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DECREASED IN INCREMENTAL INTERSTITIAL FLUID GLUCOSE PEAK AFTER CONSUMPTION OF RICE COOKED WITH LOW-CARBOHYDRATE RICE COOKER COMPARED TO CONVENTIONAL RICE COOKER IN LEAN AND OBESE ADULT POPULATION

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Abstract: *The rapid rise in glucose levels is closely related to increased free radicals and oxidative stress which are directly linked with the aging process. Carbohydrate is one of the food components which has a major impact on prandial glucose fluctuations, in addition, rice is one of the staple carbohydrates consumed in Indonesia. In recent years, low-carbohydrate rice cookers claim to be able to reduce carbohydrate content in rice. However, there are currently no in vivo study in Indonesia whether the use of these devices has an impact on reducing prandial incremental glucose peak. The aim of this study was to determine whether the consumption of rice cooked with low-carbohydrate rice cooker can provide decreased in incremental interstitial fluid glucose peak (IIFGP) compared to conventional rice cooker. This study used a quasi-experimental method to identify differences in prandial IIFGP when using a low-carbohydrate rice cooker. IIFGP was calculated from subtracting the peak with baseline interstitial fluid glucose (IFG) value during 120-minute time. There are a total of 16 participants consisting of 8 lean and 8 obese participants. The participants were paired with Freestyle Libre Continuous Glucose Monitoring for prandial glucose evaluation. Each participant will consume rice from a conventional and low-carbohydrate rice cooker on different days at the same hour and will be fasted 8-12 hours prior to the procedure. A comparison of the glucose responses from different rice cookers was carried out on the same participant. On the first procedure day, the participants were given 250 g of rice from a conventional rice cooker, afterwards the prandial glucose response was recorded for 2 hours in 5 minutes interval. On the following day, participants were given 250 g of rice from a low-carbohydrate rice cooker, then the prandial glucose response was recorded in similar manner, subsequent comparison between the two glucose responses was made. This study found differences in the IIFGP from conventional rice cooker 70.4 ± 21.0 mg/dL and low carbohydrates 60.3 ± 17.8 mg/dL, p = 0.005. Subgroup analysis of lean participants showed that there was a difference in the IIFGP between rice from a conventional rice cooker 66.6 ± 8.56 mg/dL and low-carbohydrate rice cooker 61.6 ± 9.9 mg/dL, p = 0.022. Obese participants also showed differences in IIFGP, conventional rice cooker 74.2 ± 29.0 mg/dL and low-carbohydrate rice cooker 58.9 ± 24.1 mg/dL, p = 0.029. There was also a moderate correlation between the waist to height ratio and the peak value of IFG from rice cooked with conventional rice cooker r = 0.551, p = 0.027. Low-carbohydrate rice cooker was able to improve prandial glucose response by reducing the carbohydrate component from cooked rice. Taken together, we concluded that there is a decrease in IIFGP after consumption of rice cooked with low-carbohydrate rice cooker compared to a conventional rice cooker.*

Keywords: *Low-carbohydrate rice cooker, prandial glucose, interstitial fluid glucose, body mass index, waist to height ratio*

INTRODUCTION

Aging is a process of decline in the body's physiological functions such as decreased hormone function that is influenced by various factors including genetics, telomere shortening, mutations, and oxidative stress (Pangkahila, 2019). Oxidative stress plays an important role in the aging process and is a modifiable factor that has received special attention in the anti-aging field. Oxidative stress is a condition of imbalance between free radicals and antioxidant capacity in the body. High levels of

glucose, insulin, and free fatty acids can lead to the formation of free radicals and oxidative stress (Tangvarasittichai, 2015).

The natural history of oxidative stress can be traced back from the consumption of high-carbohydrate foods that are easily digested and cause rapid fluctuations in glucose levels. Rapid fluctuations in glucose levels have the potential to reduce the duration of glucose levels in the normal range (time in range) and will trigger rapid phase insulin secretion by pancreatic β-cells to overcome fluctuations in glucose in the blood by incorporating glucose into muscle and fat cells (Veedfald et al., 2019). If glucose entering the cell exceeds the capacity of the Krebs cycle, it will be converted into free fatty acids which will then be stored in fat cells after being reorganized into triglycerides (Haslam et al., 2019). If this process continues, it can cause fat accumulation, and in adults the increase in fat only increases the size of fat cells, namely fat cell hypertrophy, which will then occur obesity (Muir et al., 2016). Fat cell hypertrophy can lead to ischemic conditions that increase pro-inflammatory cytokines such as TNFα, IL1, and IL6, and directly reduce anti-inflammatory cytokines such as adiponectin. These cytokines are one of the contributors to the formation of radical oxygen species (ROS) as an important component of increased oxidative stress (Divella et al., 2016). The body's inability to cope with oxidative stress will lead to premature aging conditions.

High glucose excursion in normal people can potentially lead to premature aging and food component that has a major impact on glucose excursion is carbohydrate. Different sources and amounts of carbohydrate intake may result in different glucose excursion, depending on the glycemic load, rather than the glycemic index alone. The glycemic index depends on the ratio of amylose and amylopectin content, which differs from rice variety and/or cooking process. In Indonesia, more than 90% of the population consume rice as their staple carbohydrate (Yanuarti & Afsari, 2014). Recently, low-carbohydrate rice cookers have been marketed, which are claimed to reduce the carbohydrate content in rice by up to 50 % and are expected to reduce the glycemic load without reducing the amount of rice consumed. Reducing the glycemic load of consumed rice can be one of the efforts to reduce glucose excursion (Livesey et al., 2008) and increase time in range (Gabbay et al., 2020).

Low carbohydrate rice cooker utilizes the properties of starch and its gelatinization temperature by using fuzzy logic for temperature control and steam cooking process to reduce starch content. It uses two stacked pots: the top pot is perforated similar to steamer basket and bottom pot is an ordinary pot such as conventional rice cooker to be filled with water. The gelatinization process during cooking will cause starch content to leach to surrounding water and as water boils and evaporated, remaining water along with leached starch content are separated from cooked rice thus reducing carbohydrate content in cooked rice.

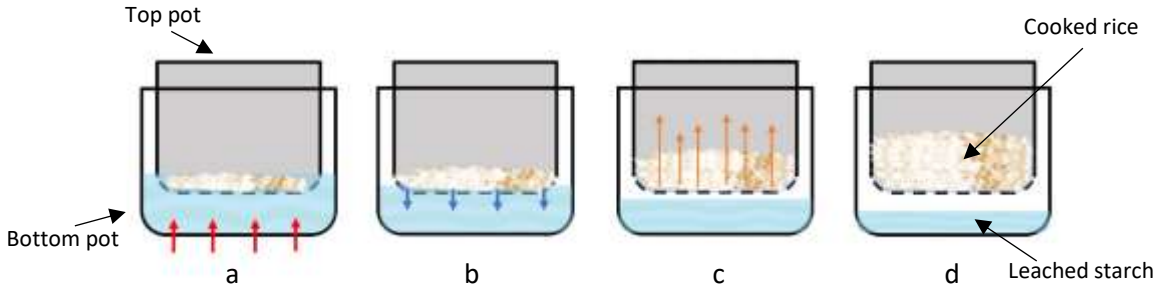

Figure 1 Low-carbohydrate rice cooker diagram. a: spread evenly the uncooked rice on the top pot then add water until water level flatly immersed the rice. b: gelatinization process cause starch content to leach to surrounding water. c: Leached starch will be separated into bottom pot and rice cooking by steam starts. d: Cooked rice on top pot is separated from leached starch on bottom pot.

Various brands of low-carbohydrate rice cookers claim to reduce carbohydrate content in rice. However, there has been no *in vivo* study in Indonesia showing the impact of the cooking process on fluctuations in prandial glucose levels that indicates consumption of rice cooked with a low-carbohydrate rice cooker can reduce glucose excursion without reducing the amount of rice consumed. Blood glucose dynamics can be monitored periodically using capillary blood glucose testing. The disadvantages of this examination method are the discomfort during blood collection and the potential loss of data outside the examination time (Heinemann, 2008). One alternative method that can monitor continuously and in real time is using continuous glucose monitoring (CGM) with a note that the glucose levels read are not blood glucose, but interstitial fluid glucose (IFG) (Rodbard, 2016). By using CGM, IFG fluctuation data can be monitored at any time so that it can provide an accurate picture of incremental interstitial fluid glucose peak (IIFGP) after rice consumption. In addition, the use of sensors installed can be used to read IFG for 14 days, thus reducing discomfort compared to using capillary blood glucose tests that requires finger pricks. This study compared the IIFGP using CGM after consuming rice cooked with conventional and low-carbohydrate rice cookers.

MATERIALS AND METHODS

Study Design

This study used a quasi-experimental method to identify differences in IIFPG in the use of low-carbohydrate rice cooker and conventional rice cooker. The study was conducted in DKI Jakarta in June 2022 - May 2023. This study was conducted in accordance with International Conference on Harmonization - Good Clinical Practice (ICH-GCP) guidelines and other applicable laws and regulations. The Research Ethics Committee Faculty of Medicine Udayana University has approved the ethical clearance for this research No.: 2379/UN14.2.2.VII.14/LT/2022.

Participant Recruitment

A total of 16 participants consisting of 8 lean and 8 obese participants from Jakarta were recruited with the criteria of age 20-40, male or female without a diagnosis of diabetes mellitus characterized by fasting blood glucose levels less than 126mg/dL, lean male or female with BMI criteria ≤23 and relative fat mass < 25 for men and 32 for women, and obese male or female with BMI criteria > 25 and relative fat mass > 25 for men and 32 for women. Exclusion criteria: those undergo radiologic examination that is Magnetic Resonance Imaging or Computed Tomography Scan, >26 Perceived Stress Scale (PSS-10) score, pregnancy, implanted medical device, and undergo glucose altering medication such as steroids, antidepressant, or beta blocker. Informed consent was given by all participants before the study. The participants were paired with Freestyle Libre CGM for prandial glucose evaluation.

Anthropometric Measurement

Body weight was measured with digital body weight (0.1kg precision), height was measured with digital stadiometer (0.1cm precision), and waist circumference was measured with body tape measure (0.1cm precision). Body mass index (BMI), waist to height ratio (WHtR), and relative fat mass (RFM) were calculated from measured data. All measurement was performed standing straight, barefoot, and unnecessary clothing, watch, and gadgets was removed.

Rice Preparation

Low-carbohydrate rice cooker (VITARICE Low Sugar Multicooker) utilized two stacked compartments to reduce carbohydrate content from rice cooked. Uncooked rice was placed on top pot (perforated allowing water to flow through) and water was filled into the bottom pot until rice in the top pot is flatly immersed in water. Conventional rice cooker (SANKEN) utilized one pot to cook rice with water, placed in the same compartment. Any starch content that leached out during cooking process is retained in the cooked rice. Both rice cookers used 300g of white rice for each cooking process, the rice was washed once with clean water and cooked without presoaking. Low-

carbohydrate rice cooker required water in the bottom pot to flatly immerse the rice in the top pot (300g rice required 1300cc water), low sugar option was used for cooking and cooking process lasted for 45 minutes. Conventional rice cooker used rice/water ratio 1:2 (300g rice required 600cc water), there was no optional cooking mode in conventional rice cooker, cooking process lasted for 25 minutes. Cooked rice was mixed well after cooking process to remove excess moisture for both rice cookers before portioning. Low-carbohydrate rice cooker produced 784,9±34,4g cooked rice, and conventional rice cooker produced 801,2±22,2g cooked rice. One portion of scrambled egg from two chicken eggs was used for each portion accompanied with packed salt and pepper.

Intervention

Participants were given written and verbal explanation and informed consent. Freestyle Libre sensor was applied on the back upper arm and calibrated for 24-hour prior intervention. Each participant consumed rice from conventional rice cooker on day one and low-carbohydrate rice cookers on the following day at the same hour, and participants were fasted 8-12 hours prior the procedure. Comparison of IIFGP from both rice cookers was conducted on the same participant. On the first procedure day, participants were given 250g of rice from the conventional rice cooker, and the prandial glucose response up to 2 hours was recorded. The second day, participants were given 250g of rice from the low-carbohydrate rice cooker, prandial glucose response up to 2 hours was recorded, and then comparison was made. During the procedure, participants must be seated for 120 minutes.

Measurement of IIFGP

IFG value was recorded with Freestyle Libre CGM for 120 minutes with 5 minutes interval providing 25 IFG data from each procedure. IIFGP was calculated from subtracting the peak with baseline IFG value during 120-minute time.

Statistical Analysis

IIFGP and IFG responses were analyzed with dependent samples T-test and subgroup analyses comparing lean and obese group, including BMI and WHtR used independent samples T-test and Pearson correlation coefficient.

RESULTS AND DISCUSSION

High excursion in prandial glucose levels, which are generally derived from carbohydrate components, can potentially cause premature aging conditions. In Indonesia, white rice is one of the main carbohydrates consumed and research shows that excessive consumption of white rice can be one of the triggers for premature aging conditions (Anjana et al., 2015; Bhavadharini et al., 2020; Yanuarti & Afsari, 2014). Some rice cookers claim to reduce up to 50% of the carbohydrate content contained in rice cooked using a low-carbohydrate rice cooker, but it is not yet known how the body responds to the consumption of rice cooked using a low-carbohydrate rice cooker. The aim of this study was to explore the prandial glucose fluctuation and correlation between conventional rice cooker and low-carbohydrate rice cooker in lean and obese participants.

1. Research Participant

Table 1. Characteristics of participants

Characteristics	Value		
Age (years)(x̄±SD)	29±3.6		
Gender			
Male n(%)	12 (75%)		
Female n(%)	4 (25%)		
Anthropometric Characteristics	Total (x̄±SD)	Lean n=8 (x̄±SD)	Obese n=8 (x̄±SD)

Body Weight (kg)	73.5±18.6	59.1±7.2	87.9±14.5
Height (cm)	170.1±7.5	165.9±6.6	174.3±6
Waist circumference all participant (cm)	89.3±15.8	76.1±5.6	
Male		79.9±5.2	102.6±10.2
Female		72.2±2.8	
BMI (kg/m^2)	25.4±5	21.4±1.8	29.3±3.9
WHtR	0.52±0.08	0.46±0.03	0.58±0.06
Relative Fat Mass	27.4±4.6	24.9±4.7	29.7±3.2

To analyze the reduction of glucose excursion from rice cooked with low-carbohydrate rice cooker, a one-group pretest-posttest study was conducted which was described by the difference in IIFGP after consumption of rice cooked with conventional and low-carbohydrate rice cookers. This study was conducted with a total of 16 participants aged 29±3.6 years consisting of 8 lean and 8 obese participants. Table 1 describes the characteristics of the participants. Participants were fitted with the Freestyle Libre sensor and reader, 24 hours prior to the procedure allowing the device to calibrate the IFG readings. Participants were given rice cooked with a conventional rice cooker as a pretest and rice cooked with a low-carbohydrate rice cooker as a posttest on the following day at the same hour. The procedure began with checking IFG levels as a baseline value, continued with finishing the meal within 5 minutes. After finishing the meal, the participants sat back and relaxed while watching a program of their choice for 120 minutes. IFG values were taken and recorded at 5-minute intervals for 120 minutes. IFG levels with 15 minutes interval (Table 2) showed largest IFG level differences between rice cookers in minute 45, even though in minute 0 and 120, differences were not noticeable.

Table 2. Prandial IFG Changes

	IFG[a] at 15 minutes interval x̄±SD									
	0	15	30	45*	60	75	90	105	120	IIFGP
Conventional whole[b]	81.5±7.9	84.6±8.3	121.7±19.5	146.9±26.4	137±27	120.3±26.1	111±24.4	106.3±20.4	103.9±17.7	70.4±21.0
Low carbohydrate whole[b]	81.6±7.6	85.4±7.5	119.6±17.6	137.6±22.4	131.9±23.5	120±23.3	110.2±21.9	104.5±18.7	103.2±17.4	60.3±17.8
Conventional lean[c]	79.2±9.7	81.2±9.3	123.9±18.2	142.4±17.1	126±19.8	110.4±23.1	101.7±21.6	100.1±18.6	101.5±18.1	66.6±8.56
Low carbohydrate lean[c]	81±9.7	84.1±8.7	119.5±16.4	138.4±14.4	128.5±17.7	112.9±16.3	103.5±16.5	98.1±8.7	101±15.7	61.6±9.9
Conventional obese[d]	83.7±5.5	88±6.2	119.5±21.7	151.4±34.1	148.1±30	130.3±26.5	120.4±24.7	112.5±21.4	106.4±18.6	74.2±29
Low carbohydrate obese[d]	82.1±4.9	86.6±4.5	119.7±16.8	136.8±20.7	135.4±22.7	127.1±24	117±21.7	110.9±22	105.5±20.3	58.9±24.1

*Largest difference seen in minute 45, [a] IFG: Interstitial fluid glucose, [b] whole: all participant, [c] lean: lean participant, [d] obese: obese participant

2. Decrease in IIFGP

The 25 IFG levels from each procedure was subtracted with the baseline value to represent complete IFG fluctuation for 120 minutes (Figure 2).

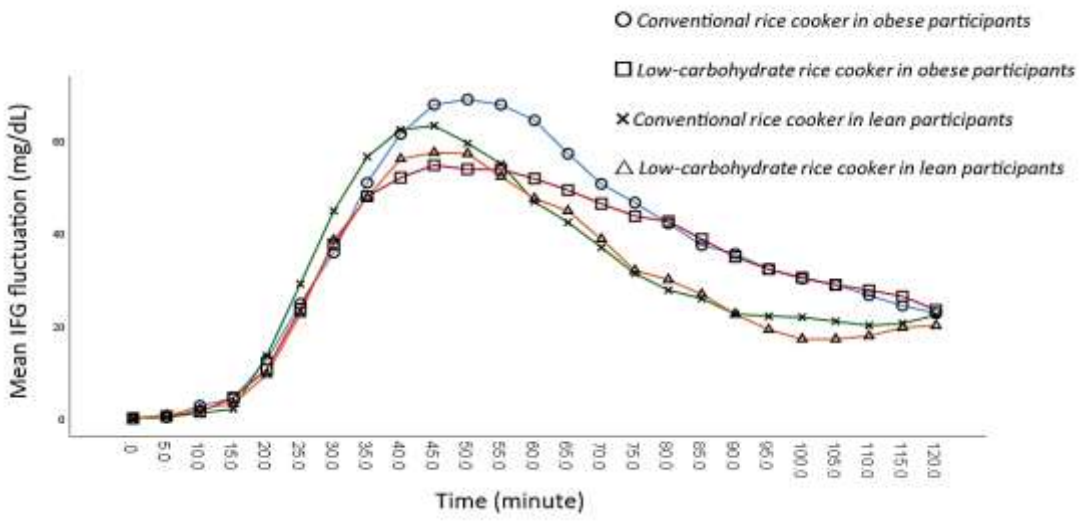

Figure 2 Interstitial fluid glucose fluctuation from conventional and low-carbohydrate rice cookers in obese and lean participants for 120 minutes, IFG levels were subtracted with each participant's baseline level forming IFG fluctuation curve. ○ Conventional rice cooker in obese participants, □ Low-carbohydrate rice cooker in obese participants, ✕ Conventional rice cooker in lean participants, △ Low-carbohydrate rice cooker in lean participants.

IIFGP was obtained from subtracting the peak and baseline values of prandial IFG in both procedures (Figure 3). The results showed that there was a difference between the IIFGP from conventional (M=70.4, SD=21.0) and low-carbohydrate (M=60.3, SD=17.8) rice cookers; t(15)=3.25, *p*=0.005 (table 3).

Table 3. IIFGP Differences Between Rice Cookers

	Conventional rice cooker x̄±SD	Low-carbohydrate rice cooker x̄±SD	*p*
All participants	70,4±21,0	60,3±17,8	**0,005***

*Significant difference by paired sample T-test, IIFGP: Incremental interstitial fluid glucose peak

This result may be caused by the cooking concept of the low-carbohydrate rice cooker which is different from the conventional rice cooker. Low-carbohydrate rice cookers are able to reduce the starch content of rice by separating the cooking water from the cooked rice. Some of the starch dissolved in the cooking water because of the gelatinization process will be separated from the final rice product resulting in rice with a lower starch content. Preliminary research has identified the presence of carbohydrates in the remaining water from low-carbohydrate rice cooker that contained leached starch (Winarno & Ratna Saraswati, 2022). Research has also examined that prandial glucose plays a role in oxidative stress, in which high glucose excursion will cause damaging effects such as cardiovascular risk and endothelial damage with the number of free radicals formed in the prandial phase will be proportional to the excursion of prandial glucose (Suh & Kim, 2015). There are no clear criteria regarding the limit of glucose excursion, however, study has examined that among those with mean amplitude of glycemic excursion (MAGE) above 65mg/dL corelates with increased level of high-sensitivity C-reactive protein (hs-CRP) as one of the markers for systemic inflammation conditions (Akasaka et al., 2017).

Table 4. IIFGP Differences Between Rice Cookers in Lean and Obese Participants

	Conventional rice cooker x̄±SD	Low-carbohydrate rice cooker x̄±SD	*p*

Lean	66,6±8,56	61,6±9,9	**0,022***
Obese	74,2±29,0	58,9±24,1	**0,029***
p	0,486[a]	0,776[a]	

*Significant difference by paired sample T-test, [a] Nonsignificant difference by independent T-test, IIFGP: Incremental interstitial fluid glucose peak

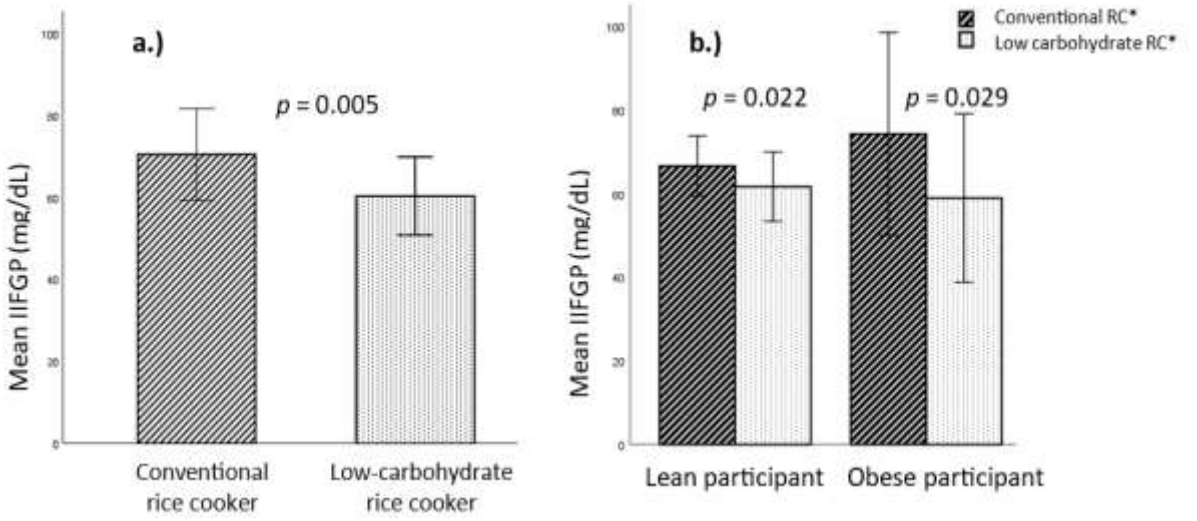

Figure 3 IIFGP Differences between conventional and low-carbohydrate rice cookers, and subgroup analysis. a.): IIFGP difference among all participants (p = 0.005). b.): Subgroup analysis, IIFGP difference among lean participants (p = 0.022), obese participants (p =0.029). *RC: Rice cooker

Subgroup analysis (Table 4) also showed differences in lean participants between the IIFGP from conventional (M=66.6, SD=8.56) and low-carbohydrate rice cooker (M=61.6, SD=9.9) t(7)=2.925, p = 0.022. In obese participants, IIFGP from conventional (M=74.2, SD=29.0) and low-carbohydrate rice cooker (M=58.9, SD=24.1); t(7)=2.742, p = 0.029. Analysis by independent T-test showed nonsignificant difference in the IIFGP between lean and obese participants in both conventional rice cookers p = 0.486 and low-carbohydrate rice cookers p = 0.776.

Obese participants showed a larger difference in IIFGP between conventional and low-carbohydrate rice cookers compared to lean participants (Figure 3). This phenomenon is thought to occur due to the decreased insulin sensitivity that causes the obese participants to have a higher IFG peak from conventional rice cooker. In addition, studies have shown that obesity leads to higher basal and prandial insulin secretion (van Vliet et al., 2020). It is thought that this is one of the reasons that the peak IFG of low-carbohydrate rice cookers is similar in the obese and lean participants as its rice has lower carbohydrate content. This could not be further evaluated due to lack of insulin sensitivity and prandial insulin response data. However, this result is consistent with previous study suggesting prandial glucose level in those with obesity is consistently higher than those without (Saraswati et al., 2022), in which decreased insulin sensitivity and increased insulin secretion can lead to similar fasting glucose in obese and lean populations (Kumar et al., 2020).

Within the 120 minutes of prandial IFG response, each participant had a peak IFG at different times ranging from minutes 30 to 60. However, in both conventional and low-carbohydrate rice cookers, the peak IFG was consolidated at minutes 45 to 50. This is in accordance with previous studies that found the highest peak of prandial glucose was found at minute 45 and formed a smaller peak at minutes 75 (Saraswati et al., 2022). The largest difference in the mean IFG values between conventional rice cooker and low-carbohydrate rice cooker was also found at minute 45, in which the mean IFG level of conventional rice cooker was 146.9 ± 26.4 mg/dL and low-carbohydrate rice cooker was 137.6 ± 22.4 mg/dL (Table 2). However, at minute 15, it was seen that rice cooked with a low-carbohydrate rice cooker tend to produce higher IFG level than rice cooked with a conventional rice cooker, indicating that the increase in IFG level occurred earlier in the low-carbohydrate rice cooker. It is thought that this is due to rice cooked with a low-carbohydrate rice cooker producing slightly

mushier rice. This is supported by a study in China that compared texture and digestion speed showing that a softer texture can speed up starch digestion process, and conversely, a harder texture can inhibit digestive enzymes from digesting starch, thus slowing down the digestion process (Hu et al., 2021). This is also supported by a study showing that the amount of water and the duration of the rice cooking process can affect the gelatinization process and glycemic response, where increasing water usage and longer cooking process will soften the rice makes it easier to digest (Kaur et al., 2016).

3. Correlation between Body Mass Index and IIFGP

Table 5. Correlation between BMI and IIFGP

	BMI	
	r	*p**
IIFGP conventional rice cooker	0.407	0.117
IIFGP low-carbohydrate rice cooker	-0.015	0.957
Peak of IFG conventional rice cooker	0.474	0.064
Peak of IFG low-carbohydrate rice cooker	0.086	0.751

* Pearson correlation is significant if $p < 0.050$, r: Pearson correlation coefficient, IIFGP: Incremental interstitial fluid glucose peak, IFG: Interstitial fluid glucose, BMI: Body mass index

There was no statistically significant correlation between BMI values and IIFGP in both conventional and low-carbohydrate rice cookers (Table 5). This result is in accordance with previous studies which showed that BMI has no significant influence on the prandial glucose response (Perälä et al., 2011). Another study that examined age and BMI as influences on glucose, cholesterol, and blood pressure levels; found that BMI was not directly related but played a role in increasing glucose levels. This may be due to the lack of components of BMI measurement which only takes into account weight and height without taking into account abdominal circumference or hip circumference so as not to identify the presence of body fat, although studies have examined that high BMI correlates with high body fat, waist to hip ratio (WHR), and risk of central obesity which corelated with insulin resistance and increased body glucose levels (Oumer et al., 2022). Other studies also support these findings that among those who are obese, generally have higher prandial insulin secretion, allowing the body to compensate for the glucose response (van Vliet et al., 2020).

4. Correlation of Waist to Height Ratio with IFG Fluctuations

Table 6. Correlation between WHtR and IIFGP

	WHtR	
	r	*p**
IIFGP conventional rice cooker	0.450	0.080
IIFGP low-carbohydrate rice cooker	0.041	0.881
Peak of IFG conventional rice cooker	**0.551**	**0.027***
Peak of IFG low-carbohydrate rice cooker	0.178	0.510

* Pearson correlation is significant if $p < 0.050$, r: Pearson correlation coefficient, IIFGP: Incremental interstitial fluid glucose peak, IFG: Interstitial fluid glucose, WHtR: Waist to height ratio

The result of this study showed a moderate correlation between WHtR values and the peak of IFG after consumption of rice cooked with a conventional rice cooker (r = 0.551; $p = 0.027$) (Table 6).

WHtR is calculated by dividing waist circumference and body height, it closely related to central obesity and cardiovascular disease, where the increase in visceral fat mass is related to insulin resistance so that more insulin is needed to get glucose from the blood into the cells, thus causing poor glucose response (Lear et al., 2010).

CONCLUSION

In conclusion, there is a decrease in IIFGP after consumption of rice cooked with low-carbohydrate rice cooker compared to a conventional rice cooker. Recommendation for future research directions is to include evaluation of hormone profile and oxidative stress biomarkers.

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