



Research article

Glycemic responses of special rice: Case study in Thai geographical indication rice cultivars

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Article Info

Article history:

Received 31 July 2023

Revised 10 December 2023

Accepted 1 January 2024

Available online 14 February 2024

Keywords:

Diabetes,
Geographical indication,
Glycemic response,
Rice,
Starch digestion

Abstract

Importance of the work: Thai geographical indication (GI) rice cultivars which are special rice types, have not been evaluated for their glycemic responses.

Objectives: This study aimed to determine the glycemic indices and glycemic loads of 10 rice varieties registered as Thai GI rice.

Materials & Methods: The 10 Thai GI rice varieties; *Kum Lanna*, *Rai Leum Pua Petchabun*, *Kalasin Kaowong*, *Hom Mali* (Phayao, Thung Kula Rong-Hai and Surin), *Leuang Patew Chumphon*, *Rai Dawk Kha Phangnga*, *Sangyod Muang Phatthalung*, and *Jek Chuey Sao Hai* were analyzed for their glycemic responses using the standard *in vivo* method.

Results: It was found that Thai GI rice varieties exhibited medium to high glycemic indices and all samples showed high glycemic load values (>20). The glycemic indices ranged from 62.3 (*Sangyod Muang Phatthalung*) to 82.3 (*Kalasin Kaowong*). Glycemic indices were discovered to be primarily impacted by variety rather than geography.

Main finding: This study was the first to report the glycemic indices of 10 Thai GI rice cultivars and updated the glycemic index database of special rice types, allowing consumers to select healthier rice varieties, such as ones with medium glycemic indices.

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<https://doi.org/10.34044/j.anres.2024.58.1.02>

Introduction

Rice (*Oryza sativa* L.) is the most popular staple food grain and an important source of biomolecules, with the peoples of the Asia Pacific region, parts of the Caribbean and Latin America largely depending on it for their caloric supply and nutrition (Sen et al., 2020).

Thailand is a major rice exporter and known for its high-quality, long-grain white rice (Chakhonkaen et al., 2012). Thailand has a vast range of rice cultivars due to its rich and diversified ecology, where rice ecology is categorized as irrigated, rainfed lowland, deep water and upland environments (Vejchasarn et al., 2021).

Thailand applies the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement of the World Trade Organization (WTO) to protect its rice biodiversity and intellectual and cultural heritage (Ngokkuen and Grote, 2013). Geographical indications (GIs) that indicate the origin and quality of a good are passionately debated in international trade. GIs overlap international trade, intellectual property and agricultural policy. Thailand's Geographical Indications Act B.E.2546 (AD 2003) protects GIs. This Act divides the hundreds of potential GI products in the country into three categories: general protection, specific GI protection and foreign product protection. Special GI products include: 1) rice, 2) silk, 3) wines and 4) spirits. The introduction of legal protection for GIs for specific commodities reflects a keen awareness of the need to emphasize the importance of certain special products, such as rice, which involves a substantial portion of Thailand's economy and labor force. The GI for Thai Jasmine Rice deserves special mention in this regard. The generic name, Thai Jasmine Rice, which is officially called “*Khao Hom Mali Thung Kula Rong-Hai*” or “*Thai Hom Mali Rice*” is protected as Thailand's No. 1 GI. This was also the first GI of Thailand to be internationally registered under the EU's Protected Geographical Indication scheme. Other renowned GIs for rice include *Surin Hom Mali Rice*, *Sangyod Muang Phatthalung Rice*, *Hang Hom Tong Sakhon Tawape Rice*, *Khao Jek Chuey Sao Hai*, *Kaowong Kalasin Sticky Rice*, *Khao Leuang Patew Chumphon* and *Khao Kum Lanna*. Clearly, the large number of GI rice products in Thailand represents its status as the world's leading pioneer of rice (Lertdhamtewe, 2014).

Given that rice is a fundamental food source for over one-half of the global population, the pace at which starch is digested in rice is of utmost importance to individuals who

prioritize their health, particularly those with diabetes (Khatun et al., 2019). The glycemic index is a measure that compares carbohydrate-rich foods to a reference food (glucose) or white bread in terms of their tendency to raise blood glucose levels when consumed. It is also known as “GI,” however to avoid confusion with “geographical indication,” the term “glycemic index” is used throughout this study.

Consumption of low glycemic index foods has been linked to a lower incidence of Type 2 diabetes mellitus, significantly less insulin resistance and a lower prevalence of the metabolic syndrome (Henry et al., 2021). The glycemic index values of rice cultivars have been observed to range from 48 for the Australian *Doongara* white rice variety to 109 for Thailand Jasmine polished, white, long grain rice (Atkinson et al., 2008). As a result, categorizing rice as high GI (>70) or low GI (55) food is challenging.

Regarding the importance of the glycemic index of rice, particularly for Thai GI rice varieties, it is essential to note their prevalence. The objective of this study was to determine the glycemic index values of these special rice varieties. The obtained information could be useful not only for health professionals and nutritionists to provide dietary guidance, but also for the general population interested in consuming suitable rice varieties.

Materials and Methods

Rice cultivars

In total, 10 Thai GI rice samples (all long grain rice) were purchased from trusted GI product markets throughout Thailand. The 10 samples were: *Kum Lanna*, *Rai Leum Pua Petchabun*, *Kalasin Kaowong*, *Hom Mali Phayao*, *Hom Mali Thung Kula Rong-Hai*, *Hom Mali Surin*, *Leuang Patew Chumphon*, *Rai Dawk Kha Phangnga*, *Sangyod Muang Phatthalung* and *Jek Chuey Sao Hai*. The rice samples were obtained as sold, reflecting the manner in which they are consumed. *Kum Lanna*, *Rai Leum Pua Petchabun*, *Rai Dawk Kha Phangnga* and *Sangyod Muang Phatthalung* are pigmented rice and marketed as brown rice (unpolished rice), while the others are marketed as white or commercially polished rice. Amylose contents were determined using a standard procedure (AACC Approved Methods of Analysis, Method 61–03; Cereals and Grains Association, 2010).

Ethics statements

This study was authorized by the Pibulsongkram Rajabhat University's Ethics Committee (Approval number: PSRU-EC 2021/044), and all volunteers provided informed written consent before participating.

Subjects

A sample of 10 healthy, non-diabetic volunteers aged between 20 and 55 (all Asians) were recruited from personnel at the Bhumibol Adulyadej Hospital, Thailand and students at Pibulsongkram Rajabhat University, Thailand. Subjects were excluded if they were overweight according to Asia Pacific recommendations (body mass index ≥ 23.0 kg/m²), on any special diets for therapeutic or other purposes, had a family history of diabetes, were ill, had a history of food allergy or were taking any drugs. In addition, subjects were excluded if their fasting blood glucose level was greater than 100 mg/dL (Shobana et al., 2012).

In vivo glycemic index determination

The study was carried out using an international standard protocol (ISO 26642:2010 Food products—Determination of the glycemic index (GI) and recommendation for food classification) which was in line with the procedures recommended by Food and Agriculture Organization/World Health Organization (1998).

Test foods and reference foods

The 10 Thai GI rice samples were used as the test foods. White bread (Farmhouse; President Bakery Public Company Ltd.; Thailand) was used as the reference food.

The available carbohydrate contents of the test and reference food samples were measured using the available carbohydrates test kit (K-AVCHO, Megazyme Ltd., Ireland), following the Association of Official Analytical Chemists (AOAC) standard method 2020.07. Briefly, the test and reference food samples were freeze-dried and ground to pass through a 0.5 mm sieve using a laboratory mill. Ground samples (~0.5 g) were weighed into separate 40 mL polypropylene tubes and then incubated with pancreatic α -amylase/amyloglucosidase for 4 hr. Aliquots (1.0 mL) were withdrawn and added to 25 mL of 50 mM acetic acid and mixed thoroughly before centrifuging at 8,000 $\times$ g for 5 min. Aliquots (0.1 mL) of this solution were analyzed for available carbohydrates (glucose, fructose and galactose

derived from free glucose, maltodextrins, sucrose, lactose and digestible starch) based on direct measurement of the glucose, fructose and galactose using a spectrophotometer at 340 nm. The full protocol can be obtained from the manufacturer's website (https://www.megazyme.com/documents/Assay_Protocol/K-AVCHO_DATA.pdf).

To prevent starch degradation, the required portions of the test foods (containing 50 g of available carbohydrate) were freshly prepared just prior to testing each morning. A rice cooker was used (Sharp; Model KSH-D11; Japan). The rice-to-water ratio was 1:2 by volume, and the cooking time was 35 min. To eliminate the influence of cooking conditions, samples of waxy and non-waxy rice were cooked in the same manner. Cooked rice samples were subjected to moisture determination using a halogen moisture analyzer (OHAUS; MB90; USA).

For the reference food, the weight (providing 50 g of available carbohydrate) for the white bread was 109 g, calculated from the available carbohydrate content determined using the available carbohydrates test kit, as described above.

Protocols

Over a period of 12 wk, on separate mornings, each subject consumed portions of the test foods and the reference food (white bread) containing 50 g of available carbohydrate. The reference food was consumed at the beginning, middle and end of the test food testing, while the 10 GI rice varieties (test foods) were consumed in random order in between the reference food sessions with a gap of at least 2 d between measurements to minimize any carry-over effects (Shobana et al., 2012).

The day before a test, the subjects were instructed to limit their consumption of alcohol and beverages containing caffeine, as well as their participation in strenuous physical activity. The night before a test, subjects were instructed not to consume or drink after 2100 hours. Before eating, capillary blood samples were collected at 25 min and 0 min (the baseline value was calculated as the mean of these two values). Prior to the finger-prick, subjects were encouraged to warm their palms to increase blood circulation. To minimize plasma dilution, fingertips were not squeezed to extract blood. Blood glucose was measured using the HemoCue® Glucose 201 System (HemoCue AB; Sweden). Following the fasting blood glucose estimation, subjects consumed a test food (the first bite was considered as 0 min) and the first capillary blood sample was taken exactly 15 min afterward. Further blood samples were obtained at 30 min, 45 min, 60 min, 90 min and 120 min.

Calculation of glycemic index and glycemic load values

The blood glucose values for every time over 2 hr were used to calculate the incremental area under the curve (iAUC) for each subject and each test individually. The incremental area under the blood glucose response curves-to-the test and the reference foods (as a ratio) was calculated geometrically using the trapezoid rule (Food and Agriculture Organization/World Health Organization, 1998), ignoring the area beneath the baseline.

The iAUC for each test food consumed by each subject was expressed as a percentage of the mean iAUC glucose for the two repeats of the reference food (white bread) consumed by the same subject (Equation 1).

$$\text{Glycemic index} = (\text{iAUC test food} / \text{iAUC reference food}) \times 100 \quad (1)$$

Then, the glycemic index of each GI rice was calculated as the mean value across all subjects consuming that GI rice.

Where the individual glycemic values for any subject were greater or less than twice the SD of the group mean, the values were considered as outliers and were excluded from the analysis.

In addition, the glycemic load of a typical serving of each GI rice was calculated (Equation 2) based on the amount of net available carbohydrate consumed multiplied by the rate at which the carbohydrate is metabolized and enters the bloodstream (glycemic index).

$$\text{Glycemic load} = (\text{glycemic index} \times \text{carbohydrate in the serving size (g)/100}) \quad (2)$$

Data management

A study-specific form was used for data entry. Case report forms were examined by research assistants for completeness and accuracy. For purposes of quality control, forms that had been reviewed and found to be comprehensive and accurate were then signed. The data were entered into a spreadsheet using the Excel software (Microsoft; USA) prior to the analysis. Password-protected, project-specific computers were used to ensure the security and confidentiality of the data.

Statistical analysis

The iAUC and glycemic index were calculated using formulas in the Excel software. Data were presented as mean $\pm$ SD values. Comparisons between the foods were made using one-way analysis of variance and Tukey's multiple comparisons test. Levels of inter- and intra-individual variation were assessed by determining the coefficient of variation (CV) [CV% = 100 $\times$ (SD / mean)]. Statistical significance was set at $p < 0.05$. All statistical analysis was performed using the Minitab® version 18 software (Minitab Inc.; USA).

Results

Thai GI rice properties

The detailed information of the selected 10 Thai GI rice analyzed in this study is shown in Table 1. In addition, Fig. 1 shows the areas where they are grown in Thailand.

The amylose and available carbohydrate contents, as well as the serving size equivalent to 50 g of available carbohydrate of the rice samples are presented in Table 2.

The amylose contents of the rice samples ranged from low amylose waxy rice (*Kum Lanna*, *Rai Leum Pua Petchabun*, *Kalasin Kaowong*) to high amylose non-waxy rice (*Leuang Patew Chumphon*), depending on the variety. Rice is generally high in carbohydrate. The amounts of available carbohydrates found in Thai GI rice (69.70–77.40 g/100g) were in agreement with other reports (Ranawana et al., 2009; Shobana et al., 2012).

Numerous rice cultivars from all parts of Thailand have been registered as Thai GI rice (Table 1 and Fig. 1). The Thai GI rice in the current study could be categorized into two groups based on amylose contents: low amylose waxy rice (*Kum Lanna*, *Rai Leum Pua Petchabun*, and *Kalasin Kaowong*) and medium-to-high amylose non-waxy rice (the remaining samples). Taking grain color into account, four varieties of rice—*Kum Lanna*, *Rai Leum Pua Petchabun*, *Rai Dawk Kha Phangnga* and *Sangyod Muang Phatthalung*—were categorized as colored rice. Notably, *Hom Mali Phayao*, *Hom Mali Thung Kula Rong-Hai* and *Hom Mali Surin* are from the same rice varieties (the famous *Thai Hom Mali* rice). *Thai Hom Mali* rice exhibits diverse qualities when grown in various locations. Consequently, three varieties of *Thai Hom Mali* rice have been designated as GI rice based on where they were grown. *Thung Kula Rong-Hai* and *Surin* are grown in northeast Thailand, whereas *Phayao* is grown in the country's north.

Table 1 Descriptions of 10 studied Thai geographical indication (GI) rice varieties

Thai GI rice cultivar	Description
<i>Kum Lanna</i>	Thai GI registration number 55100039 issued on 17 September 2008. A waxy rice with black or purple seed color obtained from Doi Saket, Omkoi, Phayao, and Puen Muang varieties. Production areas cover eight upper northern provinces of Chiang Mai, Chiang Rai, Lamphun, Lampang, Phrae, Nan, Phayao and Mae Hong Son.
<i>Rai Leum Pua Petchabun</i>	Thai GI registration number 57100063 issued on 26 April 2013. An upland waxy rice with black or purple seed color obtained from Leum Pua variety. Production area is restricted to Petchabun province at 400–800 m above sea level.
<i>Kalasin Kaowong</i>	Thai GI registration number 52100026 issued on 16 May 2007. A white waxy rice from local Gor Diew or RD6 varieties. Production areas are only from some parts of Kalasin province in Kaowong and Kuchinarai districts (only in Na Kho and Nang Hang sub-districts) and Na Khu district (only in Na Khu and Nor Kaew sub-districts).
<i>Hom Mali Phayao</i>	Thai GI registration number 57100108 issued on 1 September 2014. A fragrant non-waxy rice from KDML105 and RD15 varieties specially grown in the basin areas of Phayao province.
<i>Hom Mali Thung Kula Rong-Hai</i>	Thai GI registration number 50100022 issued on 28 April 2006. The most famous fragrant rice processed from non-waxy KDML105 and RD15 varieties grown in-season in Tung Kula Rong-Hai, extending across five provinces of north-east Thailand, namely Roi Et, Mahasarakam, Surin, Yasothon and Srisaket.
<i>Hom Mali Surin</i>	Thai GI registration number 51100023 issued on 31 January 2005. A fragrant non-waxy rice from KDML105 and RD15 varieties specially grown in Surin province.
<i>Leuang Patew Chumphon</i>	Thai GI registration number 52100025 issued on 26 September 2007. A non-waxy high amylose rice from local Leuang Patew 123 variety and grown in-season in Chumphon province.
<i>Rai Dawk Kha Phangnga</i>	Thai GI registration number 63100134 issued on 12 September 2014. An upland non-waxy rice with red or reddish-brown seed color from Dawk Kha 50 variety. Production areas are restricted to some districts of Phangnga province (Takua Thung, Thai Mueang and Muang).
<i>Sangyod Muang Phatthalung</i>	Thai GI registration number 49100011 issued on 14 March 2006. A non-waxy rice from Sang Yod rice variety locally grown in-season in Phatthalung province. The rice grain is small and slender with a red seed color.
<i>Jek Chuey Sao Hai</i>	Thai GI registration number 52100024 issued on 5 February 2007. A non-waxy high amylose rice from Jek Chuey variety. It is produced in Sao Hai, Mueng, Nong Sang, Viharn Dang, NongKae, Nong Don, and Don Pud districts/sub-districts of Saraburi province.

Table 2 Amylose contents, available carbohydrate contents and serving size equivalent to 50 g of available carbohydrate of 10 studied rice samples

Thai GI rice cultivar	Amylose content (g/100g)	Available carbohydrate (g/100g)	Serving size (g) equivalent to 50 g of available carbohydrate
<i>Kum Lanna</i>	3.35±0.21 ^e	74.50±0.71 ^{ab}	67.11
<i>Rai Leum Pua Petchabun</i>	3.36±0.50 ^e	72.90±1.27 ^{bcd}	68.59
<i>Kalasin Kaowong</i>	3.65±0.50 ^e	76.00±1.41 ^{ab}	65.79
<i>Hom Mali Phayao</i>	16.15±1.06 ^d	74.00±1.40 ^{abc}	67.57
<i>Hom Mali Thung Kula Rong-Hai</i>	16.30±0.57 ^d	77.40±0.57 ^a	64.60
<i>Hom Mali Surin</i>	15.00±0.28 ^d	74.80±1.13 ^{ab}	66.84
<i>Leuang Patew Chumphon</i>	30.80±0.28 ^a	76.75±0.35 ^{ab}	65.15
<i>Rai Dawk Kha Phangnga</i>	21.05±0.35 ^c	70.40±0.85 ^{cd}	71.02
<i>Sangyod Muang Phatthalung</i>	14.90±0.85 ^d	69.70±0.99 ^d	71.74
<i>Jek Chuey Sao Hai</i>	27.80±0.42 ^b	75.45±0.64 ^{ab}	66.27

Values (mean ± SD) in a row with different lowercase superscripts are significantly ($p < 0.05$) different.

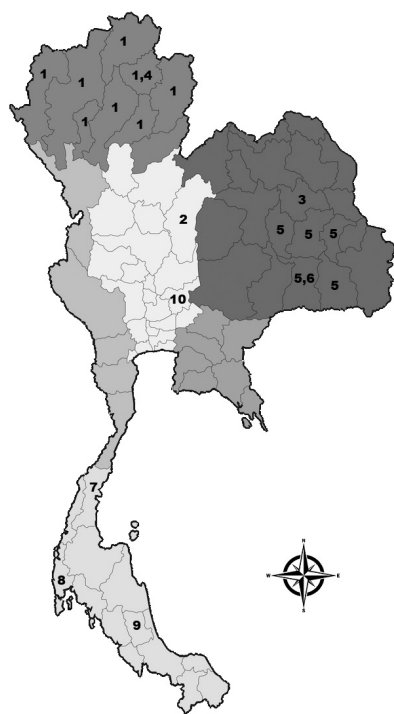


Fig. 1 Map of Thailand showing provincial areas where 10 Thai GI rice samples are cultivated, where 1 = Kum Lanna, 2 = Rai Leum Pua Petchabun, 3 = Kalasin Kaowong, 4 =Hom Mali Phayao, 5 = Hom Mali Thung Kula Rong-Hai, 6 =Hom Mali Surin, 7 =Leuang Patew Chumphon, 8 = Rai Dawk Kha Phangnga, 9 = Sangyod Muang Phatthalung and 10 = Jek Chuey Sao Hai

Descriptive characteristics of the subjects

The demographic and clinical characteristics of the 10 subjects recruited are shown in Table 3.

Table 3 Demographic and clinical characteristics of the study participants

Characteristic	Mean ± SD
Age (years)	25.0±5.0
Male (number)	4.0
Female (number)	6.0
Body mass index (kg/m ²)	21.5±1.7
Systolic blood pressure (mmHg)	110.5±9.5
Diastolic blood pressure (mmHg)	78.7±8.2
Fasting blood glucose (mmol/L)	4.7±0.6

Glycemic index and glycemic load values

The glycemic profiles for all the rice samples tested are graphically presented in Fig. 2. The mean iAUC, glycemic index and glycemic load values for all tested foods (the 10 Thai GI rice types) are given in Table 4.

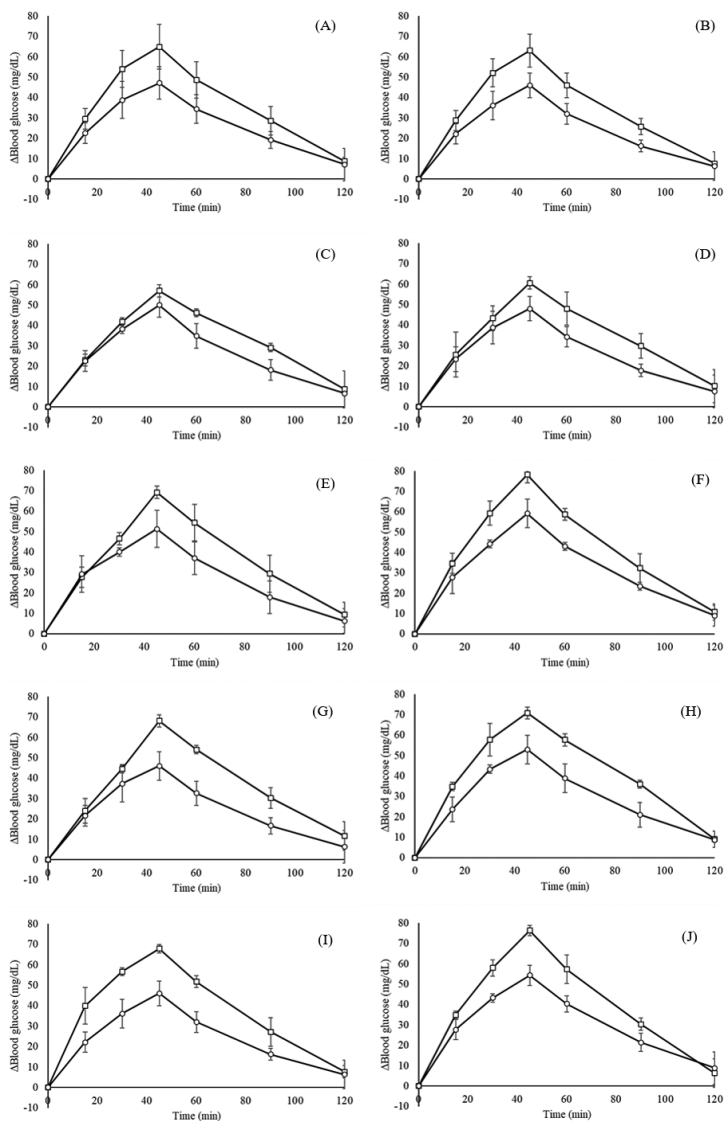


Fig. 2 Mean blood glucose concentration for 10 Thai GI rice; □ = reference (white bread) and ○ = test food (Thai GI rice): (A) Kum Lanna; (B) Rai Leum Pua Petchabun; (C) Kalasin Kaowong; (D) Hom Mali Phayao; (E) Hom Mali Thung Kula Rong-Hai; (F) Hom Mali Surin; (G) Leuang Patew Chumphon; (H) Rai Dawk Kha Phangnga; (I) Sangyod Muang Phatthalung; (J) Jek Chuey Sao Hai, where error bars = ± SD

The mean intra-individual CV of the glycemic responses to the two 50 g white bread standard tests) for the subjects was lower than 18%. Furthermore, the inter-individual CV for the glycemic responses to the standard tests were lower than 30%. These values were consistent because a low mean within-subject variation (reference CV <30%) is required for accuracy as per the guidelines in ISO 26642:2010 described above.

The glycemic index values of the tested GI rice samples ranged from 62.3 (*Sangyod Muang Phatthalung*) to 82.3 (*Kalasin Kaowong*). For practical application, glycemic index values are often grouped into categories of low (≤ 55), medium (56–70) or high (> 70). Therefore, all 10 Thai GI rice samples fell into the medium-high glycemic index categories. All the waxy rice samples had high glycemic indexes, while the waxy-colored rice samples (*Kam Lanna* and *Rai Leum Pua Petchbun*) had slightly lower glycemic index values than for the waxy-white rice (*Kalasin Kaowong*). All *Hom Mali* rice cultivars, regardless of their origin, had high glycemic index values (73.2–75.3). All non-waxy rice cultivars (*Leuang Patew Chumphon*, *Rai Dawk Kha Phangnga*, *Sangyod Muang Phatthalung* and *Jek Chuey Sao Hai*) had medium glycemic responses. Similar to waxy rice, the non-waxy colored rice, especially *Sangyod Muang Phatthalung*, had lower glycemic indexes values than the non-waxy white rice.

Because the postprandial blood glucose response is influenced not only by the glycemic index of the food, but also by the amount of ingested carbohydrate, in epidemiologic studies, the concept of glycemic load (the glycemic index of a specific food multiplied by the amount of carbohydrate contained in an average portion of the food

consumed) has been developed to better represent both the quantity and the quality of the carbohydrate consumed (Willett et al., 2002). Each unit of dietary glycemic load represents the equivalent glycemic effect of 1 g of carbohydrate from white bread, which is used as the reference food (Willett et al., 2002). Similar to the glycemic index, glycemic load values were classified as low (≤ 10), medium (> 10 to < 20) or high (≥ 20) according to Atkinson et al. (2008). The glycemic load values of all GI rice samples were calculated based on a portion size of 150 g (cooked rice), which is usually consumed by Thais and most Asians, (Table 4). Not surprisingly, the glycemic load values of all the GI rice samples were classified as high.

Discussion

The authenticity and certification of rice's geographic origin is clearly a valuable instrument for the protection of high-quality products. The shift in how consumers share information, gain knowledge and finally make decisions presents a major opportunity for professionals to enhance the effectiveness of the certification of their rice and rice products (Katerinopoulou et al., 2020). Several studies have demonstrated that providing consumers with geographical information about food products can influence their dietary choices. For example, a case study conducted with *Hom Mali Thung Kula Rong-Hai* reported that consumers were willing to pay a premium for geographically certified rice, with more comprehensive information regarding geographical indications increasing the premium further (Lee et al., 2020).

Table 4 Mean incremental area under the curve (iAUC), glycemic index and glycemic load (150g serving size, cooked rice) values for 10 studied Thai GI rice samples

Thai GI rice cultivar	Mean iAUC (mg/dL $\times$ min)	Glycemic index		Glycemic load	
		Mean $\pm$ SE	Category	Mean $\pm$ SE	Category
<i>Kam Lanna</i>	4,310.3	75.4 $\pm$ 6.2	High	49.1 $\pm$ 4.3	High
<i>Rai Leum Pua Petchabun</i>	3,703.5	79.4 $\pm$ 4.5	High	51.2 $\pm$ 3.6	High
<i>Kalasin Kaowong</i>	3,873.5	82.3 $\pm$ 6.3	High	53.4 $\pm$ 4.3	High
<i>Hom Mali Phayao</i>	4,148.4	73.2 $\pm$ 4.2	High	48.3 $\pm$ 3.5	High
<i>Hom Mali Thung Kula Rong-Hai</i>	4,392.7	75.3 $\pm$ 6.4	High	49.3 $\pm$ 4.2	High
<i>Hom Mali Surin</i>	5,032.8	75.3 $\pm$ 3.3	High	48.4 $\pm$ 2.7	High
<i>Leuang Patew Chumphon</i>	4,322.3	69.2 $\pm$ 8.1	Medium	45.2 $\pm$ 5.2	High
<i>Rai Dawk Kha Phangnga</i>	4,965.4	69.8 $\pm$ 7.3	Medium	45.1 $\pm$ 4.5	High
<i>Sangyod Muang Phatthalung</i>	4,558.5	62.3 $\pm$ 6.4	Medium	41.3 $\pm$ 4.2	High
<i>Jek Chuey Sao Hai</i>	4,200.7	69.2 $\pm$ 4.5	Medium	38.4 $\pm$ 7.2	High

Thai agencies promote varieties of Thai rice and have registered a number of GI rice cultivars for their exceptional qualities. The aim is to expand the market for both domestic and international levels, especially in Asia and parts of the Pacific where the per capita rice consumption is far higher than in all other regions (Bin Rahman and Zhang, 2022). Despite the fact that rice is the most popular grain in Asia, unfortunately, rice consumption has currently become a concern for consumers due to its typically high glycemic indexes, which is a critical issue for a balanced and healthy diet (Cabral et al., 2022). As expected, all the Thai GI rice samples in this study had medium-to-high glycemic index values and all had a high glycemic load.

In the current investigation, the glycemic response was largely influenced by the variety of rice. The glycemic index of rice was not impacted by where it had been grown. *Hom Mali Phayao*, *Hom Mali Thung Kula Rong-Hai* and *Hom Mali Surin* (three types of Hom Mali rice that are grown in different regions) all displayed similar glycemic index values and were categorized as having high glycemic indices. The rice samples with medium glycemic index values were all from high amylose rice varieties (*Leuang Patew Chumphon*, *Rai Dawk Kha Phangnga*, *Sangyod Muang Phatthalung* and *Jek Chuey Sao Hai*). In addition, all waxy rice varieties (*Kam Lanna*, *Rai Leum Pua Petchabun* and *Kalasin Kaowong*) had high glycemic responses. It has been well documented that the lower the amylose content of rice, the lower the resistant starch contents, the less the resistance to digestion and the higher the glycemic index (Kaur et al., 2016). The glycemic index of rice is not only closely related to its amylose and resistance starch contents but is also affected by its other starch traits (such as starch gelatinization and retrogradation properties, the particle size of starch granule, the ratio of amylose to amylopectin, the crystallite structure of amylopectin, the starch resistance against enzymatic hydrolysis and interactions of starch with other components) and external factors, such as cooking conditions (Huang and Hu, 2021).

It has been reported that the majority of rice varieties have a high glycemic index. Using white bread as a reference, a systematic tabulation of rice's glycemic index values (Kaur et al., 2016) revealed a wide range between 24 and 160. A dose response meta-analysis of prospective cohort studies on the association between glycemic index and glycemic load and the risk of Type 2 diabetes revealed that the glycemic index was strongly associated with incidence of Type 2 diabetes (Livesey et al., 2019). Rice is predicted to have

a greater effect on the incidence of Type 2 diabetes in populations with a high overall glycemic load and in ethnic groups that are more susceptible to insulin resistance (Gao et al., 2012). Six of the 10 countries with the highest incidence of diabetes are located in Asia and South America (van Dam, 2020), where rice is the staple diet in six of these nations. This circumstance has prompted the national agencies responsible to prioritize the development of highly satiating, postprandial glucose-slowing rice cultivars. Low glycemic index rice lines, such as *Doongara* (Kataoka et al., 2013) and *Swarna* (Fitzgerald et al., 2011) are developed and marketed as a premium product for niche markets. In addition, Thailand has reported the successful breeding of the low glycemic index rice strains named *Pink+4* (Vanavichi and Ruangpayak, 2020).

The low glycemic attribute is not only attained by selectively breeding low-glycemic cultivars or by using glycemic-lowering dietary techniques, but also by considering post-harvest processing and cooking procedures as extrinsic factors (Jukanti et al., 2020). There is also growing evidence of the health benefits of brown rice and colored rice as whole grains in regulating blood sugar, managing weight and preventing diabetes (Kweesar et al., 2022). Typically, brown rice is used to market colored rice to conserve the pigments that are abundant in the bran layer. This could help in reducing glycemic index values as evidenced in *Rai Dawk Kha Phangnga* and *Sangyod Muang Phatthalung*. In contrast, *Kam Lanna* and *Rai Leum Pua Petchabun*, despite being brown rice types, have high glycemic index values due to their relatively low amylose contents, which has a greater impact. Rice's glycemic index is known to be affected by different food processing techniques (Sivakamasundari et al., 2022). Furthermore, diet-based diversification solutions on a plate of healthy, well-balanced portions of macronutrients within a low glycemic index food matrix, as well as increased nutrient density and dietary fiber offer a sustainable solution to the growing concern in meeting the burden nutritional challenges (Jukanti et al., 2020).

GIs are intellectual property rights that serve to identify a product with a quality, reputation or other characteristics that are largely attributable to its geographical origin. Without a doubt, Thai GI rice cultivars contribute to the diversity of rice consumption and have a positive economic impact on rice growers. However, the current study revealed that the majority of Thai GI rice varieties have been classified as having a medium to high glycemic responses. Selecting medium glycemic index rice cultivars could be a healthier

choice compared to the high glycemic varieties. However, the use of rice in the food industry must align with the product specifications. Some food products require waxy rice with a high glycemic response to produce high quality products. Hence, the manipulation of the intrinsic properties of rice, as well as extrinsic modifications, such as cooking, processing and the application of dietary techniques, can be used to minimize the impact of rice glycemic response.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

This research was financially supported by Pibulsongkram Rajabhat University (Thailand), Grant No. RDI-1-64-4.

References

- Atkinson, F.S., Foster-Powell, K., Brand-Miller, J.C. 2008. International tables of glycemic index and glycemic load values: 2008. *Diabetes Care* 31: 2281–2283. doi.org/10.2337/dc08-1239
- Bin Rahman, A.N.M.R., Zhang, J. 2022. Trends in rice research: 2030 and beyond. *Food Energy Secur.* 12: e390. doi.org/10.1002/fes3.390
- Cabral, D., Fonseca, S.C., Moura, A.P., Oliveira, J.C., Cunha, L.M. 2022. Conceptualization of rice with low glycemic index: Perspectives from the major European consumers. *Foods* 11: 2172. doi.org/10.3390/foods11142172
- Cereals and Grains Association. 2010. American Association of Cereal Chemists Approved Methods of Analysis, 11th ed. Cereals and Grains Association. St Paul, MN, USA.
- Chakhonkaen, S., Pitnjam, K., Saisuk, W., Ukoskit, K., Muangprom, A. 2012. Genetic structure of Thai rice and rice accessions obtained from the International Rice Research Institute. *Rice* 5: 19. doi.org/10.1186/1939-8433-5-19
- Food and Agriculture Organization/World Health Organization. 1998. Carbohydrates in human nutrition. Report of a Joint FAO/WHO Expert Consultation (FAO Food and Nutrition Paper 66). Food and Agriculture Organization. Rome, Italy.
- Fitzgerald, M.A., Rahman, S., Resurreccion, A.P., et al. 2011. Identification of a major genetic determinant of glycemic index in rice. *Rice* 4: 66–74. doi.org/10.1007/s12284-011-9073-z
- Gao, H., Salim, A., Lee, J., Tai, E.S., Van Dam, R.M. 2012. Can body fat distribution, adiponectin levels and inflammation explain differences in insulin resistance between ethnic Chinese, Malays and Asian Indians? *Int. J. Obes.* 36: 1086–1093. doi.org/10.1038/ijo.2011.185
- Henry, C.J., Quek, R.Y.C., Kaur, B., Shyam, S., Singh, H.K.G. 2021. A glycemic index compendium of non-Western foods. *Nutr. Diabetes* 11: 2. doi.org/10.1038/s41387-020-00145-w
- Huang, M., Hu, L. 2021. Low glycemic index: The next target for rice production in China? *J. Integr. Agric.* 20: 1727–1729. doi.org/10.1016/S2095-3119(20)63299-3
- Jukanti, A.K., Pautong, P.A., Liu, Q., Sreenivasulu, N. 2020. Low glycemic index rice—A desired trait in starchy staples. *Trends Food Sci. Technol.* 106: 132–149. doi.org/10.1016/j.tifs.2020.10.006
- Kataoka, M., Venn, B.J., Williams, S.M., Te Morenga, L.A., Heemels, I.M., Mann, J.I. 2013. Glycaemic responses to glucose and rice in people of Chinese and European ethnicity. *Diabet. Med.* 30: E101–E107. doi.org/10.1111/dme.12080
- Katerinopoulou, K., Kontogeorgos, A., Salmas, C.E., Patakas, A., Ladavos, A. 2020. Geographical origin authentication of agri-food products: A review. *Foods* 9: 489. doi.org/10.3390/foods9040489
- Kaur, B., Ranawana, V., Henry, J. 2016. The glycemic index of rice and rice products: A review, and table of GI values. *Crit. Rev. Food Sci. Nutr.* 56: 215–236. doi.org/10.1080/10408398.2012.717976
- Khatun, A., Waters, D.L.E., Liu, L. 2019. A review of rice starch digestibility: Effect of composition and heat-moisture processing. *Starch* 71: 1900090. doi.org/10.1002/star.201900090
- Kweesar, F.M., Renaldi, G., Dewi, D.P.A.P., Samakradhamrongthai, R.S. 2022. Optimization of flour mix from three pigmented rice varieties to produce blended instant mixed rice using response surface methodology. *Agr. Nat. Resour.* 56: 1259–1268. doi.org/10.34044/j.anres.2022.56.6.20
- Lee, J.Y., Pavasopon, N., Napisintuwong, O., Nayga Jr, R.M. 2020. Consumers' valuation of geographical indication-labeled food: The case of Hom Mali rice in Bangkok. *Asian Econ. J.* 34: 79–96. doi.org/10.1111/asej.12196
- Lertdhamtewe, P. 2014. The protection of geographical indications in Thailand. *J. World Intellect. Prop.* 17: 114–128. doi.org/10.1002/jwip.12023
- Livesey, G., Taylor, R., Livesey, H.F., et al. 2019. Dietary glycemic index and load and the risk of type 2 diabetes: A systematic review and updated meta-analyses of prospective cohort studies. 11: 1280. doi.org/10.3390/nu11061280
- Ngokkuen, C., Grote, U. 2013. Challenges and opportunities for protecting geographical indications in Thailand. *Asia-Pacific Dev. J.* 19: 93–123.
- Ranawana, D.V., Henry, C.J.K., Lightowler, H.J., Wang, D. 2009. Glycaemic index of some commercially available rice and rice products in Great Britain. *Int. J. Food Sci. Nutr.* 60: 99–110. doi.org/10.1080/09637480802516191
- Sen, S., Chakraborty, R., Kalita, P. 2020. Rice - not just a staple food: A comprehensive review on its phytochemicals and therapeutic potential. *Trends Food Sci. Technol.* 97: 265–285. doi.org/10.1016/j.tifs.2020.01.022
- Shobana, S., Kokila, A., Lakshmi priya, N., et al. 2012. Glycaemic index of three Indian rice varieties. *Int. J. Food Sci. Nutr.* 63: 178–183. doi.org/10.3109/09637486.2011.615300

- Sivakamasundari, S.K., Priyanga, S., Moses, J.A., Anandharamakrishnan, C. 2022. Impact of processing techniques on the glycemic index of rice. *Crit. Rev. Food Sci. Nutr.* 62: 3323–3344. doi.org/10.1080/10408398.2020.1865259
- van Dam, R.M. 2020. A global perspective on white rice consumption and risk of type 2 diabetes. *Diabetes Care* 43: 2625–2627. doi.org/10.2337/dci20-0042
- Vanavichi, A., Ruangpayak, S. 2020. Thailand experience in developing wellness-driven rice as the key to fight NCDs and farmer poverty. *Sci. Technol. Cereal Oils Foods* 28: 57–63.
- Vejchasarn, P., Shearman, J.R., Chaiprom, U., et al. 2021. Population structure of nation-wide rice in Thailand. *Rice* 14: 88. doi.org/10.1186/s12284-021-00528-2
- Willett, W., Manson, J., Liu, S. 2002. Glycemic index, glycemic load, and risk of type 2 diabetes. *Am. J. Clin. Nutr.* 76: 274S–280S. doi: 10.1093/ajcn/76/1.274S