared to boiled white rice to children at breakfast caused less glucose fluctuations and better cognitive function (Taki et al., 2010). This was attributed to white bread having a lower GI than boiled white rice. Another study showed that substituting white rice with the same amount of low GI brown rice significantly lowered the risk of developing diabetes in U.S. men and women (Sun et al., 2010).

In summary, observational studies suggest that rice increases the risk of diabetes and other chronic diseases. However, the evidence is equivocal, and associations in epidemiological studies do not always prove causality. Randomized-controlled and intervention studies show that rice has a large impact both on glycaemia and diabetes indicators. They also suggest that brown rice may be a better alternative to white rice. However, the acceptability of brown rice is lower than of white rice especially in communities where it is not traditionally consumed (Kumar et al., 2011) which often becomes a stumbling block to its integration into diets.

The GI of Rice and Rice Products

The impact of rice on health appears to be mainly due to the greater GL it exerts in rice eating populations. Traditionally, rice constitutes the major proportion of the plate content in these populations and advocacy to eat less of it would not be a sustainable public health strategy. Therefore, lowering the GI of rice may be a better strategy to achieve a low GL. A large number of studies have examined the GI of different rices and these have demonstrated it to be a food with very diverse values. A recent systematic tabulation of GI values showed that rice GI ranged between 24 and 160 when white bread was used as the reference (Atkinson et al., 2008). This diversity highlights the importance of considering rice on an individual type and variety basis.

Factors Affecting the GI of Rice and Rice Products

Rice Variety and Starch Content (Amylose and Amylopectin)

The GI of rice depends on the variety. Varietal effects on GI appear to be mainly mediated by its amylose content. Based on the amylose content, rice can be classified as waxy (0–2%), very low amylose (5–12%), low amylose (12–20%), medium amylose (20–25%), and high amylose (25–33%) rice (Juliano, 1993). Apparent amylose content correlates positively with water absorption and volume expansion during cooking and with the hardness of boiled rice (Juliano, 2003). The amylose content therefore influences the textural qualities of cooked rice and is an important consideration when selecting rice for specific applications (Table 1).

The amylose:amylopectin ratio effects processing properties and eating quality. Amylose is directly related to the hardness, whiteness, and dullness of cooked rice, and volume expansion and water absorption during cooking. The texture of cooked rice has been closely correlated with the relative abundance of long chains in its amylopectin (Rani and Bhattachrya, 1995). The molecular structure of amylose is tighter and more compact, thus less susceptible to breakdown than amylopectin whose structure is more vulnerable to digestion. Therefore, the amylose:amylopectin ratio determines starch digestion rates and is thus used to predict blood glucose and insulin responses to rice (Goddard et al., 1984; Juliano and Goddard, 1986; Miller et al., 1992; Frei et al., 2003; Hu et al., 2004).

Chung et al. (2011) recently studied the in vitro digestibility of rice starches differing in amylose content (Long-grain, Arborio, Calrose, Glutinous). Long-grain rice starch showed the highest amylose content (27%) while glutinous was the lowest (4%). Long-grain rice starch had the highest gelatinization temperature (GT), and the lowest rapidly digestible starch (RDS) content (39% compared to 71% in glutinous rice). High RDS containing food have greater GIs and cause more rapid changes in blood glucose (Thondre et al., 2010).

Goddard et al. (1984) investigated the effect of amylose and amylopectin content on glucose and insulin responses to long grain (Labelle with 25% amylose and 75–77% amylopectin), medium grain (Pecos with 14–17% amylose and 83–86% amylopectin) and sweet rice (Mochi gome with 100% amylopectin). Although the nutritional composition (protein, total lipid content, fiber) of the rices was similar, the high-amylose rice showed lower initial responses and slower declines in both glucose and insulin levels. The greater levels of complexed starch lipids and lower levels of nonstarch lipids in high amylose rices were suggested to contribute to its lower impact on glycaemia. Similarly, Juliano and Goddard (1986)

Table 1 Apparent amylose content type and other properties preferred for various processed rice products

Rice product	Apparent amylose content type and other properties
Parboiled rice	High and intermediate-AC
Precooked/quick cooking rice	Waxy, Low, Intermediate and High-AC
Extruded and flat rice noodles	Mainly aged, high-AC low-GT rice
Rice made into puddings, breads, cakes, and beer adjuncts	Low starch GT
Rice wines and rice based sauces, desserts, snacks, and sweets	Waxy, low-AC
Rice cakes	Steamed rice cakes (All AC types except High)
Bake rice cakes (All AC types)	
Rice crackers	Waxy and nonwaxy
Idli (Indian steamed rice), dosa (Indian rice pancake)	High and intermediate AC (Parboiled rice preferred over raw rice)
Rice based infant food	Intermediate or high

(Source: Juliano, 2003).

Table 2 Yield and composition of defatted and protease-amylase–treated cell wall preparations obtained from different histological fractions of milling of brown rice

Rice fraction	Yield (% defatted tissue)	Composition (% of total)				Uronic acid in pectin (%)	Arabinose:xylose ratio	
		Pectic substances	Hemi-cellulose	α-cellulose	Lignin		Pectic substances	Hemi-cellulose
Caryopsis coat	29	7	38	27	32	32	1.63	0.82
Aleurone tissue	20	11	42	16	25	25	1.78	0.84
Germ	12	23	47	9	16	16	2.29	0.96
Endosperm	0.3	27	49	1	34	34	1.09	0.64

(Source: Shibuya, 1985).

observed the lowest glucose and insulin response curves when high amylose (>24%) rice was consumed. Miller et al. (1992) determined the GI of white and brown variants of three commercial rice varieties (Doongara, Calrose, and Pelde). Doongara, a high amylose rice (28% amylose) produced significantly lower GIs for both the white and brown types (Doongara white rice-64; Doongara brown rice-66). The other two medium amylose (20%) varieties, Calrose and Pelde had higher GI values (Calrose white rice—83; Calrose brown rice—87, and Pelde white rice—93; Pelde brown rice—76). But in contrast, Holt and Miller (1995) found that Doongara rice had a lower GI (54). Both studies on Doongara rice had a similar cooking time (14 minutes) but the lower GI in Holt and Miller's study was probably as a result of storing the rice overnight at 4°C. Cooling has been shown to increase-resistant starch (RS) content and thereby reduce the GI, and this is discussed later in the article. Panlasigui et al. (1991) examined three varieties of rice containing the same amount of amylose (27%) and found that they all had similar GI values (75, 78, 81).

Studies conducted on local rice varieties showed similar trends. Bangladeshi white rice varieties containing 27% and 28% amylose had GIs of 37 and 39, respectively (Larsen et al., 1996, 2000), whilst traditional and improved medium to high amylose Sri Lankan rice varieties showed GI values between 57 and 73 (Pathiraje et al., 2010). White basmati rice, a popular Indian rice with a medium amylose content (20–25%) (Bhattacharjee et al., 2002) has a GI around 50–58 (Holt and Brand-Miller, 1995; Ranawana et al., 2009).

Glutinous rice generally has a high GI due to its high amylopectin content. Hu et al. (2004) and Frei et al. (2003) found that starch hydrolysis for waxy cultivars was more rapid and more complete than for high amylose rice cultivars. Hu et al. (2004) reported that Yunuo No. 1 waxy *indica* rice containing 1% and 0.8% amylose content was high GI (106 and 101 respectively), whilst ZF201 high amylose rice containing 27% and 26% amylose content was low GI (63 and 60 respectively). Several studies show that Thai glutinous rice has a GI of over 90 (Chan et al., 2001; Ranawana et al., 2009). Japanese Koshikari rice similarly showed high GI values (Sugiyama et al., 2003; Sato et al., 2010). Frei et al. (2003) reported that waxy rice cultivars in the Philippines had GIs above 90 compared to nonwaxy cultivars. The amylose content of rice also affects the GI of processed products. Puffed rice cakes made with high amylose rice showed comparatively lower GI values in one study (Holt and Brand-Miller, 1995) .

In summary, the literature suggests that high amylose rice has notably lower GI values than the high amylopectin variants. They also produce more attenuated insulin responses. However, amylose content alone is not a good predictor of the glycemic response and other factors (discussed later) also affect starch digestion rates and glycaemia.

Cooking

Rice is predominantly eaten in the boiled form (conventional boiling or pressure cooking) and is steamed on some occasion. The method and degree of cooking, and the volume of cooking water determines the extent of starch gelatinization, and this in turn directly correlates with digestibility and the glycemic response (Collings et al., 1981). One study showed that boiling rice for only five minutes produced less swelled and intact grains (producing a lower GI) compared to rice boiled for 15 minutes where the grains were swollen and split (producing a higher GI) (Wolever et al., 1986) (Table 3).

Ranawana et al (2009) showed that basmati rice cooked for longer times elicited greater glycemic responses. White basmati rice cooked for 10 minutes had a GI of 50 (low), but basmati and wild rice, brown and white basmati rice cooked for 25 minutes also had high GI. Similarly, Al-Mssallem et al. (2011) found that rice cooked for longer had a higher GI when they compared the glycemic response of Hassawi and long-grain white rice. Parastouei et al. (2011) showed that the GI of Iranian rice differed after cooking. Rice soaked for 35 minutes and then boiled for 10 minutes elicited a GI of 55 and rice that

Table 3 Cooking time and effect on GI

Test meal	Cooking time (min)	GI
Regular rice	5	58 ± 4
Regular rice	15	83 ± 4
Parboiled rice	5	54 ± 5
Parboiled rice	15	67 ± 5
Parboiled rice	25	66 ± 4

(Source: Wolever et al., 1986).

was boiled for 5–8 minutes and then simmered for 30 minutes had a GI of 66. As might be expected, this shows that the boiling time has a greater effect on starch gelatinization than soaking. Daomukda et al. (2011) studied the degree of gelatinization of brown rice cooked by various cooking methods (electric cooking, microwaving, steaming, and conventional boiling) and found that steaming produced the least degree of gelatinization and the lowest GI. However, steamed rice cakes (Pinto) commonly consumed in the Philippines showed high GI values (80–90) (Trinidad et al., 2010) as did steamed Sri Lankan rice noodles (103) (Hettiarachchi et al, 2009). The use of milled rice flour combined with steaming may have caused a greater gelatinization and produced a higher GI in these products.

Some processed rice products requiring longer cooking times have higher GIs than those requiring shorter times presumably as a result of gelatinization and a weakened structure. Instant white rice boiled for one minute had a GI of 65 (Wolever et al., 1986) compared to instant rice cooked for six minutes which showed a higher GI of 87 (Brand et al., 1985). Holt and Brand-Miller (1995) reported a GI of 102 for instant Doongara white rice. Instantization involves precooking and dehydrating the rice which enables consumers to shorten cooking time to—two to three minutes.

The water-to-rice ratio during cooking affects the degree of gelatinization and thereby digestibility (Daomukda et al. 2011). The degree of gelatinization of cooked rice tended to decrease with decreasing ratios of water to rice. The ratios studied were 2:1, 3:1, and 4:1 (w/v). Brown rice cooked at a ratio of 2:1 yielded a hard texture which may be due to the cooking water being insufficient for complete starch gelatinization, whereas a ratio of 3:1 and 4:1 produced the rice with a more desirable texture. A water to rice ratio of 2:1 was also found to significantly increase RS content in white rice (Kim et al., 2006). There are marked differences in the way rice is cooked around the world. Whilst in predominantly rice eating countries, it is cooked such that all the cooking liquid has evaporated at the end of cooking, rice in Western countries is cooked in excess water and drained before consumption. A notable amount of starch may be lost along with the cooking liquor in the latter method.

In summary, the cooking method, cooking time, cooking conditions, and cooking liquid volume all impact on rice GI. Lesser boiled and steamed rice grains have a smaller GI. However, steamed products made with rice flour shows a high GI. The literature highlights the importance of standardizing the cooking method in GI studies.

Processing

Processing methods such as explosion puffing, extrusion, and instantization increase starch digestibility. Instantization has been shown to increase digestibility even in high amylose rices (Brand et al., 1985; Holt and Brand Miller, 1995). Puffing increases the digestibility and the GI of rice presumably due to gelatinization, and a weakened and porous structure. Puffed white rice cooked for five minutes generated a GI of 74 in an unpublished observation (Human Nutrition Unit; Sydney, Australia). Similarly rice bubbles (puffed rice) and puffed rice cakes showed GIs of 116 and 95, and 117 and 128, respectively, (Brand et al., 1985; Holt et al., 1992; Miller et al., 1992; Holt and Brand Miller, 1995). However, in contrast to instantization, puffing still produced a lower glycemic response if a high amylose rice was used.

Extrusion uses high pressure and temperature conditions to gelatinize starch and is sometimes followed by drying. The principle extruded rice-based product is noodles. Fresh rice noodles are sometimes cooked again in boiling water at the last stage to further gelatinize the starch (Hou et al., 2010). Extrusion reduces the molecular weight of both amylose and amylopectin (Politz et al., 1994). These shorter branches could form novel indigestible cross-links and lower the GI (Theander and Westerlund, 1987). Further, rice vermicelli is predominantly made with high amylose rice which inherently has a lower GI (Juliano and Goddard, 1986). Panlasigui et al. (1992) showed that extruded high amylose rice noodles lowered the in vitro starch digestion and the in vivo blood glucose response in healthy and diabetic volunteers in Toronto and Philippines. A study by Juliano et al. (1990) showed that rice noodles elicited a lower starch digestibility and glycemic index in healthy volunteers. Dry (Vietnamese) and fresh (Australian) rice vermicelli showed GI values of 61 and 40, respectively, in one study (Chan et al., 2001). Differences in GI values between these two types may have been due to the type of rice used, processing, and storage conditions. Two rice noodles, Jianxi rice vermicelli and Taiwan vermicelli, consumed in Hong Kong, was studied by Lok et al. (2010). Whilst Taiwan vermicelli had a GI of 68, Jianxi vermicelli had a GI of 56. Chinese Jianxi and Guilin vermicellis, however, showed lower GI values (37 and 40, respectively) in another study (Ranawana et al, 2009). Philippino bihon was similarly found to be low GI (49) (Trinidad et al., 2010). The higher GI values for Taiwan and Vietnamese vermicelli (compared to the Chinese types) may be due to different amylopectin contents and processing conditions. *Idiyappam* (steamed fresh rice vermicelli or string hoppers) is made from red or white rice flour and is eaten in India and Sri Lanka. Hettiaratchi et al. (2009) reported a GI of 103 for red rice *idiyappam*. Sato et al (2010) investigated the GI of Thai long-grain *indica* rice and rice vermicelli variants in healthy subjects and found that the GI of rice vermicelli (55) and rice flat noodles (kway teow) (50) made from high amylose rice was lower than that of long grain rice (60) (Sato et al., 2010).

Processes that cause amylose retrogradation such as parboiling may reduce the GI through the formation RS. Parboiling is a hydrothermal treatment where the starch in the grain undergoes gelatinization followed by retrogradation. Niba (2003) showed that moist heat processing and the postprocess storage temperature both significantly affect starch digestibility. Parboiled rice due to its harder texture is more resistant to milling losses and leaching during cooking (Bhattacharya, 2004). It is the preferred form in some communities due to its greater yield, better storability, and greater grain volume. Some studies show that parboiling reduces the GI of rice (Wolever and Jenkins, 1986; Casiraghi et al, 1993; Ranawana et al, 2009). A reduced glycemic response was observed in healthy subjects who consumed parboiled Sri Lankan rice compared to an unparboiled version (Pathiraje et al., 2010). The authors suggest that besides the retrogradation of rice starch during the parboiling process, the higher protein content in the parboiled version and the resulting protein–starch interactions may have contributed to the lower starch digestibility compared to raw rice. However, other studies show that parboiling has little effect on the GI (Larsen et al, 1996). They compared the GI of high and low amylose parboiled rice and found that although the former produced a significantly lower GI than the latter the values were not different from the unparboiled controls. Aston et al (2007) reported that easy-cook basmati rice (instant rice or minute rice) which is a pregelatinized rice, had a significantly higher GI than standard basmati rice. This was confirmed by Ranawana et al (2009) who compared the GI of raw and easy-cook Basmati rice. The authors suggested that the higher GI of the latter was possibly due to a longer cooking time which resulted in a greater degree of starch gelatinization which may have undermined the GI lowering effects of RS formed during parboiling. Although an increased RS content due to parboiling might be expected to bring down the GI, traditional parboiling may not be producing adequate amounts of RS to affect the glycemic response. Larsen et al. (2000) suggested that the effect of parboiling on the GI depends on the severity of processing. They compared the effect of nonparboiled, mildly traditional parboiled, and severely pressure parboiled rices on the GI in diabetics and found that the latter produced the lowest value. The formation of RS seemed to have little effect on the GI reduction as amounts were quite small in both traditionally (0.2%) and pressure parboiled (1.6%) rice. Differential scanning calorimetry (DSC) showed that the pressure parboiled variant had retrograded amylopectin and this may have reduced available carbohydrate content. Further, amylopectin crystallites retain some of the associating forces during reheating and could be partly responsible for the low GI of severely pressured parboiled rice (Faisant et al., 1993). The authors observed no amylose retrogradation in any of the rice samples and this concurs with other reports (Ong and Blanshard, 1995). However, Lamberts et al. (2009) using DSC and wide-angle X-ray diffraction (WAXD) showed amylose crystallites in parboiled rice, and found that amounts depended both on parboiling conditions and cultivar. Mildly parboiled rice showed lower amylose crystallites than intermediate and severely parboiled rice. Although parboiled rice may be a better alternative to white rice due to its low GI properties, there is limited acceptance of it in communities not traditionally consuming it. Parboiling alters the physical and sensory properties of rice and renders it less palatable to some (Heinemann et al., 2006).

In summary, the impact of processing on rice GI depends on the method and intensity. Processes that disrupt structure and promote gelatinization increase the GI whilst those promoting RS formation and amylose/amylopectin complexes reduce it. The relative impact also depends on the chemical composition of the starch in the rice. Parboiling has the potential to reduce the GI of rice but this may depend on the parboiling technique used and cooking conditions. Extruded rice products generally have a lower GI than whole rice. However, this may again depend on rice type, finishing method (fresh or dried) and cooking procedure.

Cooling

Cooling reduces the GI of cooked rice through retrogradation and resultant increase in RS levels (Sievert and Pomeranz, 1989; Englyst et al., 1992). Highest crystallization rates can be observed around 4°C (Baik et al., 1997). In vitro studies showed that storing cooked rice at refrigerated temperatures (4°C for 24 hours) led to a reduction in their digestibility and estimated GI for both brown (Frei et al., 2003) and milled rice (Hu et al., 2004). Goñi et al. (1997) estimated the expected GI of cooked and cooked refrigerated rice and found substantial differences between rice cultivars. Starch hydrolysis tended to be more rapid and more complete for waxy cultivars than for high amylose cultivars. Storing rice in the refrigerator led to a reduction in the estimated GI for all cultivars. The highest decrease in starch hydrolysis after cool storing was seen for the waxy cultivars which suggest that high amylopectin rice may be more susceptible to cold-induced retrogradation. Aging of noodles (as part of processing) in a cold location increased RS formation in rice noodles and lowered the GI (Sato et al., 2010). Therefore, cooling seems to reduce the digestibility of both rice grains and processed products. Cooling appears to be a simple and effective intervention to reduce the GI of rice.

Soaking

Rice is sometimes soaked prior to cooking for various reasons. Punjabi Basmati rice is commonly presoaked to elongate the grains with cooking and produce a more aesthetically pleasing product (Juliano, 2003). White and brown rice is often soaked prior to milling to soften the grain, and also is a processing step in parboiling. Brown rice is sometimes soaked in water before cooking to reduce hardness and aid in cooking. Soaking allows starch granule expansion and better gelatinization leading to improved digestibility and a higher GI. The soaking temperature and moisture content of rice kernels affects the digestive properties of the cooked rice. Han and Lim, (2009) studied the digestibility of brown rice kernels (*japonica* type) soaked in water at different temperatures (25 or 50°C) before cooking to a moisture content of 20 or 30%. The cooked brown rice that had 30% moisture before cooking was digested to a greater extent than rice with 20% moisture. Rice soaked at 50°C (equal moisture content) was digested more readily. It was suggested that the amount of soluble material leached during soaking differed according to the soaking temperature and moisture content, which subsequently affected the texture and digestive properties of the cooked rice. The rice cooked in its own soaking water was harder, more adhesive, had higher levels of RS, and exhibited smaller GI values than its distilled water cooked counterpart. Soluble material leached during soaking makes the cooked rice harder and less digestible, which the authors attributed to the interactions between these molecules and the gelatinized rice during cooking. In a study of Chinese starchy foods, Lin et al. (2010) presoaked brown rice overnight in water at a ratio of 1.5:1 before cooking and found that it elicited a high GI (82; white bread as reference), the highest in comparison to other starchy foods (taro, adlay, yam, and mung bean noodles). The authors suggested that the process of soaking, besides reducing hardness and chewy mouthfeel, allows for starch granule expansion and better gelatinization, leading to improved digestibility and a high GI. The literature thus suggests that soaking may increase the GI of rice but it is dependent on soaking and subsequent cooking conditions. Omitting this step may be beneficial if a low GI rice is required.

Germination

Pregerminated brown rice (PGBR) is a type of Japanese rice that is slightly germinated following soaking in water. Pregerminated brown rice was better than white rice in preventing rapid postprandial blood glucose and insulin increases (Ito et al., 2005). In a study using rats, Seki et al. (2005) found that insoluble dietary fiber in PGBR bran was mainly responsible for lowering postprandial blood glucose levels. Daniel (2008) reported that PGBR helps lower blood glucose level in diabetics due to the action of acylated steryl glucoside (ASG) dysfunctional enzymes. Acylated steryl glucoside is a growth factor found in brown rice after germination. Pregerminating rice appears to be an effective method of reducing the GI. However, pregerminated rice consumption is limited to a few countries and making it a culturally acceptable elsewhere would be the greatest challenge to its more widespread use. The observed beneficial effects and the dearth of literature on this product justify further research.

Fiber

The evidence on the effect of fiber on rice GI remains equivocal. While some studies have shown that brown rice has a lower GI than its white counterpart (O'Dea et al., 1981; Brand-Miller et al., 1991) other studies have shown it to be higher (Ranawana et al, 2009; Lin et al, 2010). No correlation has been observed between fiber content in rice and its GI (Jenkins et al., 1981). Therefore, it may be that the lower GI of brown rice is a result of other bran constituents. Some studies showed that the rice bran fraction reduced the glycemic response in healthy (Brand-Miller et al., 1992) and diabetic individuals (Qureshi et al., 2002). Since the bran envelopes the starchy center, it may be also acting both as a physical barrier for water entry and as an impediment to swelling. Optimum heat treatment for brown and milled rice to obtain an acceptable texture according to their minimum cooking times (24 and 14 minutes, respectively) still produced a slower digestion rate and blood glucose response for brown than milled rice (Panlasigui and Thompson, 2006). To some extent, digestive enzymes were still not able to act on the starch substrate in brown rice which suggests that the low digestibility was due to the bran creating a physical barrier. Differences in chemical composition and physicochemical properties may also contribute to the different effects of brown and milled rice (Panlasigui and Thompson, 2006). The RS content was shown to be higher in brown rice (Nugent, 2005; Sajilata et al., 2006). Antinutrition factors such as phytic acid and polyphenols, may also contribute to slow starch digestion and lower blood glucose response associated with brown rice (Yoon et al., 1983; Thompson et al., 1987). More recently, soluble viscous fiber has shown to have greater effect on carbohydrate metabolism than nonsoluble fiber. Natural viscous vegetables (natto, yam and okra) in combination with white rice, eaten in Japanese-style breakfasts, delayed gastric emptying (Taniguchi-Fukatsu et al., 2011). Also, viscous vegetables lowered blood glucose and insulin secretion, unlike milk products that lower blood glucose but stimulate insulin secretion. Two recent studies incorporated a novel functional viscous fiber, PGX® into commonly consumed starchy foods including rice (Brand-Miller et al., 2010; Jenkins et al., 2010). Both studies found a dose-dependent reduction in the GI when PGX was added to white rice (19% for 2.5g dose and 30% for 5g dose).

In summary, it is still unclear if inherent nonsoluble fiber has a direct effect on rice GI. The GI of brown rice may be lower due to a combination of factors such as reduced digestibility, higher RS content, and effects of other bran constituents. More data from well-designed studies are required for firm conclusions. Co-ingestion of viscous fiber appears to reduce the GI of rice.

Particle Size

Food particle size influences starch digestibility both in vivo and in vitro (Bjorck et al., 1994; Holt and Brand-Miller, 1994; Snow and O'Dea, 1981; Heaton et al., 1988). O'Dea et al. (1981) noted that cooking ground rice resulted in significantly higher glycemic and lipemic responses than that seen with whole rice in both normal and diabetic subjects. The higher surface area in ground rice increases digestion rate. Kim et al. (2004) looked at the influence of three processed forms of rice (garaeduk, bagsulgi, and cooked rice) on in vitro starch hydrolysis and postprandial glucose and insulin responses in diabetics. The firmer rice product (bagsulgi) was more resistant to maceration and therefore resulted in slower in vitro and in vivo digestion compared to the softer forms which underwent the same level of maceration. Ranawana et al. (2010a; 2010b) investigated between-individual variations in the degree of mastication when eating rice, and its effect on the in vivo glycemic response and found that the extent of chewing significantly impacted on the glycemic response. Those who masticated the rice to a greater extent showed a significantly larger glycemic response compared to those who did not. As an intact grain, the starch in rice resides within cells and mechanical breakdown is therefore important for its release for digestion. The findings suggest that the degree of mastication may be a significant digestion rate-limiting factor for rice, and that chewing less will result in a lower GI. The method of milling also appears to impact on the glycemic response. Tran et al. (2011) looked at the degradation of starch structure after three levels of milling of polished rice grains. They observed that the more destructive means of grinding (grinding intensity, temperature, and time) disrupts the starch crystalline structure to a greater extent and that this has nutritional implications. For instance, hammer milling caused less structural damage resulting in longer branched chain starch molecules and slower digestibility. Porridge or congee is made with broken rice and is commonly consumed in Chinese cultures. Broken rice has a greater amount of cracking within the grain which results in increased gelatinization and a digestibility (GI-86) (Chan et al., 2001). Indeed Srikaeo and Sopade (2010) found that instant rice porridges (made from Thai Jasmine rice) have a high potential GI (68 to 97). Porridges are also cooked for longer than conventional rice and the higher resulting gelatinization also increase digestibility and the GI.

In conclusion, the particle size of ingested rice appears to have a significant impact on its GI. The particle size of rice after milling will determine gelatinization rates during cooking whilst the degree of breakdown during chewing will impact on the digestion rate in the small intestine.

The Glycemic Index of Mixed Meals and Impact of Condiments

As rice is hardly consumed on its own, but in accompaniment with other foods (vegetables, pulses, legumes, nuts, seafood, and meat) this section reviews the GI of mixed meals consumed in Asia. The published GI values of mixed meals commonly consumed in Asia are assembled in Appendix A.

Sharavathy et al. (2001) studied the rate and extent of starch digestion in vitro of cereal-based Indian food preparations (with/without accompaniments). Their findings indicated that the amount of RDS and slowly digestible starch (SDS) can be manipulated relatively simply by varying the type of accompaniments. Rice roti consumed on its own had lower SDS as compared to when it was consumed with coconut chutney. Rice flour roti was classified as high GI (103) when consumed without accompaniments (Widanagamage et al., 2009).

Hettiaratchi et al. (2011) reported that the GI of Sri Lankan rice mixed meals may be reduced by including naturally occurring sources of fiber with starchy staples. The effect of consuming curry with parboiled rice (*Mottaikarupan*) in Sri Lanka was studied by Pirasath et al. (2010) where the mean GI values of parboiled rice consumed either with *Amaranthus* leaf curry, soya meat gravy, or a combination of both were 47, 56, and 55, respectively. The addition of legumes such as lentils lowers the GI of rice when consumed together (Chew et al., 1988; Chaturvedi et al., 1997; Araya et al., 2003; Hettiaratchi et al., 2009).

Sugiyama et al. (2003) fed different forms of soybean (roasted and grounded, fermented, paste) with rice and reported GI lowering effects. Beans are low GI and the attenuated GI of the rice meals was attributed to soluble fiber and antinutrients found in beans. Similarly, natto and viscous vegetables (Japanese yams, and okra) combined with white rice showed improved insulin sensitivity, lipid metabolism, and oxidative stress in overweight subjects with impaired glucose tolerance (Taniguchi-Fukatsu et al., 2011). Soluble fiber may be reducing the GI through their effects on gastric emptying and the creation of a barrier between starch and enzymes.

Studies have investigated the effect of other macronutrients on rice GI. Aston et al. (2007) determined the GI of Basmati, easy-to-cook Basmati, and easy-to-cook American rice with the addition of margarine. The GIs reported were 43, 68, and 49, respectively, for each rice type. Although the study does not provide data from controls for comparison, other studies suggest that the plain forms of these rices have a relatively higher GI (Ranawana et al, 2009). The addition of fat may have reduced the glycemic response by delaying gastric emptying and enhancing gastric inhibitory polypeptide (GIP) secretion (Collier and O'Dea, 1983; Collier et al., 1984; Ercan et al., 1994). However, Japanese low amylose (17%) rice (147g) consumed with butter (10g) had a high GI of 96 (Sugiyama et al., 2003). This suggests that the GI lowering effects are due to interactions between fat and amylose, and this concurs with previous observations (Goddard and Young, 1984). Chen et al. (2010) found that rice noodles stir-fried "Singapore-style" had a GI value of 54 (low GI) and fried rice noodles with sliced beef had a GI of 66 (medium GI). The study, however, found no relationship between the amounts of fat and protein in the foods and their GI values suggesting that the cooking method had a greater effect on GI than the macronutrient composition. Only a limited number of studies that have investigated the effects of fats on rice GI and this aspect requires further research. Steamed glutinous rice roll (89), sticky rice wrapped in lotus leaf (83), and plain steamed vermicelli roll (90) all had high GIs (Chen et al., 2010). Stir-fried vegetables and chicken when eaten with rice had a high GI (73) (Chew et al. 1988). An in vitro study reported the glycemic potential of Malaysian foods and estimated that fried rice and nasi lemak (coconut rice with accompaniments) had a medium GI of 59 and 66, respectively (Shanita et al., 2011). The same study showed that fried bee hoon made with low amylose rice had an estimated high GI (99). However, these findings need to be confirmed in vivo.

Sugiyama et al. (2003) reported the GI of low amylose (17%) high GI (80) Koshikari rice when consumed with other ingredients. Dairy products (milk, cheese, and yogurt) significantly reduced the GI of the rice when consumed together. Rice with curry and cheese (67) had a lower GI than rice consumed with curry on its own. This may be due to macronutrient effects on either or both gastric emptying and starch digestion. However, these findings are contrary to Chen et al. (2010) who showed that fat and protein had no effect on rice GI. However, dairy products have been criticized as causing excessive insulin secretion so its use in lowering the GI of rice meals has to be considered with caution.

The addition of vinegar (acetic acid) and vinegared foods to white rice reduces its GI (Brighenti et al., 1995; Liljeberg and Bjork, 1998). One study showed that rice with the addition of vinegar or vinegared foods (pickled cucumber), reduced the GI of Koshihikari low-amylose rice (Sugiyama et al., 2003). The effective dosage of vinegar was estimated to be about 0.2–1.5 g/100 g which is as low as that found in sushi (Sugiyama et al., 2003). More studies are needed to confirm the mechanism of vinegar in lowering the GI of rice.

Sakuma et al. (2009) studied the glycemic effect when rice is eaten along with barley and found that postprandial glucose and insulin levels were suppressed compared with white rice on its own. Area under the curves of plasma glucose and insulin concentrations was reduced by barley intake in a dose-dependent manner. This reduction may have been due to the effects of beta-glucan a soluble fiber found in barley and which has shown to attenuate postprandial glucose and insulin responses (Braaten et al., 1991; Granfeldt et al., 1994; Hallfrisch and Behall, 2000; Cavallero et al., 2002; Makelainen et al., 2006; Panahi et al., 2007; Thondre et al., 2010; Chillo et al., 2010). Beta-glucan has been shown to increase viscosity in the upper digestive tract (Wood et al., 1994). It may therefore be slowing gastric emptying and digestion rate but this remains to be confirmed. Consuming rice with low GI foods will reduce overall meal GI. But the cooking method and degree of processing also play an important role in the final glycemic response.

Emulsifiers appear to reduce the digestibility of starch. Guraya et al. (1997) studied the effect of rice starch–lipid complexes on in vitro digestibility of nonwaxy and waxy rice (100% amylopectin) with different amylose:amylopectin ratios. Long chain saturated emulsifiers reduced digestibility more than short chain saturated and unsaturated emulsifiers when complexed with nonwaxy and waxy rice starch. The largest decrease in digestibility was seen with Polyaldo (100% C18:0 with decaglyceryl monostearate modification) for nonwaxy rice. Waxy rice starch did not complex with most of the emulsifiers. Most emulsifiers that reduced digestibility by about 10% were composed of unsaturated monoglycerides including some acetylated and succinylated monoglycerides.

The addition of other starches (corn, tapioca, and potato) to rice starch affected digestibility and improved textural qualities of noodles (Sato et al., 2010). The authors found that rice vermicelli made from long grain rice, tapioca, and corn starch had a GI of 35. Tapioca and corn starch has GIs ranging between 46–70 and 37–62, respectively (Foster-Powell et al., 2002). Combining these two starches with rice starch to make rice vermicelli may have produced a synergistically lower GI compared to pure rice vermicelli which had a GI of 55. Instant rice vermicelli (made from long-grain rice, tapioca, and potato starch) had a GI of 59, kway teow (made from long-grain rice and potato starch) had a GI of 60 and "pho" (made from long-grain rice and tapioca starch) had a GI of 62 (Sato et al., 2010). Other studies showed that plain kway teow had a GI of 50 (Sato et al, 2010). The addition of potato starch may have increased the glycemic response of the kway teow as potato has a medium to high GI. However, like rice, potato starch varies in amylose content (14–31% amylose in normal genotypes and up to 70% amylose in waxy genotypes) (Singh et al., 2010) and the use of a high amylose variety with rice could bring down the overall GI of a meal. The presence of other additives could also influence the functional and digestion properties of rice and rice products, and the GI. For example, studies on bread and lentils have shown that salt increases postprandial glucose and insulin excursions (Thorburn et al., 1986).

In summary, the literature shows that the type and quantity of condiments and accompaniments eaten with rice impacts on the GI. The effect of proteins and fats on the GI of rice is still unclear and further work in this area is required. In general, the addition of acidic condiments, viscous fiber, emulsifiers, dairy products, vegetables, and pulses appears to reduce the GI of rice.

CONCLUDING REMARKS

The studies reviewed in this article appeared to use the recommended GI testing method (FAO/WHO, 1998; Brouns et al., 2005; ISO, 2010) and fulfilled the minimum requirements for study design, subject number, reference food, and test protocol (Appendix A). The most used reference foods were glucose and white bread. The feasibility of using white rice as the reference was evaluated in a study testing the GI of Japanese mixed meals (Sugiyama et al., 2003). The authors suggested that white rice might be a more applicable reference food in Asian GI studies as it is the principle staple food in the region. Although the authors found a strong correlation between the GI values obtained using rice and glucose standards more research is required before it can be adopted conclusively. Other studies on Asian foods have evaluated the use of wheat chapatti as a reference (Rahman et al., 1992; Dilwari et al., 1981). Using commonly consumed regional staples as the reference in GI studies is a novel and pragmatic concept which is worthy of prosecution in future research.

Rice is the main constituent in the diets of a large population segment in the world. Whilst it contributes a large GL to the diet and thereby potentially promotes impaired glucose tolerance (notably in countries and communities accustomed to rice consumption), advocacy to reduce consumption may not be a sustainable solution. Reducing the GI of rice may be the more practical approach. Whilst the review highlights the large number of variables influencing the GI of rice, it shows that rice is more often than not in the medium to high GI range. Especially white rice which is the predominant form eaten in the world and the principle type associated with poor glycemic control. The literature suggests that certain processes can reduce its GI to a low level. However, these processes almost always also change the physicochemical and sensory properties of the rice thus reducing their acceptance. It is harder to convince individuals to accept new types of rice or change traditional dietary habits. The more practical strategy may be the development of rice-accompaniment combinations that reduce the overall GI of rice meals. Future studies need to focus on macronutrient and condiment interactions with rice and their effects on the GI, and the development of optimum rice and accompaniment combinations that will be both culturally acceptable and reduce meal GI. Such developments will not only secure better health outcomes but also enable consumers to enjoy the delights of rice.

Appendix A GI of rice and rice products published (1981 to 2012)

Food	GI	Subjects (Type* and Number)	Reference food and time duration	Reference
Rice, white				
White (Oryza sativa), boiled (India)	69	Type 2, 6	Glucose, 3 hours	*Chaturvedi et al., 1997*
Rice, boiled white, type NS (India)	68	Healthy, 6	Wheat chapatti, 2 hours	*Dilwari et al, 1981*
Rice, boiled white, type NS (Canada)	80	Type 2, 6	Bread, 3 hours	*Jenkins et al., 1983*
Rice, boiled white, type NS (Pakistan)	98	Type 2, 22	Wheat chapatti, 3 hours	*Rahman et al., 1992*
Rice, boiled white, type NS, boiled 13 minutes (Italy)	102	Healthy, 14	Glucose, 2 hours	*Gatti et al., 1987*
Long grain, boiled 5 minutes (Canada)	58	Type 1, 5; Type 2, 13	Bread, 3 hours	*Wolever et al., 1986*
Long grain, white, unconverted, boiled, 15 minutes (Mahatma Brand; Australia)	50	Healthy, 6	Glucose, 2 hours	*Brand et al., 1985*
Gem long grain (Dainty Food Inc., Toronto, Canada)	79	Type 2, 10	Bread, 3 hours	*Wolever et al., 1985*
Gem long grain (Dainty Food Inc., Toronto, Canada)	82	Type 1, 6	Bread, 3 hours	*Wolever et al., 1985*
Long grain, white (Uncle Bens, Auckland, New Zealand)	56	Healthy, 14	Glucose, 2 hours	*Perry et al., 2000*
Long grain, boiled 15 minutes	83	Type 1, 5; Type 2, 13	Bread, 3 hours	*Wolever et al., 1986*
Long grain, boiled 25 minutes (Surinam)	56	Type 2,3	Glucose, 3 hours	*Liu et al., 2000*
Gem long grain (Dainty Food Inc., Toronto, Canada)	86	Type 1, 6	Bread, 3 hours	*Wolever et al. 1987*
Long grain rice (Purchased in Oxford, UK)	47	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
BR 16, 28% high-amylose (Bangladesh)	53	Type 2, 12	Bread, 3 hours	*Larsen et al., 1996*
BR 16, white long grain, 27% high-amylose, boiled 17.5min (Bangladesh)	55	Type 2, 9	Bread, 3 hours	*Larsen et al., 2000*
Milagrosa, high-amylose, 26.9% amylose, (Philippines, Aklan Province)	68	In vitro	*Frei et al., 2003*	
Manumbaeay, high-amylose, 29.9% amylose, (Philippines, Aklan Province)	87	In vitro	*Frei et al., 2003*	
Kutsiyam, intermediate-amylose, 18.7% amylose, (Philippines, Aklan Province)	69	In vitro	*Frei et al., 2003*	
Kinaures, low-amylose, 9.8% amylose	97	In vitro	*Frei et al., 2003*	
(Philippines, Aklan Province)	92	In vitro	*Frei et al., 2003*	
	109	In vitro	*Frei et al., 2003*	

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Appendix A (*Continued*)

Food	GI	Subjects (Type* and Number)	Reference food and time duration	Reference
amylose, (Philippines, Aklan Province)				
Karaya, waxy cultivar, 0% amylose, (Philippines, Aklan Province)				
ZF201, indica milled rice, 26.8% high-amylose, (China)	63	In vitro	*Hu et al., 2004*	
Jiayu293, indica milled rice, 21.3% intermediate-amylose, (China)	79	In vitro	*Hu et al., 2004*	
Zhefu504, indica milled rice, 13.1% low-amylose (China)	99	In vitro	*Hu et al., 2004*	
Yunuo No. 1, indica milled rice, 1.1% waxy, (China)	106	In vitro	*Hu et al., 2004*	
JIN3, japonica milled rice, 25.8% high-amylose (China)	78	In vitro	*Hu et al., 2004*	
Xiushui 11, japonica milled rice, 20.1% intermediate-amylose (China)	69	In vitro	*Hu et al., 2004*	
JIN1, japonica milled rice, low-amylose, 13.8% (China)	89	In vitro	*Hu et al., 2004*	
Shaonuo, indica milled rice, waxy, 0%, (China)	102	In vitro	*Hu et al., 2004*	
IIyou3027, hybrid milled rice, high-amylose, 26.5% (China)	78	In vitro	*Hu et al., 2004*	
Xieyou46, hybrid milled rice, 21.6% intermediate-amylose (China)	63	In vitro	*Hu et al., 2004*	
Fenyouxiangzan, hybrid milled rice, 14.3% low-amylose (China)	92	In vitro	*Hu et al., 2004*	
Zanuo, hybrid milled rice, 0.7%, waxy, (China)	100	In vitro	*Hu et al., 2004*	
Red rice (Thailand)	76	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Long grain rice, Indica rice (Thailand)	60	Healthy, 15	Glucose, 2 hours	*Sato et al., 2010*
White rice, (Golestan company),boiled 10 minutes (Iran)	55	Healthy, 10	Glucose, 2 hours	*Parastouei et al., 2011*
White rice, (Golestan company), boiled 5-8min, then simmered 30 minutes (Iran)	66	Healthy, 10	Glucose, 2 hours	*Parastouei et al., 2011*
Sona Masuri rice (India)	72	Healthy, N.A.	Glucose, 2 hours	*Shobana et al., 2012*
Ponni rice (India)	70	Healthy, N.A.	Glucose, 2 hours	*Shobana et al., 2012*
Surti Kolam (India)	77	Healthy, N.A.	Glucose, 2 hours	*Shobana et al., 2012*
White rice, Japonica, normal grain (Koshihikari, Japan)	89	Healthy, 15	Glucose, 2 hours	*Sato et al., 2010*
Koshihikari, low-amylose, 17% (Japan)	80	Healthy, subgroups of 9-11 (n = 58)	Glucose, 2 hours	*Sugiyama et al. 2003*
Bg 300 unparboiled rice, high amylose 27.1% (Sri Lanka)	61	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Bg 352 unparboiled rice, high amylose 27.0% (Sri Lanka)	67	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Bg 358 unparboiled rice, high amylose 29.0% (Sri Lanka)	67	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Bg 406 unparboiled rice, high amylose 24.5% (Sri Lanka)	7	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
LD 356, unparboiled rice, intermediate-amylose 21.5% (Sri Lanka)	70	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Rathkaral unparboiled, high amylose 29.5% (Sri Lanka)	60	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*

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Appendix A (*Continued*)

Food	GI	Subjects (Type* and Number)	Reference food and time duration	Reference
Wedaheenati unparboiled, high amylose 29.0% (Sri Lanka)	57	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Heendikwel unparboiled, high amylose 27.7% (Sri Lanka)	62	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Red rice (Sri Lanka)	*99*		*In vitro*	*Hettiaratchi et al., 2009*
Commercial rice varieties (Sri Lanka)	55–73 (majority medium GI	Healthy, 12	White bread, 2 hours	*Hettiaratchi et al., 2011*
Rice, brown				
Brown rice (Canada)	66	Healthy, 7	Glucose, 2 hours	*Jenkins et al. 1981*
Brown, steamed (USA)	50	Healthy, 8	Glucose, 3 hours (AUC calculated over 3 hours for 5 time points only)	*Potter et al., 1981*
Brown (Oryza sativa), boiled (South India)	50	Healthy, 12–15	Glucose, 3 hours (AUC calculated over 3h for 5 time points only)	*Kurup and Krishnamurthy., 1991*
Calrose brown (Rice Growers Co-op, Australia)	124	Healthy, 8	Bread, 2 hours	*Miller et al., 1992*
Doongara brown, high-amylose (Rice Growers Co-op, Australia)	94	Healthy, 8	Bread, 2 hours	*Miller et al., 1992*
Pelde brown (Rice Growers Co-op, Australia)	109	Healthy, 8	Bread, 2 hours	*Miller et al., 1992*
Sunbrown Quick (Rice Growers Co-op, Australia)	114	Healthy, 8	Bread, 2 hours	*Miller et al., 1992*
Tai Ken, brown rice, (Union Rice Company; Taipei, Taiwan)	82	Healthy, 10	Bread, 2 hours	*Lin et al., 2010*
Rice, basmati				
Basmati, white, boiled (Mahatma brand, Sydney, Australia)	83	Healthy,9	Bread, 2 hours	*Holt* and *Brand Miller, 1995*
Brown basmati rice	75	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
White and brown basmati rice (mixture60% white basmati, 40% brown basmati)	59	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Basmati with wild rice (83% easy-cook basmati) and 17% North American Wild rice	63	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Rice, parboiled				
Long grain, boiled 10 minutes (USA)	61	Type 2, 8	Glucose, 3 hours (GI calculated from the AUC of glucose)	*Krezowski et al. 1987*
Long grain, boiled 12 minutes (Denmark)	60	Type 2, 7	Bread, 2 hours	*Rasmussen et al, 1992*
Long grain, boiled 5 minutes (Canada)	54	Type 1, 5 Type 2, 13	Bread, 3 hours	*Wolever et al., 1986*
Long grain, boiled 15 minutes (Canada)	67	Type 1, 5 Type 2, 13	Bread, 3 hours	*Wolever et al., 1986*
Long-grain white, parboiled (Uncle Ben's; Masterfoods, Brucargo-Zaventem, Belgium)	54	Healthy,13	Glucose, 2 hours	*Al-Mssallem et al, 2011*
Hassawi rice (Al-Hassa, Saudi Arabia)	59	Healthy,13	Glucose, 2 hours	*Al-Mssallem et al, 2011*
Bg 352 parboiled rice, amylose content not determined (Sri Lanka)	60	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Bg 358 parboiled rice, amylose content not determined (Sri Lanka)	62	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
Bg 356 parboiled rice, amylose content not determined (Sri Lanka)	64	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*
	71	Healthy, 10	Glucose, 2 hours	*Pathiraje et al., 2010*

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Appendix A (*Continued*)

Food	GI	Subjects (Type* and Number)	Reference food and time duration	Reference
Bg 406 parboiled rice, amylose content not determined (Sri Lanka)				
Rice, glutinous				
Glutinous rice (Thailand)	94	Healthy, 12	Glucose, 2 hours	*Chan et al., 2001*
Glutinous rice (Thailand)	92	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Glutinous rice (Japan)	105	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	*Sugiyama et al., 2003*
Rice noodles				
Rice vermicelli, Kongmoon (China)	83	Type 1 and 2, 9	Bread, 3 hours	*Jenkins et al., 1981*
Jianxi rice vermicelli (rice, water), boiled 8 minutes (Hong Kong)	55	Healthy, 10	Glucose, 2 hours	*Lok et al., 2010*
Taiwan vermicelli (rice, water, maize starch), boiled 2 minutes (Hong Kong)	68	Healthy, 10	Glucose, 2 hours	*Lok et al., 2010*
Vermicelli, Produced from 100% long grain rice	55	Healthy, 15	Glucose, 2 hours	*Sato et al., 2010*
Vermicelli, Produced from 99% long grain rice+1% calcium	50	Healthy, 15	Glucose, 2 hours	*Sato et al., 2010*
Bihon (Philippines)	49	Healthy, 10	Glucose, 2 hours	*Trinidad et al., 2010*
Guilin rice vermicelli (purchased from Oxford, UK), cooked 8 minutes	37	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Jiangxi rice vermicelli (purchased from Oxford, UK), cooked 8 minutes	40	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Rice noodles, dried, boiled (Thai World, Bangkok, Thailand)	61	Healthy, 12	Glucose, 2 hours	*Chan et al., 2001*
Rice noodles, freshly made, boiled (Australia)	40	Healthy, 12	Glucose, 2 hours	*Chan et al., 2001*
Instant rice vermicelli (made from Thai long grain rice, tapioca starch, potato starch)	59	Healthy, 15	Glucose, 2 hours	*Sato et al., 2010*
Kway teow (made from Thai long grain rice and potato starch)	60	Healthy, 15	Glucose, 2 hours	*Sato et al., 2010*
Pho (made from Thai long grain rice and tapioca starch)	62	Healthy, 15	Glucose, 2 hours	*Sato et al., 2010*
Rice, speciality rices				
Cajun Style (Uncle Ben's; Effem Foods Ltd, Canada)	51	Type 1 and 2, 9	Bread, 3 hours	*Jenkins et al., 1981*
Garden Style (Uncle Ben's; Effem Foods Ltd, Canada)	55	Type 1 and 2, 9	Bread, 3 hours	*Jenkins et al., 1981*
Long grain and Wild (Uncle Ben's; Effem Foods Ltd, Canada)	54	Type 1 and 2, 9	Bread, 3 hours	*Jenkins et al., 1981*
Mexican Fast and Fancy (Uncle Ben's; Effem Foods Ltd, Canada)	58	Type 1 and 2, 9	Bread, 3 hours	*Jenkins et al., 1981*
Saskatchewan wild rice (Canada)	57	Type 1 and 2, 9	Bread, 3 hours	*Jenkins et al., 1981*
Easy-cook Basmati rice	80	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Easy-cook long grain rice	47	Healthy, 14	Glucose, 2 hours	*Ranawana et al., 2009*
Broken rice	86	Healthy, 12	Glucose, 2 hours	*Chan et al., 2001*
Instant rice, white, boiled 1 minutes (Canada)	65	Type 1, 5 Type 2, 13	Bread, 3 hours	*Wolever et al., 1986*
Instant rice, white, cooked 6 min (Trice Brand, Australia)	87	Healthy, 6	Glucose, 2 hours	*Brand et al., 1985*
Instant Doongara, white, cooked 5 min (Rice Growers Co-op, Australia)	132	Healthy, 9	Bread, 2 hours	*Holt* and *Brand-Miller, 1995*
Other rice products				
Rice Bubbles (Puffed rice) (Kellogg's Australia)	116	Healthy, 7	Bread, 3 hours	*Holt et al., 1992*
	95	Healthy, 6	Glucose, 2 hours	*Brand et al., 1985*

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Appendix A (*Continued*)

Food	GI	Subjects (Type* and Number)	Reference food and time duration	Reference
Rice Bubbles (Puffed rice) (Kellogg's Australia)				
Puffed rice cakes, white (Rice Growers Co-op, Australia)	117	Healthy, 6	Bread, 2 hours	*Miller et al., 1992*
Puffed rice cakes, Calrose rice, low amylose (Rice Growers Co-op, Australia)	128	Healthy, 9	Bread, 2 hours	*Holt* and *Brand-Miller, 1995*
Puffed rice cakes, Doongara rice, high amylose (Rice Growers Co-op, Australia)	85	Healthy, 9	Bread, 2 hours	*Holt* and *Brand-Miller, 1995*

GI = Glycemic Index; *Type 1 = Insulin-dependent diabetes mellitus (IDDM); Type 2 = Noninsulin-dependent diabetes mellitus (NIDDM); N.A. = Not available

The glycemic index of rice mixed meals consumed in Asia

Food	GI	Subjects (Type and Number)*	Reference food and time duration	Classification
Chinese				
Fried rice vermicelli in Singapore-style	54	Healthy, 15	Glucose, 2 hours	Low GI
Fried rice noodles with sliced beef	66	Healthy, 15	Glucose, 2 hours	Medium GI
Glutinous rice ball	61	Healthy, 15	Glucose, 2 hours	Medium GI
Salted meat rice dumpling	69	Healthy, 15	Glucose, 2 hours	Medium GI
Fried rice in Yangzhou-style	80	Healthy, 15	Glucose, 2 hours	High GI
Sticky rice wrapped in lotus leaf	83	Healthy, 15	Glucose, 2 hours	High GI
Steamed glutinous rice roll	89	Healthy, 15	Glucose, 2 hours	High GI
Plain steamed vermicelli roll	90	Healthy, 15	Glucose, 2 hours	High GI
Rice with stir-fried vegetables and chicken	73	Healthy, 8	Glucose,3 hours	High GI
Japanese				
Sushi, roasted sea algae, vinegar – low amylose content rice (17%)	55	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	Low GI
White rice with milk 100ml (taken together) low-amylose content rice (17%)	59	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	Medium GI
Butter rice low-amylose content (17%)	96	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
Curry rice low-amylose content (17%)	82	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
White rice low-amylose content (17%) with curry and cheese	67	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	Medium GI
White rice low-amylose content (17%) and salted plum (umeboshi)	98	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
White rice low-amylose content (17%) and dried fish strip	115	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
White rice low-amylose content (17%) rolled in toasted algae	94	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
White rice low-amylose content (17%) with raw egg, with soy sauce	114	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
White rice low-amylose content (17%) and pickled food (sliced cucumber mixed with vinegar)	75	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
White rice and roasted, ground soybean (beihan, kinako) low-amylose content (17%)	68	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	Medium GI
White rice and fermented soybean (natto) low-amylose content (17%)	68	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	Medium GI
Rice with soybean paste soup (miso shiru) low-amylose content (17%)	74	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI

(*Continued on next page*)

Appendix A (*Continued*)

Food	GI	Subjects (Type and Number)*	Reference food and time duration	Classification
Glutinuous rice cake (mochi) low-amylose content (17%)	101	Healthy, subgroups of 9–11 ($n = 58$)	White rice, 2 hours	High GI
Indian, Sri Lankan				
Rice with lentil and cauliflower curry	60	Healthy, 8	Glucose,3 hours	Medium GI
Rice, boiled served with *Lagenaria vulgaris* (bottle gourd) and (*Lycopersicon esculentum*) tomato curry	69	Type 2, 6	Glucose, 3 hours	Medium GI
Parboiled rice with green leaf curry (*Amaranthus*)	48	Healthy, 20	Glucose, 2 hours	Low GI
Parboiled rice with gravy (soya meat)	56	Healthy, 20	Glucose, 2 hours	Medium GI
Parboiled rice with green leaf curry and gravy	55	Healthy, 20	Glucose, 2 hours	Low GI
Red rice with lentil curry, boiled egg + *Centella asiatica (Gotu kola) salad* and coconut gravy (Kiri hodi)	63	Healthy, 12	White bread, 2 hours	Medium GI
Red rice with lentil curry, boiled egg + *Centella asiatica (Gotu kola) salad* and coconut gravy (Kiri hodi) and *Lasia spinosa* (*kohila*) salad	57	Healthy, 12	White bread, 2 hours	Medium GI
Red rice with lentil curry, boiled egg + *Centella asiatica (Gotu kola) salad*, coconut gravy and *Trichosanthes cucumerina (snake gourd)* salad	61	Healthy, 12	White bread, 2 hours	Medium GI
Red rice with lentil curry—Red rice (82% starch), Lentils curry (18% starch).	60	In vitro		Medium GI
Malaysian				
Fried rice	59	In vitro		Medium GI
Nasi lemak	66	*In vitro*		Medium GI
Fried beehoon	99	*In vitro*		High GI
Other studies				
Lentil-rice meal (70:30) (Chile)	49	*In vitro*		Low GI

Sources: Lok et al.; 2010; Pirasath et al., 2010; Chaturvedi et al., 1997; Chew et al., 1988; Sugiyama et al., 2003; Araya et al., 2003; Hettiaratchi et al., 2009; Shanita et al., 2011; Chen et al., 2010; GI = Glycemic Index; *Type 1 = Insulin-dependent diabetes mellitus (IDDM); Type 2 = Noninsulin-dependent diabetes mellitus (NIDDM).

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