Effects of oat β-glucan on endurance exercise and its anti-fatigue properties in trained rats

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ABSTRACT

Oat β-glucan was purified from oat bran and its effects on running performance and related biochemical parameters were investigated. Four-week-old male Sparsgue–Dawley rats, fed with/without oat β-glucan ($312.5\,mg\,kg^{-1}\,d^{-1}$) for 7 weeks, were subjected to run on a treadmill system to make them exhausted. All rats were immediately sacrificed after prolonged exercise, and the major metabolic substrates were measured in serum and liver. The results showed feeding dietary oat β-glucan to rats could significantly reduce the body weight and increase the maximum running time compared with normal control ($P < 0.05$). Furthermore, dietary oat β-glucan decreased the levels of blood urea nitrogen, lactate acid, and creatine kinase activity in serum, and increased the levels of non-esterified fatty acids, lactic dehydrogenase activity in serum, and the content of liver glycogen. Therefore, the present study demonstrated that dietary oat β-glucan can enhance the endurance capacity of rats while facilitating their recovery from fatigue.

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1. Introduction

Physical fatigue, commonly associated with the elevated stress level caused by a modern life style, is thought to be accompanied by deterioration in exercise performance (Tanaka et al., 2008). Regular exercise and a balanced diet are the best ways to reduce fatigue (Schwartz, 1999). Several factors have been identified to induce fatigue during exercise. First, exercise promotes the consumption and depletion of energy sources such as glycogen (Zhang et al., 2010). Second, exercise causes the production and accumulation of metabolic products such as lactic acid and ammonia in the body (Pedersen, Nielsen, Lamb, & Stephenson, 2004). Third, intense exercise can produce an imbalance between the body's oxidation and anti-oxidation system, i.e., the accumulation of reactive free radicals will put the body in a state of oxidative stress and bring injury to the body by attacking large molecules and cell organs (Wang et al., 2008). Recovery from exercise-induced fatigue requires repairing the damage that has occurred in the body and/or prompting elimination of the metabolic products accumulated during exercise.

The positive effects of nutrient supplementation on exercise capacity are well known. Fu, Ji, and Dam (2010) reported that CoQ10 can improve swimming endurance and has an anti-fatigue effect in mice. Furthermore, a high-fat diet was reported to be beneficial to prolonged intense exercise (Miller, Bryce, & Conlee, 1984). In addition, it was reported that carbohydrate supplementation could enhance exercise capacity (Kirwan, O'Gorman, & Evans, 1998; Yi, 2000) and delay fatigue (Coyle, 1992). However, people tend to take dietary supplements or "tonics" as an alternative. Accordingly, we believe that it is important to develop a safe and effective anti-fatigue food that can relieve daily stress and promote public fitness without adverse effects.

Naked oat (*Avena Nuda*) is a minor grain known to be a good source of protein, fat, minerals, B-complex vitamins, and especially soluble fiber β-glucan (Hu, Wei, & Ren, 2009). Oat is considered to be a healthy food and well accepted by people from many countries in the world (Butt, Tahir-Nadeem, Khan, & Shabir, 2008; Jenkins et al., 2002). Due to its nutritional values it has become an important base component of athletes' diet in Europe and Americas (Hu et al., 2009). β-Glucan from oats has received extensive study because of its potential functionalities. For example, oat β-glucan can help lower cholesterol (Davidson et al., 1991) and prevent diabetes (Braaten et al., 1994), colon cancer (Murphy et al., 2004), and cardiovascular diseases (Queenan et al., 2007), improve immune competence of human body (Mao et al., 2005). Curiously, there are

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few reports of the relationship between β-glucan and exercise. Oat dietary fiber was shown to exhibit significant bioactivities in exercise (Kirwan et al., 1998). Eating a meal with considerable dietary fiber (7 g of dietary fiber from whole-grain rolled oats) before prolonged moderately intense exercise significantly enhances exercise capacity. Also, oats in the diet can benefit exercise endurance by decreasing the consumption of liver glycogen. (Xu, Hu, Zhang, & Luo, 2009). Nevertheless, the specific effect of oat β-glucan on exercise performance has not been reported.

The objective of this study was to evaluate the effects of oat β-glucan on endurance during exercise and its anti-fatigue properties in Sparsgue–Dawley (SD) rats. After 7 weeks of running exercise, an exhaustive running course was recorded on treadmill, and several biochemical parameters related to fatigue were determined to elucidate the anti-fatigue activity of oat β-glucan.

2. Materials and methods

2.1. Materials

Naked oats (*Avena nuda*) were provided by researchers from Dingxi Dryland Agriculture Center in 2009, Gansu Province, China. After removing impurities, the oat seeds were steamed for 20 min to inactivate lipoxidase and then put into a hot air dryer at 38 °C for 24 h to reduce the moisture content to 12%. After that, oat seeds were peeled to get oat bran powder with particle diameter <0.8 mm using Satake mill (TM-05 C, Jiangsu, China). The milled oat bran samples were stored at 4 °C.

2.2. Isolastion and purification of oat β-glucan

β-Glucan was extracted from oat bran according to the method of Wood, Weisz, Fedec, and Burrows (1989). The oat bran powder was mixed with water (1:15, w/w) at 50 °C for 1 h, and the residues were removed using centrifugation ($3000 \times g$). The protein was precipitated and removed at its pI (pH 4.3), whereas the starch that remained in the supernatant was hydrolyzed with alpha amylase (Mikkelsen et al., 2010). The suspended gum containing β-glucan in the supernatant was separated by pouring the supernatant into absolute ethyl alcohol (1:1, v/v), followed by centrifugation at $4000 \times g$ for 10 min. The precipitant was freeze-dried and stored at 4 °C until use.

3. Analysis of oat β-glucan

3.1. Chemical composition

The β-glucan content of sample was determined enzymatically by AACC 32-23 using the mixed β-glucan linkage kit from Megazyme (Megazyme Ltd., Co., Wicklow, Ireland). Proteins in the oat β-glucan were quantified according to the Bradford's method (Bradford, 1976) using bovine serum albumin (BSA) as the standard. In addition, ash contents were measured according to AOAC (1990).

3.1.1. Molecular weight determination

The molecular weight distribution profile was obtained by a high performance size-exclusion chromatograph (HPSEC) equipped with multiple detectors: a refractive index detector (RI), a right angle laser light scattering detector (RALLS) and a low angle laser light scattering detector (LALLS) for direct molecular determination (Viscotek, tetra detector array from Malvern company).

3.1.2. IR spectral analysis

The structural characteristic of oat β-glucan were determined using a Fourier-transform IR spectrophotometer (Thermo Nicolet, USA) equipped with OPUS 3.1 software. The purified oat β-glucan

Table 1
Diet compositions in experiment.

Ingredient	Level (%)			
	NC	OG	NCE	OGE
Oat β-glucan	0	0.45[a]	0	0.45[a]
Corn starch	56	55.55	56	55.55
Rice bran	10	10	10	10
Fish powder	26	26	26	26
Soybean oil	2	2	2	2
Bone powder	3	3	3	3
Yeast powder	2.3	2.3	2.3	2.3
Salt	0.5	0.5	0.5	0.5
Vitamin-mineral mixture	0.2	0.2	0.2	0.2
Total	100	100	100	100
Energy kcal/100 g	538	543	538	543

[a] Rats in OG and OGE were administered with oat β-glucan (312.5 mg kg^{-1} body weight) dissolved in 2 mL distilled water by gastrogavage.

were ground with KBr powder and then pressed into pellets for transform IR spectral measurement in the frequency range of 4000–400 cm^{-1} (Kumar, Joo, Choi, Koo, & Chang, 2004).

3.2. Animals and experimental diets

This study was approved by the Animal Ethics Committee of Northwest A&F University (Yangling, China). Thirty-two male SD rats (Fourth Military Medical University, Xi'An, Shaanxi, China; License NO. SCXK (Military) 2010-007), with a body weight range of 152.3–163.8 g, were used. They were maintained under controlled temperature (22 ± 2 °C), humidity (55%), and air flow conditions with a fixed 12-h light-dark cycle (light 8:00 AM to 8:00 PM). They were allowed free access to water and standard diet.

After 1 week acclimation, thirty-two male rats were randomly divided into four groups and each group consisted of 8 rats as follows:

- Group 1: Normal control group (NC)
- Group 2: Oat β-glucan group (OG)
- Group 3: Normal control exercise group (NCE)
- Group 4: Oat β-glucan exercise group (OGE)

All the rats were fed with normal laboratory food, the compositions of diets were listed in Table 1. Rats in OG and OGE were administered with oat β-glucan (312.5 mg kg^{-1} body weight, according to the dosage of FDA (Hasler, 1998) dissolved in 2 mL distilled water by gastrogavage every morning. Meanwhile, the NC and NCE rats were administered with 2 mL physiological saline.

3.3. Exercise training protocol and running performance test

Thirty minutes after administration, NCE and OGE rats were subjected to running on a treadmill (at 0° slope). The treadmill running protocol consisted of adaptation training and intensive training (Fig. 1). The adaptation training was designed so that all rats were subjected to run at 15, 22, 27, 31, and 35 m/min from week one to five, respectively, for 20 min/day for 5 days/week. Subsequently, all rats entered intensive training, which allowed them to run at the set speed of 35 m/min for 20 min/day, 5 days/week, for 2 weeks (Lu & Lu, 2003).

After 7-week exercise training, rats were all food-deprived for 4 h before testing their endurance on a treadmill. The speed began at 12 m/min, and was increased every 3 min at the increment of 3 m/min until reaching 24 m/min. Whenever a rat was unable to keep pace with the treadmill for up to 10 s, it was removed from the treadmill and placed in a supine position to check if it was exhausted. If the rat could not right itself, it was considered as
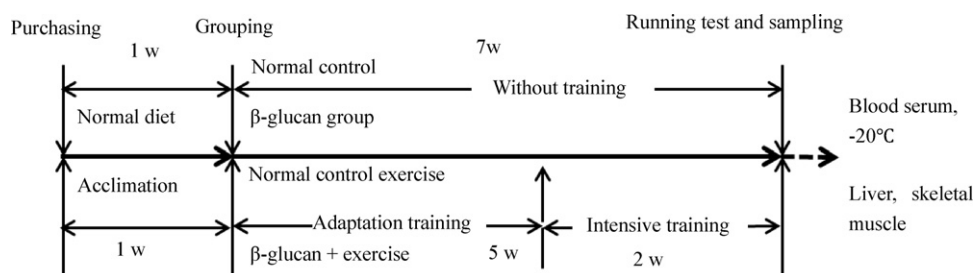
Fig. 1. Experiment scheme.

exhausted and immediately anesthetized for surgery. Otherwise, exercise was continued until exhaustion occurred. To avoid bias, rat identification was concealed from the investigator assessing the exhaustion criteria in all rats.

3.4. Sample collection

After the end of the running performance test, exhausted animals were immediately anesthetized with 10% chloral hydrate (3.5 mL kg^{-1} body weight, intraperitoneal injection). Blood samples were collected in heparinized tubes from the femoral artery. Serum was centrifuged at $200 \times g$ at 4 °C for 10 min and stored at -80 °C in a deep freezer for further analysis. Liver and gastrocnemius muscles were quickly dissected and washed in ice-cold saline solution. The samples were then frozen in liquid nitrogen and kept at -80 °C until analysis of glycogen content was conducted.

3.5. Measuring biochemical parameters related to fatigue

Lactic acid (LA), blood urea nitrogen (BUN), non-esterified fatty acid (NEFA), creatine kinase (CK), and lactic dehydrogenase (LDH) in serum, liver glycogen and skeletal muscle were tested on a UV9100 spectrophotometer (Beijing Ruili Analytical Instrument Corp., Beijing, China) using commercial kits purchased from Nanjing Jiancheng Bioengineering Institute (Nanjing, China).

Briefly, the LD assay was based on p-hydroxybiphenol colorimetry (Loomis, 1961), while the BUN assay was based on utilizing urease, a metabolic enzyme, to specifically detect urea in serum (Gentzkow, 1942). NEFA was estimated by the method of Dole (1956). CK assay methods were the same as those described by Dinovo, Miyada, and Nakamura (1973). The assay for LDH was based on a decrease in absorbance at 340 nm resulted from the oxidation of NADH, with one unit causes the oxidation of one micromole of NADH per minute at 25 °C and pH 7.3, under the specified conditions. The assay for glycogen in liver and muscle was based on anthrone-sulfuric acid colorimetry (Roe & Dailey, 1966).

3.6. Statistical analysis

The data were reported as mean $\pm$ SD ($n = 8$). Differences among means were determined by analysis of variance (ANOVA) with Tukey's HSD post hoc test, which were analyzed with SPSS (SPSS for Windows, Version Rel. 10.0.5., 1999, SPSS Inc., Chicago, IL). Statistical significance was declared at $P < 0.05$.

4. Results

4.1. Purification of oat β-glucan and its physicochemical properties

In this study, the chemical components of purified sample were 91.3% β-glucan, 1.4% protein, and 2.6% ash on the dry weight bases.

The molecular weight was measured by HPLC with a size exclusion column. The result of HPLC analysis of β-glucan was shown in Fig. 2. Based on a calibration curve obtained from the elution retention times of dextran with various molecular weight cutoffs, the average molecular weight of β-glucan was estimated to be 1.92×10^5 Da.

The FT-IR analysis of oat β-glucan was shown in Fig. 3. There were many peaks from 3399.31 cm^{-1} to 548.55 cm^{-1}, which demonstrated that oat β-glucan had typical polysaccharide absorption peak. The band at 3399.31 cm^{-1} region would be attributed to the stretching vibration of O—H in the constituent sugar residues (Kanmani et al., 2011). The band at 2921.31 cm^{-1} would be associated with the stretching vibration of C—H in the sugar ring. The band at 1643.67 cm^{-1} would be due to the stretching vibration of C=O and —CHO. The absorptions around 1365.74 cm^{-1} represented internal C—H deformation. The two strong absorptions at 1079.51 cm^{-1} and 1025.59 cm^{-1} would be dominated by glycosidic linkage C—O—C stretching vibration due to the different units of $(1 \rightarrow 3)$ and $(1 \rightarrow 4)$ in oat β-glucan (Shen, Lee, Lee, & Lee 2005). The bands at 1008 cm^{-1} and 986 cm^{-1} would be associated with the stretching vibration of C—O—H. Moreover, the absorption peak at 864 cm^{-1} was the stretching vibration of C—H in β-D-pyranose, which indicated oat β-glucan was a contained β-D-pyranose ring polysaccharide with β-glycosidic linkage.

4.2. Behavior, body weight and feed efficiency

All of the rats remained healthy, and there were no treatment-related changes in behavior or appearance in any of them during the experiment. The effects of β-glucan on body weight and feed efficiency of rats are presented in Table 2. There was no significant difference in the initial body weights among the groups. However, body weight gain in OG and OGE rats were significantly lower than those in the NC rats after a 7-week trial ($P < 0.05$), with the weight gain in the OGE group being the least significant ($P < 0.01$). In addition, compared to the NC group, rats in the OG and OGE groups had significant decrease in food efficiency ratio (FER). Compared to the NCE group, rats in the OGE group had significant decrease in body weight gain and FER ($P < 0.05$).

4.3. Effect of oat β-glucan on forced running capacity

The effect of β-glucan on forced running capacity, viz., the maximum running time, of rats is shown in Fig. 4. Rats with dietary supplementation significantly prolonged their running time to exhaustion ($P < 0.05$). In the NC group, the mean running time to exhaustion was 46.6 ± 3.8 min, while that in the NCE group was 56.1 ± 6.6 min to exhaustion, 20.4% longer than that in the NC group. However, there was no significant difference ($P > 0.05$). Additionally, the rats in OG and OGE groups could run for 69.7 ± 9.3 and 71.8 ± 4.8 min, which were 49.6% and 54.1%, longer than those in the NC group, respectively ($P < 0.05$).
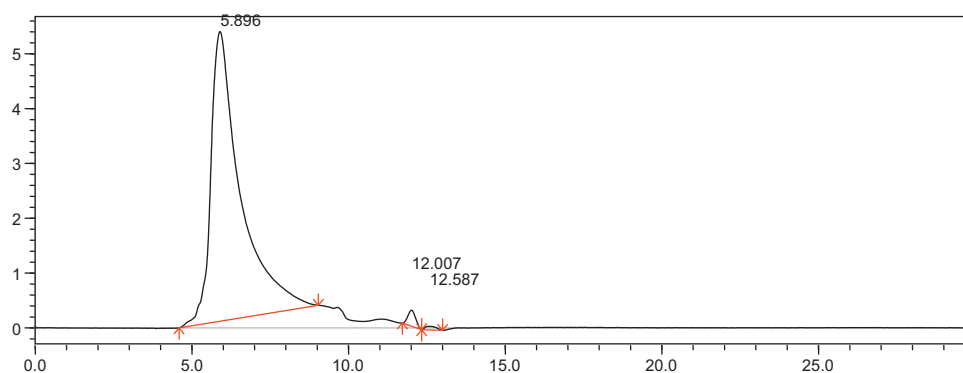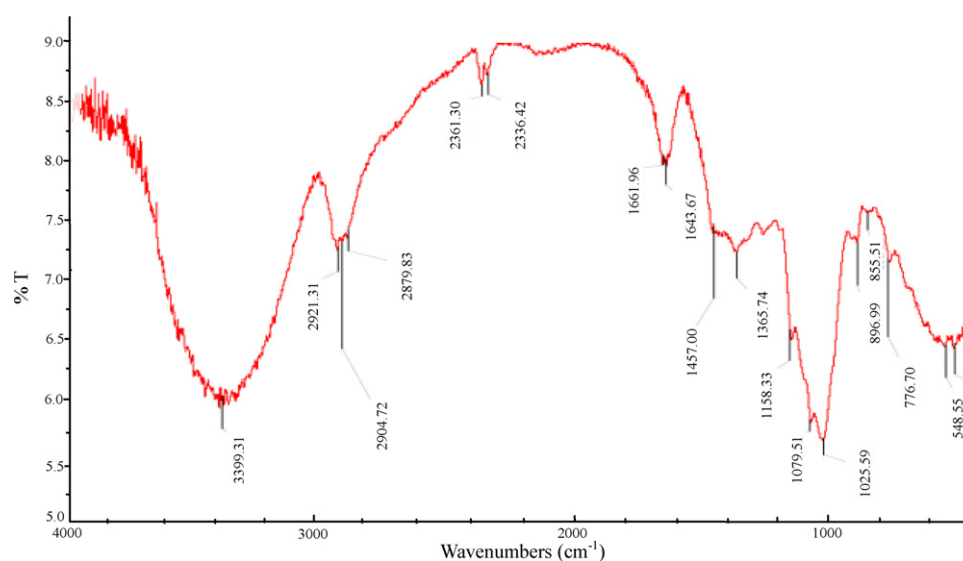
Fig. 2. HPLC analysis of oat β-glucan.

Fig. 3. FT-IR spectrums of oat β-glucan.

4.4. Effects of oat β-glucan on BUN, LA, and NEFA in blood serum

Compared to the NC group, rats in OG and OGE groups showed a significant reduction in BUN and LA after exercise ($P < 0.05$) (Table 3). As shown in Table 3, compared to the NC group, the BUN levels of the rats were significantly reduced by 17.5% and 24.1% in the OG and OGE group, respectively ($P < 0.05$). Also, the LA values of rats from these two groups had a similar trend in the BUN levels, which were significantly lower than those in other groups ($P < 0.01$). The NEFA content was significantly increased in rats supplemented with oat β-glucan in the OGE group ($P < 0.05$). Compared to the NCE group, rats in OGE as also showed a significant reduction in BUN and LA ($P < 0.05$). However, there was no difference in NEFA content.

4.5. Effects of oat β-glucan on glycogen contents of liver and gastrocnemius muscle

Post-exercise glycogen concentrations in the liver and gastrocnemius muscle are presented in Fig. 5. Compared to the NC group, rats in the OGE group had significantly higher glycogen levels ($P < 0.05$), which were 51.2 ± 11.6 mg/g in liver (Fig. 5a) and 1.9 ± 0.2 mg/g in gastrocnemius muscle (Fig. 5b), respectively. Also, the glycogen level in liver of rats in the OG group was significant higher than the levels of rats in the NC group ($P < 0.05$). However, there was no difference observed in muscle glycogen between rats in the OG and NC groups ($P > 0.05$).
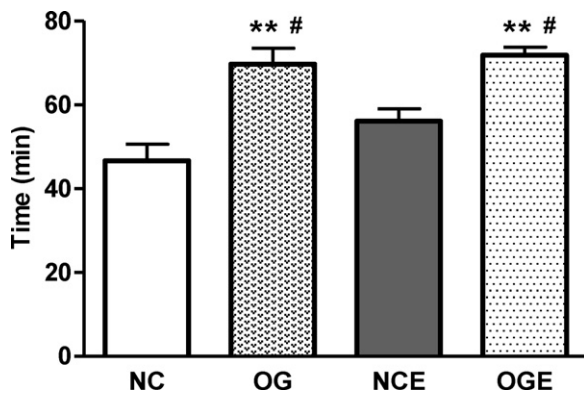
Table 2
Effects of oat β-glucan on body weight and feed efficiency in rats[a].

Body weight (g)	Group ($n = 8$)			
	NC	OG	NCE	OGE
Initial body weight	176.58 ± 4.61	181.49 ± 3.82	180.34 ± 2.92	183.72 ± 3.02
Final body weight	492.93 ± 16.12	$465.78 \pm 20.12^{*}$	483.35 ± 11.98	$458.16 \pm 19.92^{**,\#}$
Body weight gain	315.95 ± 16.56	$283.91 \pm 11.43^{*}$	303.08 ± 19.12	$274.87 \pm 16.56^{**,\#}$
Feed efficiency (g/g)	0.24 ± 0.036	$0.18 \pm 0.019^{*}$	0.22 ± 0.021	$0.17 \pm 0.025^{*,\#}$

[a] Data are mean $\pm$ SD ($n = 8$).
* Compared with NC group: $P < 0.05$.
** Compared with NC group: $P < 0.01$.
\# Compared with NCE group: $P < 0.05$.

Fig. 4. Effect of oat β-glucan on running time to exhaustion of rats.

Table 3
Effects of oat β-glucan on BUN, LA, and NEFA in blood serum of rats after treadmill task [a].

Group (n = 8)	BUN (mmol/L)	LA(mmol/L)	NEFA(μmol/L)
NC	40.34 ± 2.53	28.84 ± 0.79	38.26 ± 2.92
OG	33.28 ± 2.37[*]	20.37 ± 2.13[**,#]	48.87 ± 11.98
NCE	35.11 ± 1.74	26.62 ± 1.72	41.35 ± 19.12
OGE	30.64 ± 0.79[**,#]	15.81 ± 1.22[**,##]	52.92 ± 19.12[*]

[a] Data are mean ± SD values (n = 8).
[*] Compared with NC group: $P < 0.05$.
[**] Compared with NC group: $P < 0.01$.
[#] Compared with NCE group: $P < 0.05$.
[##] Compared with NCE group $P < 0.01$.

4.6. Effects of oat β-glucan on lactate dehydrogenase activity and creatine kinase activity

Serum lactate dehydrogenase and creatine kinase activity were also determined in order to evaluate the effects of oat β-glucan on the anti-fatigue capacity (Fig. 6). As shown in Fig. 6a, compared to the NC group, rats fed with β-glucan in the OG and OGE groups had significantly higher lactate dehydrogenase activities, 5789.4 ± 467.0 and 6112.3 ± 521.4 U/mL, respectively ($P < 0.01$). In addition, the lactate dehydrogenase activity in OGE group was significantly higher than that in the NCE group ($P < 0.05$). On the contrary, the creatine kinase activity in OG and OGE rats were found to be 594.49 ± 46.1 and 604.2 ± 30.7 U/L, respectively, which were significantly lower ($P < 0.01$) than those either in the NC or in the NCE group (Fig. 6b).

5. Discussion

In the present study, rats both in the OG and OGE group were fed with diets containing oat β-glucan and showed significant reduction in their weight gain. These decreases in body weight gain were associated with the significant reduction in FER, which could be attributed to the fact that oat β-glucan is a good source of soluble dietary fiber. It is well recognized that dietary fiber provides less energy and promotes satiation as a substitute for nutrients in diets (Lairon, 2007). In addition, it was also demonstrated that soluble dietary fibers can be easily swollen and hydrated in a small intestine and cause an increase in intestinal viscosity (Danielson, Newman, Newman, & Berardinelli, 1997), which could lead to a feeling of fullness in the stomach and slow down the absorption rate of nutrients while binding with dietary fat (Howarth, Saltzman, & Roberts, 2001; Robert, David, & Russell, 2004). Hence, high swelling powder and viscosity of oat β-glucan could contribute to the weight control process.

A direct measure of anti-fatigue effect is the increase in exercise tolerance. Running to exhaustion is an experimental exercise model which works well for evaluating the endurance capacity of rats and gives a high reproducibility (Hirai, Visneski, Kearns, Zelis, & Musch, 1994; Kirwan et al., 1998; Kuwahara et al., 2010). Reduced susceptibility to fatigue is correlated with longer running times (Fu et al., 2010). Our study found that OG and OGE with oat β-glucan treatments prolonged the running time of rats, indicating that oat β-glucan possess an anti-fatigue effect.

Serum urea nitrogen, a product of energy metabolism, is another sensitive index of fatigue status. The less an animal is adapted to exercise, the more the BUN level increases (Zhang, Yao, & Bao, 2006). The lower BUN levels observed in this study indicate the positive effect of oat β-glucan on enhancing endurance (Jia & Wu, 2008; Wang et al., 2008).

Lactate is produced by anaerobic glycolysis, which can be further degraded via the tricarboxylic acid cycle for the production of ATP by oxidative phosphorylation under normal circumstances (Katz & Sahlin, 1988). However, it is necessary to maintain the proper degree of acidity in the cell because the excessive accumulation of lactic acid may be a factor in fatigue (Jia & Wu, 2008). In a high-intensity exercise (intensive exercise period in Fig. 1), it was suggested that the increase in blood lactate and consequent lactic acidosis observed in skeletal muscles during exercise was a major cause of muscle fatigue. Therefore, the accumulation of serum LA is an important parameter of fatigue. Lower serum lactate concentration was observed in the OG and OGE rats, which presumably reflects a lower intramuscular lactate concentration and an increased relative contribution of aerobic metabolism to ATP production during an exercise session (Hsu, Ho, Lin, Su, & Hsu, 2005).

Increased fatty acid utilization during exercise reduces carbohydrate utilization, which leads to a decreased glycogen depletion rate and enhanced endurance exercise performance (Azevedo, Linderman, Lehman, & Brooks, 1998). We observed a significant increase in NEFA concentration in OG and OGE rats. This result indicates that oat β-glucan improves exercise capacity due to the enhanced availability of NEFA.
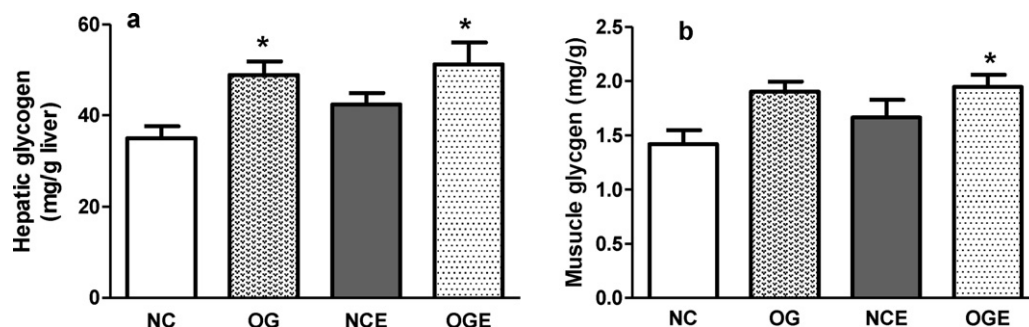

Fig. 5. Effects of oat β-glucan on glycogen contents of liver (a) and gastrocnemius muscle (b).
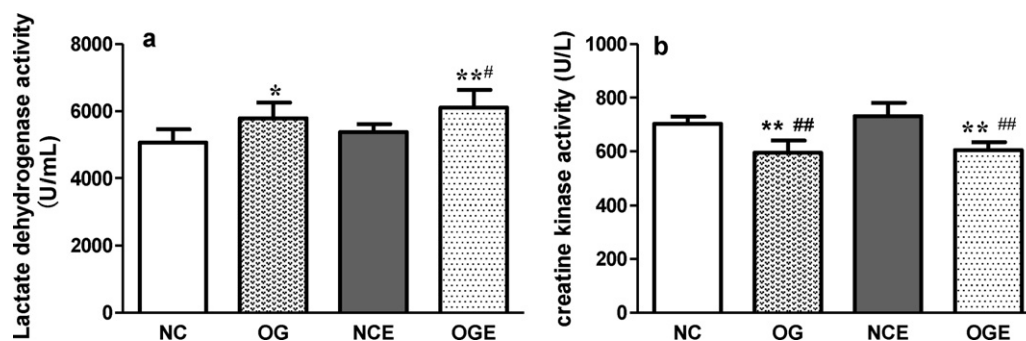
Fig. 6. Effects of oat β-glucan on lactate dehydrogenase activity (a) and creatine kinase activity (b).

The amount of energy stored as glycogen is of great significance in determining the capacity for prolonged strenuous exercise (Hermansen, Hultman, & Saltin, 1967; Pruett, 1970). When muscle glycogen stores are depleted during exercise, repletion of liver glycogen may be the rate-limiting factor in the restoration of the capacity for prolonged strenuous exercise. Repletion of glycogen stores takes longer in liver than in muscle (Terjung, Baldwin, Mole, Klinkerfuss, & Holloszy, 1972). Therefore, liver glycogen depletion might be an important factor in the development of fatigue. Results from this study showed that rats in the OG and OGE groups significantly increased their liver glycogen concentration, compared with NC rats, indicating oat β-glucan may take part in the improvement of metabolic control of exercise and the activation of energy metabolism (Wang, Shieh, Kuo, Lee, & Pan, 2006), which can enhance the exercise endurance by increasing the storage of liver glycogen. Nutritional supplementation with carbohydrate before exercise could have an unpredictable effect on exercise performance and muscle fatigue (Coyle, 1992; Wagenmakers et al., 1991), which were in good agreement with our present results.

LDH is known to be an accurate indicator of muscle damage as it catalyzes the interconversion of pyruvate and lactate (Kim, Park, Han, & Park, 2003). Our results showed that rats in OG and OGE had a higher level in LDH activity after exercise than those in the NC group. This suggests that oat β-glucan prevents fatigue by accelerating metabolic rate of lactic acid in muscle, and is also consistent with our observation that the rats fed oat β-glucan had a low LA level after exercise.

CK is known to be an accurate indicator of muscle damage. The normal function of CK in cells is to add a phosphate group to creatine, turning it into the high-energy molecule phosphocreatine. Majority of the CK normally exists in the muscle. However, during the process of muscle degeneration, the muscle cells lyse and their contents find their way into the bloodstream (Coombes & McNaughton, 2000). Thus, an increase in blood CK indicates that muscle damage has occurred or is occurring. Our study found that oat β-glucan could lower the value of CK activity in the serum of rats. This action further confirmed that oat β-glucan has the ability to delay fatigue of skeletal muscle.

6. Conclusion

In the present study, the effects of oat β-glucan on exercise endurance and its anti-fatigue properties were investigated. The results demonstrated that oat β-glucan prolonged the exhaustion running time, increased the levels of NEFA and glycogen in liver and skeletal muscle, and decreased the levels of BUN and LA. It also improved the serum LDH activity and decreased the CK activities in the rats. The results indicated that oat β-glucan can elevate the endurance capacity and facilitate recovery from fatigue. It may be used as a natural ingredient for the development of a dietary agent

to alleviate fatigue. Further research is needed to characterize its anti-fatigue mechanism(s) at the cellular and molecular levels.

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