Beneficial Effects of Thai Purple Sticky Rice Supplement in Streptozotocin Induced Diabetic Rats

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ABSTRACT

This study was conducted to evaluate antihyperglycemic and hypolipidemic effects of anthocyanin-rich bran from Thai purple sticky rice in streptozotocin (STZ) induced diabetic rats. Male Wistar rats were divided into five groups: normal rats control (NC), normal rats which received purple rice bran (NR), diabetic rats control (DMC), diabetic rats which received purple rice bran (DMR), and diabetic rats which treated with insulin (DMI). NR and DMR groups received normal diet with purple rice bran at dose 50 g/kg diet. Insulin (20 Units/kg BW) was injected (intraperitoneally) to DMI rats throughout the experimental period. After STZ-induced diabetic condition had been established, 8 weeks treatment with purple rice bran or insulin injection successfully decreased plasma glucose, triglyceride (TG), and free fatty acid (FFA) levels but did not change plasma cholesterol level when compared with DMC. Interestingly, no change in plasma glucose level was noted in NR when compared with NC. At the end of the study, an oral glucose tolerance test (OGTT) was performed to determine the insulin sensitivity. The results demonstrated that purple rice bran and insulin treatment significantly decreased $TAUC_g$, $BAUC_g$, and $IAUC_g$ from OGTT compared to DMC. These findings indicated that purple rice bran profoundly improved the whole body insulin sensitivity. Based on these results, we found that the anthocyanin-rich bran from purple sticky rice has beneficial effects in STZ-induced diabetic rats. This purple rice bran may be a good candidate for promising neutraceutical treatment for the diabetic management. However, the mechanisms of antihyperglycemic and hypolipidemic actions of the purple rice bran need to be further investigated.

Key words: Anthocyanin, Purple rice bran, Diabetes mellitus, Antihyperglycemia, Hypolipidemia

INTRODUCTION

Type 1 diabetes mellitus (T1DM) is a chronic metabolic disorder characterized by high blood glucose levels due to an absolute or relative deficiency of circulating insulin levels (Kaleem et al., 2008). The prevalence of diabetes mellitus has been rapidly increasing in worldwide. Accordingly, effective blood glucose control is the key for preventing or reversing diabetic complications and improving the quality of life in patients with diabetes. Sustained reduction in hyperglycemia decrease the risk of developing microvascular complication and most likely reduce the risk of macrovascular complications, which account for major morbidity and mortality associated with T1DM (Daneman, 2006). However, management of diabetes mellitus without any side effects is still a challenge to the medical system. There is an increasing demand by patients to use natural products with antidiabetic activity, because insulin and oral hypoglycemia drugs have undesirable side effects (Rao and Rao, 2001). Up to date, several plants are known to have antidiabetic properties, and a large number of compounds from plant extracts have been reported to have beneficial effects for the relief of diabetes (Anhauser, 2003; Atta Ur and Zaman, 1989)

Kum Doi Saket is the one of local, purple glutinous rice cultivars in Thailand, that has been demonstrated to have the antioxidant and anticancer properties (Punyatong et al., 2010). Purple rice, purple sticky rice or purple-black rice (*Oryza sativa* L.) contains a much higher content of

anthocyanins in the aleurone layer than white rice and has been used traditional food and widely consumed as a health-promoting food in China and other Eastern Asia countries for thousands of years (Wang et al., 2007). Anthocyanins are the largest group of water-soluble pigments in the plant kingdom. They are widely available in the human diet in cereals, beans, fruits, vegetables, and red wine, suggesting that we ingest large amounts of anthocyanins daily from plant-based diets (Wu et al., 2006). *In vivo* and *in vitro* studies indicate that anthocyanins have several salutary effects, such as antioxidant (Hu et al., 2003; Ichikawa et al., 2001; Kim et al., 2007), anti-inflammatory (Hu et al., 2003), anti-arterosclerotic (Xia et al., 2006), anticancer (Chen et al., 2006), antihyper-lipidemia (Guo et al., 2007; Kwon et al., 2007), and antihyperglycemia activities (Sasaki et al., 2007). Recently, Takikawa et al. (2010) have demonstrated that purified dietary C3G (a typical anthocyanin) reduces the blood glucose level and improves insulin sensitivity in type 2 diabetic (T2DM) mice. Similarly, Guo et al. (2007) found that dietary anthocyanin-rich extract from black rice is a capable of preventing and ameliorating the hyperlipidemia and insulin resistance induced by a high-fructose diet. However, whether the Thai purple sticky rice bran, Kum Doi Saket, exhibits antidiabetic property in T1DM rats remains uncertain. In the present study, STZ-induced diabetic rats were used to investigate the characteristic of antihyperglycemic and hypolipidemic effects of Thai purple rice bran.

MATERIALS AND METHODS

Preparation of Thai purple rice bran diet

Thai purple rice bran genotype Kum Doi Saket (*Oryza sativa* L. cv. Kum Doi Saket) was kindly provided by Dr. Dumnern Karladee, Faculty of Agriculture, Chiang Mai University, Thailand. The purple rice bran was mixed with control diet at a dose of 50 g/kg diet. The compositions of the control diet (C.P. Mice Feed Food no. 082; energy content 4.02 kcal/g diet) and purple rice bran supplement diet (energy content 2.31 kcal/g diet) are given in Table 1.

Table 1. Compostition of normal diet and purple rice bran diet.

Ingredient	Control diet	Purple rice bran diet
CHO; Cornstarch, g	52.27	30.05
Fat; Soybean, g	8.83	5.08
Protein; Casein, g	28.38	16.32
Vitamin and minerals, g	6.90	3.97
Fiber, g	3.62	2.08
Purple rice bran, g	-	5.00
Water, ml	-	37.50
Total	100.00	100.00

Animals

Male adult Wistar rats, weighing 180-200 g, were obtained from the National Laboratory Animal Center, Mahidol University. All animals were housed under controlled temperature at 25 ± 2°C with a 12-hour light: dark cycle. The experimental protocol was adhered the "Guide for the Care and Use of animals in compliance with the National Institutes of Health guideline for the care and treatment of animals" and followed Faculty of Medicine, Chiang Mai University, Standard Operating Procedures for animal care and research.

Induction of experimental diabetes

Diabetes was induced by a single intraperitoneal (i.p.) injection of streptozotocin (STZ) at a dose of 65 mg/kg BW dissolved in 0.01 M citrate buffer (pH 4.4). Each animal with a fasting

blood glucose concentration above 250 mg/dl was considered diabetic.

Experimental design

In this study, a total of 50 rats (20 normal; 30 diabetic rats) were used and divided into five groups of 10 rats in each. Group I: normal rats control (NC); Group II: normal rats received purple rice bran (NR) at a dose of 50 g/kg diet; Group III: diabetic rats control (DMC); Group IV: diabetic rats received purple rice bran (50 g/kg diet) (DMR); Group V: diabetic rats treated with insulin i.p. injection (20 Units/kg BW/day) (DMI). Animals were given food and water *ad libitum.* Food intake and body weight were recorded every day. An oral glucose tolerance test (OGTT) was assessed at week 8th of supplemental period. Blood samples were collected and then plasma was separated immediately. Visceral fat including retroperitoneal, epididymal, and peripheral fat pad were excised for weighing. Skeletal muscles were separated and frozen immediately in liquid nitrogen. Blood and tissue samples were stored at -70°C for subsequent biochemical analysis.

Study of oral glucose tolerance test (OGTT)

After an overnight fasting, the animals were orally gavaged with a dose 2 g/kg BW of glucose solution. Blood glucose levels were measured at 0 minute as baseline value and then at 15, 30, 60, and 120 minutes after glucose administration. The increment of plasma glucose following the glucose load was expressed in term of the area under the curve (AUC) using the trapezoidal rule (Dokken and Henriksen, 2006).

Determination of homeostasis model assessment index (HOMA)

Insulin resistance was assessed by the homeostasis model assessment of insulin resistance (HOMA). HOMA is a mathematical model describing the degree of insulin resistance starting from fasting plasma insulin and glucose concentration (Dokken and Henriksen, 2006). HOMA index is calculated as follows:

HOMA = [fasting plasma insulin level (ng/dl) x fasting plasma glucose level (mg/dl)]/405.1

Measurements of plasma glucose, triglyceride (TG), free fatty acid (FFA), cholesterol, and insulin

Plasma glucose, TG, and cholesterol levels were analyzed using a commercial enzymatic colorimetric kit (Biotech, Bangkok, Thailand). Plasma FFA level was analyzed using a commercial enzymatic kit (NEFA C, Wako pure chemical, Japan). The plasma insulin concentrations were determined using a sandwich ELIZA technique (Rat/Mouse Insulin ELIZA kit, LINCO Research, USA).

Determination of glucose transporter 4 (GLUT4)

Soleus muscle was homogenized in 6 volume of ice-cold lysis buffer. Homogenates were incubated on ice for 20 minutes and then centrifuged at 1300×g for 20 min at 4°C. Total protein concentration was determined with the Bradford protein assay reagent (Bio-Rad), using BSA as a standard. Aliquots (35 µg) of muscle homogenate was subjected to SDS-PAGE (10% gel) and electrophoretically transferred to nitrocellulose membrane. Blotted protein was then probed with anti-GLUT4 (Chemicon International, USA) at 4°C overnight. Membrane was then probed with HRD-conjugated secondary anti-rabbit antibodies (Chemicon International, USA). Probed proteins were visualized on Kodak Hyperfilm (Kodak, Rochester, NY) using an enhanced ECL kit (GE Healthcare, Piscataway, NJ). The band intensities were quantified with a densitometer using Scion Image software. The concentrations of GLUT4 protein were express relative to total GLUT4 protein in control group.

Statistical analysis

Data are presented as means ± SE. Statistical analyses were calculated using analysis of variance (ANOVA). The *post hoc* Fisher's test was used to identify specific mean differences. $P<0.05$ was considered to be statistically significant.

RESULTS

There was no significant different in body weight and plasma glucose level before induction of diabetic condition (data not show). Table 2 show the general characteristics of age-matched control and STZ-induced diabetic rats before the supplemental period. The results showed that diabetic rats significantly ($P<0.05$) less weight gained compared to healthy age-matched control animals even though the analysis of dietary records demonstrated that the average energy intake in diabetic rats was significantly higher than in age-matched control rats. After STZ injection, diabetic rats had significantly elevated fasting plasma glucose level and trend to increased plasma TG level in comparison with age-matched control despite of no significant changed of plasma insulin level. After 14 days, STZ injection did not alter the plasma cholesterol concentration and HOMA index in the experimental study. Following 8 weeks of experimental period, the purple rice bran supplement had no effects on body weight, visceral fat mass, the fasting plasma glucose, insulin, cholesterol, FFA levels, and HOMA index when compared between NC and NR groups (Table 3). Surprisingly, the trend of decreased of plasma TG concentration was exhibited in NR group when compared with NC group. As shown in Table 3, the body weight was significantly decreased in the DMC group compared with the NC group. In contrast, energy intake during the experimental period was significantly higher in the DMC group than in the NC group. Furthermore, the visceral fat mass was not significantly different in between normal control and diabetic rats. The persistent elevation of plasma glucose, FFA levels, and HOMA index were noted in DMC group when express relative to NC group. The decreasing plasma insulin concentration in DMC group did not exhibit when compared with NC group. The period of 8 weeks supplement with purple rice bran in diabetic rats successfully decreased the plasma glucose (30%), TG (36%), and FFA (32%) levels in diabetic rats but did not alter the plasma cholesterol level when compared with DMC. In addition, the purple rice bran supplement elicited no significant effect on plasma insulin level in diabetic rats. Glucose-lowering effect was significantly greater in DMI group (57%) than in DMR group (30%). HOMA index was significantly decreased in DMR when compared with DMC group (38%) indicating the improvement of insulin sensitivity. The significantly decrease of HOMA index was not found in DMI compared with DMC group. Nevertheless, the significant increase of plasma insulin concentration was precisely noted in DMI compared with DMC group.

Table 2. General characteristic of age-matched control and STZ-induced diabetic rats.

	Age-matched control	STZ-induced diabetic
Initial weight, g	310.50 ± 8.71	264.00 ± 7.29*
Energy intake, kcal/day	116.25 ± 6.56	121.74 ± 1.81*
Fasting plasma parameters		
Glucose, mg/dl	136.61 ± 3.03	334.08 ± 21.88*
Insulin, ng/ml	2.25 ± 0.39	1.40 ± 0.42
Triglyceride, mg/dl	68.44 ± 1.99	79.08 ± 7.68
Cholesterol, mg/dl	111.63 ± 3.66	109.49 ± 2.48
HOMA index	1.02 ± 0.19	1.45 ± 0.56

Values are mean ± SE.

*$P<0.05$ when compared with NC

Table 3. Effects of Thai purple rice bran supplement on body weight, visceral fat mass, energy intake and fasting plasma paramenters.

	NC	NR	DMC	DMR	DMI
Body weight, g	432.00 ± 1.22	442.00 ±8.74	328.57 ± 25.11*	378.33 ±17.77#	433.57± 14.62#,+
Visceral fat mass, g	28.11 ± 1.42	36.48 ± 5.04	23.17 ± 7.93	28.12 ± 4.01	25.79 ± 0.15
Energy intake, kcal/day	87.07 ± 1.34	105.40 ± 1.63*	106.77 ± 3.14*	126.81 ± 4.82#	92.28 ± 9.19+
Fasting Plasma Parameters					
Glucose, mg/dl	154.45 ± 6.18	151.50 ± 5.85	371.91 ± 23.31*	260.84 ± 29.07#	161.75 ± 33.89#,+
Insulin, ng/ml	2.73 ± 0.51	3.09 ± 0.92	2.20 ± 0.10	2.98 ± 0.16	9.52 ± 0.48#,+
FFA, mmol/l	0.66 ± 0.03	0.63 ± 0.05	0.99 ± 0.06*	0.70 ± 0.06#	0.77 ± 0.02#
TG, mg/dl	62.37± 9.17	40.11 ± 4.56*	86.97 ± 5.64*	56.00 ± 4.42#	49.10 ± 3.24#
Cholesterol, mg/dl	85.92 ± 5.28	85.69 ± 4.43	74.55 ± 3.38	73.15 ± 1.75	66.46 ± 5.30
HOMA index	1.12 ± 0.22	1.11 ± 0.32	2.21 ± 0.04*	1.387 ± 0.14#	1.69 ± 0.22

Values are mean ± SE FFA: free fatty acid, TG: triglyceride, HOMA index: homeostasis model assessment of insulin resistane, NC: normal rats control, NR: normal rats received purple rice bran, DMC: diabetic rats control, DMR: diabetic rats received purple rice bran, DMI: diabetic rats treated with insulin.
*$P<0.05$ when compared with NC
#$P<0.05$ when compared with DMC
+$P<0.05$ when compared with DMR

At the end of experimental period, an OGTT was performed to determine the whole body insulin sensitivity. Significant difference of the plasma glucose level between NC and NR groups was not exhibited at all-time points throughout the experimental period (Figure 1). During the two hours following glucose loading, the plasma glucose levels in the DMC group were significantly higher than those in the NC group. All-time points during the test, purple rice bran supplement and insulin treatment in diabetic rats significantly decreased plasma glucose level compared with DMC group. These results were support by the area under the curve for glucose concentrations (AUC_g) obtained from the OGTT.

As shown in Figure 2, the total area under the curve for glucose ($TAUC_g$), the incremental area under the curve for glucose ($IAUC_g$), and the basal area under the curve for glucose ($BAUC_g$) were not differ between NC and NR groups. Likewise, the $TAUC_g$, $IAUC_g$ and $BAUC_g$ were significantly increased in the DMC group when compared with NC group. The results demonstrated that the $TAUC_g$, $IAUC_g$, and $BAUC_g$ in the purple rice bran and insulin treatment groups were significantly lower than in the DMC group. These findings indicated that purple rice bran supplement profoundly improved the whole body insulin sensitivity.

Results in Figure 3 illustrated the amount of total GLUT4 concentration in soleus muscle using western blot analysis. The significant difference of the GLUT4 concentration between NC and NR groups was not exhibited. We found that the total GLUT4 level in DMC group was 17% lower than those in the NC group ($P<0.05$). Interestingly, treatment of diabetic rats with purple rice bran or insulin injection significantly reversed the effects of STZ-induced diabetic rats on the total GLUT4 protein expression (12.47% and 16.19%, respectively, $P<0.05$).
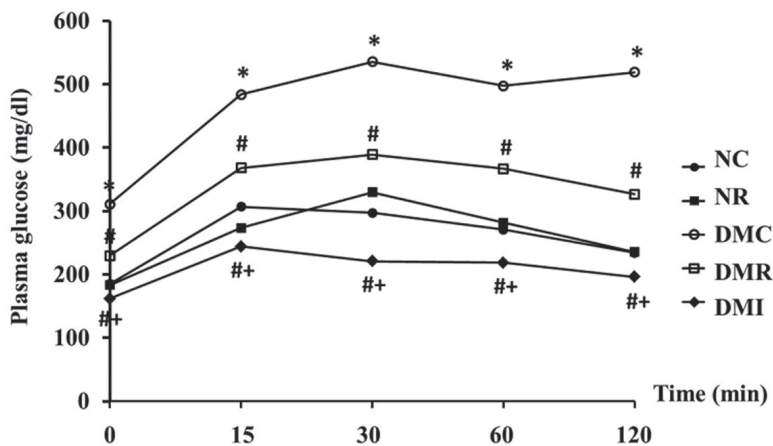

Figure 1. Effects of Thai purple rice bran supplement on plasma glucose response during oral glucose tolerance test.
Values are mean ± SE. NC: normal rats control, NR: normal rats received purple rice bran, DMC: diabetic rats control, DMR: diabetic rats received purple rice bran DMI: diabetic rats treated with insulin.
*$P<0.05$ when compared with NC
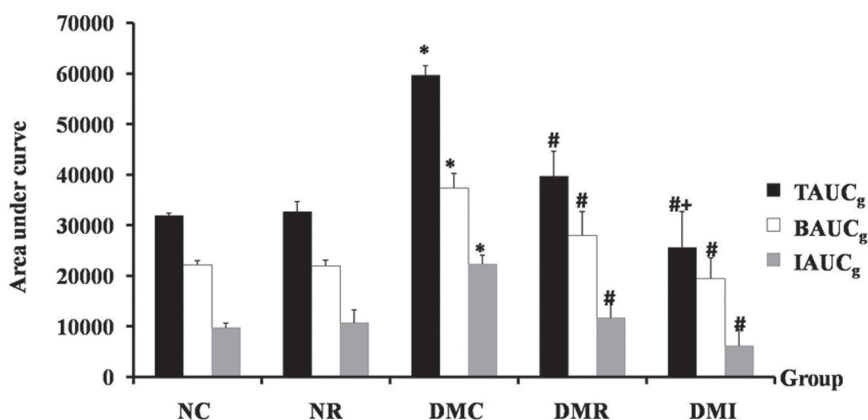#$P<0.05$ when compared with DMC
+$P<0.05$ when compared with DMR

Figure 2. Effects of Thai purple rice bran supplement on area under the curve for glucose during oral glucose tolerance test.

Values are mean ± SE. The total area under the curve for glucose (TAUC$_g$), the incremental area under the curve the glucose (IAUC$_g$), and the basal area under the curve for glucose (BAUC$_g$), NC: normal rats control, NR: normal rats received purple rice bran, DMC: idabetic rats control, DMR: diabetic rats received purple rice bran, DMI: idabetic rats treated with insulin.

*P<0.05 when compared with NC
#P<0.05 when compared with DMC
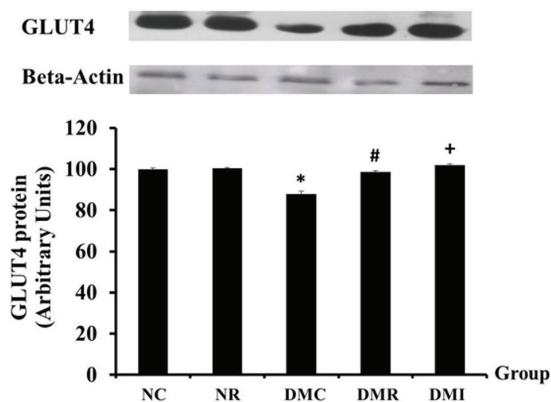+P<0.05 when compared with DMR

Figure 3. Effects of Thai purple rice bran supplement on total GLUT4 expression in STZ-induced diabetic rats.

Values are mena ± SE. The mean value in the NC group was arbitrarily set as 100%. NC: normal rats control, NR: normal rats received purple rice bran, DMC: diabetic rats control, DMR: diabetic rats received purple rice bran, DMI: diabetic rats treated with insulin.

*P<0.05 when compared with NC
#P<0.05 when compared with DMC
+P<0.05 when compared with DMR

DISCUSSION

Diabetes mellitus (DM) is one of the most severe metabolic disorders in human that affects the metabolism of carbohydrates, fat, and protein. DM is characterized by hyperglycemia as a result of a relative or an absolute lack of insulin or the action of insulin on its target tissue or both (Kaleem et al., 2008). Owing to the increasing worldwide incidence of diabetes and particularly the adverse side effect associated with the therapeutic agents used for treating diabetes mellitus, there has been a growing interest in herbal remedies. In the present study, we have firstly demonstrated that Thai purple rice bran (*Oryza saliva* L. cv. Kum Doi Saket) supplement at a dose of 50 g/kg diet daily over a duration of 8 weeks to STZ-induced type 1 diabetic rats can have marked beneficial effects in reducing plasma glucose level and improving the abnormal plasma triglyceride and free fatty acid levels, indicating antidiabetic and hypolipidemic effects.

STZ is a monofunctional nitrosourea derivative; one of the most commonly used substances to induce diabetes in the experimental animals (Szkudelski, 2001). It is well-know that a single, intraperitoneal injection of STZ at a high dose severely impairs insulin secretion mimicking type 1 diabetes (T1DM) (Zhang et al., 2010), resulting in hyperglycemia and loss in body weight. In this study, a dose of 65 mg/kg BW of STZ injection in normal Wistar rats was sufficient in destroying part of the pancreatic β-cell, as can be observed in the data depicting the plasma glucose and insulin levels after 14 days of STZ injection (Table 2). Fasting plasma glucose level was significantly elevated in diabetes group compared to its age-matched control group. Reduction of plasma insulin levels observed in the STZ group versus the control group was not statistically significant. STZ selectively destroys pancreatic β-cells (Junod et al., 1967) leading to decrease in amount of produced insulin and subsequent reduction of plasma insulin levels. However, the normal plasma insulin level was observed in our animal study. It could be due to increased production of endogenous insulin by the residual β-cells to compensate for the loss of β-cell (Persaud et al., 1999). In addition, the increased of plasma triglyceride and free fatty acids were noted. Likewise, the decrease of body weight in STZ-diabetic rats was found despite increasing energy intake and hyperphagia. It might be due to excessive breakdown of tissue protein. The loss in body weight in STZ-induced diabetic rats as well as type 1 diabetic patients was described previously (Bwititi et al., 2001). Therefore, the diabetic condition was characterized in our experimental diabetic rat model.

Thai purple rice genotype Kum Doi Saket (*Oryza sativa* L. cv. Kum Doi Saket) is a local cultivar of rice that is rich anthocyanins and gamma oryzanol in the aleuron layer. Some studies have regarded anthocyanin-rich purple rice or black rice as a healthy food or functional food in terms of obesity prevention, cardiovascular health, anti-inflammatory and anticancer effects (Prior and Wu, 2006; Wang et al., 2007). Anthocyanins, as a major sub-group of flavonoids, are water-soluble plant pigment responsible for the blue, purple and red color of much plant tissue. Recently, Takikawa et al. (2010) has reported that dietary anthocyanin-rich bilberry extract ameliorates hyperglycemia and insulin sensitivity in diabetic mice (Takikawa et al., 2010). Similarly, the results of this our present study have demonstrated that a supplement of Thai purple rice bran genotype Kum Doi Saket (50 g/kg diet) to STZ-induced diabetic rats for 8 weeks have significantly lowered the increasing level of fasting plasma glucose when compared to the untreated diabetic rats. This antihyperglycemic effect was found without any significant alteration of plasma insulin level, suggesting the modulation of insulin sensitivity. In addition, Thai purple rice bran also improved glucose tolerance as evidence by the lowered glucose response and decreased $TAUC_g$ and $IAUC_g$ from the OGTT (Figure 1 and 2, respectively). Because OGTT is usually used to study the response to insulin receptor to the elevation of exogenous glucose: therefore, the test serves as a measure of whole body sensitivity of insulin receptors to a glucose loading. In diabetic rats, the sensitivity of insulin receptors to glucose was significantly reduced (Asare et al., 2011). Accordingly, Thai purple rice bran supplement could improve the sensitivity of insulin receptors to exogenous glucose in STZ-induced diabetic rats. It is supported by the significant decreased of HOMA index in DMR group (Table 3). One important physiological effect of insulin is to enhance glucose uptake into the peripheral target cells; especially muscle cells, thereby regulation blood glucose level (Hundal

et al., 1992). Possible mechanism of improved insulin sensitivity was elucidated using Western blot analysis of total GLUT4 protein expression, which it is an insulin sensitivity membrane protein responsible for the transport of glucose from blood into the cell. The results showed that total GLUT4 protein expression significantly reduced (15%) in treated diabetic rats (Figure 3). Similarly, Liao et al. (2010) have been demonstrated that both the total and membrane GLUT4 level in STZ-induced diabetic rats was significantly lower than in the normal rats. Interestingly, the total GLLUT4 protein expression significantly restored in diabetic rats treated with Thai purple rice bran compared to the DMC group. These results imply that it could be the insulin receptor signaling pathway through which anthocyanin-rich purple rice bran would exert its antidiabetic effect. This observation is strengthened by the finding of significant decreased in plasma triglyceride and free fatty acid levels in DMR and DMI groups when compared with DMC group (Table 3). Elevated plasma FFA level and resultant lipid intermediate compounds, can directly interrupt insulin signaling by impairing the process of insulin-dependence protein phosphorylation and glucose transport, which develop to insulin resistance (Boden, 2004; Dresner et al., 1999). The lipid lowering effects of anthocyanins have been reported by a number of studies (Jayaprakasam et al., 2006; Tsuda et al., 2003). Recently, Guo et al. (2007) have demonstrated that anthocyanin-rich extract from black rice (5 g/kg of high-fructose diet) ameliorated the hyperlipidemia and glucose intolerance in rats.

Furthermore, there is considerable evidence supporting that lack of insulin or insulin action upregulate the lipolysis, resulting in high production of FFA and TG (Liao et al., 2010). Elevated plasma FFA levels promote fat oxidation and decrease carbohydrate oxidation. Consequently, extensive oxidations of fatty acids which commonly found in type 1 diabetes mellitus produce an abundant of highly reactive molecular species, and increased oxidative stress (Boden, 2004). It is well recognized that oxidative stress plays critical role in the pathogenesis of various diseased, including diabetes, insulin resistance, hypertension and atherosclerosis (Baynes and Thorpe, 1999; Houstis et al., 2006). In addition, anthocyanin significantly inhibited the oxidative stress, prevented the insulin resistance occurrence in fructose-fed rats (Guo et al., 2007). The present study clearly illustrated that hyperlipidemia, an increase both plasma FFA and TG levels, in STZ-induced diabetic rats were countered by Thai purple rice bran supplement. Similar results were found in diabetic rats treated with insulin injection. These finding suggested that the decreased oxidative stress by anthocyanin-rich rice bran and insulin treatment may partly contribute to improved dyslipidemia and consequently increased insulin sensitivity conclusion in these diabetic rats.

CONCLUSION

This study has firstly demonstrated that Thai purple sticky rice bran supplement is capable of ameliorating the hyperglycemia and dyslipidemia in STZ-induced diabetic rats. The underlying mechanism may be related to improving the plasma lipids concentrations which consequently enhance insulin sensitivity or/and inhibited oxidative stress. The results indicated that anthocyanin-rich Thai purple sticky rice is a promising nutraceutical ingredient, and may possess clinical importance in treatment and prevention of diabetes mellitus. Further investigations, however, are in progress to elucidate the detailed mechanism of antihyperglycemic and hypolipidemic effects.

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