

Nutritional value of *Lycium ruthenicum* Murr. and its relieving resistance to exercise-induced fatigue

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Summary. *Lycium ruthenicum* Murr. has high medicinal value. This paper mainly studied the nutritional value of *Lycium ruthenicum* Murr. and its alleviating resistance to exercise-induced fatigue. Firstly, the nutritional composition and value of *Lycium ruthenicum* Murr. were introduced briefly. Then the alleviating resistance of *Lycium ruthenicum* Murr. to exercise-induced fatigue was analyzed by swimming experiment in mice. The mice were divided into low, medium and high *Lycium ruthenicum* Murr. groups, and a blank group which took distilled water. Swimming experiment was conducted after 30 days of continuous feeding, and then the changes of blood sugar, lactic acid and glycogen in mice before, after exercise, after exercise and 30 minutes after exercise were compared. The results showed that 30 minutes after exercise, the group with high dose of *Lycium ruthenicum* Murr. had higher content of blood sugar, hepatic glycogen and muscle glycogen and lower content of lactic acid. The experimental results demonstrate that *Lycium ruthenicum* Murr. can increase blood sugar, reduce lactic acid content and increase glycogen reserve in mice, which has good alleviating resistance to exercise-induced fatigue.

Key word: *Lycium ruthenicum* Murr., nutritional value, exercise-induced fatigue, anti-fatigue

Introduction

Lycium ruthenicum Murr. is a perennial shrub which belongs to Solanaceae and Lycium (1), and its fruit is atropurpureus. It usually distributes in areas with high degree of salinization, such as the north-west area of China (2). It has strong resistance to high temperature, drought (3) and cold, showing extremely strong adaptivity (4), and it can prevent wind and fix sand, showing a high ecological value as a kind of shrub for controlling salinization and desertification. In addition, *Lycium ruthenicum* Murr. has functions of nourishing the liver and eyes, invigorating the kidney and benefiting the essence, and its nutritional value is much higher than that of Chinese wolfberry. It is a kind of medicinal and edible substance (5). Its chemical constituents and pharmacological effects have been extensively studied. Wang et al. (6) studied the anthocyanin content of *Lycium ruthenicum* Murr. from different areas and found that the total composition of

anthocyanin was the same, but the concentration of anthocyanin was significantly different, indicating that the regional environment would have a significant impact on anthocyanin. Duan et al. (7) studied the effects of *Lycium ruthenicum* Murr. on radiation damage of peripheral blood system in mice. Taking *Lycium ruthenicum* Murr. as a variable, mice were divided into different groups. Then the DNA, Caspase-3, Caspase-6 and P53 of mice were compared. The results showed that *Lycium ruthenicum* Murr. could significantly increase hemoglobin and DNA of mice and reduce the serum content of Caspase-3, Caspase-6 and P53, which showed that it could protect radiation damage. Peng et al. (8) analyzed the effect of lycium barbarum polysaccharide and found that LRGP3 could reduce cell inflammation through inhibiting TLR4/NF- κ B signal. Gong et al. (9) studied the immune regulation function of *Lycium ruthenicum* Murr. by injecting low, medium and high doses of *Lycium ruthenicum* Murr. into

mice and found that *Lycium ruthenicum Murr.* could promote the recovery of spleen and thymus indicators, enhance the phagocytic function of macrophages, and thus play an immunoregulatory role. In this study, the alleviating resistance of *Lycium ruthenicum Murr.* to exercise-induced fatigue was analyzed by swimming experiment in mice. The alleviating effect of *Lycium ruthenicum Murr.* on fatigue in mice was proved by comparing the blood sugar and lactic acid of different mice, which provides some theoretical bases for the further application of *Lycium ruthenicum Murr.* in alleviating fatigue.

Nutritional value of *Lycium ruthenicum Murr*

Nutritional components

Lycium ruthenicum Murr. contains abundant anthocyanin (10). It is the natural wild plant with the highest anthocyanin content. In *Lycium ruthenicum Murr.*, the content of polysaccharide is between 10% and 17%, and the content of flavone is about 2.71%; therefore it can reduce blood lipid and antioxidant (11). The content of protein is about 11%. The content of fat is about 5%–6%. *Lycium ruthenicum Murr.* contains abundant unsaturated fatty acids and rich minerals including macroelements such as sodium, magnesium and iron and microelements such as manganese, zinc and chromium; therefore it has anti-cancer efficacy.

Nutritional value

(1) Bacteriostasis and anti-inflammation

The ethanol and water extracts of *Lycium ruthenicum Murr.* have inhibitory effects on *Escherichia coli*, *Penicillium niger* and *Aspergillus niger*, and anthocyanin plays the main function. Anthocyanins can significantly inhibit the growth of *Escherichia coli* (12) and promote the abnormal growth of bacterial cells, leading to disintegration of bacteria.

(2) Prevention and treatment of diabetes mellitus

The main epitope of diabetes mellitus is persistent hyperglycemia. Polysaccharides in *Lycium ruthenicum Murr.* can alleviate the symptoms of diabetes mellitus to a certain extent and reduce blood sugar concentration. Flavone in *Lycium ruthenicum Murr.* also play a very good role in regulating blood lipids.

(3) Antioxidation

Aging is caused by free radicals produced by cell metabolism. Polyphenols, polysaccharides, anthocyanins and flavones in *Lycium ruthenicum Murr.* have scavenging effects on free radicals (13); therefore it can relieve aging, resist oxidation, and potentially prevent Alzheimer's disease (14).

(4) Improving immune function

Polysaccharides in *Lycium ruthenicum Murr.* can activate macrophages to promote its immune function.

(5) Anticancer

Anthocyanin can inhibit the growth of cancer cells and induce apoptosis of cancer cells. It can inhibit cancer by regulating the activity of enzymes.

(6) Fatigue resistance

Exercise-induced fatigue refers to a phenomenon that the body can not maintain the established intensity of exercise (15). After a long period of high-intensity exercise, the metabolism of the body will produce a large number of unstable free radicals, destroy human cells and tissues, consume a large amount of glycogen, and disturb blood sugar level; as a result, the body is in a serious hypoxic condition, lactic acid accumulates, muscle tissue is acidic, and body proteins are metabolized in large quantities, leading to the decrease of vitality of the body and exercise-induced fatigue. Exercise-induced fatigue will not only make athletes perform poorly, but also increase the risk of sports injury (16). Anthocyanins and flavones in *Lycium ruthenicum Murr.* can scavenge free radicals. Polysaccharides can increase glycogen reserves, supplement amino acids, stabilize blood sugar levels, and alleviate exercise-induced fatigue. In this study, the fatigue resistance of *Lycium ruthenicum Murr.* was studied in mice.

Relieving resistance of *Lycium ruthenicum Murr.* to exercise-induced fatigue

Experimental materials

Ninety-six specific pathogen free (SPF) mice with weight between 20 g and 22 g were purchased from the Animal Laboratory Center of Jilin University (license number: SCXK (Ji) 2013-0001). 600 g of *Lycium ruthenicum Murr.* which was purchased from Huirentang in Lanzhou, China was immersed in distilled water for

30 min and decocted twice with slow fire after adding ten times of distilled water, 0.5 h each time. The water decoction obtained was combined and condensed to 500 ml, i.e., concentration of 1.2 g/ml. Moreover liver glycogen, muscle glycogen and lactic acid reagent kits (Nanjing Jiancheng Bioengineering Institute, China), fully automatic biochemical analyzer (Beckmancoulter Company, USA) and centrifuge (Shanghai Precision Instrument Co., Ltd., China) and electronic balance, water box and swimming box from laboratory were also used. The temperature of the laboratory was between 20 °C and 25 °C.

Experimental methods

The ninety-six mice were randomly divided into four groups: low *Lycium ruthenicum Murr.* group (3 mg/g), middle *Lycium ruthenicum Murr.* group (6 mg/g), high *Lycium ruthenicum Murr.* group (12 mg/g) and blank group (0.2 mL/g distilled water). Each group was divided into a pre-exercise group, a post-exercise group and a post-exercise 30 minutes group with 8 mice in each group. The mice were fed for 30 days by means of gavage, once a day, and 20 minutes of swimming training was given every other day. One hour after the last time of feeding, the mice were placed in a swimming box with a diameter of 1 m and a water depth of 30 cm to swim for 40 minutes. Samples were taken immediately in the pre-exercise group, immediately after swimming in the post-exercise group and 30 minutes after swimming in the post-exercise 30 minutes group.

Observation indicators

(1) Blood sugar and lactic acid: 1.5 ml of orbital blood was taken and transferred to a 2 mL EP tube, and the serum was precipitated one night at 4 °C. Then the blood sugar and lactic acid were measured by the fully automatic biochemical analyzer.

(2) Liver glycogen and muscle glycogen: Mice were killed, and the liver and quadriceps femoris muscle were taken. The liver and quadriceps femoris muscle were washed and dried, and 1 g of tissue was cut into pieces and put into a tube which was loaded with 1.5 ml of 30 % KOH. After 15 min of boiling water bath, it was cooled and diluted to 100 ml. Then anthranone color developing agent was added, and colorimetric

assay was performed using a 721 spectrophotometer at the wavelength of 620 nm. The content of hepatic glycogen and muscle glycogen was calculated.

Statistical Analysis

The collected data were analyzed by SPSS17.0 software. When $P < 0.05$, it means that there was a statistically significant difference.

Experimental results

Effect of *Lycium ruthenicum Murr.* on blood sugar in mice

Figure 1 is a comparison of blood sugar values among groups. It can be seen from Figure 1 that before the experiment, there was no significant difference in the blood sugar of mice. After exercise, the blood sugar of each group decreased, and then recovered slightly 30 minutes after exercise, but there were significant differences among the groups. Firstly, after exercise, the blood sugar of the blank group was 6.34 ± 2.07 mmol/L, which was significantly lower than that before exercise. Compared with the blank group, the blood sugar of the low *Lycium ruthenicum Murr.* group was $P > 0.05$, but there were significant differences between the middle *Lycium ruthenicum Murr.* group and the high *Lycium ruthenicum Murr.* group ($P < 0.05$). There were also significant differences between the high *Lycium ruthenicum Murr.* group and the middle *Lycium ruthenicum Murr.* group. From the data of 30

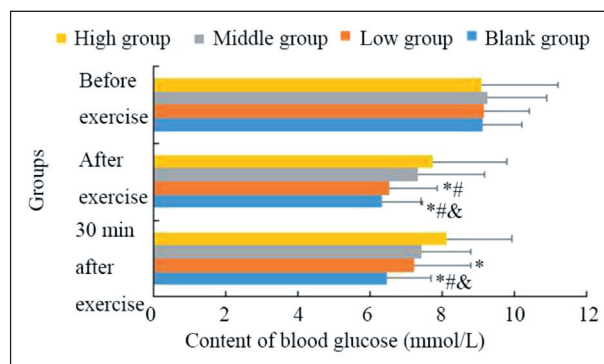


Figure 1. Effects of *Lycium ruthenicum Murr.* on blood sugar in mice
* indicated $P < 0.05$, compared with the blank group
indicated $P < 0.05$, compared with the low *Lycium ruthenicum Murr.* group
& indicated $P < 0.05$, compared with the middle *Lycium ruthenicum Murr.* group

minutes after exercise, there was significant difference between the *Lycium ruthenicum Murr.* group and the blank group in blood sugar values. The blood sugar rebound value of the *Lycium ruthenicum Murr.* groups was higher than that of the blank group. The blood sugar value of the high *Lycium ruthenicum Murr.* group was the highest, which was 8.12 ± 1.21 mmol/L. Compared with the other two groups, $P < 0.05$, indicating that the intake of *Lycium ruthenicum Murr.* could promote the recovery of blood sugar after fatigue in mice.

Effect of Lycium ruthenicum Murr. on blood lactic acid in mice

The blood lactic acid content of mice before exercise was about 4 mmol/L, which increased significantly after exercise. The blood lactic acid value of the blank group reached 11.36 ± 2.07 mmol/L, which was significantly higher than that of the mice which took

Lycium ruthenicum Murr.; the higher the content of *Lycium ruthenicum Murr.*, the lower the value of the blood lactic acid. The blood lactic acid value of the high *Lycium ruthenicum Murr.* group was the lowest, 8.27 ± 1.33 mmol/L, which was significantly different with the low and middle *Lycium ruthenicum Murr.* groups. 30 minutes after exercise, the blood lactic acid content of the *Lycium ruthenicum Murr.* groups was also significantly lower than that of the blank group, and the blood lactic acid content of the high *Lycium ruthenicum Murr.* group was 7.13 ± 1.21 mmol/L, which was significantly different with that of the other three groups ($P < 0.05$). It indicated that the supplementation of *Lycium ruthenicum Murr.* could significantly reduce the blood lactic acid content, thus alleviating fatigue.

Effects of Lycium ruthenicum Murr. on hepatic glycogen and muscle glycogen in mice

It was found from Table 1 that the content of liver glycogen and muscle glycogen in mice decreased due to exercise-induced fatigue, but gradually recovered 30 minutes after exercise. Firstly, in the comparison before exercise, the content of two glycogens in mice which took *Lycium ruthenicum Murr.* were higher than that in the blank group; the content of hepatic glycogen in the blank group before exercise were 4.42 ± 0.51 mmol/L, while that in the high *Lycium ruthenicum Murr.* group was 6.48 ± 0.41 mmol/L. After exercise, the content of hepatic glycogen in the blank group was 4.12 ± 0.27 mmol/L, while that in the *Lycium ruthenicum Murr.* groups were 3.95 ± 0.31 , 4.22 ± 0.29 and 4.89 ± 0.32 mmol/L, respectively, which were significantly higher than that in the blank group after exercise ($P < 0.05$).

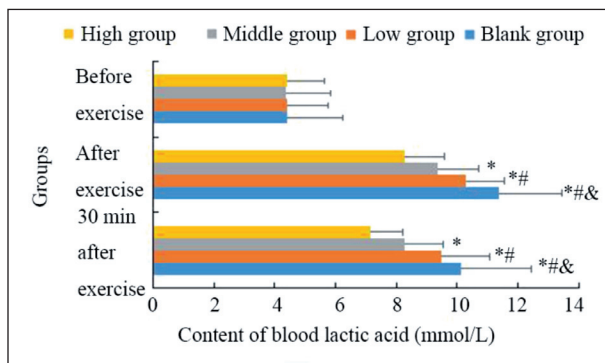


Figure 2. Effects of *Lycium ruthenicum Murr.* on blood lactic acid in mice
 * indicates $P < 0.05$, compared with the blank group,
 # indicates $P < 0.05$, compared with the low *Lycium ruthenicum Murr.* group
 & indicates $P < 0.05$, compared with the middle *Lycium ruthenicum Murr.* group

Table 1. Effects of *Lycium ruthenicum Murr.* on hepatic and muscular glycogen in mice (mmol/L)

		Blank group	Low <i>Lycium ruthenicum Murr.</i> group	Middle <i>Lycium ruthenicum Murr.</i> group	High <i>Lycium ruthenicum Murr.</i> group
Glycogen	Before exercise	4.42 ± 0.51	4.81 ± 0.44	$5.42 \pm 0.48^*$	$6.48 \pm 0.41^{\#}$
	After exercise	4.12 ± 0.27	3.95 ± 0.31	$4.22 \pm 0.29^*$	$4.89 \pm 0.32^{\#\&}$
	30 minutes after exercise	4.27 ± 0.12	4.01 ± 0.13	$4.54 \pm 0.11^*$	$5.31 \pm 0.14^{\#\&}$
Muscle glycogen	Before exercise	1.32 ± 0.08	1.41 ± 0.07	$1.83 \pm 0.09^*$	$2.34 \pm 0.11^{\#\&}$
	After exercise	1.24 ± 0.34	1.28 ± 0.36	$1.41 \pm 0.32^*$	$1.81 \pm 0.38^{\#\&}$
	30 minutes after exercise	1.31 ± 0.21	1.35 ± 0.23	$1.68 \pm 0.22^*$	$2.21 \pm 0.21^{\#\&}$

* indicates $P < 0.05$ compared with the blank group; # indicates $P < 0.05$ compared with the low *Lycium ruthenicum Murr.* group; & indicates $P < 0.05$ compared with the middle *Lycium ruthenicum Murr.* group

Similar results were found in the values 30 min after exercise, and the comparison of results of muscle glycogen was similar to that of liver glycogen. These findings suggested that the intake of *Lycium ruthenicum Murr.* could increase the content of liver glycogen and muscle glycogen in mice, thus achieving the function of anti-fatigue.

Discussion

Resistance of Lycium ruthenicum Murr. to exercise-induced fatigue

Lycium ruthenicum Murr. increased glycogen energy in mice *in vivo*, thus alleviating fatigue after swimming for 30 minutes. According to the mechanism of exercise-induced fatigue, *Lycium ruthenicum Murr.* increased the energy material reserve in mice, reduced the accumulation of blood lactic acid, and promoted the rise of blood sugar, so that the body can continue to exercise after vigorous exercise. It was found from the results that the more the intake of *Lycium ruthenicum Murr.*, the more obvious the alleviating resistance to exercise-induced fatigue. Taking 30 minutes after exercise as an example, the blood sugar content of the blank group was 6.47 ± 1.83 mmol/L, while that of the high *Lycium ruthenicum Murr.* group was 8.12 ± 1.21 mmol/L, which was significantly higher than that of the blank group, indicating that *Lycium ruthenicum Murr.* promoted the recovery of blood sugar in mice, thus helping mice recover from exercise-induced fatigue more quickly; the blood lactate content of the blank group was 10.12 ± 1.83 mmol/L 30 minutes after exercise, and that of the high *Lycium ruthenicum Murr.* group was 7.13 ± 1.21 mmol/L. *Lycium ruthenicum Murr.* can effectively reduce the production of blood lactic acid. Lactic acid accumulation may be one of the causes of exercise-induced fatigue, and the inhibition of *Lycium ruthenicum Murr.* on lactic acid alleviated exercise-induced fatigue in mice. The glycogen reserve in *Lycium ruthenicum Murr.* groups was always significantly higher than that in the blank group, indicating that *Lycium ruthenicum Murr.* could increase the glycogen content in mice to alleviate exercise-induced fatigue.

According to the experimental results, *Lycium ruthenicum Murr.* can increase glycogen reserve, pro-

mote blood sugar recovery and reduce lactic acid accumulation, thus achieving the alleviation of fatigue. Exercise-induced fatigue is similar to exercise-induced fatigue of mice. It can be inferred that *Lycium ruthenicum Murr.* as an anti-fatigue food has certain feasibility and it can improve the energy content of human body, stabilize blood sugar, reduce lactic acid, regulate metabolic substance, and increase glycogen reserve, so as to relieve fatigue of body.

Economic value analysis of Lycium ruthenicum Murr.

Lycium ruthenicum Murr. can be eaten raw, cooked or medicated. It has significant effect in reducing blood lipid and blood sugar. It can develop hypoglycemic products suitable for diabetic patients and obese people. It can be used for developing health food as it can regulate immune function and resist fatigue (17). Anthocyanin in *Lycium ruthenicum Murr.* can be used as natural colorant (18). It can also reduce the morbidity and mortality of cardiovascular and cerebrovascular diseases (19), protect the liver, regulate cholesterol, and inhibit lipid accumulation (20). In addition, *Lycium ruthenicum Murr.* as fodder has a high feeding value for animals such as camels and goats and plays a role in health care for livestock.

The role of *Lycium ruthenicum Murr.* in food and medicine suggests its great economic value. But at present, the yield of wild *Lycium ruthenicum Murr.* is low, the price is high, and the market penetration rate is not high. With the continuous excavation of value of *Lycium ruthenicum Murr.*, people's demand for *Lycium ruthenicum Murr.* has begun to increase. We can reasonably develop *Lycium ruthenicum Murr.* production areas, coordinate planting and processing, and develop ecological industries, which can not only protect the ecological functions of the western region, but also achieve sustainable economic development.

The alleviation of exercise-induced fatigue has attracted more and more attention. This study has proved that *Lycium ruthenicum Murr.* can alleviate exercise-induced fatigue in mice and achieved some results. In the future work, the application of *Lycium ruthenicum Murr.* as food and medicine will be further studied, and moreover the alleviation resistance of *Lycium ruthenicum Murr.* to human exercise-induced fatigue will be analyzed.

Conclusion

Lycium ruthenicum Murr., a kind of precious Chinese medicinal material, has functions such as resisting aging and fatigue, reducing blood lipid and lowering blood sugar. In this study, the alleviating resistance of *Lycium ruthenicum* Murr. to exercise-induced fatigue in mice was analyzed. It was found that *Lycium ruthenicum* Murr. could effectively promote the recovery of blood sugar, reduce the production of lactic acid, and increase the glycogen reserve in mice, so as to alleviate the fatigue of mice caused by intense exercise.

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