International Food Research Journal 29(6): 1304 - 1313 (December 2022)
Journal homepage: *http://www.ifrj.upm.edu.my*

Chemical composition, glycaemic index, and antidiabetic property of analogue rice made from composite tubers, germinated legumes, and cereal flours

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Article history

Received:
8 March 2021
Received in revised form:
14 February 2022
Accepted:
11 April 2022

Keywords

germinated,
dietary fibre,
glycaemic index,
atherogenic index

Abstract

The dependence on rice as a source of carbohydrates in Indonesia is among the highest in Asia. Innovations to develop products that can be used as a carbohydrate source, and have functional values beneficial to health are currently needed. The present work thus aimed to determine the chemical composition, glycaemic index, and antidiabetic property of three analogue rice types. The formulation of three types of analogue rice was done by combining natural tuber flour, modified tuber flour, germinated cereals, and germinated legumes. The glycaemic index was assessed using experimental animal. The antidiabetic properties of three types of analogue rice were assessed by food efficiency ratio, glucose profile, lipid profile, and atherogenic index. Results showed that analogue rice had high dietary fibre, resistant starch, and protein, and low fat and carbohydrate. The three types of analogue rice were classified as low glycaemic index based on glycaemic response tests. The glycaemic index of analogue rice I, II, and III were 41.23 ± 3.39, 42.55 ± 3.21, and 40.19 ± 3.34, respectively. The ability of analogue rice to decrease glucose, triglycerides, total cholesterol, low-density lipoprotein, atherogenic index; and increase high-density lipoprotein in diabetic mice was affected by its low glycaemic index and chemical composition benefits. The ability to improve the characteristics of glucose and lipids should support the development of analogue rice as a functional food.

DOI
https://doi.org/10.47836/ifrj.29.6.07

Introduction

Diabetes is a group of metabolic diseases with hyperglycaemia characteristics that cause insulin secretion, insulin action, or both. Chronic hyperglycaemia can be associated with long-term damage, dysfunction, or failure of various organs including the eyes, kidneys, nerves, heart, and blood vessels. Diabetes consists of (i) type 1, caused by pancreatic beta cell damage which results in an absolute deficiency of insulin; the number of people with type 1 diabetes is about 5 - 10% and (ii) type 2, caused by insulin resistance which is dominated by relative insulin deficiency, insulin secretion defects, and insulin resistance (ADA, 2014); the number of people with type 2 diabetes is about 90 - 95%. Hyperglycaemia can lead to an increasing number of reactive oxygen species that can cause damage to pancreatic beta cells, thus resulting in a decrease in the release of insulin amounts, a signalling insulin that can lead to serious diabetes complications (Kawahito *et al.*, 2009). Therefore, products that can control hyperglycaemia and oxidative stress can be used as a strategy for the management of diabetes mellitus, for example, functional foods with a low or moderate glycaemic index and antioxidant activity, and rich in dietary fibre (Origbemisoye and Ifesan, 2020).

Research has been done to obtain products that can serve as anti-hyperglycaemia and reduce oxidative stress, either in drugs or foods. Functional foods are widely developed to treat diabetes mellitus, including foods rich in antioxidants, dietary fibre, and resistant starch, and low in glycaemic index (Aggarwal *et al*., 2017). So, there is an opportunity to develop functional foods that have good nutritional content such as dietary fibres and antioxidants, and are low in glycaemic index to reduce oxidative stress and serve as hypoglycaemic.

Analogue rice is an artificial rice made from several sources of carbohydrates, proteins, and fats. Analogue rice is one of the products that can be developed into functional food. The development was carried out by formulating tubers, legumes, and

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cereals with an extruder into a form of rice granule. Cassava, and white and orange sweet potatoes, are local Indonesian tubers which are carbohydrate and fibre sources. Legumes and cereals are sources of proteins and fibres, but still have a distinctive flavour and anti-nutritional substances. The germination process modification can decrease the distinctive flavour in cereal- and legume-based products, and decrease the anti-nutritional factors, namely tricine inhibitors, phytic acid, pentosan, and tannin (Kumar and Gautam, 2019). The germination in legumes and cereals can improve their functional properties to positively increase antioxidant activity (Khang *et al.*, 2016). Besides, the extrusion process can also increase antioxidant activity (Hegazy *et al.*, 2017). Research shows that consumption of germinated cereals and legumes can even lower the glucose and lipids in diabetic trial animals, and lipid in high-fat trial animals (Liyanage *et al.*, 2018).

Several previous studies have shown that analogue rice, which is made from composite flour from tubers, beans, and grains, has not changed its value due to the process of its components. Therefore, the analogue rice produced is still high in carbohydrates and low in fibres (Saragih *et al*., 2019). As a functional food, analogue rice can be used to improve the blood sugar and lipid status of diabetic patients. As such, further research is needed to achieve better characteristics of analogue rice, that is, low glycaemic index, low carbohydrate, high protein, high fibre, easily digestible starch, and contains antioxidants.

The present work thus aimed to determine the potential of analogue rice made from composite flour tubers, germinated legumes, and cereals as functional foods to prevent and manage diabetes.

Materials and methods

Preparation of analogue rice

The analogue rice used in the present work were of three types, which were made from various composite flours. Three analogue rice were selected based on 30 semi-trained panellists. These panellists have been given explanations to identify certain features selected from a limited range, and process the test data first, so as not to use very different data. The sensory characteristics of analogue rice evaluated were colour, aroma, taste, texture, and overall acceptability. The composition of analogue rice constituents consisted of native tuber flour, modified tuber flour with an autoclaving-cooling process of three cycles, germinated legume, and germinated cereal. The ingredients used for the formulation of analogue rice I was cassava flour (25%), modified cassava (5%), germinated soybean flour (20%), germinated sorghum flour (20%), and sago starch (30%). The ingredients for the formulation of analogue rice II was orange sweet potato flour (25%), modified orange sweet potato (5%), germinated cowpea (*Vigna unguiculata*) flour (20%), germinated yellow cornflour (20%), and sago starch (30%). The ingredients for the formulation of analogue rice III was white sweet potato flour (25%), modified white sweet potato flour (5%), germinated mung bean (*Vigna radiata*) flour (20%), germinated white cornflour (20%), and sago starch (30%) (Nugraheni *et al.*, 2021).

Chemical composition

Chemical characteristics such as proximate analysis was determine following the established standards such as moisture content, ash content, fat content using the Soxhlet method, protein content using the Kjeldahl method (AOAC, 1990), and carbohydrate content using the difference method.

Glycaemic index of analogue rice

Experimental animals were obtained from the Food and Nutrition Center of Gadjah Mada University. The ethics commission has approved the experimental animals' treatment through a certificate of ethics concern number: 154.3/FIKES/PL/VII/2020.

The mice used were Wistar rats aged 2 - 3 months. The mice were adapted in advance for 1 w, and given standard feed and drink *ad libitum*. The mice were fasted for 10 h (except water), and the mice's fasting sugar levels were measured. The mice were grouped into six groups: group I, administration of NaCMC 0.1% 0.5 mL; group II, administration of pure glucose dose 2.5 g/kg BB; group III, commercial rice administration dose 2.5 g/kg BB; group IV, administration of analogue rice I dose 2.5 g/kg BB; group V, administration of analogue rice II dose 2.5 g/kg BB; and group VI, provision of analogue rice III dose 2.5 g/kg BB.

All samples were administered orally once, in suspense NaCMC 0.1%. After administering the test samples, glucose levels were measured at 30, 60, 90, and 120 min using the Gluco test tool. The glycaemic index value of analogue rice was determined by comparing the AUC value of mice's blood glucose after sampling with the standard glucose AUC value of IG 100. The AUC calculation followed a trapezoidal formula that formed in the lower area of the curve between time (h) and glucose levels (mg/dL).

Antidiabetic properties

Experimental animals

Thirty-six Wistar rats aged 10 w, weighing between 150 - 250 g, were used. All mice were caged, and air ventilation in the cage was sufficient. Cage conditions were uncontrolled light, room temperature of 28 - 32°C, and humidity of 58 ± 4%. Standard feed was given for 7 d using the 1993 AIN standard (Reeves *et al.*, 1993).

Experimental animal induction using alloxan

The acclimatisation stage before induction was carried out for 5 d. The mice were fasted overnight. The next day, the mice were injected with alloxan in a single dose of 150 mg/kg (dissolved in aquadest), intraperitoneally. Post-induction, the mice were reacclimatised for 5 d. The mice were declared with diabetes when blood glucose levels were > 150 mg/dL (Agunbiade *et al.*, 2012).

The mice were divided into six groups, each group consisting of 6 mice: group I (NSF), normal standard feed healthy mice (without alloxan induction) were given a standard feed diet of AIN-93; group II (DSF), diabetic mice standard feed, alloxan-induced mice were fed AIN standard feed AIN-93; group III (DCR), diabetic mice were given a commercial rice diet; group IV (DAR I), diabetic mice were given analogue rice I; group V (DAR II), diabetic mice were given analogue rice II; and group VI (DAR III), diabetic mice were given analogue rice III.

Feeding either standard feed, commercial rice, or analogue rice I - III were carried out for 28 d, as much as 15 g, every morning. Drinking water was given *ad libitum*. Every day the cage was cleaned, the rest of the feed was weighed daily. Blood samples were taken every 7 d to analyse the glucose and lipid profiles. The withdrawal of blood (1.5 mL) was from the orbital sinus.

Food efficiency ratio (FER)

The FER was calculated using Eq. 1:

$$Food\ efficiency\ ratio = \frac{Body\ weight\ gain}{food\ intake} \quad \text{(Eq. 1)}$$

Determining glucose levels and serum lipids

Fasting glucose levels was determined by the enzymatic method glucose oxidase-phenol 4-aminoantipirin (GOD-PAP). Determination of serum glucose levels used was by an analysis kit from Dia Sys consisting of a standard solution and reagents. A total of 10 μL serum and 1,000 μL GOD-PAP reagent were homogenised with a vortex. The solution was incubated at room temperature for 20 min, and absorbance measured by a spectrophotometer at 500 nm. The fasting glucose was calculated using Eq. 2:

$$Fasting\ Glucose : \left(\frac{mg}{dL}\right) = \frac{\Delta\, sample}{\Delta\, standard} \times standard \quad \text{(Eq. 2)}$$

Lipid profile measurements included triglycerides, total cholesterol, LDL, and HDL (Zou *et al.*, 2005). The determination of atherogenic index was performed using Eq. 3 (Muruganandan *et al.*, 2005):

$$\text{Atherogenic index} = \frac{\text{Total Cholesterol} - \text{HDL c}}{\text{HDL c}} \quad \text{(Eq. 3)}$$

Results dan discussion

Chemical composition

The chemical composition is presented in Table 1. Analogue rice water contents varied from 6.41 ± 0.20% in analogue rice I to 9.80 ± 0.16% in analogue rice III, as compared to commercial rice (10 ± 0.26%). The protein contents of analogue rice were between 7.72 ± 0.04 to 11.04 ± 0.03%, which were higher than commercial rice (6.30 - 7.10%). The lipid contents of analogue rice were between 0.55 ± 0.09 to 1.11 ± 0.01%, which were lower than commercial rice. The soluble dietary fibre contents of analogue rice ranged from 7.72 ± 0.04 to 9.49 ± 0.09%, and insoluble dietary fibre contents ranged from 8.82 ± 0.01 to 14.39 ± 0.10%, which were higher than commercial rice. The carbohydrate contents of analogue rice ranged from 68.91 ± 0.54 to 70.50 ± 0.09%, which were lower than commercial rice. The resistant starch contents of analogue rice ranged from 2.06 ± 0.01 to 3.43 ± 0.01%, which were higher than commercial rice. Analogue rice I, II, and III had high dietary fibre and resistant starch as compared to commercial rice (Table 1).

The protein content in analogue rice was higher than in commercial rice, which came from legumes *Vigna unguiculata* and *Vigna radiata*. Analogue rice I, II, and III had high dietary fibres which came from legumes and cereals used namely soybean flour, germinated sorghum flour, germinated *Vigna unguiculata* flour, germinated yellow corn flour, germinated *Vigna radiata* flour, and germinated white corn flour. Research showed that legumes and cereals are good sources of dietary fibres for the body (Saldívar and Hernández, 2020). Analogue rice had higher content of resistant starch than commercial rice, which came from modified tuber flour and extrusion process in analogue rice preparation. Research showed that the extrusion process can increase product's resistant starch levels (Hasjim and Jane, 2009). Several studies showed that the average daily intake of resistant starch globally is estimated at 3 - 10 g/day (Goldring, 2004; Murphy *et al.*, 2008). With resistant starch contents of three types of analogue rice in the range of 2.06 - 3.43%, the consumption of 150 g analogue rice could meet the needs of resistant starch to maintain bowel health. The recommended daily fibre intake is 25 - 32 g (Barber *et al*., 2020), and 150 g of analogue rice per day could meet the requirement.

Table 1. Chemical composition of commercial and three types of analogue rice.

Parameter	Commercial rice (C64)	Analogue rice I	Analogue rice II	Analogue rice III
Moisture	10 ± 0.26[d]	6.41 ± 0.2[a]	8.17 ± 0.23[b]	9.80 ± 0.16[c]
Ash	0.8 ± 0.02[a]	2.12 ± 0.15[b]	2.13 ± 0.08[b]	2.53 ± 0.33[c]
Protein	7.21 ± 0.01[a]	11.04 ± 0.03[d]	7.72 ± 0.04[b]	7.78 ± 0.03[c]
Lipid	1.7 ± 0.02[d]	1.11 ± 0.01[c]	0.55 ± 0.09[a]	0.84 ± 0.08[b]
Soluble dietary fibre	1.55 ± 0.08[a]	8.73 ± 0.09[c]	7.72 ± 0.04[b]	9.49 ± 0.09[d]
Non-soluble dietary fibre	1.02 ± 0.01[a]	8.82 ± 0.01[b]	14.39 ± 0.10[d]	10.15 ± 0.07[c]
Carbohydrate	77.10 ± 0.09[d]	70.50 ± 0.09[c]	69.71 ± 0.03[b]	68.91 ± 0.54[a]
Resistant starch	1.69 ± 0.01[a]	2.06 ± 0.01[b]	3.27 ± 0.03c[c]	3.43 ± 0.01[d]
Amylose	22.40 ± 0.08[d]	16.98 ± 0.06[c]	16.79 ± 0.06[b]	16.60 ± 0.04[a]
Amylopectin	59.57 ± 0.14[d]	52.49 ± 0.18[c]	50.22 ± 0.28[b]	47.71 ± 0.15[a]

Values are mean ± SD of six replicates (n = 6). Different lowercase superscripts in the same column indicate significant difference ($p < 0.05$).

Glycaemic index

Glycaemic index provides more accessible and helpful information in controlling fluctuations in blood glucose levels. The food glycaemic index is the level of food based on its effect on blood sugar levels. Foods that raise blood sugar quickly have high GI. Conversely, foods that raise blood sugar slowly have low GI.

The glycaemic index of analogue rice is presented in Table 2. Results showed that analogue rice III had the lowest glycaemic index (40.19). Significant differences were observed in commercial rice glycaemic index as compared to analogue rice I, II, and III. Differences in the glycaemic index of analogue and commercial rice could be influenced by chemical composition (Table 2). Analogue rice contained fibre (soluble and insoluble), resistant starch, and higher protein content than commercial rice. Also, analogue rice had slightly lower carbohydrate content than commercial rice. This is in line with several studies suggesting that food with high fibre, resistant starch, and protein contents, and low in carbohydrates, could affect its glycaemic index (Kumar *et al*., 2018). Commercial rice belonged to the category of medium glycaemic index. Analogue rice I, II, and III belonged to the category of low glycaemic index. Low glycaemic index means analogue rice raises blood sugar slowly. Low IG-based food undergoes a slow digestive process, so the rate of abdominal emptying is slow. This causes a slower suspension of food (chyme) reaching the small intestine, thus resulting in slower absorption of glucose in the small intestine. Consequently, fluctuations in blood glucose levels are relatively small.

The role of dietary fibre in helping lower GI values is thought to be related to its components' physiological function. Components of dietary fibre can be grouped into soluble and insoluble fibres, or fermented and unfermented. The primary function of insoluble dietary fibre is to prevent diseases related to the digestive tract. The function of soluble food fibre is mainly to slow down digestion in the intestine, provide longer satiety, and slow down the rate of increase in blood glucose; thus, insulin is needed to transfer glucose into the body's cells and convert it into less energy. The extrusion process in the preparation of analogue rice can increase the level of resistant starch. This is in line with several studies that stated that the extrusion process can increase resistant starch content, and lower the glycaemic index of food (Scazzina *et al*., 2013).

Table 2. Glycaemic index of commercial rice and three types of analogue rice.

Parameter	Glucose	Commercial rice	Analogue rice I	Analogue rice II	Analogue rice III
IG	100[e]	73.00 ± 4.78[d]	41.23 ± 3.39[b]	42.55 ± 3.21[c]	40.19 ± 3.34[a]

Values are mean ± SD of six replicates (n = 6). Different lowercase superscripts in the same row indicate significant difference ($p < 0.05$).

Antidiabetic analogue rice

Body gain, food intakes, and food efficiency ratio

Feeding on analogue rice significantly improved the weight and food efficiency ratio (FER) in diabetic mice. Conversely, commercial rice was not able to fix the FER of diabetic mice. Diabetic mice fed with analogue rice had lower food intake than standard feed diabetic mice and commercial rice feed (DCR), but higher than normal mice ($p < 0.05$). Diabetic mice with analogue rice feed had a lower FER than normal mice but were better than diabetic mice ($p < 0.05$). Based on Table 3, analogue rice consumption could improve the FER of mice suffering from diabetes mellitus.

During the treatment, mice's weight was observed to increase in the analogue rice diet group. This indicates that the analogue rice diet had a different metabolism to the standard feed diet to inhibit lipogenesis. The weight gain of mice showed that mice were able to adapt to the feed provided, and improve mice suffering from diabetes. Weight loss is possible due to the disruption of carbohydrate metabolism in the presence of diabetes induction by using alloxan injection. Weight loss is also possible due to proteolysis and lipolysis, and severe dehydration. People with diabetes experience a decrease in glucose uptake to maintain the balance of energy by using energy reserves sourced from proteins and fats. This causes weight loss. Weight gain and food efficiency ratio (FER) signified improvement in metabolism with analogue rice consumption. Based on Table 3, analogue rice had high dietary fibre and resistant starch, which could positively impact people with diabetes mellitus. Several studies have shown that resistant starch and dietary fibre could improve insulin sensitivity, glucose metabolism, lipids, and digestion (Jyoshna and Hymavathi, 2017).

Table 3. Effect of analogue rice and commercial rice on body weight gain, food intake, and food efficiency ratio (FER) in alloxan-induced diabetic rats fed with experimental diets for six weeks.

Parameter	Initial body weight (g)	Final body weight (g)	Bodyweight gain (g/period)	Food intakes (g/period)	FER
NSF	182 ± 5.61[a]	209 ± 5.80[d]	27 ± 0.82[f]	317 ± 8.00[a]	0.09 ± 0.00[e]
DSF	184 ± 7.29[c]	161 ± 7.92[a]	-23 ± 1.03[a]	376 ± 4.00[e]	-0.06 ± 0.00[a]
DCR (C64)	183 ± 10.44[b]	170 ± 10.07[b]	-13 ± 2.42[b]	388 ± 2.00[f]	-0.03 ± 0.01[b]
DAR I	187 ± 6.36[d]	201 ± 5.71[c]	14 ± 1.17[c]	358 ± 8.00[c]	0.04 ± 0.00[c]
DAR III	199 ± 3.93[f]	220 ± 3.79[f]	21 ± 1.94[d]	367 ± 11.00[d]	0.06 ± 0.01[d]
DAR IV	194 ± 3.60[e]	217 ± 3.89[e]	23 ± 1.97[e]	355 ± 9.00[b]	0.06 ± 0.01[d]

Values are mean ± SD of six replicates (n = 6). Different lowercase superscripts in the same column indicate significant difference ($p < 0.05$). NSF: normal standard feed; DSF: diabetic standard feed; DCR: diabetic commercial rice; DAR I: diabetic analogue rice I; DAR II: diabetic analogue rice II; and DAR III: diabetic analogue rice III.

Glucose profile

Figure 1 shows the effect of analogue rice consumption for 28 days on fasting glucose levels of mice. The decrease in glucose was observed in mice fed with analogue rice, regardless with analogue rice I, II, or III. Commercial rice consumption did not lower the blood glucose levels in diabetic mice. Glucose levels of mice fed with commercial rice diet for 28 days did not differ significantly from diabetic mice with standard feed ($p < 0.05$). Analogue rice I, II, and III lowered blood glucose in diabetic mice by 37, 40.31, and 41.32%, respectively.

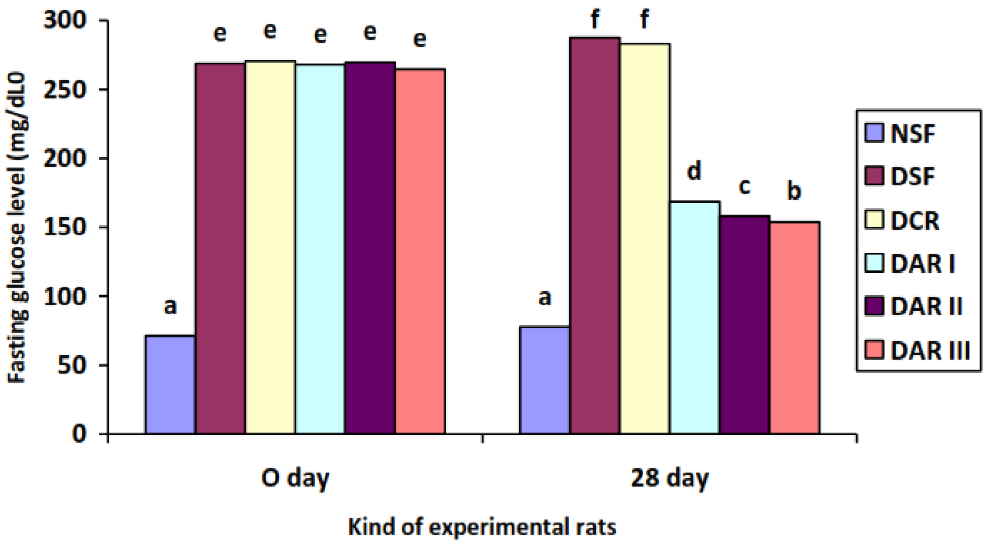

Figure 1. Fasting glucose levels after feeding with analogue rice and commercial rice in diabetic rats. Values are mean ± SD of six replicates (n = 6). Different lowercase superscripts in the same column indicate significant difference ($p < 0.05$). NSF: normal standard feed; DSF: diabetic standard feed; DCR: diabetic commercial rice; DAR I: diabetic analogue rice I; DAR II: diabetic analogue rice II; and DAR III: diabetic analogue rice III.

Figure 1 shows that the administration of analogue rice improved fasting glucose level in diabetic mice. The decrease in glucose profile in mice fed with analogue rice I, II, and III, might have been caused by insoluble dietary fibre and soluble dietary fibre contents. These came from cereals and legumes used as constituents of analogue rice. Dietary fibre has a physiologically positive impact on postprandial blood glucose reduction (Babio *et al*., 2010). Dietary fibre can absorb water and bind to glucose, thus reducing its availability. A sufficient dietary fibre also causes a complex of carbohydrate and fibre, so digestive carbohydrate is reduced. This can then prevent the increase in blood glucose, and keep it under control.

Foods containing high dietary fibre can improve insulin resistance, thus decreasing glucose profile (Weickert and Pfeiffer, 2018). The consumption of dietary fibre can lower serum glucose levels through three mechanisms: first, increasing the viscosity of fluids in the small intestine and inhibiting glucose diffusion; second, dietary fibre binds to glucose, lowers glucose availability in the small intestine, and inhibits the enzyme alpha-amylase activity (Ou *et al.*, 2001); and third, dietary fibre can reduce glucose absorption by slowing down digestion and food absorption. Dietary fibre can increase insulin sensitivity, thus resulting in decreased blood glucose levels (Ismaiel *et al.*, 2016).

Some dietary fibres can be fermented, thus resulting in short-chain fatty acids (SCFAs) that affect glucose metabolism and lower insulin resistance (Dong *et al.*, 2019). Insoluble dietary fibre can improve insulin sensitivity. Soluble or insoluble dietary fibre can regulate the hormones glucose-dependent insulin tropic polypeptide and glucagon-like peptide-1, which stimulate postprandial insulin production, delay gastric emptying, and enhance glucose tolerance (Kaczmarczyk *et al.*, 2012; Zhou *et al.*, 2015).

Resistant starch consumption can increase insulin sensitivity and increase GLP-1 production, thus mediating glucose-dependent insulin secretions, and increasing insulin levels (Shen *et al.*, 2011).

Resistant starch plays the role of prebiotic ace inside the colon. Resistant starch is fermented by probiotic bacteria, thus resulting in SCFA, which play a role in increasing the production and secretion of GLP-1 in the intestinal wall. The increase in GLP-1 will induce the proliferation of pancreatic beta cells, and increase insulin secretion (MacDonald *et al.*, 2002).

Serum lipid profile and atherogenic index

Mice fed with three types of analogue rice showed a significant decrease in serum lipide profile (Table 4). The consumption of analogue rice decreased the serum triglycerides, total cholesterol, LDL (low-density lipids), and increased HDL (high-density lipoprotein) levels. The lipid profiles (TC, TG, LDL, and HDL) and atherogenic index of mice fed with commercial rice were no different from diabetic mice fed with standard feed ($p < 0.05$). The diet of diabetic mice with commercial rice was unable to significantly lower triglycerides, total cholesterol, LDL, and atherogenic index in diabetic mice.

Table 4. Effects of analogue rice and commercial rice on serum lipid profile and atherogenic index in alloxan-induced diabetic rats fed with experimental diets for six weeks.

Parameter	TC	TG	HDL	LDL	AI
NSF	103.14 ± 3.25^{a}	81.2 ± 2.46^{a}	74.58 ± 1.60^{f}	35.37 ± 1.27^{a}	0.38 ± 0.06^{a}
DSF	186.76 ± 4.31^{e}	134.19 ± 2.83^{f}	20.34 ± 1.87^{b}	86.39 ± 2.05^{e}	8.18 ± 0.77^{e}
DCR (C64)	190.94 ± 2.98^{g}	129.93 ± 2.80^{e}	19.66 ± 1.45^{a}	85.71 ± 2.85^{e}	8.71 ± 0.66^{f}
DAR I	154.01 ± 3.10^{d}	109.4 ± 1.83^{d}	45.42 ± 2.60^{c}	61.22 ± 1.58^{d}	2.39 ± 0.13^{d}
DAR II	140.77 ± 2.99^{c}	97.44 ± 2.12^{c}	58.31 ± 2.70^{d}	50.34 ± 3.76^{c}	1.41 ± 0.11^{c}
DAR III	137.98 ± 3.37^{b}	95.73 ± 1.85^{b}	64.41 ± 1.86^{e}	46.26 ± 1.27^{b}	1.14 ± 0.07^{b}

Values are mean ± SD of six replicates ($n = 6$). Different lowercase superscripts in the same column indicate significant difference ($p < 0.05$). NSF: normal standard feed; DSF: diabetic standard feed; DCR: diabetic commercial rice; DAR I: diabetic analogue rice I; DAR II: diabetic analogue rice II; and DAR III: diabetic analogue rice III.

The decrease in total cholesterol, triglycerides, LDL, and increase in HDL is thought to be related to analogue rice's dietary fibre content. Soluble fibre physically binds to bile acids and cholesterol, which results in the absorption of cholesterol, and impacts the increased synthesis of bile acids, thus reducing liver cholesterol, and increasing regulation of LDL receptors (Liyanage *et al.*, 2018).

There are several mechanisms to decrease lipid profile, including increasing synthesis and excretion of bile acids, decreasing triglyceride absorption, inhibiting endogenous synthesis of cholesterol by SCFA produced in the colon, and modifying the lipoprotein metabolism through an increased number of LDL liver receptors. Decreased absorption of bile acids leads to the loss of steroids from the body through faecal excretion, thus resulting in increased cholesterol catabolism, increased secretion of bile acids, decreased secretion of lipoprotein cholesterol, and total reduction of cholesterol (Ruiz-Roso *et al.*, 2010). Dietary fibre affects the production of SCFA, of which butyric acid is an example. The presence of butyric acid plays a role in improving insulin sensitivity (Li *et al.*, 2020).

Some studies have shown that fibre consumption lowers lipid profile, thus impacting the decrease of an atherogenic index (Esmael *et al.*, 2015). Diabetic mice fed with analogue rice had a low atherogenic tendency. Diabetic mice fed with commercial rice had an atherogenic index not significantly different from the diabetic mice fed with standard feed. Diabetic mice fed with analogue rice feed III had the least atherogenic index than diabetic mice fed with analogue rice I and II. The result obtained in the present work was a decrease in the atherogenic index in mice fed with analogue rice, which might be related to dietary fibre and resistant starch. Several studies have shown that dietary fibre and resistant starch can increase HDL levels, and decrease the total cholesterol profile (Chung *et al.*, 2011).

The administration of analogue rice improves lipid metabolism so that it can act as anti-atherogenic. Increased levels of HDL-cholesterol plasma in mice fed with analogue rice increased the potential for anti-atherogenicity. HDL is part of an anti-atherogenic effect that inhibits the oxidation of LDL (*e.g.*, oxidation by transitional metal ions) and prevents lipid hydroperoxide formation. Atherogenic index of plasma (AIP) is a strong marker to predict atherosclerosis and coronary heart disease (Njajou *et al.*, 2009).

Conclusion

Analogue rice I, II, and III were high in dietary fibre, resistant starch, and protein, and low in fat and carbohydrate. Analogue rice I, II, and III were considered as low glycaemic index foods. The consumption of analogue rice could improve food efficiency ratio, and lower glucose profile in diabetic mice. Analogue rice I, II, and III could also lower lipide profiles (triglycerides, total cholesterol, LDL, and atherogenic index), and increase HDL. The present work demonstrated that analogue rice I, II, and III could be functional foods for people who have problems managing glucose and lipid profiles.

Acknowledgement

The authors would like to thank the Directorate General of Higher Education of the Republic of Indonesia and Yogyakarta State University, which facilitated and funded the present work (grant no.: 058/SP2H/LT/DPRM/2020).

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