Antioxidant effects of live and heat-killed probiotic *Lactobacillus plantarum* Ln1 isolated from kimchi

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Abstract The aim of this study was to evaluate the probiotic properties of *Lactobacillus plantarum* Ln1 isolated from kimchi and the antioxidant activities of live and heat-killed cells. *L. plantarum* KCTC 3108, which has been used as a commercial probiotic strain, was used as a control. *L. plantarum* strains (Ln1 and KCTC 3108) can survive under artificial gastric conditions (pH 2.5 in 0.3% pepsin for 3 h and 0.3% oxgall for 24 h), and adhere strongly to HT-29 cells. In addition, *L. plantarum* Ln1 did not produce carcinogenic β -glucuronidase, whereas it showed a higher β -galactosidase production of 3067.42 mU/mL. The antioxidant activity of *L. plantarum* Ln1 was assessed using the 2,2-diphenyl-1-picryl-hydrazyl (DPPH) and 2,2'-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) radical scavenging, β -carotene and linoleic acid inhibition, and reducing power assays. In all these methods, live *L. plantarum* Ln1 showed a higher antioxidant activity than the control strain. In heat-killed cells of *L. plantarum* Ln1, β -carotene bleaching inhibitory activity and reducing power was higher than DPPH and ABTS radical scavenging activity. These results suggested that live or heat-killed *L. plantarum* Ln1 isolated from kimchi might be useful as an antioxidant probiotic.

Keywords *Lactobacillus plantarum* · β -Galactosidase activity · Antioxidant activity · Live probiotic · Heat-killed probiotic

Introduction

The term “probiotic” is defined as live microorganisms that, when administered at an adequate dose, confer a health benefits to the host (Basholli-Salihi et al. 2014). Probiotics have been reported to have several positive and long-lasting beneficial effects on human health (Cuello-Garcia et al. 2015; Park and Bae 2015). Previous studies have reported that probiotics have anticancer, antioxidant, antiallergy, blood lipids reducing, and immune function enhancing activities (Lee et al. 2014; Son et al. 2017). There has recently been a growing interest in heat-killed lactic acid bacteria (LAB), since they can be stored for a longer time and transported more easily than live LAB. Therefore, heat-killed probiotics are readily available as probiotic food ingredients. However, the functionality of heat-killed probiotics is limited in terms of their immune effects (Adams 2010).

Kimchi is a traditional Korean fermented healthy food made from Chinese cabbage with salt, red pepper, garlic, and green onion. Kimchi contains biologically active components including flavonoids, polyphenols, vitamins, and LAB (Jang et al. 2015). *Leuconostoc mesenteroides* and *Lactobacillus plantarum* are both abundant during the fermentation of kimchi, and various other kinds of LAB have also been isolated during fermentation, including *Lactococcus* spp., *Lactobacillus* spp., *Pediococcus* spp., and *Leuconostoc* spp. (Choi et al. 2002). The LAB isolated from kimchi have been investigated for their potential nutritional and pharmacological effects including antimicrobial, antioxidant, antitumor, and other activities (Lee et al. 2015).

Excessive amount of reactive oxygen metabolites in the body can result in cellular damage which, in turn, promotes chronic disease including atherosclerosis, arthritis,

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diabetics, neurodegenerative diseases, cardiovascular diseases, and cancer (Amaretti et al. 2013; Firuzi et al. 2011). To neutralize the oxidant molecules, some antioxidants are endogenously generated in the human body, while others are obtained from food, such as vitamin C, vitamin E, and polyphenolic compounds. Lactobacilli and Bifidobacteria, which have been used as probiotics, show antioxidative activities including reactive oxygen species scavenging, metal ion chelation, enzyme inhibition, and reduction activity (Lee et al. 2015; Wang et al. 2017).

The objective of this study was to evaluate the probiotic properties of *L. plantarum* Ln1 isolated from kimchi. In addition, the antioxidant activities of the isolated strains were investigated using live and heat-killed cells.

Materials and methods

Bacterial strains and culture conditions *L. plantarum*

Ln1 was isolated from kimchi and grown in lactobacilli MRS broth (BBL™, BD Biosciences, Franklin Lakes, NJ, USA) at 37 °C for 15 h. *L. plantarum* KCTC 3108, which is used commercially as a probiotic strain, was used as a control strain in this study and was obtained from Korean Collection for Type Cultures (Jeolla-do, Korea).

Tolerance to artificial gastric juice and bile acid

The tolerance of the isolated strains to artificial gastric conditions was measured according to the method of Lee et al. (2015). An overnight culture of the LAB strains was re-suspended in MRS broth (pH 2.5) containing 0.3% (w/v) pepsin (Sigma-Aldrich, St. Louis, MO, USA) for 3 h at 37 °C.

To determine their tolerance to bile salt, an overnight culture of each LAB strain was re-suspended in MRS broth containing 0.3% (w/v) oxgall for 24 h at 37 °C.

The survival rate was determined by comparing the number of bacterial cells after reaction with the initial number of bacterial cells, as follows:

$$\text{Survival rate (\%)} = \frac{\text{Number of bacterial cells after reaction (CFU/mL)}}{\text{Initial number of bacterial cells (CFU/mL)}} \times 100.$$

Ability to adhere to HT-29 cells

HT-29 cells (human colon adenocarcinoma, KCLB 30038) were obtained from the Korean Cell Line Bank (Seoul, Korea). The cell line was cultured in Roswell Park

Memorial Institute 1640 medium (Hyclone, Logan, UT, USA) containing 10% (v/v) fetal bovine serum and 1% (v/v) penicillin–streptomycin at 37 °C in 5% CO₂.

For determination of the adhesion ability of the LAB strains, HT-29 cells were seeded at 1×10^5 cells/well in 24 well-tissues culture plates and incubated at 37 °C. After incubation for 24 h, the LAB strains (2×10^7 CFU/well) were added to HT-29 cells and incubated for 2 h. The non-adherent cells were removed by washing three times with phosphate-buffered saline (PBS; Hyclone). Triton X-100 (Sigma-Aldrich) solution was used to detach the bacteria. The number of detached LAB was determined by performing serial dilutions, spreading them on MRS agar, and incubating them for 24 h at 37 °C.

The ability of the LAB strains to adhere to HT-29 cells was calculated as the percentage of adherent bacteria as a proportion of the initial number of bacterial cells, as follows:

$$\text{Adhesion ability (\%)} = \frac{\text{Adherent bacterial cells (CFU/mL)}}{\text{Initial number of bacterial cells (CFU/mL)}} \times 100.$$

Determination of enzyme production using API ZYM kit

Enzyme production was assessed using an API ZYM kit (BioMérieux, Marcy l'Étoile, France). LAB strains were centrifuged ($14,240 \times g$, 5 min, 4 °C) and the cell pellet was resuspended in sterile saline containing 0.85% sodium chloride. Then, 10^6 CFU/mL of LAB was inoculated into each cupule. After incubation at 37 °C for 4 h, the API ZYM A and ZYM B reagents were sequentially added to each cupule. The level of enzyme production was assessed by substrate hydrolysis as measured by the degree of color change.

β-Galactosidase activity of the LAB strains

The β-galactosidase activity of the LAB strains was assessed according to the method of Vidhyasagar and Jeevaratnam (2013) with minor modifications. The LAB strains were incubated in MRS broth and the cells were recovered by centrifugation at $14,250 \times g$ for 10 min at 4 °C, and washed twice with sterile PBS. The cell pellets were resuspended in Z buffer (60 mM Na₂HPO₄, 40 mM NaH₂PO₄, and 50 mM β-mercaptoethanol, pH 7.0). One hundred microliters of the cell culture was mixed with 900 μL of Z buffer, 100 μL of chloroform, and 50 μL of 0.1% sodium dodecyl sulfate. Then, the absorbance was measured at 560 nm using Z buffer as a blank. For the enzymatic assays, an aliquot of the cell suspension

(900 μL) was mixed with 200 μL of Z buffer containing 4 mg/mL orthonitrophenyl- β -galactoside (Sigma-Aldrich) and incubated at 37 °C for 15 min. The reaction was stopped by adding 300 μL of 1 M sodium carbonate in a dropwise manner. Then, the reaction mixture was centrifuged at 12,000 $\times g$ for 10 min at 4 °C, and the absorbance was measured at 420 and 550 nm. Enzymatic activity was expressed in Miller units according to the following equation:

$$\beta\text{-Galactosidase activity (mU/mL)} \\ = 1000 \times \left(\frac{A_{420} - 1.75 \times A_{550}}{15 \text{ min} \times 1 \text{ mL} \times A_{550}} \right).$$

β -Glucosidase activity of the LAB strains

β -Glucosidase activity was assayed by the method of Rekha and Vijayalakshmi (2010) with minor modifications. The grown LAB strains were centrifuged for 10 min at 12,450 $\times g$ at 4 °C, washed twice with PBS, and resuspended in PBS. After pre-incubation at 37 °C for 10 min, 200 μL of cell suspension (2×10^7 CFU/mL) and 400 μL of 5 mM *p*NPG (*para*-nitrophenyl β -D-glucopyranoside) (Sigma-Aldrich) were incubated at 37 °C for 30 min. The reaction was stopped with the addition of 1 M sodium carbonate. β -Glucosidase activity was measured at 405 nm using a X-ma 3200 spectrophotometer (Human Corporation, Seoul, Korea). One activity units were defined as the release of 1 μM of *p*-nitrophenol from the substrate per min.

Preparation of samples for antioxidant activity assays

Lactobacillus plantarum strains Ln1 and KCTC 3108 were inoculated in MRS broth and incubated at 37 °C for 15 h. To obtain heat-killed LAB, the grown cells were heated at 80 °C for 30 min. The live and heat-killed cells were centrifuged (14,240 $\times g$, 5 min, 4 °C) and washed twice with peptone water. The washed bacterial cells were resuspended in peptone water to a final concentration of 10^7 CFU/mL.

2,2-diphenyl-1-picryl-hydrazyl (DPPH) radical scavenging activity

The antioxidant activity was measured by the DPPH radical scavenging assay (Li et al. 2012) with minor modifications. One hundred and twenty microliters of live and heat-killed LAB strains (10^7 CFU/mL) was mixed with 120 μL of 400 μM DPPH solution (Das and Goyal 2015). The mixture was shaken and reacted at 37 °C for 30 min in

the dark. The absorbance of the mixture was measured at 517 nm using a spectrophotometer. The percentage scavenging of DPPH radicals was calculated using the following formula:

$$\text{DPPH radical scavenging activity (\%)} \\ = \left(1 - \frac{A_{\text{sample}}}{A_{\text{control}}} \right) \times 100.$$

2-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) radical scavenging activity

The antioxidant activity was measured by the ABTS radical scavenging assay (Ji et al. 2015) with minor modifications. The ABTS⁺ solution was produced by the reaction of 14 mM ABTS in water with 5 mM potassium persulfate in the dark at room temperature for 16 h. The ABTS⁺ solution was diluted with distilled water until it reached an absorbance of 0.7 at 734 nm. One hundred and fifty microliters of live or heat-killed LAB (10^7 CFU/mL) was added into 150 μL of ABTS⁺ solution. The mixture was incubated at 37 °C for 10 min then the absorbance was determined at 734 nm. The percentage scavenging of ABTS radicals was calculated using the following formula:

$$\text{ABTS radical scavenging activity (\%)} \\ = \left(1 - \frac{A_{\text{sample}} - A_{\text{blank}}}{A_{\text{control}}} \right) \times 100.$$

β -Carotene bleaching inhibitory activity

A β -carotene solution was prepared by dissolving 2 mg of β -carotene, 44 μL of linoleic acid, and 0.2 mL of Tween[®] 80 in 10 mL of chloroform. The mixtures were evaporated to remove the chloroform using a rotary evaporator at 40 °C and were immediately diluted with 100 mL of distilled water. Four and a half milliliters of the emulsion was mixed with 0.5 mL of LAB strains (10^7 CFU/mL) and incubated in a water bath at 50 °C for 8 h, and then the absorbance of the emulsion was measured at 470 nm. The remaining β -carotene in the mixture was calculated according to the following equation:

$$\beta\text{-Carotene bleaching inhibitory activity (\%)} \\ = \frac{A_{\text{sample, 2 h}} - A_{\text{control, 2 h}}}{A_{\text{control, 0 h}} - A_{\text{control, 2 h}}} \times 100.$$

Reducing power

The reducing power assay was carried out according to the previously reported method (Das and Goyal 2015) with

modifications. Two hundred microliters of live or heat-killed LAB strains (10^7 CFU/mL) was mixed with 0.2 mL of 0.2 M sodium phosphate buffer (pH 6.6) and 0.2 mL of 1% potassium ferricyanide, and the mixture was incubated at 50 °C for 20 min. Then, 0.2 mL of 10% trichloroacetic acid was added and the mixture was centrifuged at $780\times g$ for 10 min. The upper layer of the supernatant (0.5 mL) was mixed with 0.1 mL of 0.1% ferric chloride and 0.4 mL of distilled water; then the mixture was reacted for 10 min and its absorbance was measured at 700 nm using a spectrophotometer. L-Cysteine was used as a control standard.

Statistical analysis

The results for each treatment were obtained in triplicate, and a one-way analysis of variance (SPSS software version 19; IBM, Armonk, NY, USA) was performed to determine the significance of differences among mean values.

Results and discussion

Tolerance to artificial gastric juice and bile acid

LAB strains encounter the low pH (2.5–3.5) environment of the stomach and 0.3% bile salt through the gastrointestinal tract (Lee et al. 2015). The tolerance of *L. plantarum* (Ln1 and KCTC 3108) to gastric conditions is presented in Table 1. The cell number of *L. plantarum* Ln1 decreased by 0.05 log CFU/mL under artificial gastric conditions (0.3% pepsin, pH 2.5 for 3 h; 89.13% survival rate) and increased by 0.16 log CFU/mL under bile salt conditions (0.3% oxgall for 24 h; 144.54% survival rate). The cell number of *L. plantarum* KCTC 3108 decreased by 0.15 log CFU/mL under artificial gastric conditions (70.79% survival rate) and increased by 0.03 log CFU/mL

under bile salt conditions (107.15% survival rate). In previous reports, the survival of *Lactococcus lactis* KC24 isolated from kimchi decreased by 2.7 log CFU/mL for 2 h (Lee et al. 2015) and that of *L. plantarum* Lb41 decreased by 0.06 log CFU/mL for 3 h (Jeon et al. 2016). The cell number of *L. plantarum* CGMCC 1.557 isolated from vegetables decreased by 1.19 log CFU/mL after incubation in 0.3% bile for 24 h (Ren et al. 2014). Our data indicated that *L. plantarum* Ln1 exhibited a better tolerance to acidic conditions and a higher survival in artificial bile salts than the previously reported strains. Thus, *L. plantarum* Ln1 could be stable in the human intestine.

Ability to adhere to HT-29 cells

For probiotics to effectively colonize the human intestinal epithelium and competitively inhibit the binding of pathogenic bacteria to the intestinal wall, it is essential for them to have the ability to adhere to intestinal cells (Son et al. 2017). The adhesion rate of *L. plantarum* (Ln1 and KCTC 3108) to HT-29 cells in vitro is exhibited in Table 1. The initial inoculum of *L. plantarum* Ln1 was 9.06 log CFU/well. After 2 h, the number of bacteria adhering to HT-29 cells was 7.49 log CFU/well (2.69% adhesion rate). *L. plantarum* KCTC 3108 showed a lower adherence rate than *L. plantarum* Ln1. The inoculation of *L. plantarum* KCTC 3108 at 8.31 log CFU/well resulted in adherence at 6.65 log CFU/well after 2 h (2.19% adhesion rate). In our study, *L. plantarum* Ln1 showed a better capacity to adhere to intestinal cells than *L. plantarum* KCTC 3108 did. Previously, *L. plantarum* AL3, AL8, CL5, CL9, and GL2 were reported to have adherence rates of 0.2–2.0% (Pennacchia et al. 2006), and *L. plantarum* Lb41 also adhered strongly to HT-29 cells (7.5% adhesion rate) (Jeon et al. 2016). Therefore, the intestinal adherence of *L. plantarum* Ln1 could be acceptable for its use as a probiotic.

Table 1 Tolerance to artificial gastric acid and bile salts, and adherence to intestinal cells of *L. plantarum* strains

Treatment	Cell no. (Log CFU/mL)	
	<i>L. plantarum</i> Ln1	<i>L. plantarum</i> KCTC 3108
<i>Tolerance to artificial gastric acid and bile salts</i>		
Initial cell no.	8.47 $\pm$ 0.02 ^a	8.59 $\pm$ 0.05 ^b
pH 2.5, 0.3% (w/v) pepsin, 3 h ¹	8.42 $\pm$ 0.02 ^a	8.44 $\pm$ 0.04 ^a
0.3% (w/v) oxgall, 24 h ²	8.63 $\pm$ 0.10 ^b	8.62 $\pm$ 0.01 ^b
<i>Adhesion to HT-29 cell</i>		
Initial cell no.	9.06 $\pm$ 0.00 ^d	8.31 $\pm$ 0.04 ^c
Adhesion cell no.	7.49 $\pm$ 0.15 ^b	6.65 $\pm$ 0.13 ^a

Values are expressed as mean $\pm$ standard deviation

^{a–d}Different superscript letters in the same row indicate statistical differences ($P < 0.05$)

¹Cell no. after 3 h incubation

²Cell no. after 24 h incubation

Enzyme production determined using API ZYM kit

To investigate whether *L. plantarum* Ln1 may produce any enzymes with possible hazards to human health, enzyme production was determined using API ZYM kit. β -Glucuronidase-like carcinogenic enzyme can be generated by microorganisms (Lee et al. 2014, 2015). *L. plantarum* Ln1 produced various non-hazardous enzymes including leucine arylamidase, valine arylamidase, acid phosphatase, and naphthol-AS-BI-phosphohydrolase (Data not shown). *L. plantarum* Ln1 also produced β -galactosidase and β -glucosidase at 40 and 30 nM, respectively, but it did not produce hazardous β -glucuronidase. Similarly, *L. plantarum* KCTC 3108 produced acid phosphatase and naphthol-AS-BI-phosphohydrolase at 5 and 10 nM, respectively, but not hazardous β -glucuronidase.

Production of β -galactosidase

β -Galactosidase plays a leading role in the hydrolysis of lactose into galactose and glucose (Vidhyasagar and Jeevaratnam 2013). Therefore, β -galactosidase has been used commercially to help lactose-intolerant people improve their digestion and to catalyze the crystallization of lactose in dairy products (Gobinath and Prapulla 2015; Vidhyasagar and Jeevaratnam 2013). *L. plantarum* Ln1 showed a higher β -galactosidase production (3067.42 mU/mL) than *L. plantarum* KCTC 3108 (2128.83 mU/mL) (Table 2). Previously, *L. plantarum* MCC2156 showed a maximum β -galactosidase production of 3105 mU/mL under optimized conditions (Gobinath and Prapulla 2015). In addition, *L. plantarum* Ln4 isolated from kimchi produced β -galactosidase at 3320.99 mU/mL (Son et al. 2017). Therefore, *L. plantarum* Ln1 may be useful as a probiotic strain for treating lactose intolerance and for preventing the crystallization of frozen dairy products.

Production of β -glucosidase

β -Glucosidase has been reported to have an important role in catalyzing the transformation of polyphenol glycosides to their aglycones in food matrices, and it influences the thermal stability of probiotics (Basholli-Salih et al. 2014). The production of β -glucosidase is exhibited in Table 2. The production yields of β -glucosidase by *L. plantarum* Ln1 and *L. plantarum* KCTC 3108 were 7.04 and 1.49 mU/mL, respectively. Previous studies have shown that *L.*

plantarum LSP-24 isolated from colostrum milk produced β -glucosidase at 56–300 mU/mL (Gouripur and Kaliwal 2017). The lower result for the production of β -glucosidase as compared with the result of the API[®] ZYM kit may be explained by differences in the composition of the culture medium.

Antioxidant activity of live and heat-killed *L. plantarum* Ln1

Oxidative stress occurs as a result of metabolic activity, and the supply of the body's endogenous antioxidant is insufficient to handle or neutralize all the naturally generated free radicals (Halliwell and Gutteridge 1989). Probiotics may modulate the host's defenses against oxidative stress through metal ion chelating, antioxidant activity, regulating signaling pathways, modulating the intestinal microflora, etc. (Wang et al. 2017). Recently, some reports were determined that *L. rhamnosus* could play an important role in antioxidant effect by using some peptide to remove oxygen radicals (Rajoka et al. 2017). The cell surface compounds such as proteins or polysaccharides of *L. plantarum* C88 have an antioxidant activity by decrement of free radicals (Li et al. 2012). Therefore, the antioxidant activity of *L. plantarum* Ln1 was investigated using the DPPH and ABTS radical scavenging, β -carotene bleaching, and reducing power assays.

DPPH radical scavenging activity of *L. plantarum* Ln1

The DPPH radical scavenging activity of *L. plantarum* Ln1 is shown in Fig. 1. The live and heat-killed *L. plantarum* Ln1 exhibited DPPH radical scavenging activities of 24.16% and 17.60%, respectively, at 10^7 CFU/mL. The live cell number of *L. plantarum* Ln1 was higher than that of *L. plantarum* KCTC 3108 with 21.13%. Das and Goyal (2015) reported similar results for *L. plantarum* B4496, which showed a DPPH radical scavenging activity of about 15% at 10^6 CFU/mL.

ABTS radical scavenging activity of *L. plantarum* Ln1

The ABTS radical scavenging activity of live *L. plantarum* Ln1 (78.04%) was higher than that of heat-killed *L. plantarum* Ln1 (70.18%) (Fig. 2). For comparison, the live and

Table 2 β -Galactosidase and β -glucosidase production of *L. plantarum* strains

Enzyme	<i>L. plantarum</i> Ln1	<i>L. plantarum</i> KCTC 3108
β -Galactosidase (mU/mL)	3067.42 $\pm$ 98.87	2128.83 $\pm$ 49.31
β -Glucosidase (mU/mL)	7.00 $\pm$ 0.14	1.49 $\pm$ 0.03

All values are mean $\pm$ standard deviation

Fig. 1 DPPH radical scavenging activity of live and heat-killed cells of *L. plantarum* Ln1 and KCTC 3108 at 10^7 CFU/mL. Each value represents mean $\pm$ standard deviation ($P < 0.05$). Filled squares, live cells; opened squares, heat-killed cells

heat-killed *L. plantarum* KCTC 3108 exhibited ABTS radical scavenging activities of 82.28% and 77.74%, respectively. Previously, Ji et al. (2015) reported that culture filtrates of *Lactobacillus* sp. and *Leuconostocs* sp. exhibited ABTS radical scavenging activities of greater than 50%.

β -Carotene bleaching inhibitory activity of *L. plantarum* Ln1

The β -carotene bleaching assay is based on the mechanism that lipid radicals produced by the auto-oxidation of linoleic acid attack the double bonds of β -carotene, causing its bleaching, and antioxidant substances can protect β -carotene against bleaching depending on their antioxidant ability. Our results showed that the β -carotene bleaching inhibition activities of live and heat-killed *L. plantarum*

Fig. 2 ABTS radical scavenging activity of live and heat-killed cells of *L. plantarum* Ln1 and KCTC 3108 at 10^7 CFU/mL. Each value represents mean $\pm$ standard deviation ($P < 0.05$). Filled squares, live cells; opened squares, heat-killed cells

Ln1 were 49.97% and 58.33%, respectively (Fig. 3). For comparison, the β -carotene bleaching inhibitory activities of live and heat-killed *L. plantarum* KCTC 3108 were 48.26% and 61.20%, respectively. These results are lower than those for the standard strain; however, our results were higher than those in a previous study, which reported that *L. plantarum* Ln4 and *Lactococcus lactis* KC24 had antioxidant activities of 38.42 and 35.15%, respectively (Lee et al. 2015; Son et al. 2017).

Reducing power of *L. plantarum* Ln1

At 10^7 CFU/mL, heat-killed *L. plantarum* Ln1 and KCTC 3108 exhibited reducing power values of 45.90 and 60.75 μ M, while live *L. plantarum* Ln1 and KCTC 3108 exhibited the lower values of 25.75 and 37.15 μ M, respectively (Fig. 4). The reducing power of *L. plantarum* NRRL B-4496 was 20, 32, and 63 μ M at 10^6 , 10^8 , and 10^{10} CFU/mL, respectively (Das and Goyal 2015). These results showed the potential antioxidant effects of heat-killed *L. plantarum* Ln1.

Conclusion

L. plantarum Ln1 isolated from kimchi showed potential probiotic and antioxidant activities comparable to those of existing commercial probiotic strains. *L. plantarum* Ln1 showed a high tolerance to gastric and bile salts, as well as a high rate of intestinal cell adhesion, while it did not produce hazardous β -glucuronidase, which is related to a higher adherence to colon cell lines. *L. plantarum* Ln1 showed a high production of β -galactosidase, indicating that it could be helpful for improving the digestion of dairy products by lactose-intolerance patients. The DPPH radical

Fig. 3 β -Carotene bleaching inhibitory activity of live and heat-killed cells of *L. plantarum* Ln1 and KCTC 3108 at 10^7 CFU/mL. Each value represents mean $\pm$ standard deviation ($P < 0.05$). Filled squares, live cells; opened squares, heat-killed cells

Fig. 4 Reducing power of live and heat-killed cells of *L. plantarum* Ln1 and KCTC 3108 at 10^7 CFU/mL. Each value represents mean $\pm$ standard deviation ($P < 0.05$). Filled squares, live cells; opened squares, heat-killed cells

scavenging and β -carotene bleaching inhibitory activities of live *L. plantarum* Ln1 cells were higher than those of live *L. plantarum* KCTC 3108 cells. In addition, the reducing power and β -carotene bleaching inhibitory activities of heat-killed cells of *L. plantarum* Ln1 and KCTC 3108 were higher than those of the live cells. Therefore, both live and heat-killed *L. plantarum* Ln1 might have useful applications in the food and pharmaceutical industries.

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