Comparative Effects of Extracts from Black Rice or Pathum Rice Combined with Cereals on Blood Glucose Levels, Serum Insulin Levels and Blood Chemistry in Diabetic Rats

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Abstract

Rice is one of the major cereal crops in several Asian countries. It contains a variety of nutrients and provides valuable health benefits. The antidiabetic activity of rice combined with cereals has not been studied. Therefore, the present study was carried out to determine and compare the effects of extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE) on body weight, blood glucose levels, serum insulin levels and blood chemistry of Streptozotocin (STZ)-induced diabetic rats. The results revealed that BRCE exhibited the highest activity in reducing fasting blood glucose (FBG) levels and increasing serum insulin levels, and also recovered the lipid profiles, renal function and hepatic function resulting from STZ in the diabetic rats, followed by BRE, PTRCE and PTRE, respectively. Also, BRCE exhibited an activity with similar potential to Glibenclamide. The findings indicate that the rice extracts possess antidiabetic activity which exerts the activity by increasing serum insulin resulting in reduction of blood glucose. Rice combined with cereals provides better antidiabetic activity and could be a source of valuable antidiabetic materials.

Keywords: Black rice, Pathum rice, Cereals, Blood glucose, Blood Chemistry, Serum insulin, Diabetes

Introduction

Diabetes mellitus (DM) is a metabolic disease characterized by chronic hyperglycemia resulting from defective insulin secretion, insulin action, or both, leading to impaired carbohydrate, lipid, and protein metabolism. The chronic hyperglycemia of DM has been reported to be associated with severe damage and failure of the eyes, kidneys, nerves, heart and blood vessels [1]. Several chemicals and synthetic drugs are used for controlling blood sugar. Due to adverse side effects, medical plants that have less adverse side effects in comparison to synthetic drugs are used as alternative therapy for blood sugar control.

Rice (*Oryza sativa*) is one of the major cereal crops in several countries in Asia. It contains carbohydrate, minerals, vitamins, protein, fat, and fiber [2] and bioactive compounds such as vitamin E, γ-oryzanol and γ -aminobutyric acid (GABA) that are associated with diabetes. Its vitamin E extracts reduce blood glucose levels in diabetic rats [3]. Its γ-oryzanol inhibits α-glucosidase [4] and reduces blood glucose levels in diabetic rats [5]. GABA [6], tocopherols and tocotrienols (vitamin E) [7] increase insulin secretion. In addition, regular consumption of GABA increases insulin secretion and decreases blood glucose levels [8,9].

Black rice (BR) is one of the pigmented rice that provides many health benefits, including the prevention and treatment of diabetes [10]. Ethanol extract of black rice bran decreases blood sugar levels and increases insulin levels in diabetic rats [11,12]. Extracts of BR suppress postprandial blood sugar elevation, leading to preventing the progression of diabetic symptoms [13].

Pathum rice is the 2nd most popular Thai fragrant rice. It gives a soft texture and fragrant smell almost the same as those of the most popular Thai Jasmine rice [14].

Cereals are one of edible grains. They include rice, wheat, rye, oats, barley, millet, and maize. Edible grains from other plants such as black beans, hairy basil and Job's tears are pseudocereals. Cereals contain a variety of nutritive values and are rich in fiber that are digested slowly, release glucose slowly and are absorbed into bloodstream gradually, hence consumption a variety of food from cereals can help regulate insulin release and prevent spikes in postprandial blood glucose level. High intakes of whole grain foods protect against the development of type II diabetes mellitus (T2DM) and reduce incident diabetes both for the general population and for people with diabetes [15].

Due to researches in bioactivities of Pathum rice both in individual and in combination with cereals have not been established, therefore the present study was carried out *in vivo* to determine the effects of extract from Pathum rice on the body weight, blood glucose levels, serum insulin levels and blood chemistry in Streptozotocin-induced diabetic rats and compared to the extracts from Black rice, Black rice combined with cereals (black beans, hairy basil and Job's tears), and Pathum rice combined with cereals.

Materials and methods

Plant materials

Plants used in the present study, including Black rice (*Oryza sativa* L. indica), Pathum rice (*O. sativa* L. Japonica), black beans (*Vigna mungo* (L.) Hepper), hairy basil (*Ocimum×africanum* Lour.), and Job's tears (*Coix lachryma-jobi* L.) were collected from the local farms in Pathum Thani Province, in the central part of Thailand.

Preparation of extracts

All the plant samples were dried and powdered. The extracts, including the extracts of Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE) were prepared by maceration of 400 g of plant powder in 1 litter of 95 % ethanol solution at room temperature for 7 days. After maceration, the mixtures were filtered. The filtrates were evaporated

using a Rotary evaporator and then dried in a hot air oven [16]. For BRCE and PTRCE, the powder of Black rice or Pathum rice was added with the powder of cereals at a ratio of 300 g of rice powder: 100 g of black bean powder: 100 g of hairy basil powder: 100 g of Job's tear powder prior to maceration process. The obtained extracts were stored at 4 °C before being used.

Experimental animals

Male albino Sprague Dawley rats weighing 220 - 255 g were employed. The rats were obtained from the Laboratory Animal Centre, Rajamangala University of Technology Thanyaburi (RMUTT), Thailand. They were fed with commercial rat chow and water *ad libitum* in a Laboratory condition of 23 ± 2 °C, relative humidity (50 - 55 %) and exposed to 12 h day-night circle, maintained and performed following the guidelines of the Committee Care and Use of Laboratory Animal Resource, National Research Council Thailand and the Institutional Animal Care and Use Committee, RMUTT, Thailand (Ethical approval No. RMUTT.SCI.2021.R001).

Induction of diabetes

The overnight fasting rats were induced to be diabetes by a single peritoneal injection of 65 mg/kg body weight Streptozotocin (STZ) [17], freshly prepared in 20 mM citrate buffer, pH 4.5. After STZ injection, they were given 2 % sucrose in drinking water for 48 h to alleviate the initial hypoglycemic phase. Diabetes was confirmed by measuring fasting blood glucose (FBG) levels. The rats with FBG at or above 126 mg/dL were considered to be diabetes [17].

Experimental design

The rats were divided into 7 groups with 8 rats in each group as follows:

Group I was normally treated with distilled water and Group II - VII were diabetic rats treated with distilled water, Glibenclamide, BRE, PTRE, BRCE, and PTRCE, respectively.

Distilled water, 0.5 mg/kg Glibenclamide, and mg/kg of BRE, PTRE, BRCE, or PTRCE at a dose of 10 mL/kg was administered orally to the rats once daily for 4 weeks. The body weight, fasting blood glucose (FBG) levels, serum insulin levels and blood chemistry of the STZ-induced diabetic rats were measured.

Body weight and blood glucose levels

Body weight and FBG levels of the rats were determined at the initial stage and after the 4 week-administration. FBG levels were measured from a drop of fasting blood that was obtained from rat tail vein puncturing, using a glucometer and blood glucose test strips.

Serum insulin and blood chemistry

After a 4-week administration, the rats were fasted overnight and sacrificed by cervical decapitation. Blood samples were collected from the rat hearts by cardiac puncturing for the determination of serum insulin levels and blood chemistry. The serum insulin levels were measured using a radio-immune assay kit and detected using an automatic gamma counter. The blood chemistry, including total cholesterol (TC), triglycerides (TG), low-density lipoprotein (LDL); high-density lipoprotein (HDL), total protein (TP), blood urea nitrogen (BUN), creatinine (Crea), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase (ALP) were measured using enzyme colorimetric methods.

Statistical analysis

The data were analyzed statistically and expressed as mean ± standard error of the mean (S.E.M.). Statistical differences among treatments were calculated by one-way analysis of variance (ANOVA) and significant differences were assessed by post hoc tests (least significant difference, LSD). P-values of less than 0.05 ($p < 0.05$) are considered to indicate a significant difference.

Results and discussion

Streptozotocin (STZ) is one of the most common substances that used to induce diabetes in animals. It can cause diabetes close to type-II diabetes [18] by the destruction of pancreatic insulin-secreting β-cells of islets of Langerhans thus inducing hyperglycemia [19]. Induction of diabetes with STZ decreases nicotinamide adenine dinucleotide (NAD) in pancreas islet β-cells and causes histopathological effects in β- cells which probably intermediates induction of diabetes [20]. In the present study, STZ at a dose of 65 mg/kg was used to induce diabetes to determine the effects of the extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE) on the body weight, FBG levels, serum insulin levels and blood chemistry of the STZ-induced diabetic rats.

Body weight

At initial, the body weight of the rats was not different and ranged from 237.80 - 239.12 g. At the end of the experiments, the body weight of the diabetic controls (298.54 ± 9.26 g) was decreased significantly ($p < 0.05$) in comparison to normal controls (351.12 ± 8.94 g). The body weight of the diabetic rats treated with Glibenclamide, BRE, PTRE, BRCE, and PTRCE was 347.16 ± 9.12, 343.39 ± 7.14, 336.56 ± 8.21, 341.23 ± 8.63, and 339.87 ± 7.57 g, which was not different but increased significantly ($p < 0.05$) in comparing to that of the diabetic controls (**Table 1**).

The body weight was found to be decreased in the STZ-induced diabetic controls due to induction of diabetes with STZ is associated with the characteristic loss of body weight, which results from increasing muscle wasting and loss of tissue proteins because protein and fat are broken down to provide energy instead of blood glucose [21]. Administration of BRE, PTRE, BRCE, and PTRCE 300 mg/kg once a day for 4 weeks caused an increase in the body weight of the diabetic-treated rats. The action of the extracts to increase the body weight of diabetic rats is probably due to their hypoglycemic property that increases the utilization of the blood glucose and in turn, prevents the breakdown of fat and protein to provide energy.

Blood glucose levels

At initial, the FBG level of the diabetic controls was 187.49 ± 3.87 mg/dL, which was significant ($p < 0.05$) higher than that of the normal controls (84.56 ± 2.75 mg/dL). After 4 weeks of administration, the FBG level of the diabetic controls (226.16 ± 8.70 mg/dL) was still significant ($p < 0.05$) higher than that of the normal controls (87.07 ± 9.62 mg/dL). However, the FBG levels in the diabetic rats treated with BRE, PTRE, BRCE, PTRCE, and Glibenclamide were 169.51 ± 2.19, 180.37 ± 3.56, 165.42 ± 3.14, 169.81 ± 2.93 and 162.23 ± 3.72 mg/dL, respectively, and were decreased significantly ($p < 0.05$) in comparing to those in the diabetic controls (**Table 1**).

According to FBG levels in the diabetic controls both at the initial stage and after 4- administration was higher than those in the normal controls, but they were found to be decreased in the diabetic rats treated with BRE, PTRE, BRCE, and PTRCE. This indicates the hypoglycemic effect of the extracts. This result is in line with the ethanol extracts of black rice bran (EEBRE) that can decrease blood sugar levels in diabetic rats [12] and γ-oryzanol, a bioactive rice compound that can reduce blood glucose levels in diabetic rats [5].

Table 1 Body weight and fasting blood glucose levels, at initial and after 4-week treatment, of the normal controls, diabetic controls and diabetics treated with glibenclamide (Glib) and the extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE).

Group	Body weight (g)		Fasting blood glucose (mg/dL)	
	Initial	**Final**	**Initial**	**Final**
Normal controls (I)	238.93 ± 7.84^{aA}	351.12 ± 8.94^{cB}	$84.56 + 2.75^{aA}$	87.07 ± 3.62^{aA}
Diabetic controls	239.12 ± 5.67^{aA}	298.54 ± 9.26^{aB}	$187.49 + 3.87^{bA}$	226.16 ± 2.77^{cB}
Diabetics + Glib 0.5 mg/kg	237.80 ± 4.93^{aA}	347.16 ± 9.12^{bcB}	$179.24 + 3.81^{bB}$	$162.23 + 3.72^{bA}$
Diabetics + BRE 300 mg/kg	238.19 ± 6.77^{aA}	341.39 ± 7.14^{bcB}	$185.92 + 2.97^{bB}$	169.51 ± 2.19^{bA}
Diabetics + PTRE 300 mg/kg	$239.11 + 4.94^{aA}$	337.56 ± 8.21^{bcB}	$186.87 + 2.82^{bB}$	180.37 ± 3.56^{bcB}
Diabetics + BRCE 300 mg/kg	238.87 ± 5.69^{aA}	343.23 ± 8.63^{bcB}	$187.23 + 2.65^{bB}$	$165.42 + 3.14^{bA}$
Diabetics + PTRCE 300 mg/kg	237.96 ± 6.57^{aA}	339.87 ± 7.57^{bcB}	$185.99 + 1.69^{bB}$	169.81 ± 2.93^{bB}

Values are expressed as means ± S.E.M, n = 8 rats in each group. There were significant differences between the means followed by different alphabetical superscript letters (a, b, c in the same column and A, B in the same row) at $p < 0.05$.

Serum insulin levels

After 4 week-administration, serum insulin level of the diabetic controls (12.14 ± 1.39 µIU/mL) was significant ($p < 0.05$) lower than that of the normal controls (23.98 ± 1.28 µIU/mL). In contrast, it was increased slightly in the diabetic rats treated when compared to that in the diabetic controls. Serum insulin levels in the diabetic rats treated with BRE, PTRE, BRCE, PTRCE, and Glibenclamide were 15.84 ± 1.83, 13.14 ± 1.61, 16.46 ± 1.37, 14.15 ± 1.29 and 17.27 ± 1.56 µIU/mL, respectively. Serum insulin levels in the diabetic rats treated with PTRE and PTRCE were increased slightly but were increased significantly ($p < 0.05$) in the diabetic rats treated with BRCE compared to that in the diabetic controls (12.14 ± 1.39). Interestingly, BRCE increased serum insulin levels with a similar potent to Glibenclamide (**Table 2**).

Serum insulin level was found to be lower in the STZ-induced diabetic rats. This is probably a result of STZ that destroys pancreatic insulin-secreting β-cells of islets of Langerhans. However, serum insulin levels were increased in the diabetic rats treated with BRE, PTRE, BRCE, and PTRCE), indicating the extracts can recover the destruction of pancreatic insulin-secreting β-cells, which leads to an increase in insulin secretion from β-cells. This result goes hand in hand with the ethanol extract of black rice bran [12].

Table 2 Serum insulin levels of normal controls, diabetic controls, and diabetic rats treated with glibenclamide (Glib) and the extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE), after 4 weeks of administration.

Group	Serum insulin levels (µIU/mL)
Normal controls	23.98 ± 1.28^{c}
Diabetic controls	12.14 ± 1.39^{a}
Diabetics + Glib. 0.5 mg/kg	17.27 ± 1.56^{b}
Diabetics + BRE 300 mg/kg	15.84 ± 1.83^{ab}
Diabetics + PTRE 300 mg/kg	13.14 ± 1.61^{a}
Diabetics + BRCE 300 mg/kg	16.46 ± 1.37^{b}
Diabetics + PTRCE 300 mg/kg	14.15 ± 1.29^{ab}

Values are expressed as means ± S.E.M, n = 8 rats in each group. There are significant differences between means that have different alphabetical superscript letters in the same column at $p < 0.05$.

Blood chemistry

Lipid profiles; The lipid profiles including total cholesterol (TC), triglyceride (TG) and low - density lipoprotein (LDL) were increased significantly ($p < 0.05$), whilst the high - density lipoprotein (HDL) was decreased significantly ($p < 0.05$) in the diabetic controls in comparison to those in the normal controls. In contrast, TC, TG and LDL were decreased slightly, meanwhile, HDL was increased slightly in the diabetics treated when compared to those in the diabetic controls. However, the lipid profiles of the diabetic rats treated with the extracts were not significantly different and were close to those in the diabetic rats treated with Glibenclamide (**Table 3**).

According to diabetes mellitus is mainly associated with and increased cholesterol or LDL-C, TC and TG, and decreased HDL-C [22]. Hyperlipidemia was reported as common in diabetic patients and it is characterized by increased triglyceride and reduced HDL levels [23]. In the present study, the levels of TC, TG and LDL were increased, but HDL was decreased in the STZ diabetic controls. In contrast, oral administration of the extracts 300 mg/kg b.w., once a day for 4 weeks decreased TC, TG and LDL levels, but increased HDL levels in the diabetic-treated rats. The extracts probably reduce hyperlipidemia in diabetic rats by inhibiting the absorption of cholesterol and enhancing the activity of LDL receptors [24].

Table 3 Lipid profiles of normal controls, diabetic controls, and diabetic rats treated with glibenclamide (Glib) and extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE).

Groups	Lipid profiles (mg/dl)			
	TC	TG	LDL	HDL
Normal controls	62.08 ± 0.52[a]	117.37 ± 0.27[a]	15.17 ± 0.16[a]	60.86 ± 0.31[b]
Diabetic controls	78.62 ± 0.39[b]	128.33 ± 0.48[b]	24.53 ± 1.02[b]	46.52 ± 0.37[a]
Diabetics+Glib. 0.5 mg/kg	69.65 ± 0.20[ab]	121.04 ± 0.24[a]	19.82 ± 0.07[ab]	53.64 ± 0.41[ab]
Diabetics+BRE 300 mg/kg	75.81 ± 0.09[b]	127.04 ± 0.14[b]	22.82 ± 0.07[b]	51.44 ± 0.72[a]
Diabetics+PTRE 300 mg/kg	77.34 + 0.08[b]	126.94 ± 0.34[b]	23.91 + 0.42[b]	50.86 ± 0.31[a]
Diabetics+BRCE 300 mg/kg	74.86 ± 0.28[b]	124.38 ± 0.26[b]	21.77 + 0.65[b]	52.17 ± 0.51[a]
Diabetics+PTRCE 300 mg/kg	76.47 ± 0.15[b]	126.12 ± 0.31[b]	22.99 + 0.34[b]	51.96 ± 0.65[a]

Values are expressed as means ±S.E.M, n = 8 rats in each group; There is no significant difference between means have the same alphabetical superscripts letter in the same row at $p < 0.05$. TG = Triglyceride; LDL = Low- density lipoprotein; HDL = High-density lipoprotein.

Blood chemistry for renal function

Total protein (TP), blood urea nitrogen (BUN) and creatinine (Crea) in the diabetic controls (6.94 ± 0.31 g/dL, 16.87 ± 1.47 and 0.71 ± 0.15 mg/dL, respectively) were increased significantly ($p < 0.05$) in comparing to those in the normal controls (5.06 ± 0.12 g/dL, 14.04 ± 0.33 and 0.58 ± 0.18 mg/dL, respectively). On the other hand, TP, BUN and Crea in the diabetic rats treated with BRE, PTRE, BRCE, and PTRCE were not different, but were decreased slightly when compared to those in the diabetic controls (**Table 4**).

TP, BUN and Crea in the diabetic controls were increased. However, administration of BRE, PTRE, BRCE, and PTRCE slightly reduced TP, BUN, and Crea in the diabetic rats. Indicating the extracts ameliorate renal dysfunction resulting from STZ-induced diabetes.

Table 4 Blood chemistry (parameter for renal function) of normal controls, diabetic controls, and diabetic rats treated with glibenclamide (Glib) and extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE).

Groups	Blood chemistry, parameter for renal function		
	TP (g/dL)	BUN (mg/dL)	Crea (mg/dL)
Normal controls	5.06 ± 0.12^a	14.04 ± 0.33^a	0.58 ± 0.18^a
Diabetic controls	6.94 ± 0.31^b	16.87 ± 1.47^b	0.71 ± 0.15^b
Diabetics + Glib,0.5 mg/kg	5.15 ± 0.43^a	14.92 ± 0.18^a	0.61 ± 0.34^a
Diabetics + BRE,300 mg/kg	5.91 ± 0.63^{ab}	15.63 ± 0.11^{ab}	0.68 ± 0.61^b
Diabetics + PTRE,300 mg/kg	6.17 ± 0.63^b	16.07 ± 0.12^b	0.69 ± 0.53^b
Diabetics + BRCE 300 mg/kg	5.08 ± 0.63^a	15.37 ± 0.09^{ab}	0.63 ± 0.27^{ab}
Diabetics + PTRCE 300 g/kg	6.04 ± 0.63^b	15.95 ± 0.36^{ab}	0.64 ± 0.61^{ab}

Values are expressed as means $\pm$S.E.M, n = 8 rats in each group; There is no significant difference between means have the same alphabetical superscripts letter in the same row at $p < 0.05$. TP = Total protein; BUN = Blood urea nitrogen; Crea = Creatinine.

Blood chemistry for hepatic function

Aspartate aminotransferase (AST), alanine aminotransferase (ALT) and alkaline phosphatase (ALP) in the diabetic controls were 148.53 ± 0.18, 52.81 ± 0.63 and 122.06 ± 3.17 UL, respectively. They were increased significantly ($p < 0.05$) when compared to those in the normal controls (126.16 ± 0.32, 43.07 ± 0.42 and 98.19 ± 0.17 UL, respectively). In contrast, they were increased in the diabetic rats treated with Glibenclamide (130.87 ± 0.23, 46.09 ± 0.37 and 101.87 ± 0.19 UL), BRE (139.16 ± 0.16, 49.32 ± 0.08, 108.01 ± 0.13 UL), PTRE (141.16 ± 0.75, 50.09 ± 0.61, 107.88 ± 0.39 UL), BRCE (138.16 ± 0.14, 47.09 ± 0.25 and 104.38 ± 0.43 UL), and PTRCE (139.02 ± 0.63, 49.09 ± 6.05 and 106.08 ± 0.79 UL), and closed to those in the normal controls. (126.16 ± 0.32, 43.07 ± 0.42 and 98.19 ± 0.17 UL), as shown in **Table 5**.

An increase in AST, ALT and ALP was observed in STZ diabetic rats. It represents that liver damage occurred in diabetic rats. Conversely, oral administration of the extracts reduced the elevated level of AST, ALT and ALP, indicating the extracts improve the pathological hepatic function resulting from STZ.

Table 5 Blood chemistry (parameter for hepatic function) of normal controls, diabetic controls, and diabetic rats treated with glibenclamide (Glib) and extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE).

Groups	Blood chemistry, parameter for hepatic function		
	AST (UL)	ALT(UL)	ALP(UL)
Normal controls	126.16 ± 0.32^a	43.07 ± 0.42^a	98.19 ± 0.17^a
Diabetic controls	148.53 ± 0.18^b	52.81 ± 0.63^b	122.06 ± 3.17^b
Diabetics+Glib,0.5 mg/kg	130.87 ± 0.23^a	46.09 ± 0.37^{ab}	101.87 ± 0.19^a
Diabetics+BRE,300 mg/kg	139.16 ± 0.16^{ab}	49.32 ± 0.08^b	108.01 ± 0.13^{ab}
Diabetics+PTRE,300 mg/kg	141.16 ± 0.75^b	50.09 ± 0.61^b	107.88 ± 0.39^{ab}
Diabetics+BRCE 300 mg/kg	138.16 ± 0.14^{ab}	47.09 ± 0.25^{ab}	104.38 ± 0.43^{ab}
Diabetics+PTRCE 300 mg/kg	139.02 ± 0.63^{ab}	49.09 ± 6.05^b	106.08 ± 0.79^{ab}

Values are expressed as means $\pm$ S.E.M, n = 8 rats in each group; There is no significant difference between means have the same alphabetical superscripts letter in the same row at $p < 0.05$. AST = Aspartate aminotransferase; ALT = Alanine aminotransferase; ALP = Alkaline phosphatase.

Overall, the extracts exhibited antidiabetic activity which is almost the same as Glibenclamide, an antidiabetic drug. It is possible that the mechanism of action on antidiabetic activity of the extracts may be due to the extracts improving the STZ-induced damage pancreatic β-cells of islets of Langerhans and stimulating serum insulin secretion from the remnant pancreatic β-cells or due to their ability to restore the function of pancreatic tissues by causing an increase insulin output [25]. BRE and BRCE exhibit antidiabetic and hypolipidemic activities and improve renal and hepatic functions with higher potential than PTRE and PTRCE. This is due to anthocyanins in BR that exhibit antidiabetic properties or lower blood glucose by increasing the secretion of insulin and reducing the digestion of sugars in the small intestine [26]. In addition, BR can increase fatty acid metabolism, reduce the risk of elevated blood sugar levels and high cholesterol and lower the risk of developing liver disease [27].

Conclusions

In the present study, the extracts from rice and rice combined with cereals including the extracts from Black rice (BRE), Pathum rice (PTRE), Black rice combined with cereals (BRCE), and Pathum rice combined with cereals (PTRCE) exhibit antidiabetic activity by reducing blood glucose levels, increasing insulin levels and improving the impairment resulting from STZ. In addition, the extract from black rice (BRE) possesses higher activity than the extract from Pathum rice (PTRE). Furthermore, combination with cereals (black beans, hairy basil seeds, and Job's tears) increases the antidiabetic activity of rice as BRCE and PTCE display a reduction of FBG levels, an increase in insulin levels and an improvement of pathological impairment resulting from STZ-induced diabetes greater than those from BRE and PTRE.

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