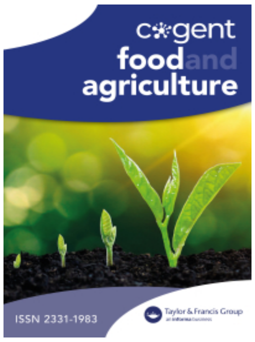

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Glycaemic and satiety responses associated with the consumption of parboiled and braised rice: a systematic review and meta-analysis

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ABSTRACT
The post-harvest processing of rice grains, and its subsequent cooking methods could affect postprandial glycaemic and satiety responses and help prevent hyperglycaemia. In some Asian and West African countries including Ghana, rice is frequently parboiled and cooked in water with oil (braised rice). This systematic review investigated the postprandial glycaemic responses associated with the consumption of parboiled rice compared with (i) non-parboiled rice, and (ii) braised rice. A systematic search for published articles was conducted using PubMed and Cochrane Library databases. Following the screening process, five papers on parboiled rice and one on braised rice were identified and selected for this review. Meta-analysis of eligible interventions revealed that consumption of parboiled rice significantly attenuated postprandial blood glucose response (n=5, SMD= −0.87 unit, 95% CI [−1.27, −0.48], $p<0.0001$), but not insulin (n=2, SMD= −0.17 unit, 95% CI [−0.89, 0.54], $P=0.20$) compared to control non-parboiled rice. However, no meta-analysis was conducted to test for the plausible association between the consumption of parboiled rice and postprandial satiety, due to limited studies. Importantly, we propose that studies including parboiled rice and braised rice using real-life recipes are needed to inform dietary recommendations with potential to lower postprandial blood glucose and insulin responses.

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SUBJECTS
Food Additives & Ingredients; Food Chemistry; Food Engineering

Introduction

In 2019, the global prevalence of type-2 diabetes mellitus (T2DM) stood at 8.3% of adults aged 20–79 years, and this proportion is expected to increase to 9.2% and 9.6% by 2030 and 2045, respectively (Saeedi et al., 2019). This prevalence translated into 463 million people in 2019 and predicted to be 578 and 700 million people in 2030 and 2045, respectively (Saeedi et al., 2019). The same authors reported that, five countries in Asia including China, India, Pakistan, Indonesia and Bangladesh where rice is commonly consumed as a staple food, ranked amongst the top ten countries with the highest number of adults with T2DM (Saeedi et al., 2019). In Asia 758 kcal/capita/day of rice was reportedly consumed in 2018 (FAOSTAT, 2021). Diet quality and quantity is an important determinant in the development of T2DM (Min et al., 2018). Refined carbohydrate foods, such as white rice, have a significant role in determining postprandial glycaemic response (Livesey et al., 2019). Dietary patterns that promote chronic postprandial hyperglycaemia and postprandial hyperinsulinaemia are risks for developing T2DM (Jin et al., 2021). The higher propensity for insulin resistance for Asians (Sequeira et al., 2020), coupled with the widespread consumption of rice constitute an interest in understanding the glycaemic properties of rice.

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Postprandial glycaemic response is partly determined by the starch digestibility and the amount of digestible starch of foods (Kumar et al., 2022); in addition to the insulin secretory response and insulin sensitivity of an individual (González-Rodríguez et al., 2019). Whilst the inter-individual variability in postprandial glycaemic response has recently gained attention as part of personalised nutrition initiative (Zeevi et al., 2015), the same amount of digestible carbohydrate can raise the postprandial blood glucose to different extent within an individual, due to the variable glycemic index (GI) of foods. GI has long been developed to systematically rank the ability of foods on raising postprandial glycaemia following the ingestion of fixed amount of digestible carbohydrate (Foster-Powell & Miller, 1995). Taken together, postprandial blood glucose responds to both GI and the variable amount of digestible carbohydrate, constituting the glycaemic load (GL). Hence, lowering the GL for better management of postprandial glycaemia involves lowering the GI of foods and the amount of carbohydrates consumed.

Cooked white rice is generally known to be a high glycaemic index food (Atkinson et al., 2021) because it elicits a high postprandial glycaemic response when consumed. Interestingly, white rice has been used as a 'control' or 'reference' food in place of white bread or glucose solution in glycaemic response studies (Atkinson et al., 2021; Sugiyama et al., 2003). A significant association between the frequent consumption of high glycaemic index foods and T2DM development has been reported (Livesey et al., 2019). In a recent meta-analysis of prospective studies involving 132,373 individuals aged 35–70 years from 21 countries with follow-up over 9.5 years, the authors found that consumption of cooked white rice (≥450 g/day compared with <150 g/day) was associated with increased (1.2x hazard ratio) risk of developing T2DM (Bhavadharini et al., 2020). Regionally, the same authors reported that the hazard ratio was highest in South Asians (1.6x), no significant association in China, but in other parts of the world including Africa the hazard ratio was 1.4x (Bhavadharini et al., 2020).

The increased postprandial glucose response associated with the consumption of white rice is attributed to factors including its high digestibility of starch (Lal et al., 2021) and negligible dietary fibre content (Lal et al., 2021; Saleh et al., 2019) and the low amylose content of rice starch. Whilst rice variety does play a role in determining GI (Kumar et al., 2022), there are various opportunities to lower postprandial glucose response of rice by modifying the structural properties of the rice by adopting post-harvest processing techniques and consumer processing methods (cooking) (Carcea, 2021). One of the postharvest rice processing techniques is parboiling, which is a hydrothermal process that expands rice grain and kernel hardness due to increased starch gelatinisation (Kwofie & Ngadi, 2017). During rice parboiling, certain physicochemical processes including: transformation of rice starch from crystalline state into an amorphous form (Boers et al., 2015), complex interaction between intrinsic amylose-lipid and amylose-protein fractions of the rice (Kumar et al., 2022; Toutounji et al., 2019), protein denaturation and subsequent disruption of bonds that stabilize rice proteins (Cheng et al., 2019) and increased retrogradation of gelatinised rice starch resulting in higher production of resistant starches take place (Boers et al., 2015; Kumar et al., 2022; Toutounji et al., 2019). Consequently, enzymatic digestion of rice starch is impaired due to the higher concentration of starch resistant to digestion (Kumar et al., 2022).

When cooking braised rice, the addition of cooking oil to the water could potentially alter the glycaemic and satiety responses as they affect the properties of rice starch. Interestingly, cooking rice grain with some cooking oil added to the water is a common practice in West African and Asian countries to improve the flavour of rice (Kaur et al., 2015). This practice could also attenuate the glycaemic response as an oil coating could enhance the complex interaction between lipids and starch amylose and thus impair digestive enzymes from accessing rice starch substrate for digestion (Debet & Gidley, 2006; Krishnan et al., 2021; Kumar et al., 2022; Wee & Henry, 2020). In Ghana for instance, for 200 g of raw rice, about 15 mL of cooking oil is added to about 300 g of the water used for the rice cooking. The commonly used oils for rice cooking include Frytol™ (deodorised palm nut oil), soybean oil and coconut oil.

Satiety is the sensation of fullness associated with the consumption of food (Benelam, 2009). Foods that promote satiety may be protective towards excessive weight gain (Hansen et al., 2019), a known risk factor for onset of several diet-related non-communicable diseases including T2DM and cardiovascular diseases (Dai et al., 2020). A systematic review of resistant starch on metabolic profiles (Guo et al., 2021; Maher & Clegg, 2019) has been conducted. The authors reported that even though there is inconsistent evidence in the association between resistant fibre intake and improved satiety, its effect on modulating postprandial glycaemic and insulinaemic responses is well established (Guo et al., 2021). Additionally, lipids especially those rich in medium-chain triglycerides regulate satiety as they are involved in increasing the concentration of PYY and leptin postprandially (Maher & Clegg, 2019). That notwithstanding, the possibility that the addition of cooking oil in rice may increase total energy intake should not be ignored (Stubbs et al., 2000). In 2015, a systematic review without a quantification by meta-analysis on the effect of rice characteristics and processing on postprandial glycaemic and insulinaemic responses was reported (Boers et al., 2015). The authors identified that the variation in glucose and insulin response to rice could be mainly attributed to 1) the intrinsic properties of the starch, 2) post harvest parboiling and 3) consumer processing (cooking, storing and reheating) (Boers et al., 2015). However, recent systematic review and meta-analyses with dual focus on the effect of parboiling and cooking rice with oil on postprandial glycaemic responses is lacking, necessitating this review work. The primary objectives of this systematic review were to: 1) investigate the effect of parboiled rice consumption on glycaemic response and 2) assess the impact of the use of oil in rice cooking water on glycaemic responses. It is hypothesised that both parboiled rice and braised rice significantly decrease postprandial glucose and insulin response.

Methods

Search strategy

This systematic review was conducted in accordance with the guidelines of the recently updated Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Page et al., 2021). A systematic search for the consumption of parboiled and braised rice and its impact on glycaemia and satiety perception was conducted on October 04, 2022 using two electronic databases namely PubMed, and the Cochrane Library. The search terms employed on the two electronic databases included (parboil* rice OR braise* rice OR oil rice OR oil cook* rice OR oil boil* rice OR angwa moo OR angwamo OR omɔ kɛ fɔ OR omor ker for) AND (blood glucose OR serum glucose OR plasma glucose OR glycaemic response OR glycemic response OR glycaemia OR glycemia OR serum insulin OR plasma insulin OR satiety effect* OR appetite control OR appetite regulate* OR fullness OR fullness sensation OR fullness feel* OR hunger suppress* OR fullness feel* OR hunger OR hunger suppress* OR ghrelin OR leptin OR cholecystokinin OR CCK OR glucagon-like peptide 1 OR GLP-1 OR peptide YY OR PYY).

The search terms were first applied to the PubMed database and then adapted for use in the Cochrane Library database. No date or language restrictions were used during the electronic database search. References from both PubMed and Cochrane Library were imported into a reference manager (Endnote). Duplicates within the various databases and between the databases were critically removed in two steps: automatic removal and manual removal with the use of the reference manager (Endnote), Articles obtained from the final reference lists were critically checked to identify potentially relevant studies.

Eligibility criteria

The inclusion criteria for selection involved: (i) studies published in peer-reviewed journals in English and had their full-text articles accessible; (ii) studies that had the overarching aim of investigating the glycaemic and satiety effect associated with the consumption of the test meals 'parboiled' and 'oil cooked rice'; (iii) studies conducted in human participants (healthy and participants with type 2 diabetes). The exclusion criteria employed for the review include: (i) studies that were published as review articles and scientific conference reports; (ii) studies that were reported in language other than English; (iii) non-human studies (only *in vitro* and animal models were used); (iv) studies that included additives or other food complements; (v) participants with insulin-dependent diabetes; (vi) studies that used food materials other than 'white rice' as the 'control'.

Data extraction

Characteristics extracted included country of study, year of publication, study design, sample size, age and sex of participants, study objective and study outcomes (glucose, insulin, and satiety).

Data extraction was independently conducted by authors I. A. and J. C.C., where there was non-agreement between the data extraction, it was resolved by discussion between I.A., J.C.C. and J.J.L.

Meta-analysis

Meta-analysis was conducted for postprandial glucose and insulin outcomes. Data on (i) mean incremental area under the curve (iAUC) or area under the curve (AUC) glucose and insulin over the study-specified postprandial period, (ii) standard deviation (SD), and (iii) number of participants (n) were entered into Review Manager (Version 5.4.1, The Cochrane Collaboration) software. When the data was only available in the form of graphs, pdf-measurement tool (Adobe Acrobat Pro DC, Burlington, NJ, USA) was used to estimate the values. When SD was not available in text, conversion from standard error or confidence interval was conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions Version 6.2 (Higgins et al., 2021). The effect of parboiled rice on postprandial glucose and insulin was compared against control non-parboiled rice. For studies reporting multiple treatment arms, we chose the most relevant non-parboiled rice arm in the order of white rice, jasmine rice, followed by white bread, as the control non-parboiled rice in our meta-analysis. Where multiple doses of parboiled rice and non-parboiled rice were reported in Hamad et al. (2018), the treatments were combined into parboiled rice treatment against non-parboiled rice treatment (Higgins et al., 2021). We were unable to perform a meta-analysis on postprandial satiety as the types of appetite questionnaire used were not comparable between studies that reported satiety outcomes. Since both AUC and iAUC glucose were reported over postprandial periods of different length, the overall effect was computed as standardised mean difference (SMD) with 95% confidence interval, using random effect model, and presented as forest plot. Between-study heterogeneity was computed as I^2, whereby I^2 of ≤40%, 30–60%, 50–90%, and 75–100% represent low, moderate, substantial and considerable heterogeneity, respectively (Higgins et al., 2021).

Risk of bias

An assessment of the risk of bias was completed for each of the study included in this systematic review. This followed the Cochrane risk of bias tool for randomised controlled trials based on these parameters: random sequence generation, allocation concealment, selective reporting, incomplete outcome data, and blinding of participants or study personnel (Higgins et al., 2011).

Results

A total of 182 records were retrieved from the databases PubMed (n = 107) and Cochrane Library (n = 75). The removal of duplicates from the retrieved articles (n = 182) yielded 152 studies. Following the screening of titles and abstracts of the studies (n = 152), a further (n = 98 studies) were excluded for not meeting the eligibility criteria. Consequently, a total of 6 full-text studies that met the systematic review criteria were assessed in the qualitative synthesis, after 48 full-text articles were excluded with reasons including papers been systematic review (n = 1), review articles (n = 4), conference papers (n = 1), non-human study (n = 6), unrelated to study outcomes (n = 15), non-acute study (n = 1), clinical trial protocols (n = 6), other language than English (n = 1), cooked rice with additives (n = 10) and insulin dependent participants (n = 3). A flowchart showing the detailed study selection process is shown in Figure 1.

Geographically, most of the studies were conducted in Asia/Australasia specifically in Kuwait (n = 1) (Hamad et al., 2018), New Zealand (n = 2) (Kataoka et al., 2013; Lu et al., 2017) and Singapore (n = 1) (Sun et al., 2018). Denmark (n = 2) (Larsen et al., 1996; Rasmussen et al., 1992) was the only country in Europe that recorded studies that met the inclusion criteria.

Six studies (Hamad et al., 2018; Kataoka et al., 2013; Larsen et al., 1996; Lu et al., 2017; Rasmussen et al., 1992; Sun et al., 2018); included in this systematic review is summarised in Table 1. Only one (Larsen et al., 1996) of the five studies reported the parboiling conditions that paddy rice was subjected to prior to milling. Four of the studies reported that the parboiled rice was commercially obtained. One

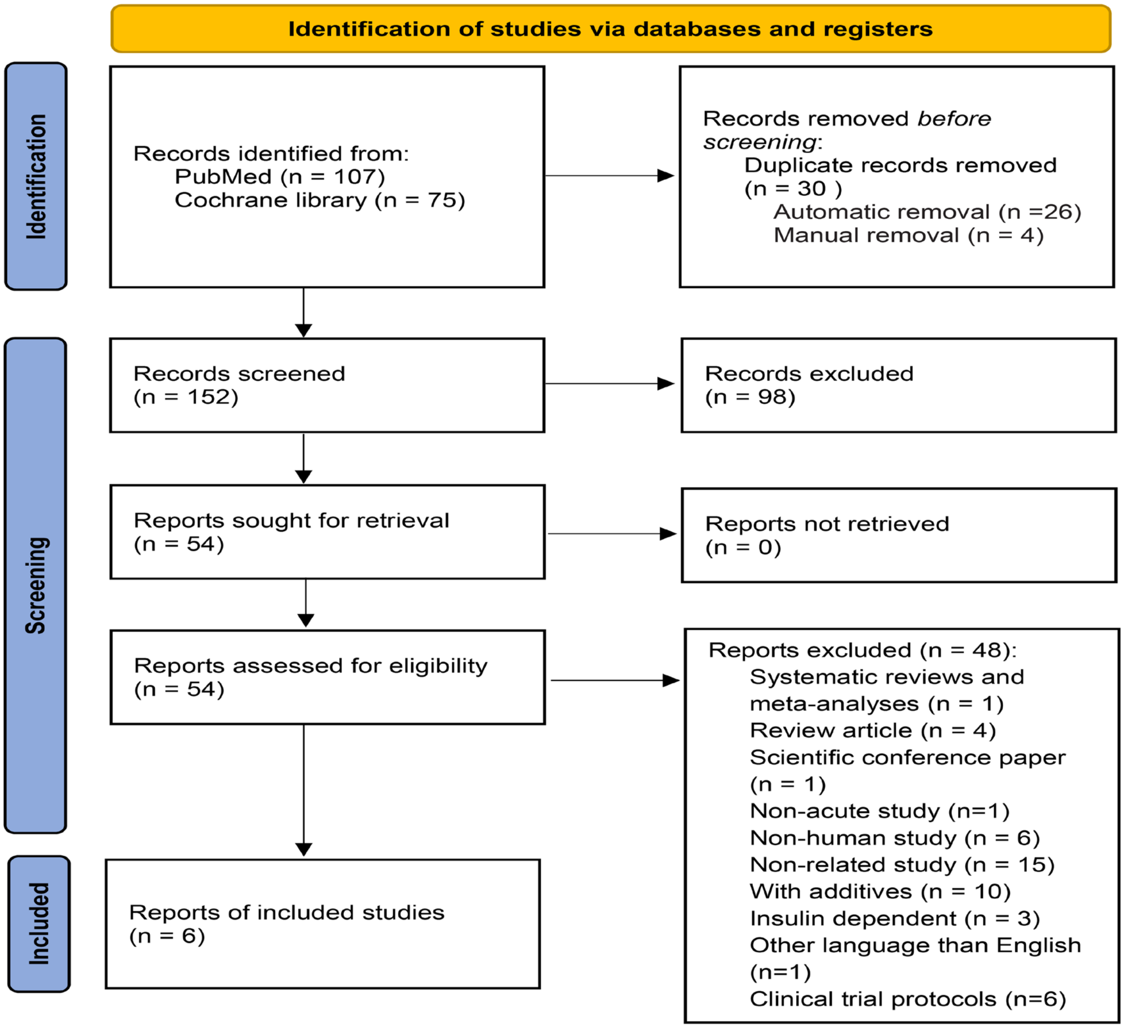

Figure 1. Flowchart summarizing studies evaluated and selected for the systematic review.

of the studies (Sun et al., 2018) reported non-parboiled rice cooked with fat (oil). The risk of bias for all the included studies was high (Table 2).

Four studies were eligible for meta-analysis of postprandial glucose response (Hamad et al., 2018; Larsen et al., 1996; Lu et al., 2017; Rasmussen et al., 1992) (Figure 2). One study from the systematic review was excluded from the meta-analysis because the outcome was reported as geometric mean and range (Kataoka et al., 2013). Hamad et al. (2018) study was conducted on 2 different populations (healthy and people with T2DM), hence is reported separately in the meta-analysis. Meta-analysis showed parboiled rice had a significantly lower postprandial glucose (SMD = −0.87, 95% CI [−1.27, −0.48], $p < 0.001$) when compared to control non-parboiled rice. The heterogeneity between studies was low (I^2 = 36%, $p = 0.18$).

Two studies were eligible for meta-analysis of postprandial insulin response (Larsen et al., 1996; Rasmussen et al., 1992) as other studies did not report postprandial insulin outcome (Figure 3). Meta-analysis showed parboiled rice did not significantly affect postprandial insulin response (SMD = −0.17, 95% CI [−0.89, 0.54], $p = 0.63$) when compared to control non-parboiled rice. The heterogeneity between studies was low (I^2 = 40%, $p = 0.20$).

Discussion

In this systematic review, we evaluated and summarised the changes in blood glucose and insulin associated with the consumption of cooked parboiled rice (Table 1). We found only one of the studies that

Table 1. General characteristics of studies selected for the systematic review.

Author and publication year	Country of study	Study design	Nature of study	Participants information	Objective	Parboiling conditions	Amount served	Findings
Lu et al. (2017)	New Zealand	Randomised, crossover design	Acute (120 minutes of digestion)	18 females and 10 males who are healthy and aged 18–45 years	Determine the glycaemic response associated with hot- and cold-stored parboiled rice consumption compared to medium grain white rice	Commercially available parboiled rice with no specification (time, temperature, pressure)	140 g of cooked rice	Freshly cooked and reheated parboiled rice significantly attenuated postprandial glucose incremental area under the curve. Reheated parboiled rice significantly suppressed how hungry participants felt for almost 30 min.
Rasmussen et al. (1992)	Denmark	Randomised crossover design	Acute (240 minutes of digestion)	5 females and 2 males living with non-insulin-dependent type 2 diabetes aged 58–64 years	Determine the glycaemic response associated with parboiled white rice consumption	Commercially available parboiled rice with no specification (time, temperature, pressure)	20 and 60 g raw parboiled white rice equivalent to 24 and 48 available CHO respectively	Consumption of 25 and 50 g CHO as parboiled white significantly attenuated postprandial glucose and insulin responses.
Hamad et al. (2018)	Kuwait	Randomised crossover design	Acute (120 minutes of digestion)	12 females and 8 males who are healthy individuals. Another group comprised of 9 females and 6 males who are living with noninsulin-dependent, type 2 diabetic. The participants were aged over 21 years	Investigate the effect of parboiled rice (PBR) consumption on of blood glucose concentration and satiety effect	Commercially available parboiled rice with no specification (time, temperature, pressure)	85 g of cooked parboiled rice equivalent to 50 g available parboiled rice	Cooked parboiled rice attenuated postprandial blood glucose response in healthy and type 2 diabetic participants. Reduction in prospective food consumption over the 120 min was about 50% compared to white rice in the healthy participants.
Kataoka et al. (2013)	New Zealand	Randomised crossover design	Acute (120 minutes of digestion)	15 males and 16 females who are Chinese and 17 males and 15 females who are Europeans aged 18–50 years	To compare glycaemic response associated with parboiled and other four rice varieties consumption using glucose solution and Jasmine rice as control	Commercially available parboiled rice with no specification (time, temperature, pressure)	50 g of carbohydrate	In both Chinese and European New Zealanders, cooked parboiled rice attenuated postprandial glucose iAUC.

(*Continued*)

Table 1. Continued.

Author and publication year	Country of study	Study design	Nature of study	Participants information	Objective	Parboiling conditions	Amount served	Findings
Larsen et al. (1996)	Denmark	Randomised crossover design	Acute (180 minutes of digestion)	7 males and 5 females living with non-insulin-dependent diabetes aged 45–76 years	Investigate the effect of parboiling and amylose on blood glucose and insulin response in non-insulin dependent diabetic participants	Soaking paddy rice at 28–30 °C, for 30–36 hours, steaming the rice at atmospheric pressure, followed by sun-drying.	50 g available CHO	Parboiled rice attenuated postprandial glucose and insulin iAUC
Sun et al. (2018)	Singapore	Randomised, crossover, single-blinded	Acute (240 minutes of digestion)	20 healthy Chinese men aged 22–39 years	Evaluate differences in postprandial glucose and lipid responses after a mixed meal containing low- or high-glycemic-index (GI) carbohydrate and three different types of fat varying in the degree of saturation in healthy subjects	Not described	50 g of available carbohydrate cooked with 40 g of dietary fat	No significant difference in postprandial glucose response after consumption of low- or high-glycaemic index carbohydrate (rice) with butter, olive oil and grapeseed oil.

iAUC – incremental area under the curve and CHO – carbohydrate.

Table 2. Assessment of risk of bias for selected studies.

	Assessment criteria (reasons)						
Reference	Random sequence generation	Allocation sequence concealment	Selective reporting	Blinding of participants and personnel	*Blinding of outcome assessment	Incomplete outcome data	Other bias	*Overall bias
Lu et al. (2017) New Zealand	Unclear (inadequately described 'participants were randomly assigned')	Unclear (not described)	Low (data on all outcomes of interest were presented)	High (no blinding)	Low (not done, but outcome not likely to be influenced by blinding)	Low (outcome was reported for all study participants)	Low (no other bias detected)	High
Rasmussen et al. (1992) Denmark	Unclear (inadequately described 'participants were randomly assigned')	Unclear (not described)	Low (data on all outcomes of interest were presented)	High (no blinding)	Low (not done, but outcome not likely to be influenced by blinding)	Low (outcome was reported for all study participants)	Low (no other bias detected)	High
Hamad et al. (2018) Kuwait	Unclear (Not described)	Unclear (not described)	Low (data on all outcomes of interest were presented)	High (single blinded but unclear whether participants or researchers were blinded)	Low (not done, but outcome not likely to be influenced by blinding)	Low (outcome was reported for all study participants)	Low (no other bias detected)	High
Kataoka et al. (2013) New Zealand	Unclear (Not described)	Unclear (not described)	Low (data on all outcomes of interest were presented)	High (no blinding)	Low (not done, but outcome not likely to be influenced by blinding)	Low (drop-out was reported)	Low (no other bias detected)	High
Larsen et al. (1996) Denmark	Unclear (inadequately described 'participants were randomly assigned')	Unclear (not described)	Low (data on all outcomes of interest were presented)	High (no blinding)	Low (not done, but outcome not likely to be influenced by blinding)	Low (drop-out was reported)	Low (no other form of bias)	High
Sun et al. (2018) Singapore	Unclear (Not described)	Unclear (not described)	Low (data on all outcomes of interest were presented)	High (no blinding)	Low (not done, but outcome not likely to be influenced by blinding)	Low (drop-out was reported)	Low (no other bias detected)	High

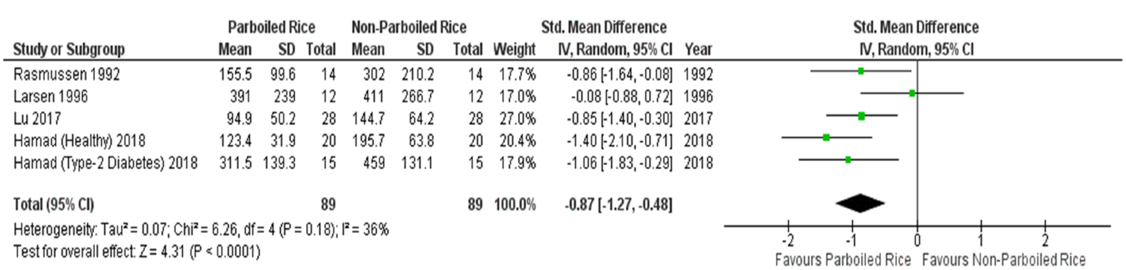

Figure 2. Forest plots from clinical trials showing the favorable effect of parboiled rice consumption on post-prandial glucose response.

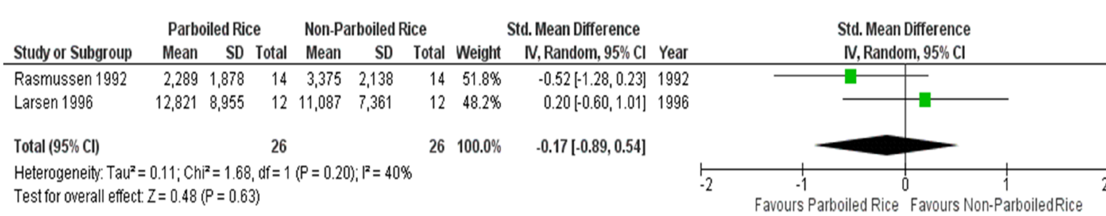

Figure 3. Forest plots from clinical trials showing the effect of parboiled rice consumption on post-prandial insulin response.

investigated glycaemic responses (in humans) to rice cooked with cooking oil (Sun et al., 2018). Generally, the six studies were randomised crossover in design and acute in duration (120, 180 or 240 minutes of digestion), which is typical for most glycaemic response studies conducted in human participants.

Overall, this systematic review demonstrated that parboiled rice significantly lowered postprandial glucose response. The effect size was −0.87, which was considered as a large effect (Takeshima et al., 2014), hence the effect was clinically significant. Lu et al. (2017) highlighted the effect of different parboiled rice cooking treatment on the magnitude of its glycaemic response reduction. The authors reported that for freshly cooked parboiled rice, reduction in incremental area under the glucose curve was 34%; whereas freshly cooked parboiled rice, refrigerated at 4 °C overnight and microwaved the next day recorded 42% reduction in incremental area under the glucose curve in healthy participants. A similar observation was made when the consumption of cooked 20 and 60 g raw parboiled white rice by people with non-insulin dependent T2DM resulted in postprandial glucose response attenuated by 53% and 47% respectively compared to the control white bread counterpart (Rasmussen et al., 1992). Larsen et al. (1996) however reported no effect on the postprandial glucose response associated with parboiled rice consumption. The results demonstrated that parboiled rice attenuated glucose incremental area under the curve by 48% whilst it's non-parboiled counterpart recorded 46% when compared with control white bread, but this was non-significant. Larsen et al. (1996) explained that, the non-significant change in the glucose response between the intake of the parboiled and non-parboiled rice could be attributed to the use of traditional parboiling method which is a mild hydrothermal process compared to the industrial parboiling process which is a harsher hydrothermal process used in the production of most parboiled rice. Hamad et al. (2018) reported that variations exist in the rate at which glycaemic response is attenuated in healthy and participants living with T2DM. The authors reported that cooked parboiled rice significantly attenuated postprandial blood glucose response by almost 43% and 32% respectively compared to control white rice in the healthy and participants living with T2DM. Explanation to the variation in glycaemic response properties of rice is attributed to factors including rice variety, starch content and composition (amylose/amylopectin ratio), post-harvest processing including parboiling and cooking method of rice employed (Boers et al., 2015). Casiraghi et al. (1993) reported that some post-harvest treatments of rice including parboiling and quick-cooking favourably impacts on the glycaemic response properties of rice starch. During rice parboiling, rice starch undergoes rapid transformation in their physicochemical properties due to processes including gelatinisation and recrystallisation (Oli et al., 2014). Parboiling, additionally increases the gelatinization temperature of rice and this is dependent on the intensity of heat treatment (Islam et al., 2002). Zavareze et al. (2010) concluded that the severity of these heat treatments are the main reason why pressure parboiling lowers glycaemic response, especially of high-amylose starches. Additionally, Ranawana et al. (2009) stated that gelatinisation of the rice starch, followed by retrogradation of amylose and amylopectin leads to higher levels of resistance starch (RS) which results in lower postprandial glucose response.

Ethnicity and body composition (Boers et al., 2015), physiological state, medical condition and need for thermoregulation may affect the impact of parboiled rice on glycaemic responses (Bagger et al., 2011; Hamad et al., 2018). Specifically, no studies with participants of African ethnicity could be found. In comparing European New Zealanders with Chinese living in New Zealand, the attenuation of postprandial glucose response was higher among the Chinese following the ingestion of rice (Kataoka et al., 2013). This study showed cooked parboiled rice attenuated iAUC by 44% and 20% respectively using glucose solution and white jasmine rice as control in Europeans and 29% and 14% respectively using glucose solution and white jasmine rice as control in Chinese (Kataoka et al., 2013). Explanation of the variation in glycaemic response to parboiled rice consumption due to ethnicity difference is reported in the thin-on-the-outside-fat-on-the-inside TOFI_Asia study (Sequeira et al., 2020). The authors reported that factors including higher fasting plasma glucose, glycated haemoglobin and fasting insulin, as well as higher total abdominal and visceral adipose tissue could be partly responsible for the higher postprandial glucose response (Sequeira et al., 2020). Therefore, this review is of high relevance to Asian adults as modifying the rice cooking method may be beneficial for lowering postprandial glucose response in Asian adults who tends to have higher postprandial glucose increase following rice consumption.

Overall, meta-analysis conducted on pooled data from five articles showed that the consumption of parboiled rice was significantly associated with a lower postprandial glucose response. This could be attributed to the improved glycaemic properties including grain hardness (Kwofie & Ngadi, 2017) restricting ease of rice starch digestibility by amylase enzymes. The gelatinisation of the rice starches that occur during parboiling additionally ensures that less starch/modified starch is available for amylase to act on thus impairing digestibility (Boers et al., 2015). In a broader perspective, for populations that commonly consumes rice as carbohydrate-containing staple food, this meta-analysis provided a preliminary evidence that replacing white refined non-parboiled rice with a parboiled counterpart may be incorporated as part of a lifestyle intervention to lower postprandial glucose excursion.

Since insulin secretory response is also a determinant for postprandial glycaemia, two studies (n = 2) (Larsen et al., 1996; Rasmussen et al., 1992) investigated insulin response as additional outcome associated with the consumption of parboiled rice. The consumption of cooked parboiled rice containing 50 g available carbohydrate by 7 non-insulin dependent T2DM was found to significantly attenuate insulin response by about 44% when compared to its white bread counterpart (Rasmussen et al., 1992). However, this significant effect was not observed when 25 g available carbohydrate of the same rice was served to the participants. It was expected that the slower release of glucose into the circulation would lower the response of pancreatic β-cells in secreting insulin. In contrast Larsen et al. (1996) reported a non-statistically significant increase (14%) in insulin iAUC following the consumption of parboiled rice compared to its non-parboiled counterpart. Whilst more studies are necessary to understand the effect of parboiling on postprandial insulin response, the current evidence could not confirm that parboiling would decrease postprandial insulin response compared to non-parboiled rice.

Food processing associated with the change of textural and nutritional properties has been implicated to impact satiety response (Fardet, 2016). Two (n = 2) (Hamad et al., 2018; Lu et al., 2017) out of the six articles selected for the review reported on satiety changes associated with the consumption of parboiled rice. Lu et al. (2017) reported that microwave heated parboiled rice significantly suppressed hunger ratings at t = 30 and 60 min compared to its white rice counterpart. However, the effect of hunger suppression was not maintained until the end of intervention at t = 120 min. In contrast, Hamad et al. (2018) reported that when parboiled rice is consumed, reduction in prospective food consumption over the 120 min was about 50% lower than non-parboiled white rice in the healthy participants, but not among individuals with T2DM. Therefore, the overall effect of parboiling on postprandial satiety is unclear. Increased satiety sensation is often associated with food texture. Parboiling treatment modifies the rice matrix, resulting in rice grains with harder texture (Kwofie & Ngadi, 2017), hence require more time and effort to chew (Lu et al., 2016). Consequently, increased oral processing time has been hypothesised to promote subjective feelings of satiety (Chambers et al., 2015; Miquel-Kergoat et al., 2015). Fardet (2016) also showed that foods that promote lower glycaemic response are likely to be structurally more complex, hence beneficial for promoting subjective feelings of satiety. Whilst the overall effect of parboiling on postprandial satiety is unclear due to small number of studies, its effect on promoting postprandial satiety is plausible and require further investigations. Evidence for greater postprandial satiety when consuming cooked parboiled rice is required before practical recommendations could be made to promote the consumption of parboiled rice for weight management.

Sun et al. (2018) investigated the glycaemic response following consumption of rice cooked with three different fats (oils) (butter, refined olive oil and refined grapeseed oil) as part of a mixed meal. The authors reported no significant difference in postprandial glucose after the consumption of the isocaloric rice-based meals. However, the effect on starch digestibility using *in vitro* models of the use of two types of oil including vegetable oil (unsaturated oil) and ghee (clarified butter, saturated) and their timing of addition to white and red rice has been reported (Kaur et al., 2015). In this particular study, the timing of oil addition into the rice was classified into three involving 'after' (rice is first cooked by boiling 20 min. Cooked rice is then added to fat to be stir-fried for 1 min), 'during' (rice is cooked by boiling for 20 min in water and fat) and 'before' (raw rice is fried in fat quickly for 1 min, then water is added to boil the rice for 20 min till cooked). The results revealed that oil addition 'after' (stir-frying) to white or red rice impacted the physicochemical properties of the rice starch resulting in the production of higher concentration of starch that is slowly digestible by starch digestion enzymes, corresponding to the attenuated glucose response using *in vitro* model. Ren at al. (2016) studied the physicochemical changes associated with resistant starches from boiled rice prepared with the addition of soybean and coconut oil to the water medium used for the rice cooking. The authors prior to freeze drying the rice, stored the freshly cooked rice under two conditions: (i) 12 h refrigeration and (ii) refrigeration for 12 h and microwave heating. The results revealed that the resistant starches from the cooked rice were transformed and this was attributed to factors including retrogradation and the amylose-lipid interaction (Ren et al., 2016). Thus, these factors could be responsible for the improved glycaemic response associated with *in vitro* digestion of oil cooked rice.

There appears to be a geographical publication bias in this systematic review as no study from Africa was recorded in the final articles that were selected. This is surprising because institutions including Alliance for a Green Revolution in Africa (AGRA) and Japan International Cooperation Agency (JICA) for instance are aggressively promoting rice breeding leading to Africa becoming self-sustainable in rice production (Bado et al., 2018). Parboiling of rice has been a local technology adopted by rice producers in these African countries. It was thus expected that several of the works included for this systematic review should come from Africa. This geographical publication bias could be attributed to factors including the high cost associated with conducting clinical trials such as glycaemic and insulinaemic responses associated with the rice intake. There is generally a lower level of funding for research emerging from Africa and this may have contributed to the lack of study emerging from the continents in the selected studies. With the sudden rise in type 2 diabetes in Africa, government should prioritise funding glycaemic and insulinaemic response to local rice cultivars from the continent.

Strengths and limitation

The main strength of this systematic review include that the search terms used for the article extraction were extensive allowing for the retrieval of potentially all original research on the outcome of interest. We demonstrated that despite the small number of studies identified for systematic review and meta-analysis, most studies revealed significant attenuation of postprandial glucose upon the ingestion of parboiled rice compared to non-parboiled rice except one study. The effect is significant and consistent, as shown by the low heterogeneity in the meta-analysis. Therefore, parboiled rice, when substituted for non-parboiled rice counterpart, has a great potential in reducing postprandial glycaemic response.

The overall risk of bias for most of the studies was generally high (Table 2). This is a common challenge with undertaking glycaemic response study. Due to the relatively high dosage of food required (50 g available carbohydrate) to be provide for participants, blinding of participants and personnel to the test meals is usually difficult. There was no record of selective reporting in the studies selected for the review. Although there was no blinding of outcome of interest for all the five studies selected for this systematic review, this had no influence on the glycaemic and insulin responses towards parboiled rice consumption. The rationale is that enumeration of the glycaemic and insulin responses is a physiological process. However, for the two studies ($n = 2$) that assessed satiety measures, the lack of the blinding may possibly affect the outcome of interest. This is because factors including subjective chewing of rice can impact on satiety outcomes.

Firstly, this review is limited because there were only five studies available for review meriting completion of more original investigations into the effects of parboiling and braising. Only one of the five studies included in the review satisfactorily described the parboiling processes the rice was subjected to before purchase. This makes it difficult to establish plausible relationships between the degree of parboiling and its effect on the glycaemic properties of the rice. Furthermore, the studies investigated the glycaemic effect of rice when consumed alone. In real life, rice is a staple that is often consumed along with other foods. It is known that co-ingestion of protein, fat, and dietary fibre with carbohydrate-rich foods significantly attenuate postprandial glucose response (Wee & Henry, 2020). A significant effect of postprandial glucose and insulin attenuation, as well as increased satiety, when replacing non-parboiled rice with parboiled rice in a mixed meal must be demonstrated to promote the consumption of parboiled rice for glycaemic and appetite control.

Conclusion

The consumption of parboiled rice was associated with improved postprandial glucose response. Meta-analysis of the pooled data from five interventions revealed that consumption of parboiled rice significantly attenuated postprandial glucose response, whereas the postprandial insulin response to parboiled rice was equivocal compared to control. Despite a possible association between the consumption of parboiled rice and improved postprandial response, the number of studies are limited. Mixed meal studies focusing on the consumption of parboiled rice and its effect of postprandial and long-term glucose, insulin and satiety responses are needed to inform dietary recommendations. No clinical study investigated the effect of cooking oil with plain or parboiled rice on glycaemic and satiety responses, hence creating a potential research gap of relevance to Africa that should be investigated.

Authors' contributions

Conceptualization, methodology, supervision, software, data curation, validation, writing–original draft, writing–review and editing: I.A. Methodology: J.C.C. and J.A.Y. Supervision and writing– review and editing: P.T. Methodology, supervision, validation, formal analysis, writing– review and editing: J.J.L. Methodology, supervision, writing– review and editing: E.R. All authors have approved the final draft of the manuscript.

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