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Bamboo shoot fiber improves insulin sensitivity in high-fat diet-fed mice

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ABSTRACT

The aim of this study was to evaluate the role of bamboo shoot fiber (BSF) in regulating insulin sensitivity in mice. Two BSFs were obtained from *D. hamiltonii* and *D. latiforus*. C57BL/6 mice were fed a low-fat diet or a high-fat diet with 10% fiber as cellulose (HFC), or two BSFs (HFDH or HFDL) for 13 weeks. Compared with the HFC group, HFDH and HFDL groups exhibited considerably less body weight gain, lower levels of fasting glucose and insulin, and lower values of glucose areas under the curve during glucose and insulin tolerance tests. BSF groups also had lower glucoses stimulated insulin concentrations. In addition, more phosphorylation of Akt in insulin target tissues was associated with higher protein expression levels of PGC-1α and phosphorylated AMPK and p38 in BSF fed mice. These results indicated that BSF improved insulin sensitivity in high-fat diet-fed mice through enhancing insulin signaling and activating PGC-1α.

1. Introduction

Improved insulin sensitivity has proved to be one mechanism linking cereal fiber consumption to reduced risk of developing diabetes in humans (Robetson, Bickerton, Dennis, Vidal, & Frayn, 2005; Weickert et al., 2006). In animal studies, many types of dietary fiber from varying sources have been identified to be effective in improving metabolic disorders in mice (Dewulf et al., 2011; Li, Huang, Dong, Zhu, & Li, 2017; Neyrinck et al., 2012; Wang et al., 2007; Weitkunat et al., 2017). However, the differential effect between soluble and insoluble dietary fiber on the phenotype of mice on a high-fat diet over long-term has been recognized (Isken, Klaus, Osterhoff, Pfeiffer, & Weickert, 2010), underscoring the important role of insoluble dietary fiber in suppressing obesity and insulin resistance. Emerged as a new vegetable source insoluble dietary fiber, bamboo shoot fiber (BSF) has been recommended as a novel ingredient for functional foods (Nirmala, Bisht, & Laishram, 2014). BSF showed therapeutic potential in controlling metabolic diseases due to its huge influence on gut microbes (Li, Guo, Ji, & Zhang, 2016). However, the effect of BSF on insulin sensitivity has not been examined.

Despite insoluble dietary fiber has been shown to improve insulin sensitivity in clinical and animal studies, little is known about their influence on insulin signaling and key regulators of insulin sensitivity. Butyrate, a main fermentation product of insoluble dietary fiber, was shown to improve insulin sensitivity and increase energy expenditure in high-fat diet-fed mice through activation of PPARγ coactivator-1α (PGC-1α) (Gao et al., 2009). Recently, we showed that the insoluble dietary fiber isolated from bamboo shoot *Dendrocalamus hamiltonii* was the most effective among several commonly consumed dietary fibers in China in suppressing high-fat diet-induced body fat mass accumulation in mice (Li et al., 2016). Since obesity is linked to insulin resistance (Kahn, Hull, & Utzschneider, 2006) and loss of body weight always improves insulin sensitivity (McAuley & Mann, 2006), we hypothesized that BSF is effective in improving insulin sensitivity in high-fat diet-fed mice through activating PGC-1α regardless of bamboo species. While bamboo shoot *D. hamiltonii* is mainly produced and consumed locally in Xishuangbanna area which is located on the borders of southwest China, bamboo shoot *D. latiforus* is more widely grown in south China and consumed by people in the whole country. Therefore, in this experiment, we prepared isoenergenic high-fat diets containing either

Abbreviations: Akt, protein kinase B; AMPK, adenosine monophosphate (AMP)-activated protein kinase; BSF, bamboo shoot fiber; GTT, glucose tolerance test; HFC, high-fat diet with 10% fiber as cellulose; HFDH, high-fat diet with 10% fiber as BSF from *D. hamiltonii*; HFDL, high-fat diet with 10% fiber as BSF from *D. latiflorus*; HOMA-IR, homeostasis model assessment for insulin resistance; ITT, insulin tolerance test; NEFA, Non-esterified fatty acid; PGC-1α, Peroxisome proliferator-activated receptor (PPAR)-γ coactivator-1α; WAT, white adipose tissue

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cellulose, or BSF from either *D. hamiltonii* or *D. latiforus* with the aim to investigate the effect of BSF on insulin sensitivity in high-fat diet-fed mice and to explore underlying molecular mechanisms.

2. Materials and methods

2.1. Bamboo shoot fibers

Bamboo shoot fiber (BSF) from *D. hamiltonii* was extracted as previously reported (Li et al., 2016), providing 73.4% insoluble fiber and 1.1% soluble fiber. BSF from *D. latiflorus* was purchased (Liangxin Food Co., Ltd, Guangdong, China), providing 74.4% insoluble fiber and < 0.1 soluble fiber.

2.2. Animals and diets

Animal experiments were performed in accordance with the National Laboratory Animal Care and Use guidelines and regulations in China. All procedures were approved by the Institutional Animal Care and Use Committee of Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences. Female C57BL/6 mice (8 weeks) were obtained from Vital River Laboratories (Beijing, China). After a 2-week acclimatization, the mice received a low-fat control diet (LF, AIN-93; 10% energy from fat) for another 2 weeks before being randomly assigned to 4 groups (n = 9/group) including one group continued to be on the LF diet and three groups on high-fat diets (AIN-93 adapted; 60% of energy from fat) supplemented with 10% of microcrysslline cellulose (HFC) or the two BSFs mentioned above (HFDH and HFDL) for 13 weeks (Table 1). The mice were housed e at 22 ± 2 °C with a 12-h light/dark cycle in humidity-controlled environment with free access to food and water.

2.3. Biochemical analysis

At the end of the experiment, blood samples were collected from tail vein after an overnight fasting. Blood glucose was measured with a glucose meter (Bayer, Mishawaka, USA). Plasma was isolated as previously described (Zhang, Boudyguina, Wilson, Gebre, & Parks, 2008). Plasma insulin concentration was measured using the mouse insulin ELISA kit (Mercodia, Uppsala, Sweden). The homeostasis model assessment for insulin resistance (HOMA-IR) was calculated by multiplying fasting glycemia (mmol/L) and fasting insulinemia (pmol/L) divided by 22.5 (Neyrinck et al., 2012). Plasma triglyceride, total cholesterol, HDL and LDL cholesterol were determined by commercially available kits (BioSino, Beijing, China). Non-esterified fatty acid (NEFA) was measured using the LabAssay™ NEFA kit (Wako, Osaka, Japan).

Table 1
Ingredient and nutrient composition of the experimental diets.

Ingredients (g/100 g)	LF	HFC	HFDH	HFDL
Casein	20.0	25.0	25.0	25.0
Corn starch	55.5	15.2	15.2	152
Sucrose	10.0	10.0	10.0	10.0
Palm oil	4.4	33.5	33.5	33.5
Microcrystalline cellulose	5.0	10.0	–	–
BSF from *D. hamiltonii*	–	–	10.0	–
BSF from *D. latiflorus*	–	–	–	10.0
AIN-76 mineral mix	3.5	3.5	3.5	3.5
AIN-76 vitamin mix	1.0	1.0	1.0	1.0
DL-methionine	0.3	0.3	0.3	0.3
Choline bitartrate	0.2	0.2	0.2	0.2
TBHQ	0.1	0.04	0.04	0.04
Cholesterol	–	1.0	1.0	1.0
Sodium cholate	–	0.3	0.3	0.3
Calories (kcal/100 g)	413.1	571.1	573.5	569.0

BSF, bamboo shoot fiber. LF, low-fat control diet; HFC, high-fat diet with 10% fiber as cellulose; HFDH, high-fat diet with 10% fiber as BSF from *D. hamiltonii*; HFDL, high-fat diet with 10% fiber as BSF from *D. latiflorus*.

2.4. Glucose and insulin tolerance tests

At week 11, oral glucose tolerance test (GTT) was performed as described (Li et al., 2016). Overnight-fasted mice were gavaged D-glucose solution (1 g/kg body weight). Blood glucose concentrations at 0, 15, 30, 60, and 120 min were measured as described above. At week 12, insulin tolerance test (ITT) was performed as described with slight modifications (Oishi et al., 2015). Five-hour-fasted mice were intraperitoneally administered human insulin (0.5 U/kg body weight). Blood glucose levels were measured in the same way as in GTT. The incremental area under the curve (AUC) was calculated according to Wolever, Jenkins, Jenkins, and Josse (1991).

2.5. Insulin challenge and western blotting

At the end of the experiment, mice were fasted for 16 h and then injected human insulin in the same way as in ITT. The mice were killed5 min later, liver, skeletal muscle, and adipose tissues (parametrial and subcutaneous) were immediately frozen in liquid nitrogen and stored at −80 °C. Proteins from these tissues were extracted in RIPA Lysis buffer (Beyotime, China), separated by SDS-PAGE, and transferred to PVDF membranes (Millipore, USA) as previously described (Ji et al., 2016). The membranes were blocked and then incubated overnight with the following primary antibodies at 4 °C: phosphor-AMPKα (Thr172), AMPKα, phosphor-Akt (Ser473), Akt, Pgc-1α, p-p38 (Tyr182), and β-actin. The membranes were then incubated with horseradish peroxidase (HRP)-conjugated secondary antibody and visualized using Chemiluminescent HRP Substrate (Millipore, USA). Images were detected and quantified by densitometry using Image Lab software (Bio-Rad, USA).

2.6. Statistical analysis

Data are presented as mean ± SEM. The parametric distribution of data was confirmed using D'Agostino and Pearson omnibus normality test. Statistical analysis was performed by one-way ANOVA followed by Tukey's *post-hoc* test using GraphPad Prism 5.0 (GraphPad Software, La Jolla, CA, USA). $p < 0.05$ were considered statistically significant difference.

3. Results

3.1. Bamboo shoot fiber suppressed high-fat diet-induced body weight gain

There was no difference in body weight among all diet groups at baseline. After 13 weeks, mice fed the high-fat diet with 10% cellulose (HFC) weighed 30% more than mice on the low-fat diet (LF) (HFC: 29.7 g vs. LF: 22.8 g, $p < 0.001$, Fig. 1A). The more body weight was accompanied by more liver weight and more fat mass (parametrial and subcutaneous) (Fig. 1C-E). Both bamboo shoot fiber (BSF) diet groups (HFDH and HFDL) weighed considerably less (HFDH: 22.7 g and HFDL: 22.1 g, Fig. 1A) and accumulated much less fat mass (Fig. 1D, E), compared with the HFC group. Only a slight difference existed between the two BSF groups. There was no difference in food intake in all high-fat diet groups (Fig. 1B). Elevated total cholesterol levels were observed in all high-fat diet groups compared with the LF group (HFC: 4.08 mmol/L, $p < 0.001$, HFDH: 2.68 mmol/L, $p < 0.01$, HFDL: 3.25 mmol/L, $p < 0.001$ vs. LF: 1.73 mmol/L, Table 2). However, total cholesterol levels in both BSF groups were significantly lower than that in the HFC group ($p < 0.001$). Moreover, both BSF groups exhibited significantly lower LDL cholesterol levels compared with the HFC group (HFDH: 1.50 mmol/L and HFDL: 1.51 mmol/L vs. HFC: 2.20 mmol/L, $p < 0.01$, Table 2).