Antioxidant activity of *Lactobacillus plantarum* strains isolated from traditional Chinese fermented foods

Shengyu Li, Yujuan Zhao, Li Zhang, Xue Zhang, Li Huang, Da Li, Chunhua Niu, Zhennai Yang, Qiang Wang

**Abstract**

Eleven *Lactobacillus plantarum* strains isolated from traditional Chinese fermented foods were investigated for their *in vitro* scavenging activity against hydroxyl and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radicals, and their resistance to hydrogen peroxide. *L. plantarum* C88 at a dose of 10^10 CFU/ml showed the highest hydroxyl radical and DPPH scavenging activities, with inhibition rates of 44.31% and 53.05%, respectively. Resistance of intact cells to hydrogen peroxide was also found in all strains. *L. plantarum* C88 was the most resistant strain against hydrogen peroxide. When *L. plantarum* C88 was administered to senescent mice suffering oxidative stress induced by D-galactose, the serum superoxide dismutase activity and both its lysates and intact cells were capable of increasing the glutathione redox ratio in blood sera, and improving antioxidative systems are generally not enough to prevent the living organisms from oxidative damage. Antioxidant treatments using substances that delay or prevent the oxidation of cellular substrates have shown the potential to help the human body reduce oxidative damage. Although several synthetic antioxidants including butylated hydroxyanisole and butylated hydroxytoluene have been widely used in retarding lipid oxidation, their safety has recently been questioned, due to liver damage and carcinogenicity (Luo & Fang, 2008). Therefore, exploitation of safer, natural antioxidants from bio-resources that can replace synthetic antioxidants has received a great deal of attention in recent years.

Lactic acid bacteria (LAB) are Gram-positive bacteria, widely distributed in nature, and industrially important as they are used in a variety of industrial food fermentations. The potential benefits of LAB for human health include stimulation of the immune system, balancing intestinal flora, reducing serum cholesterol, and reducing the risk of tumours, etc. Lately, some LAB strains have been found with other important biological functions, such as anti-ageing and antioxidant activities (Ayeni et al., 2011; Kuda, Kaneko, Yano, & Mori, 2010; Lee et al., 2010). *Lactobacillus rhamnosus* GG was found to inhibit lipid peroxidation *in vitro* due to iron chelation and superoxide anion scavenging ability (Abotupa, Saxelin, & Korpela, 1996). *Lactobacillus fermentum* ME-3 isolated from a healthy Estonian child possessed Mn-superoxide dismutase activity and both its lysates and intact cells were capable of increasing the glutathione redox ratio in blood sera, and improving...
the composition of the low-density lipids (LDL) and post-prandial lipids (Mikelsaar & Zilmer, 2009). A fermented sea tangle solution with Lactobacillus brevis BJ20 exhibited strong DPPH scavenging, superoxide radical scavenging, and xanthine oxidase inhibition activities in vitro (Lee et al., 2010). Probiotic Lactobacillus casei Zhang was shown to alleviate oxidative stress by reducing lipid peroxidation and improving lipid metabolism both in blood and liver (Zhang, Du, Wang, & Zhang, 2010). Lactobacillus plantarum 7FM10 isolated from the traditional Japanese food narezushi exhibited DPPH and superoxide radical scavenging capacities (Kanno, Kuda, An, Takahashi, & Kimura, 2012).

Fermented products have been consumed for thousands of years in China. As the number who consume traditional Chinese fermented foods is increasing, there is an increasing interest in enhancing food safety, improving organoleptic attributes, enriching nutrients, and increasing health benefits (Liu, Han, & Zhou, 2011). These functional properties have partly been ascribed to the higher antioxidant properties of LAB involved in many fermentation processes of traditional Chinese foods (Huang, Lai, & Chou, 2011; Wang et al., 2008). So far, little attention has been paid to the antioxidant activities of L. plantarum strains isolated from traditional Chinese products. Therefore, in the present study, the potential antioxidant activity of 11 L. plantarum strains isolated from traditional Chinese fermented foods was examined for their in vitro scavenging activity against hydroxyl and DPPH free radicals, and for their resistance to hydrogen peroxide. The in vivo antioxidant effect of a selected antioxidant L. plantarum strain chosen as a result of the in vitro tests was further studied in terms of certain antioxidant enzyme activities and lipid peroxidation levels, using model mice suffering oxidative stress induced by D-galactose to explore underlying molecular mechanisms.

2. Materials and methods

2.1. Bacterial strains

Eleven Lactobacillus strains were used in this study, including 2 strains (C88 and C10) isolated from traditional fermented dairy tofu in Inner Mongolia of China (Zhang, Li, Zhao, Niu, & Yang, 2010), 8 strains (S7-2, S5-2, S6-1, S3-8, S4-5, S2-5, S5-6 and S4-2) from naturally fermented sauerkraut obtained from local families in the northeast region of China (Wang, Zhang, Li, Niu, & Yang, 2010), and a strain (K25) from Tibetan Kefir grains (Wang et al., 2012). Bacteria isolated from these naturally fermented products were identified using the method described earlier (Wu et al., 2009). All the strains were identified as L. plantarum by API 50 CHL kit (bioMérieux Inc., Marcy l’Etoile, France) and 16S rDNA sequencing analysis. These strains were maintained as frozen (−80 °C) stocks in MRS broth supplemented with 20% (v/v) glycerol. They were transferred at least three times consecutively using a 1% (v/v) inoculum in MRS broth at 37 °C for 18 h before use.

2.2. In vitro determination of antioxidant activity of L. plantarum strains

2.2.1. Preparation of cells and intracellular cell-free extracts

The 11 L. plantarum strains were grown in MRS broth at 37 °C for 18 h. The bacterial cells were harvested by centrifugation (6000g, 10 min, 4 °C), washed twice with deionised water and resuspended in deionised water. The bacterial counts in the cell pellet were adjusted to 10^7, 10^8 and 10^9 CFU/ml. The intracellular cell-free extracts were prepared by the method of Lin and Yen (1999) with minor modifications. The cells (10^8, 10^9 or 10^10 CFU/ml) were incubated with 1 mg/ml lysozyme at 37 °C for 30 min followed by ultrasonic disruption (JY92-IIIDN, Ningbo Scientz Biotechnology Co. Ltd., China). Sonication was performed for five 1-min intervals in an ice bath. After removing the cell debris by centrifugation (8000g, 10 min, 4 °C), the resulting supernatant was obtained as the intracellular cell-free extract of the L. plantarum strains.

2.2.2. Resistance to hydrogen peroxide

The method of Buchmeier et al. (1997) was used with some modifications. The overnight cultures of the L. plantarum strains were inoculated at 1% (v/v) into MRS broth and MRS broth containing 0.4, 0.7 or 1.0 mM hydrogen peroxide (30 wt.% solution in water, Sigma–Aldrich Chemicals, Steinheim, Germany), and incubated at 37 °C for 8 h. The cell growth was measured spectrophotometrically (Cary 300 UV–Vis, Varian Inc., Palo Alto, CA) at 600 nm. Results were given as optical density (OD).

2.2.3. Scavenging of hydroxyl radical

The hydroxyl radical scavenging assay was conducted by a Fenton reaction method (He, Luo, Cao, & Cui, 2004). Briefly, the reaction mixture containing 1.0 ml of brilliant green (0.435 mM), 2.0 ml of FeSO4 (0.5 mM), 1.5 ml of H2O2 (3.0%, w/v), and 1.0 ml of intracellular cell-free extract in different concentrations was incubated at room temperature for 20 min, and the absorbance was measured at 624 nm. The absorbance change of the reaction mixture indicated the scavenging ability of the L. plantarum strains for hydroxyl radicals. Hydroxyl radical scavenging activity is expressed as:

Scavenging activity (%)=\left[\frac{(A - A_0)}{(A_{blank} - A_0)}\right] \times 100

where A is the absorbance in the presence of the sample, A_0 is the absorbance of the control in the absence of the sample, and A_{blank} is the absorbance without the sample and Fenton reaction system.

2.2.4. Scavenging of DPPH free radical

The DPPH radical-scavenging capacity of L. plantarum was determined according to the method described by Kao and Chen (2006) with some modifications. Briefly, 1.0 ml of L. plantarum cells with 10^7 or 10^10 CFU/ml, was added to 2.0 ml ethanolic DPPH radical solution (0.05 mM). The mixture was mixed vigorously and incubated at room temperature in the dark for 30 min. The controls included only deionised water and DPPH solution. The blanks contained only ethanol and the cells. The absorbance of the resulting solution was measured in triplicate at 517 nm after centrifugation at 8000g for 10 min. The scavenging ability was defined as:

Scavenging activity (%)=\left[1 - \frac{(A_{blank} - A_{control})}{(A_{sample} - A_{blank})}\right] \times 100

The scavenging ability of the L. plantarum strains for DPPH free radical was also evaluated considering the cell surface properties of the strains by the method of Kos et al. (2003) with some modifications. Briefly, the overnight culture of a selected strain with good antioxidant activity was centrifuged (6000g, 10 min), and the cell pellet was washed twice with distilled water and resuspended in phosphate buffered saline (pH 7.0) to approximately 10^{10} CFU/ml. The cell suspensions were added with trypsin (0.5 mg/ml), pepsin (0.5 mg/ml), or protease K (0.5 mg/ml) for hydrolysing cell surface proteins, with metaperiodate (10 g/l) for oxidising surface polysaccharides, and with LiCl (5 M) for removing S-layer proteins. The mixture was incubated at 37 °C for 30 min and centrifuged (6000g, 10 min) to remove supernatant. Then, the bacterial cells were washed twice with PBS and resuspended in PBS for the assay of the DPPH free radical scavenging ability of the strains.
2.3. In vivo assessment of antioxidant effects of the L. plantarum strains on d-galactose-induced ageing mice

2.3.1. Animals and administration
All experimental procedures were performed following the requirements of the Provisions and General Recommendations of Chinese Experimental Animal Administration Legislation. Six-week-old male Kunming mice with body weights of 18–22 g were purchased from the Experimental Research Center of Animal Medicine (Changchun, China). Animals were housed under standard conditions (25 °C, 12 h light/dark cycle), and were allowed free access to food and water during the experimental period.

On the basis of the in vitro antioxidant activity assay, one L. plantarum strain with good antioxidant activity was selected for further in vivo assessment of antioxidant effect on d-galactose-induced ageing mice using the procedure described below. After one week acclimatisation to the laboratory environment, mice were randomly divided into five groups of 10 each. Mice of normal control and d-galactose (d-gal) model group were administered by oral gavage with normal saline at a dose of 20 ml/kg body weight once daily, and mice of positive group were treated by vitamin E (1.0 mg/ml, w/v) at the same dose and frequency. Mice of high- and low-dose groups were treated by oral gavage with the selected L. plantarum strain at a dose of 4.0 × 10^10 and 4.0 × 10^8 CFU/d once daily, respectively. The ageing model was induced by subcutaneous injection with 5% (w/v) d-gal dissolved in normal saline at a dose of 500 mg/kg body weight once daily for 6 weeks, while the mice in the control group were treated with the same volume of sterile normal saline.

Twenty-four hours after the final administration, mice were anaesthetised with ether and blood samples were collected from each treatment group. Serum samples were obtained by centrifugation (3000g, 10 min, 4 °C) and stored at −80 °C for further analysis. The brains, spleens, kidneys, hearts, and livers were weighed and their weights relative to the final body weights (organ index) were calculated. Ten percent liver and brain homogenates were obtained by homogenising frozen liver and brain tissue in cold normal saline. The homogenates were then centrifuged at 3000 g for 10 min at 4 °C, and the protein concentration was determined by Lowry's method.

2.3.2. Biochemical assays
Malondialdehyde (MDA) levels, glutathione peroxidase (GSH-Px) activities and total antioxidant capacity (T-AOC) in liver, and superoxide dismutase (SOD) activities in serum were all determined spectrophotometrically using commercially available assay kits (Nanjing Jiancheng Bioengineering Institute, China) following the manufacturer's protocols: the thiobarbituric acid method for MDA levels, 5,5'-dithiobis-p-nitrobenzoic acid method for GSH-Px activity in the cytosolic fraction of organs, the method of ferric reducing/antioxidant power assay for T-AOC, the auto-oxidation of hydroxylamine assay at 560 nm for SOD activity. Enzyme activity was expressed as nanomoles per milligram protein.

2.4. Statistical analysis
Tests were carried out in triplicate for all experiments. All data were presented as mean ± standard deviations (S.D). Statistical comparisons were made using the statistical software package SPSS 12.0. Significant differences between treatments were tested by analysis of variance (ANOVA) followed by a comparison between treatments performed using Fisher’s least significance difference (LSD) method, with levels of significance of p < 0.05 and p < 0.01.

3. Results

3.1. In vitro antioxidant activity of L. plantarum strains

3.1.1. Scavenging of hydroxyl radical with intracellular cell-free-extracts

The results of scavenging for hydroxyl radical with the intracellular cell-free extracts of the 11 L. plantarum strains are shown in Fig. 1. All the strains demonstrated hydroxyl radical scavenging activity in a dose-dependent manner within the test concentration range of 10^6–10^10 CFU/ml. Among the 11 strains tested, L. plantarum C88 had the highest hydroxyl radical scavenging ability with an inhibition rate of 44.31% at 10^10 CFU/ml. L. plantarum strains C10, S3-8, S4-5, and K25 also scavenged hydroxyl radical well.

3.1.2. Resistance of intact cells to hydrogen peroxide

The effect of hydrogen peroxide on the viability of the L. plantarum strains is shown in Table 1. The growth pattern of these strains as influenced by hydrogen peroxide was compared with the control groups. All 11 strains showed tolerance to 0.4 mM hydrogen peroxide for 8 h, despite variations in the degree of viability. Strains C88, C10 and K25 were the most resistant strains against hydrogen peroxide, with optical densities more than 0.7 after incubation for 8 h with 1.0 mM hydrogen peroxide, while strains S5-2, S5-6 and S7-2 were the most sensitive.

3.1.3. DPPH radical scavenging activity

The DPPH free radical scavenging activity of the L. plantarum strains measured at 10^10 and 10^9 CFU/ml is shown in Fig. 2. L. plantarum C88 had the highest radical-scavenging activity (53.05%), followed by L. plantarum C10, S3-8, S5-6, and K25 at a dose of 10^10 CFU/ml. However, all the strains showed lower DPPH radical-scavenging activities at the dose of 10^9 CFU/ml. L. plantarum C88 was further subjected to different treatments to characterise the cell surface components responsible for its DPPH radical-scavenging ability. Fig. 3 shows that the DPPH radical-scavenging activity of L. plantarum C88 decreased significantly after enzymatic and chemical treatments of the bacterial cells. Metaperiodate treatment of L. plantarum C88 for oxidising cell surface carbohydrates resulted in the lowest radical scavenging activity of all the treatments. Moreover, when the surface proteins were removed by 5.0 M LiCl, the DPPH radical-scavenging activity of L. plantarum C88 was decreased markedly (Fig. 3).

Fig. 1. Scavenging activities on hydroxyl radicals using different concentrations of intracellular cell-free extracts of L. plantarum strains incubated at 37 °C for 18 h. Each value is expressed as mean ± S.D (n = 3).
Table 1  
Resistance of *L. plantarum* strains at different hydrogen peroxide concentrations.

<table>
<thead>
<tr>
<th>Strains</th>
<th>Hydrogen peroxide (mM)</th>
<th>0</th>
<th>0.4</th>
<th>0.7</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>C10</td>
<td>2.50 ± 0.15</td>
<td>2.04 ± 0.03</td>
<td>1.37 ± 0.04</td>
<td>0.70 ± 0.10</td>
<td></td>
</tr>
<tr>
<td>C88</td>
<td>2.53 ± 0.07</td>
<td>2.09 ± 0.14</td>
<td>1.40 ± 0.06</td>
<td>0.74 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>S2-5</td>
<td>2.47 ± 0.09</td>
<td>1.87 ± 0.11</td>
<td>1.15 ± 0.13</td>
<td>0.66 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>S3-8</td>
<td>2.50 ± 0.05</td>
<td>1.92 ± 0.07</td>
<td>1.36 ± 0.09</td>
<td>0.60 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>S4-2</td>
<td>2.53 ± 0.07</td>
<td>1.77 ± 0.12</td>
<td>1.07 ± 0.16</td>
<td>0.51 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>S4-5</td>
<td>2.47 ± 0.14</td>
<td>1.93 ± 0.07</td>
<td>1.37 ± 0.07</td>
<td>0.55 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>S5-2</td>
<td>2.47 ± 0.06</td>
<td>1.98 ± 0.08</td>
<td>1.23 ± 0.11</td>
<td>0.44 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>S5-5</td>
<td>2.48 ± 0.09</td>
<td>1.92 ± 0.10</td>
<td>1.36 ± 0.08</td>
<td>0.45 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>S6-1</td>
<td>2.48 ± 0.11</td>
<td>1.93 ± 0.12</td>
<td>1.22 ± 0.13</td>
<td>0.61 ± 0.07</td>
<td></td>
</tr>
<tr>
<td>S7-2</td>
<td>2.49 ± 0.08</td>
<td>1.98 ± 0.16</td>
<td>1.20 ± 0.05</td>
<td>0.45 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>K25</td>
<td>2.47 ± 0.03</td>
<td>2.03 ± 0.08</td>
<td>1.38 ± 0.12</td>
<td>0.71 ± 0.03</td>
<td></td>
</tr>
</tbody>
</table>

Growth of *L. plantarum* strains was determined by measuring absorbance at a wavelength of 600 nm after 8 h incubation at 37 °C. The results are expressed as mean ± S.D.; each data point is the average of 3 independently replicated experiments (n = 3). Different means in the same column followed by different superscripts are significantly different (p < 0.05).

3.2. Effect of administration of *L. plantarum* C88 on *d-gal*-induced ageing mice

3.2.1. Change of general appearance, body weight and organ index

Among the 11 *L. plantarum* strains, strain C88 with good in vitro antioxidant properties was further subjected to in vivo studies using senescent mice suffering oxidative stress induced by *d-gal*. Compared with that of normal control mice, the hair of the *d-gal* model group ones gradually lost elasticity and became brittle; the skin became thin and sagged little by little. Table 2 shows that the body weight of the *d-gal* model mice was significantly lower than that of the mice administrated with strain C88. The spleen index (0.37) of the *d-gal* model mice decreased significantly (p < 0.05) as compared with the normal control group and the C88-treated mice (0.42–0.44). However, there was no significant difference in liver, heart, and kidney indices between C88-treated and *d-gal* model mice (p > 0.05).

3.2.2. Effect on antioxidative status of *d-gal*-induced ageing mice

The effect of administration with *L. plantarum* C88 on the antioxidative status of the *d-gal*-treated mice was shown in Table 3. Compared to the *d-gal* model group, the MDA levels in the liver of the high- and low-dose C88 groups decreased significantly (p < 0.05) in a dose-dependent manner, and they reached almost the same level as the normal control group at the *L. plantarum* C88 dose of 4.0 × 10^10 CFU/d. There was no significant difference between the high-dose C88 group and the vitamin E group, indicating successful blocking of lipid oxidation in liver by strain C88. *d-Gal* treatment of mice resulted in a severe decrease of the SOD activity in serum, but administration with *L. plantarum* C88 at both low and high doses attenuated the decrease of the antioxidative enzyme, and caused a subsequent recovery towards normality. Similarly, *L. plantarum* C88 was also able to increase the GSH-Px activity in liver in a dose-dependent manner compared to the *d-gal* model (p < 0.05). Upregulation of GSH-Px activities by *L. plantarum* C88 at a dose of 4.0 × 10^10 CFU/d was comparable to that observed for the *d-gal* model group.

The T-AOC activities in liver of the *d-gal* model group mice decreased significantly (p < 0.05) compared to the normal control group. Administration with *L. plantarum* C88 significantly (p < 0.05) enhanced the T-AOC activities in mice when compared to *d-gal* model animals. The level of T-AOC at the C88 dose of 4.0 × 10^10 CFU/d showed the largest increase, almost reaching the level of the normal control group.

4. Discussion

Hydroxyl radical has been reported to be the most harmful ROS that is responsible for the oxidative injury of biomolecules, and it is mainly originated from Fenton reaction in the presence of transition metals such as iron (Fe^{2+}) and copper (Cu^{2+}). Chelation of these ions by certain antioxidants may inhibit the generation of hydroxyl radicals (Kao & Chen, 2006). Some LAB strains, such as *Streptococcus thermophilus* 821 (Lin & Yen, 1999), *Bifidobacterium longum* 15708 (Lin & Yen, 1999), and *L. casei* KCTC 3260 (Lee, Hwang, Chung, Cho, & Park, 2005), were reported to possess antioxidative activity by removing transition metal ions that might otherwise participate in hydroxyl-radical-generating Fenton-type reactions. In this study, the intracellular cell-free extracts of *L. plantarum* C88, C10, and K25 showed strong hydroxyl radical scavenging activity (Fig. 1), probably due to their capability of chelating metal ions such as Fe^{2+} (data not shown).

Compared with hydroxyl radical, hydrogen peroxide is a weak oxidant, but it may give rise to hydroxyl radical that causes oxida-
The present study further confirmed that the cell-surface proteins RH (Xu, Shen, Ding, Gao, & Li, 2011), and lipoteichoic acid from the cell surface of bifidobacteria (Yi, Fu, Li, Gao, & Zhang, 2009). The cell-surface compounds of LAB might ameliorate the synthesis of essential antioxidant enzymes, including SOD, GSH-Px, and hepatic catalase.

The cell-surface compounds, including SOD, GSH-Px, and hepatic catalase, are important buffers in the non-enzymatic antioxidant defence system. Several antioxidant enzyme activities (Hsieh, Wu, & Hu, 2011). In this study, administration with L. plantarum C88 was found to improve the antioxidant status of the oral-gal-induced oxidative stress mice in terms of the MDA levels, GSH-Px activities and T-AOC activities in liver, and serum SOD activities (Table 3). As an end product of lipid peroxidation, MDA could react with biomolecules and exert cytotoxic and genotoxic effects, and the levels of MDA are often used as an indicator of oxidative damage and ageing in an organism. We found significantly decreased levels of liver MDA in the L. plantarum C88 groups compared to the oral-gal model group, and the liver MDA level of the high dose (4.0 × 10⁶ CFU/d) group recovered to normal levels (Table 3). Other in vivo research showed that MDA levels in serum and muscle were reduced for pigs fed with L. fermentum compared with a basal diet (Wang et al., 2009). Supplementation of L. casei Zhang greatly decreased MDA levels both in serum and liver of hyperlipidemic rats (Zhang, Du et al., 2010). SOD and GSH-Px are intracellular antioxidant enzymes that protect against oxidative stress (Bhatia, Shukla, Venkata Madhu, Kaur Gambhir, & Madhava Prabh, 2003).

D-Gal injection to induce oxidative stress in model animals was employed previously for studying ageing-related changes due to increased production of free radicals and decreased antioxidant enzyme activities (Hsiieh, Wu, & Hu, 2011). In this study, administration with L. plantarum C88 was found to improve the antioxidant status of the oral-gal-induced oxidative stress mice in terms of the MDA levels, GSH-Px activities and T-AOC activities in liver, and serum SOD activities (Table 3). As an end product of lipid peroxidation, MDA could react with biomolecules and exert cytotoxic and genotoxic effects, and the levels of MDA are often used as an indicator of oxidative damage and ageing in an organism. We found significantly decreased levels of liver MDA in the L. plantarum C88 groups compared to the oral-gal model group, and the liver MDA level of the high dose (4.0 × 10⁶ CFU/d) group recovered to normal levels (Table 3). Other in vivo research showed that MDA levels in serum and muscle were reduced for pigs fed with L. fermentum compared with a basal diet (Wang et al., 2009). Supplementation of L. casei Zhang greatly decreased MDA levels both in serum and liver of hyperlipidemic rats (Zhang, Du et al., 2010). SOD and GSH-Px are intracellular antioxidant enzymes that protect against oxidative stress (Bhatia, Shukla, Venkata Madhu, Kaur Gambhir, & Madhava Prabh, 2003).

The total antioxidant capacity (T-AOC) reflects the capacity of the non-enzymatic antioxidant defence system. Several antioxidant enzymes, including SOD and GSH-Px are important buffers in the interception and degradation of superoxide anion and hydrogen peroxide. Our study indicated that administration of L. plantarum C88 could enhance the levels of SOD and GSH-Px in oral-gal treated mice. Similarly, Wang et al. (2009) reported that L. fermentum could keep normal pigs growing healthily through increasing antioxidant enzymes, including SOD, GSH-Px, and hepatic catalase. L. casei Zhang possessed a favourable antioxidative capacity on hyperlipidemic rats (Zhang, Du et al., 2010). SOD and GSH-Px are intracellular antioxidant enzymes that protect against oxidative stress (Bhatia, Shukla, Venkata Madhu, Kaur Gambhir, & Madhava Prabh, 2003).

In conclusion, the antioxidant activity of L. plantarum C88 isolated from traditional Chinese fermented foods was demonstrated by using both in vitro and in vivo methods. The in vitro results indicated that L. plantarum C88 had strong hydroxyl radical and DPPH free radical scavenging activity, and hydrogen peroxide...
resistant ability. The in vivo results indicated that administration of *L. plantarum* C88 improved significantly the antioxidant status of the α-gal-induced oxidatively stressed mice through the obvious improvement in antioxidant indices, including MDA levels, SOD, GSH-Px, and T-AOC activities. Therefore, *L. plantarum* C88 could be considered as a potential antioxidant strain to be applied in functional foods, but further investigation is needed on the mechanism responsible for the varying degrees of antioxidant activity of different *L. plantarum* strains.

Acknowledgements

The financial support for this work from Natural Science Foundation of China (31071574), China Agriculture Research Systems (CARS-37), and National Public Benefit Research (Agriculture) Foundation (200903043) is gratefully acknowledged.

References


