ORIGINAL PAPER

Acute exercise with *Salicornia herbacea* L. powder ingestion increases lipids metabolism in STZ-induced diabetic rats

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(Received: 2012/08/30, Revised: 2012/09/18, Published online: 2012/09/28)

ABSTRACT

This study was carried out to investigate the effect of *Salicornia herbacea* L. (SHL) intake and acute exercise on lipids metabolism in streptozotocin (STZ)-induced diabetic rats. Four different groups of 40 STZ-induced diabetic Sprague-Dawley male rats were given a diet of feed mixed with SHL powder for 6 weeks. To adapt to the acute swimming exercise, the exercise group went through a period of swimming induction over one week. Then, they performed the acute swimming exercise the next day. 24 hours after the acute swimming exercise, the rats were sacrificed and samples were collected and analyzed. There was no significant change in body weight as compared to the control group. Stored fat was found to have decreased in the group which was fed a diet supplemented with SHL powder. There was a significant reduction in blood glucose, triglyceride and total-cholesterol in the SHL intake group only. There was no change in L-FABP and CPT-1 protein expression determined to have occurred due to acute exercise, but there was a statistically significant increase in the expression of both proteins determined for the SHL group. Moreover, the SHL group with acute exercise exhibited an increase in cytochrome C oxidase. Based on the results above, it seems that SHL powder could help to prevent various diabetic complications. In addition, it seems necessary to prove the effectiveness of SHL as a healthy functional food by carrying out further research on its intake in relation to metabolic syndromes and exercise capabilities.

Keywords: *Salicornia herbacea* L., streptozotocin, L-FABP, CPT-1, rats

INTRODUCTION

As many Korean people's dietary habits have changed to that of an excessive intake of nutrition, serious social issues relating to diseases of the metabolic syndrome are becoming more and more prevalent for those lacking in physical activity. However, people have been more aware of the seriousness of this issue through various public media campaigns, and an awareness of the necessity to increase physical activity and to choose healthy functional foods is prevalent within society. In such a trend, people pay more attention to medicinal herbs as substitutional food. As for the functions of medicinal herbs, it has been reported that they are some of the safest foods, which are not medicines. [1], and have anti-obesity [2] and anti-diabetic properties [3]. The reason that successful medical applications of natural substances attract so much attention is that many synthetic substances

are more likely to have toxic effects when absorbed into the body, and the dose of synthetic substances must, therefore, be strictly regulated. Besides, as a part of the prevention against various metabolic disorder-caused complications, exercise is also recognized as a main health factor. It is known that highly intensive exercise activates AMP-activated protein kinase (AMPK) as well as peroxisome proliferative activated receptor, gamma, coactivator-1 alpha (PGC-1 α) and exercise on a regular basis prevents initial diseases related to hyperglycemia [4,5].

Glasswort is a plant belonging to *Salicornia*, *Chenopodiaceae*, and grows on salt marshes in the west and south-west coasts of Korea, *Salicornia herbacea* L. is called 'Hamcho' in Korean. It has bright green nodes on its green stem, which change color to either red or purple in the autumn. As a salt plant (halophyte), *Salicornia herbacea* L. is efficacious against anti-diabetes and anti-hyperlipidemia [6] because it has a great

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deal of various salts accumulated in the body of the plant, and contains natural minerals, such as Mg, Ca, Fe and K in abundance [7]. According to previous research on *Salicornia herbacea* L., it helps to reduce blood glucose as well as body weight in streptozotocin-induced diabetic mice [8]. When *Salicornia herbacea* L. extract was administered to 3-week-old *db/db* mice for 6 weeks, it reduced blood lipid and the concentration of glucose by suppressing pancreatic lipase, resulting in its being efficacious against anti-hyperlipidemia [9]. As dietary supplements and exercise are paid continuously more attention for the treatment of diabetes, this study investigated the activity of powdered *Salicornia herbacea* L., through investigating the effect of the swimming exercise and a *Salicornia herbacea* L. supplemented diet on the lipid metabolism of streptozotocin-induced diabetic rats.

METHODS AND MATERIALS

Animal care and experimental design

Four-week-old Sprague-Dawley male rats (Orient Bio, Korea) were used in the experiment. Rats were individually kept in cages at a controlled environmental temperature of 23–25 °C and relative humidity at 60% with 24 hours of air circulation via forced ventilation. The animal room was set to a 12 h light/dark cycle, being kept in darkness from 08:00–20:00. The rats were adapted to their environment for 2 weeks, and upon reaching 6-weeks of age, they were divided into four groups ($n = 10$ per group) following a randomized blockade design: a diabetic control (DBC), diabetes with acute exercise (DBEX), diabetes + *Salicornia herbacea* L. added diet (DBS), and a diabetes + acute exercise + *Salicornia herbacea* L. added diet (DBEXS), respectively. During experimental periods, their body weight was measured twice weekly, on Tuesdays and Thursdays, and the average was obtained and recorded. After 12 h fasting, rats were randomly selected and were injected i.p. with STZ (Sigma, St Louis, MO, USA) in citrate buffer (pH 4.5) at a single dosage of 70 mg/kg of body weight [10]. Two days after STZ administration, their body weight was measured daily. The blood glucose concentration was measured by using a blood drawn from the tail vein with glucometer (Accu-Check, KoreaRoche, Korea). When fasting blood glucose level is higher than 200 mg/dl, rats were defined as diabetic.

Dietary intake

Rats were fed an AIN-76 based diet mixed with/without

Table 1. Composition of the diet (g/kg diet)

Constituents	Control diet	Experimental diet
Casein	200	200
Sucrose	200	200
Corn starch	400	400
Corn oil	60	60
Cellulose	50	-
Mineral mix ¹⁾	35	35
Vitamin mix ²⁾	10	10
D,L-methionine	3.5	3.5
<i>Salicornia herbacea</i> L.	-	50

¹⁾ Mineral mix: AIN-76

²⁾ Vitamin mix: AIN-76

5% of *Salicornia Herbacea* L. [12] and they were provided with water and the diet *ad libitum* for 6 weeks. Powdered-*Salicornia herbacea* L. was purchased from the Sinan-gun Agriculture Association. The diet composition is shown in Table 1.

Swimming exercise adaptation and acute exercise

After diabetes was induced, rats were drawn into the swimming pool, of 50 cm depth and 25 cm width, for acute swimming exercise adaptation on the final week (5th week). The exercise duration started at 5 minutes and it was increased gradually, reaching a duration of 30 minutes on Day. This means that they swam for 30 minutes for just one day.

Blood and Tissue sampling

After 24 h of acute swimming exercise and 12 h of fasting, rats were anesthetized with ether, and their abdomens were opened. After collecting blood samples from the abdominal aorta using a syringe, the liver and fats (perirenal, mesenteric, and epididymal) were carefully extracted and were weighed (Precisa XT200A, Switzerland). Blood samples were separated via centrifugation (Hanil Science, Korea) at 700 × g for 15 minutes; and the plasma (top layer) was stored at -70 °C (Nihon Freezer, Japan) for future analysis.

Levels of blood glucose, total cholesterol (TC), and triglyceride (TG) were determined using an enzymatic quantification analysis kit (Asan Pharmaceutical, Korea) using spectrophotometry (Optizen, Mecasys, Korea).

Western blot analysis FABP, CPT-1 in liver

Liver tissue was mixed with 20 mM Tris-cl, 5 mM EDTA, 2 mM PMSF, protease inhibitor cocktail (Sigma, St Louis,

MO, USA) for homogenization. After centrifugation at $1,200 \times g$ for 10 minutes, the top layer was collected. The protein level of this layer was quantified according to the Bio-Rad protein quantification reagent methods, and was then made into samples by mixing with Laemmli sample buffer. Sample proteins of equal amount were separated using sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS-PAGE) and were transferred to the polyvinylidenedifluoride (PVDF) membrane. Upon completion of the transfer they were blocked at room temperature for one hour using 5% bovine serum albumin (BSA) containing TBST buffer (50 mmol/L Tris-HCl, 150 mmol/L NaCl, and 0.05% Tween-20). The primary antibodies of L-FABP (1:1000; abcam, ab7874, UK), CPT-1 (1:200; Santa Cruz, sc-20669, USA) were diluted respectively at 1:200, and were incubated overnight at 4°C and washed 5 times for 10 minutes with TBST (5% tween-20). The secondary antibodies were diluted with goat anti-rabbit IgG (Santa cruz Biotechnology, CA, USA) at 1:2,000, set for an hour to react, and were then washed 5 times for 10 minutes with TBST (5% tween-20). An enhanced chemiluminescence kit was used to obtain a fluorescent signal from the membrane on an X-ray film. The amounts of certain proteins were determined by using densitometry (Bio-Rad, USA).

Cytochrome c oxidase (COx) activity analysis

COx in liver was determined using a colorimetric-assay kit (Sigma, St. Louis, USA). Briefly, determination of COx activity was based on a colorimetric assay that quantifies the oxidation of ferrocytochrome c to ferricytochrome c via cytochrome c oxidase, a reaction that results in a decrease in absorbance at 550 nm. The decrease in absorbance at 550 nm was monitored using a spectrophotometer (UV 2101-PC; Shimadzu, Kyoto, Japan) combined with a temperature-regulated (25°C) 6-cell position chamber (CPS 260, Shimadzu, Kyoto, Japan). The spectrophotometer was calibrated to zero using assay buffer (10 mM Tris-HCl and 120 mM KCl, pH

7.0, 25°C). In a cuvette, 0.95 mL of assay buffer was combined with 50 μL of enzyme buffer (10 mM Tris-HCl and 250 mM sucrose, pH 7.0, 4°C) and 50 μL of isolated mitochondria. The reaction was initiated by the addition of 50 μL of ferrocytochrome c (reduced with 0.1 M dithiothreitol), and the decrease in absorbance at 550 nm was measured every second for 1 min using a kinetics program.

Statistical analysis

Data were statistically analyzed with SPSS/PC 18.0 (SPSS Inc., USA). All test results were expressed as means and standard error. In order to verify the significance of each group, one-way analysis of variance (ANOVA) was conducted. Post hoc tests were conducted on any items that indicated asignificant difference by using the Scheffé procedure. The significance levels were all set at $p < 0.05$.

RESULTS

Body weight change

Changes in body weight during the experimental period as shown Fig. 1. Overall, there was no significant difference among groups. The body weight of DBC was increased by about 30%, DBEX by about 20%, DBS by 27%, and DBEXS by approximately 22%. Weight gain was suppressed in the swimming group. DBS also showed a similar trend to DBC.

The rate of increase in body weight shown in Table 2. Perirenal fat gain was found to be significantly higher in the DBC ($p < 0.05$). Perirenal fat of the DBEX and DBEXS groups was also significantly lower than that of the DBS group ($p < 0.05$). Mesenteric fat was most abundant in the DBC group ($p < 0.05$). That of the DBEXS group was the lowest compared to other groups ($p < 0.05$). Epididymal fat of the DBC group was significantly higher than that of other

Table 2. Changes of weight gain rate and stored fat amount

	DBC	DBEX	DBS	DBEXS
Body weight gain (%) ¹⁾	$29.72 \pm 5.10^{\text{NS}}$	$19.78 \pm 3.40^{\text{NS}}$	$27.06 \pm 4.82^{\text{NS}}$	$21.42 \pm 6.23^{\text{NS}}$
Perirenal fat (g)	$2.60 \pm 0.17^{\text{a}}$	$0.90 \pm 0.13^{\text{b,c}}$	$1.21 \pm 0.28^{\text{b}}$	$0.46 \pm 0.09^{\text{c}}$
Mesentary fat (g)	$2.22 \pm 0.22^{\text{a}}$	$1.63 \pm 0.09^{\text{b}}$	$1.56 \pm 0.14^{\text{b}}$	$1.16 \pm 0.73^{\text{c}}$
Epididymal fat (g)	$3.65 \pm 0.32^{\text{a}}$	$2.34 \pm 0.18^{\text{b}}$	$2.30 \pm 0.26^{\text{b}}$	$2.10 \pm 0.24^{\text{b}}$
Sum of fats (g)	$8.47 \pm 0.56^{\text{a}}$	$4.89 \pm 0.20^{\text{b}}$	$5.07 \pm 0.38^{\text{b}}$	$3.72 \pm 0.25^{\text{c}}$
Fat ratio (%) ²⁾	$3.58 \pm 0.18^{\text{a}}$	$2.24 \pm 0.13^{\text{b}}$	$2.21 \pm 0.17^{\text{b}}$	$1.67 \pm 0.94^{\text{c}}$

Data are mean $\pm$ SE.

¹⁾ calculated from the division of pre-/post-body weight

²⁾ calculated from the division of post-body weight/sum of fats; DBC: diabetic control; DBEX: diabetes with acute exercise; DBS: Diabetes + *Salicornia herbacea* L. added diet; DBEXS: Diabetes + acute exercise + *Salicornia herbacea* L. added diet, respectively. NS: not significant; different superscripts means significant within horizontal line at $p < 0.05$.

Fig. 1. Changes of body weight during experimental periods. Bars are mean $\pm$ SE. DBC: diabetic control; DBEX: diabetes with acute exercise; DBS: Diabetes + *Salicornia herbacea* L. added diet; DBEXS: Diabetes + acute exercise + *Salicornia herbacea* L. added diet, respectively.

groups ($p < 0.05$). Total fat was significantly higher in the DBC group than in any other group ($p < 0.05$), while that of the DBEXS group was the lowest of all groups ($p < 0.05$). The DBC group had the highest body fat ratio ($p < 0.05$), while the DBEXS group had the lowest ($p < 0.05$).

Changes of serum levels

Compared to the DBC, the mean difference of blood glucose concentration in the DBS and DBEXS was approximately 100 mg/dl, blood triglyceride levels about 300 mg/dl, and total cholesterol approximately 50 mg/dl with them, respectively. The glucose, triglyceride, and total cholesterol concentration of *Salicornia herbacea* L. supplemented groups (DBS and DBEXS) were significantly lower than those of non-supplemented groups ($p < 0.05$). However, there was no significant difference in the concentrations of glucose, triglyceride and total cholesterol between DBC and DBEX groups.

Changes in the metabolism of liver lipids

The liver fatty acid binding protein expression was increased by approximately 6%, 43%, and 50% in the DBEX, DBS, and DBEXS groups, respectively, compared to the

Fig. 2. Changes of liver fatty acids binding protein expression. Bars are mean $\pm$ SE. DBC: diabetic control; DBEX: diabetes with acute exercise; DBS: Diabetes + *Salicornia herbacea* L. added diet; DBEXS: Diabetes + acute exercise + *Salicornia herbacea* L. added diet, respectively. Different letters indicate a significant difference at $p < 0.05$.

Fig. 3. Changes of liver carnitine palmitoyltransferase-1 protein expression. Bars are mean $\pm$ SE. DBC: diabetic control; DBEX: diabetes with acute exercise; DBS: Diabetes + *Salicornia herbacea* L. added diet; DBEXS: Diabetes + acute exercise + *Salicornia herbacea* L. added diet, respectively. Different letter means significant at $p < 0.05$.

DBC. Those of the DBS and the DBEXS groups were significantly higher compared to the others ($p < 0.05$). There was no statistically difference in levels of L-FABP between DBS and DBEXS groups.

Carnitine palmitoyltransferase-1 protein expression was increased 3%, 30%, and 26% in the DBEX, DBS, and DBEXS groups compared to the DBC group, respectively, while expression in the DBS and the DBEXS groups was significantly higher compared to the other groups ($p < 0.05$). There was no difference in L-FABP between DBS and DBEXS groups.

Cytochrome C oxidase concentrations in the groups were 0.056 ± 0.01 unit/mg in the DBC, 0.090 ± 0.01 unit/mg in the

Table 3. Changes of blood glucose, TG and TC concentrations

	DBC	DBEX	DBS	DBEXS
Glucose (mg/dl)	354.71 $\pm$ 12.51 ^a	341.72 $\pm$ 7.43 ^a	246.69 $\pm$ 12.65 ^b	251.49 $\pm$ 10.94 ^b
Triglyceride (mg/dl)	688.22 $\pm$ 48.30 ^a	633.68 $\pm$ 22.70 ^a	365.41 $\pm$ 21.55 ^b	399.85 $\pm$ 15.61 ^b
Total cholesterol (mg/dl)	266.23 $\pm$ 12.45 ^a	246.82 $\pm$ 15.65 ^a	195.31 $\pm$ 7.24 ^b	205.31 $\pm$ 8.08 ^b

Data are mean $\pm$ SE. DBC: diabetic control; DBEX: diabetes with acute exercise; DBS: Diabetes + *Salicornia herbacea* L. added diet; DBEXS: Diabetes + acute exercise + *Salicornia herbacea* L. added diet, respectively. Different letters indicate significant differences at $p < 0.05$.

Fig. 4. Changes of liver cytochrome C oxidase. Bars are mean $\pm$ SE. DBC: diabetic control; DBEX: diabetes with acute exercise; DBS: Diabetes + *Salicornia herbacea* L. added diet; DBEXS: Diabetes + acute exercise + *Salicornia herbacea* L. added diet, respectively. Different letters indicate significant differences at $p < 0.05$.

DBEX, 0.088 ± 0.01 unit/mg in the DBS, and 0.125 ± 0.01 unit/mg in the DBEXS, respectively. Compared to the DBC, the other three groups were significantly higher ($p < 0.05$), and the DBEXS group showed the significantly highest concentration compared to the DBEX and DBS ($p < 0.05$).

DISCUSSION

This study aimed to investigate the effect of *Salicornia herbacea* L. intake and acute exercise on the lipid metabolism of streptozotocin-induced diabetic rats. Forty SD male rats were raised in four different groups, some of which were provided a diet including *Salicornia herbacea* L. powder for 6 weeks. In order to adapt to the acute swimming exercise, they went through a period of adaptation in the pool for 1 week, and were sacrificed 24 hours after the acute swimming exercise.

Because Type 1 diabetes was induced in all the experimental groups, this study failed to determine a reduction of weight caused by diabetes [11]. All groups showed a similar tendency of weight reduction, which was determined to be caused by the intake of *Salicornia herbacea* L. powder [12] which seems to result from the activation of lipid metabolism. Especially, the groups which were fed a diet including *Salicornia herbacea* L. showed the most fat out of the fecal ingredients. We assumed that the absorption of fat was suppressed by the dietary fiber of the supplement [12]. Besides, it was also found that the tendency for weight to increase was somewhat suppressed when rates performed acute exercise without taking *Salicornia herbacea* L. This result is in agreement with that of Thivel *et al.* [13], that when adults took high intensity exercise, 11% of all the energy from 24 hours' intake of food was suppressed at most,

and another report [14] that when Wistar rats were loaded with high intensity exercise, their appetite was suppressed. On the basis of this result, it was supposed that the exercise during the period of adaptation became a stressful circumstance similar to representing a highly-intensive exercise, and it was also presumed that the kidney damage was caused by the exhausting acute swimming exercise. Similarly, it was reported that muscular damage was caused by acute exercise, although it was moderate aerobic exercise [16]. In addition, when the same relative-strength exercise was loaded, non-trained rats secreted relatively more stress hormones than trained ones [17].

Meanwhile, considering the change of fat deposition between groups, it was assumed that the intake of *Salicornia herbacea* L., which contains up to 70% dietary fiber suppressed the amount of fat absorbed and functioned to accelerate the excretion of fat [12,18]. This result indicates that the synergistic effect of *Salicornia herbacea* L. and acute exercise resulted in the highest level of DBEX and DBEXS in the DBC group. However, with long-term exercise combined, there would be actual synergistic effect indeed. Moreover, it was previously found that when the concentration of Mg in the blood was higher, there was less possibility that rats would develop metabolic syndromes and abdominal obesity [19]. It was reported that the content of Mg is very high in *Salicornia herbacea* L. (587 mg per 100g) [20]. This study induced Type 1 diabetes with streptozotocin, and when insulin resistance increases and fat is excessively stored in the abdomen, diabetes-complications are accelerated [21]. Accordingly, this study considered that reducing abdominal fat through the intake of *Salicornia herbacea* L. would be one of the most desirable ways to control such side effects.

One of the most problematic symptoms associated with diabetes is hyperglycemia. This study found the concentration of blood glucose was reduced with an intake of *Salicornia herbacea* L. But there was no difference found when only exercise was applied as a treatment. It was previously reported that there was no difference in the levels of stress hormones in rats/mice who were treated with acute swimming exercise, compared to a control, because of the homeostasis of blood glucose was sustained [22]. On the other hand, it was found that groups having taken *Salicornia herbacea* L. showed a lower concentration of blood glucose than other groups. This result corresponds to the results of previous research which has reported that *Salicornia herbacea* L. extracts help to reduce the blood glucose and blood lipid in diabetic rats [8,9]. We thought that natural minerals contained in *Salicornia herbacea* L. function to regulate the secretion of endogenous

glucose by suppressing carbohydrate oxidation during carbohydrate metabolism. In addition, the results of this study seem to be similar to those of another report that the blood glucose of diabetic rats decreased when administered with *Salicornia herbacea* L.-polysaccharide, compared to the control group [23]. It was also reported that a week after rats took food containing 4% of salt, sugar transporters increased, implying the active properties of *Salicornia herbacea* L. to be related to its salt content [24]. Another report showed that *Salicornia herbacea* L. in the diet significantly increases the excretion of carbohydrate and fat with feces [12]. These two studies [12,24] well explain the reduction of blood glucose in this study.

This study found that there was no change of blood triglyceride and total cholesterol in the DBEX and DBEXS groups. Interestingly, this result was rather different from those of two other reports which stated that blood triglyceride increased without a change in blood cholesterol when 30 minutes' acute exercise performed [25,26]. Similarly, further previous research insisted that there was no change in blood lipid by acute exercise [27]. However, their research was conducted on subjects without diabetes, and hence, may have differed for this reason. In subjects with diabetes, lipids are generally found in higher concentrations in the blood [28,29]. The rise of insulin resistance also contributes to a significant increase of blood lipids [30]. Our data showed the increased intra-abdominal fat has been shown to be associated with insulin resistance and further aggravating diabetic complications [21]. As a result, it seems that as diabetes induced intra-abdominal fat increases, the concentration of blood lipid sustains the possibility of raising insulin resistance. However, when rats took *Salicornia herbacea* L., there was a significant reduction in triglyceride and total cholesterol. From this point of view, there was no change determined to have occurred due to acute exercise alone, and this result has been previously described [25-27]. Therefore, we theorized that *Salicornia herbacea* L. might have been the main factor in reducing the concentration of blood lipids. It was reported that when rats took *Salicornia herbacea* L. powder, a significant reduction of blood lipids was attributed to a significant increase of high-density-lipoprotein-cholesterol in blood, while raising the content of lipid in the feces [12]. There are further studies which have stated that when the content of either insoluble or soluble dietary fiber was high, blood lipid was reduced, and when Type 2 diabetic rats took *Salicornia herbacea* L., a reduction in triglyceride and cholesterol took place [6,31].

To investigate changes in the activation of lipid metabolism, this study analyzed the expression of L-FABP and CPT-1 proteins in the liver, and the activation of cytochrome C

oxidase in the mitochondria. Due to the increase of insulin resistance, the expression of L-FABP of fat cells increases [32], and L-FABP then accelerates the metabolism of long chain fatty acids [33]. From this point of view, we predicted an increase in the expression of L-FABP by exercise as shown in previous research [34,35]. However, after one week of adaptation, all of the experimental groups showed little and non-significant increases through acute exercise, as compared to the DBC group. On the other hand, there was a significant increase of L-FABP in the *Salicornia herbacea* L. group. Previous researches revealed that when dietary fiber was sufficiently provided, L-FABP increased as well [12]. This study assumed that a sufficient supply of dietary fiber through the intake of *Salicornia herbacea* L. for a long period would lead to an increase in the expression of L-FABP protein [36]. Furthermore, the same result was found in the expression of CPT-1 protein as the increase of L-FABP protein. In other words, there was a significant increase in CPT-1 protein through the intake of *Salicornia herbacea* L., while no change was observed for the acute exercise group. Considering a previous report on the significant increase of the expression of CPT-1 protein through dietary fiber and on the reduction of stored fat induced by the increase of CPT-1 [37], this study considered that a reaction similar to FABP occurred [38,39].

As cytochrome C oxidase (COx) is an enzyme directly affecting fat oxidation in the mitochondria, its activation increases during exercise [40]. In this study, COx increased when rats performed exercise. When rats were undergoing the period of adaptation for a week, the fat oxidation increased. In fact, those applied to acute exercise only, all the findings seem to support the result of this study, such as an increase of lipolysis [41,42], an increase of fat oxidation [43,44] and an increase of COx [45]. Besides, the *Salicornia herbacea* L. groups showed an increase of COx and a synergistic effect of DBEX and DBS doing DBEXS at the same time, compared to the DBC group. This finding implies that the increase of intra-abdominal fat and the rise of the concentration of blood lipids were effectively suppressed by *Salicornia herbacea* L. supplementation and short-term exercise.

CONCLUSION

This study aimed to investigate the effect of *Salicornia herbacea* L. intake and acute exercise on the lipid metabolism of streptozotocin-induced diabetic rats. 40 SD male rats were raised, some of which were fed a *Salicornia herbacea* L. powder-supplemented diet for 6 weeks. There was no

significant change in body weight. Stored fat was decrease when *Salicornia herbacea* L. was taken. There was significant reduction of blood glucose, triglyceride, and blood total cholesterol in the *Salicornia herbacea* L. supplemented groups only. Moreover, there was no difference of the expression of L-FABP and CPT-1 proteins in the acute exercise groups, though it showed a statistically significant increase through the intake of *Salicornia herbacea* L. COx showed a synergistic effect through the intake of *Salicornia herbacea* L. along with acute exercise. With all the results above, this study asserted that for streptozotocin-induced diabetes, taking *Salicornia herbacea* L.-mixed foods will prevent various diabetic complications. Additionally, future studies should be conducted to verify the effect of *Salicornia herbacea* L. as a health functional supplement.

ACKNOWLEDGMENT

This study was carried out with the supported of the National Research Foundation of Korea Grant funded by the Korean Government (NRF N0. 2011. 354-G00109), and was also partly supported by the Forest Science & Technology Projects (Project No. S121010L080010), Korea Forest Service.

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