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Probiotic characterization of *Lactobacillus brevis* KU15153 showing antimicrobial and antioxidant effect isolated from kimchi

Hye Ji Jang[1] · Na-Kyoung Lee[1] · Hyun-Dong Paik[1]

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Abstract *Lactobacillus brevis* KU15153 was isolated from kimchi and probiotic characterization was performed including analysis of its antimicrobial and antioxidant effects. *Lactobacillus rhamnosus* GG (LGG) was used as a probiotic control. *L. brevis* KU15153 survived under artificial gastric conditions and was non-hemolytic, showed antibiotic susceptibility, and did not produce carcinogenic β-glucuronidase. *L. brevis* KU15153 adhered strongly to HT-29 cells in the direct adherent assay and showed high cell surface hydrophobicity. Particularly, *L. brevis* KU15153 showed antimicrobial activity against the food-borne pathogens *Escherichia coli* ATCC 25922, *Listeria monocytogenes* ATCC 15313, *Salmonella* Typhimurium P99, and *Staphylococcus aureus* KCCM 11335. Antioxidant activity was assessed using the DPPH radical scavenging assay and β-carotene and linoleic acid inhibition assay. *L. brevis* KU15153 showed higher antioxidant activity than LGG. These results suggest that *L. brevis* KU15153 has potential for use as a probiotic organism.

Keywords Probiotic · Kimchi · *Lactobacillus brevis* · Antimicrobial effect · Antioxidant effect

✉ Hyun-Dong Paik
hdpaik@konkuk.ac.kr

Hye Ji Jang
gpwljjj@naver.com

Na-Kyoung Lee
nakyoung_lee@nate.com

[1] Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 05029, Republic of Korea

Introduction

Kimchi, a traditional fermented food and representative ethnic food in Korea, has been reported as a healthy food (Bae et al., 2018; Park et al., 2018). Kimchi is prepared from Chinese cabbage or radish with various seasonings such as ground red pepper, garlic, ginger, fish sauce, shrimp sauce, and other ingredients (Lee et al., 2014). Kimchi is commonly stored at a low temperature for several months to multiple years. During fermentation, diverse lactic acid bacteria (LAB) are present, such as *Lactobacillus* sp., *Leuconostoc* sp., *Lactococcus* sp., *Weissella* sp., and *Pediococcus* sp. (Park et al., 2018). Particularly, *Lactobacillus* sp. become the predominant species during incipient fermentation; these bacteria produce lactic acid and decrease the pH (Lee et al., 2016). LAB strains were investigated to determine their probiotic properties and diverse effects including anti-obesity, antioxidant, and antidiabetic activities.

Probiotic are defined by the World Health Organization as live microorganisms having a health benefit to the host when administered at adequate levels (FAO/WHO, 2002; Kimoto-Nira et al., 2015; Vitali et al., 2012). Probiotics have diverse functional effects such as antioxidant, antidiabetic, antiallergy, blood lipids reducing, anti-inflammatory, and anticancer effects to improve host health (Jeon et al., 2016; Lee et al., 2015). Probiotics should be investigated to determine their characteristics including resistance to gastric and bile with adhesion effects in the human intestinal tract to evaluate probiotic potential (Son et al., 2018).

LAB are generally recognized as "generally recognized as safe" and used as food supplements and food preservation because of their diverse probiotic properties (Aarti et al., 2017; Son et al., 2018). *Lactobacillus acidophilus*, *L.*

rhamnosus, *L. helveticus*, *L. bulgaricus*, *L. plantarum*, *L. salivarius*, *L. reuteri*, *L. casei*, *L. brevis*, *Bifidobacterium infantis*, *B. lactis*, *B. bifidum*, *Pediococcus acidophilus*, and *Streptococcus thermophilus* are representative LAB probiotic strains. Among these strains, *L. brevis* is commonly isolated from fermented foods, plants, and the human intestinal tract and have been investigated for their probiotic potential (Lee et al., 2014; Sharma et al., 2017). *Lactobacillus brevis* KB290 was reported to reduce the incidence of influenza (Sharma et al., 2017; Waki et al., 2014). *L. brevis* CD2 showed anti-inflammatory effects and *L. brevis* B23 was found to have antimicrobial effect (Riccia et al., 2007; Rushdy and Gomaa, 2013).

The aim of the present study was to assess the probiotic potential of *L. brevis* KU15153 isolated from kimchi such as its stability to gastric conditions, safety, antimicrobial activity, and antioxidant effects.

Materials and methods

Microorganisms and culture conditions

Lactobacillus brevis KU15153 was isolated from kimchi, and was grown in lactobacilli MRS broth (BD BBL, Franklin Lakes, NJ, USA). *Lactobacillus rhamnosus* GG (LGG, KCTC 5033) was used as a commercial probiotic strain and was obtained from the Korean Collection for Type Cultures (Jeolla-do, Korea). *Escherichia coli* ATCC 25922, *Listeria monocytogenes* ATCC 15313, *Salmonella* Typhimurium P99, and *Staphylococcus aureus* KCCM 11335 were incubated in tryptic soy broth (TSB; BD BBL, Sparks, MD, USA) at 37 °C for 24 h.

To obtain pellets of the LAB strains, the strains were centrifuged (14,240 × *g*, 5 min, 4 °C) and washed twice with peptone water. The washed LAB cells were resuspended in peptone water.

Tolerance to artificial gastric juice and bile acid

The resistance of LAB strains to artificial gastric juice and bile salts was determined as described by Lee et al. (2015) with some modifications. LAB strains were grown in MRS broth at 37 °C for 24 h and then resuspended in the MRS broth (pH 2.5) containing 0.3% (w/v) pepsin (Sigma-Aldrich, St. Louis, MO, USA) for 3 h at 37 °C. To assess the tolerance of the strains to bile salt, an overnight culture of the LAB strains was resuspended in MRS broth containing 0.3% (w/v) oxgall and incubated for 24 h at 37 °C. Survival rates were confirmed by counting the viable cells on MRS plates.

Hemolytic activity

The LAB strains were streaked onto Columbia agar containing 5% (w/v) sheep blood and incubated for 24 h at 37 °C for hemolysis (Jeon et al., 2017; Taheur et al., 2016). α-Hemolysis, β-hemolysis, and γ-hemolysis appeared as a green-hued zone, clear zone, and no clear zone the around the colonies, respectively. *E. coli* ATCC 25922, *S.* Typhimurium P99, and *S. aureus* KCCM 11335 and were used as positive controls for α- and for β-hemolysis, respectively.

Antibiotic susceptibility

The antibiotic susceptibilities of the LAB strains were measured according to Clinical and Laboratory Standards Institute guidelines (CLSI, 2014). The disc diffusion method was used to evaluate the susceptibility to clinically important antibiotics, such as ampicillin, gentamicin, kanamycin, streptomycin, tetracycline, ciprofloxacin, chloramphenicol, and doxycycline. The LAB strains (1×10^6 CFU/mL) were spread onto MRS agar, and antibiotic discs were placed on the MRS agar surface. After incubation for 24 h at 37 °C, the diameters (mm) of the clear zones were measured.

Production of enzymes

Enzyme production of was analyzed using the API ZYM kit (BioMerieux, Marcy-lÈtoile, France). The LAB strains were incubated in MRS broth at 37 °C for 24 h. The overnight cultures of LAB strains were centrifuged (14,240 × *g*, 5 min, 4 °C). The cell pellet was resuspended in PBS (phosphate-buffered saline, Hyclone, Logan, UT, USA). Next, 65 µL of the LAB strains (10^6 CFU/mL) was inoculated into each cupule. After incubation at 37 °C for 4 h, ZYM A and ZYM B reagents were sequentially dropped into each cupule. Enzyme production was measured by substrate hydrolysis measured as the color change of the sample.

Adhesion ability to HT-29 cells

HT-29 cells were obtained from the Korean Cell Line Bank (KCLB 30038, Seoul, Korea). The culture conditions were RPMI 1640 medium (Hyclone) with 10% (v/v) fetal bovine serum and 1% (v/v) penicillin/streptomycin, and incubated at 37 °C with 5% CO_2.

For the adhesion ability, HT-29 cells were seeded into 24-well polystyrene plates at 1×10^5 cells/well. And the plates incubated at 37 °C in a 5% CO_2 incubator. After incubation for 24 h, 2×10^7 CFU/well of the LAB strains were added to pre-seeded HT-29 cells and incubated for

2 h and then washed thrice with PBS. Next, 1 mL of 1% (v/v) Triton X-100 (Sigma-Aldrich) solution was added to detach the bacteria during incubation for 10 min. After diluting the detached LAB strains, the strains were spread onto MRS agar and incubated for 24 h at 37 °C.

Cell surface hydrophobicity test

The hydrophobicity of LAB strains was measured as described previously with some modifications (Saini and Tumar, 2017; Taheur et al., 2016). Three solvents were used to characterize the cell surface: chloroform (monopolar and Lewis-acid solvent), ethyl acetate (monopolar and Lewis-base solvent), and xylene (apolar solvent). The LAB were incubated in MRS broth at 37 °C for 24 h. These cultures were centrifuged at 14,240 × *g* for 5 min. The culture supernatants were washed twice and resuspended in PBS. The resuspended cells were adjusted to an OD_{600} of 0.5 ($OD_{Initial}$). Next, 3 mL of the resuspended cells was mixed with 1 mL of solvents (chloroform, ethyl acetate, and xylene) and pre-incubated for 10 min at 37 °C. The mixture was mixed for 1 min and incubated at 37 °C for 20 min. Incubated mixture was separated into two phases (water and solvent). One milliliter of the aqueous phase was collected and the absorbance was measured at 600 nm (OD_{Time}). The cell surface hydrophobicity was expressed as follows:

$$\text{Cell surface hydrophobicity}\,(\%) = \left(1 - \frac{OD_{Time}}{OD_{Initial}}\right) \times 100.$$

Antimicrobial activity to pathogens

The antimicrobial activity of the LAB strains was determined using a modified deferred method described by Son et al. (2017). For this assay, indicator pathogenic strains, such as *L. monocytogenes* ATCC 15313, *S.* Typhimurium, *E. coli* ATCC 25922, and *S. aureus* KCCM 11335 were used. To assess the antimicrobial activity, 3 µL of LAB strains (approximately 10^9 CFU/mL), was spotted onto MRS agar and incubated for 24 h at 37 °C. Next, 100 µL of the indicator pathogens strain (approximately 10^6 CFU/mL) was inoculated into 4 mL of TSA soft agar, and the soft agar was overlaid. The plate was incubated for 24 h at 37 °C. The clear zones were measured and represented as diameters (mm).

Inhibition of adherence of pathogens to HT-29 cells

The inhibition of pathogen adherence was evaluated by using modified method described by Jeon et al. (2017). HT-29 cells (1×10^5 cells/well) were seeded into 24-well plates and incubated at 37 °C in a 5% CO_2 incubator for 24 h. Approximately 10^6 CFU/well of pathogens with or without *L. brevis* KU15153 were adjusted and incubated at 37 °C for 2 h. After incubation, non-adherent cells were washed twice with PBS. And then the cells were added to 1 mL of 1% (v/v) Triton X-100 solution to detach the HT-29 cells. The mixture was spread onto Oxford, XLD, EMB, and MSA agar for *E. coli*, *L. monocytogenes*, *S.* Typhimurium, and *S. aureus,* respectively, to count the number of viable cells.

Auto-aggregation and co-aggregation assay

Auto-aggregation was measured as the auto-aggregation percentage (Lee et al., 2015). Bacterial cells were centrifuged at 14,240 × *g* for 10 min and washed twice with PBS. The bacterial cells were adjusted to an OD_{600} of 0.3 ± 0.05. To evaluate auto-aggregation, each bacteria suspension (4 mL) was incubated at 37 °C for 4 and 24 h. The absorbance was read at 600 nm at 0, 4, and 24 h after incubation. Auto-aggregation was expressed as follows:

$$\text{Auto-aggregation}\,(\%) = \left(1 - \frac{OD_{Time}}{OD_{Initial}}\right) \times 100$$

where OD_{Time} and $OD_{Initial}$ represented the absorbance at a specific incubation time and initial time, respectively.

To examine co-aggregation, each LAB bacterial suspension (2 mL) was mixed with each pathogen (2 mL) and incubated at 37 °C for 4 and 24 h. The absorbance was measured at 600 nm. Co-aggregation was expressed as follows:

$$\text{Co-aggregation}\,(\%) = \left[1 - \frac{OD_{Mix}}{\left(\frac{OD_P + OD_L}{2}\right)}\right] \times 100$$

where OD_P, OD_L, and OD_{Mix} represented absorbance of pathogen, LAB, and mixed strains, respectively.

Antioxidant activity

Lactobacillus brevis KU15153 and LGG were cultured at 37 °C for 24 h. The LAB strains were centrifuged (14,240 × *g*, 5 min, 4 °C) and washed twice with PBS. The washed bacterial cells were resuspended in PBS to 10^7 CFU/mL.

DPPH radical scavenging assay was measured as described by Lee et al. (2015). First, 120 µL of resuspended LAB strains (10^7 CFU/mL) was added to 120 µL of 400 µM DPPH solution (Das and Goyal, 2015) in similar proportions. The mixture was shaken and reacted at 37 °C for 30 min in the dark space. The absorbance was measured at 517 nm. The percentage scavenging of DPPH radicals was expressed as follows:

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

The β-carotene-linoleic inhibition assay was conducted as described by Jang et al. (2018). A β-carotene solution was prepared by adding 2 mg of β-carotene, 44 μL of linoleic acid, and 0.2 mL of Tween 80 in 10 mL of chloroform. Next, the chloroform in mixtures were removed using a rotary evaporator at 40 °C and then the mixture was immediately mixed with 100 mL of distilled water. Part of this mixture (4.5 mL) was added to 0.5 mL of LAB strains (10^7 CFU/mL). The mixture was incubated at 50 °C water bath for 2 h. The absorbance was measured at 470 nm, and the remaining β-carotene in the mixture was expressed as follows:

$$\text{β-Carotene bleaching inhibitory activity}\,(\%) = \frac{A_{\text{Sample,2h}} - A_{\text{Control,2h}}}{A_{\text{Control,0h}} - A_{\text{Control,2h}}} \times 100.$$

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 the mean values.

Results and discussion

Tolerance to artificial gastric juice and bile acid

Probiotic organisms must survive in low pH environments (pH 2.5–3.5) and under the 0.3% bile salt conditions of the gastrointestinal tract (Lee et al., 2015). The tolerance of *L. brevis* KU15153 and LGG to gastric conditions is presented in Table 1. The cell number of *L. brevis* KU15153 decreased by 0.15 log CFU/mL under artificial gastric conditions (70.79% survival rate) and increased by 0.65 log CFU/mL under bile salt conditions (104.47% survival rate). However, the cell number of LGG showed survival rates of 52.48% and 101.91% under artificial gastric conditions and bile salt conditions, respectively. *L. rhamonsus* KCTC 12202BP and *L. brevis* G1 showed 81.28% and 87.09% survival rates at pH 2.5 in the presence of 0.3% pepsin, respectively (Son et al., 2017). *L. rhamonsus* KCTC 12202BP and *L. brevis* G1 survival increased in 0.3% oxgall for 24 h. These results indicate that compared to LGG, the survival of *L. brevis* KU15153 was higher survival in artificial gastric and bile salts.

Hemolytic activity

Lactobacillus brevis KU15153 and LGG showed no hemolysis (γ-hemolysis) when incubated on sheep blood plates at 37 °C for 24 h under anaerobic conditions (data not shown). However, *S. aureus* KCCM 11335 showed α-hemolysis. Additionally, *S.* Typhimurium P99 and *E. coli* ATCC 25922 showed β-hemolysis. Therefore, the selected *L. brevis* KU15153 is non-pathogenic and considered as safe organism for human health.

Antibiotic susceptibility of the LAB strains

Antibiotic susceptibility tests of probiotics are necessary to determine the safety of these organisms in humans or animals. *L. brevis* KU15153 was resistant to streptomycin and ciprofloxacin and susceptible to ampicillin, gentamycin, kanamycin, tetracycline, chloramphenicol, and doxycycline (data not shown). In a previous study, *L. brevis* KU15006 was resistant to gentamycin, kanamycin, streptomycin, and ciprofloxacin, while ampicillin,

Table 1 Tolerance to artificial gastric acid and bile salts and adherence to intestinal cells of LGG and *L. brevis* KU15153

Treatment	Cell no. (Log CFU/mL)	
	LGG	*L. brevis* KU15153
Tolerance to artificial gastric acid and bile salts		
Initial cell no.	8.76 ± 0.06^{c}	8.30 ± 0.02^{d}
pH 2.5, 0.3% (w/v) pepsin, 3 h	8.48 ± 0.03^{b}	8.15 ± 0.10^{c}
0.3% (w/v) oxgall, 24 h	9.04 ± 0.03^{d}	8.95 ± 0.02^{e}
Adhesion to HT-29 cell		
Initial cell no.	8.77 ± 0.04^{c}	7.94 ± 0.01^{b}
Adhesion cell no.	7.51 ± 0.14^{a}	6.89 ± 0.06^{a}

LGG, *L. rhamnosus* GG

Values are expressed as mean ± standard deviation

[a–e]The superscript letters in the same row indicate statistical differences ($p < 0.05$)

tetracycline, chloramphenicol, and doxycycline susceptible to the other antibiotics (Son et al., 2017).

Enzyme production determined using API ZYM kit

Enzyme production is an important criterion among probiotic properties (Cole et al., 1989). Increases in β-glucuronidase in the feces are involved in gastric cancer and inflammatory bowel disease (Mroczynska et al., 2013). Thus, probiotic strains should not produce carcinogenic enzymes such as β-glucuronidase. *L. brevis* KU15153 produced various non-hazardous enzymes including acid phosphatase, leucine arylamidase, naphthol-AS-BI-phosphohydrolase, and valine arylamidase, and did not produce the hazardous β-glucuronidase. LGG did not produce β-glucuronidase (data not shown).

Ability to adhere to HT-29 cells

The adherence ability of HT-29 cells is essential for identifying potential probiotic bacteria. The capacity of LAB strains to adhere to HT-29 cells was assessed, and the results are shown in Table 1. The initial inoculum of *L. brevis* KU15153 was 7.94 log CFU/well. After 2 h, the number of adherent bacteria to HT-29 cells was 6.89 log CFU/well for LGG (5.62% adhesion rate). LGG showed a lower adhesion rate than *L. brevis* KU15153 (8.91% adhesion rate). *Leuconostoc mesenteroides* H40, *L. plantarum* (FI10604, Lb41, and Ln1), *L. brevis* FI10700, and *Lactobacillus perolens* FI10842) showed variable adhesion rates (2.86–12.37%) (Jang et al., 2018; Jeon et al., 2016; Son et al., 2018). As a result, the intestinal adhesion ability of *L. brevis* KU15153 was higher than that of LGG and showed values acceptable for use as a probiotic.

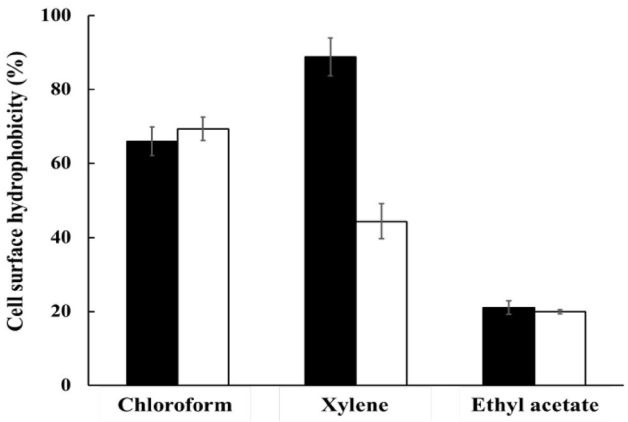

Fig. 1 Cell surface hydrophobicity of LGG and *L. brevis* KU15153 to solvents. Filled square, LGG (*L. rhamnosus* GG); Open square, *L. brevis* KU15153. Each value represents the mean ± standard deviation, and different letters on each bar represent significant difference between values ($p < 0.05$)

Cell surface hydrophobicity test

The cell surface hydrophobicity of a probiotic is associated with its adhesion ability. The cell surface hydrophobicity results are shown in Fig. 1. *L. brevis* KU15153 showed higher affinity in chloroform (69.25%) than in ethyl acetate (19.88%) and xylene (44.34%). Lee et al. (2015) reported that the hydrophobicity values of *L. lactis* KC24 were 54.41, 18.44, and 3.66% in chloroform, xylene, and ethyl acetate, respectively. Therefore, *L. brevis* KU15153 was characterized as s Lewis acid; these characteristics in solvents may greatly influence adhesion ability ($p < 0.05$) (Taheur et al., 2016).

Antimicrobial activity using modified deferred method

The antimicrobial activity of *L. brevis* KU15153 was assessed using a modified deferred method (Table 2). *L. brevis* KU15153 showed distinct antibacterial activity against *E. coli* ATCC 25922, *L. monocytogenes* ATCC 15313, *S.* Typhimurium P99, and *S. aureus* KCCM 11335. Among the pathogens, *S. aureus* KCCM 11335 showed the largest inhibition zone. These antimicrobial activities originated from the production of metabolites such organic acids (lactic acid, acetic acid, etc.), hydrogen peroxide,

Table 2 Antagonistic effects against foodborne pathogens of LGG and *L. brevis* KU15153 by deferred method

Pathogens	Inhibitory diameter (mm)	
	LGG	*L. brevis* KU15153
Escherichia coli ATCC 25922	18.67 ± 4.73^{b}	13.00 ± 2.00^{a}
Listeria monocytogenes ATCC 15313	22.33 ± 0.58^{b}	14.67 ± 1.15^{ab}
Salmonella Typhimurium P99	3.00 ± 0.00^{a}	16.67 ± 2.89^{ab}
Staphylococcus aureus KCCM 11335	22.33 ± 8.69^{b}	18.00 ± 3.00^{b}

LGG, *L. rhamnosus* GG

All values are mean ± standard deviation

$^{a–b}$The superscript letters in the same row indicate statistical differences ($p < 0.05$)

diacetyl, and bacteriocin, among other molecules (Oliveira et al., 2017; Šušković et al., 2010).

Inhibition of adherence of pathogens to HT-29 cells

Adhesion to HT-29 cells was assessed by counting the number of bacteria adhered to HT-29 cells (Table 3). *E. coli* ATCC 25922, *L. monocytogenes* ATCC 15313, *S.* Typhimurium P99, and *S. aureus* KCCM 11335 numbers were reduced to 0.59, 0.12, 0.95, and 0.49 CFU/mL, respectively. Particularly, *S.* Typhimurium P99 with *L. brevis* KU15153 to HT-29 cell was decreased remarkably. In a previous study, adhesion of *L. monocytogenes* and *S. aureus* to Caco-2 cells was reduced by *L. lactis* KC24 (Lee et al., 2015). These results indicate that *L. brevis* KU15153

Table 3 Inhibition activity of *L. brevis* KU15153 against adherence of foodborne pathogens to HT-29 cells

Pathogens	Adherent cell no. (Log CFU/mL)	
	Pathogen	Pathogens with *L. brevis* KU15153
Escherichia coli ATCC 25922	7.49 ± 0.84^{b}	6.90 ± 0.09^{d}
Listeria monocytogenes ATCC 15313	5.17 ± 0.17^{a}	5.05 ± 0.14^{b}
Salmonella Typhimurium P99	5.70 ± 0.11^{a}	4.75 ± 0.26^{a}
Staphylococcus aureus KCCM 11335	6.99 ± 0.02^{b}	6.50 ± 0.01^{c}

All values are mean ± standard deviation

[a–d]The superscript letters in the same row indicate statistical differences ($p < 0.05$)

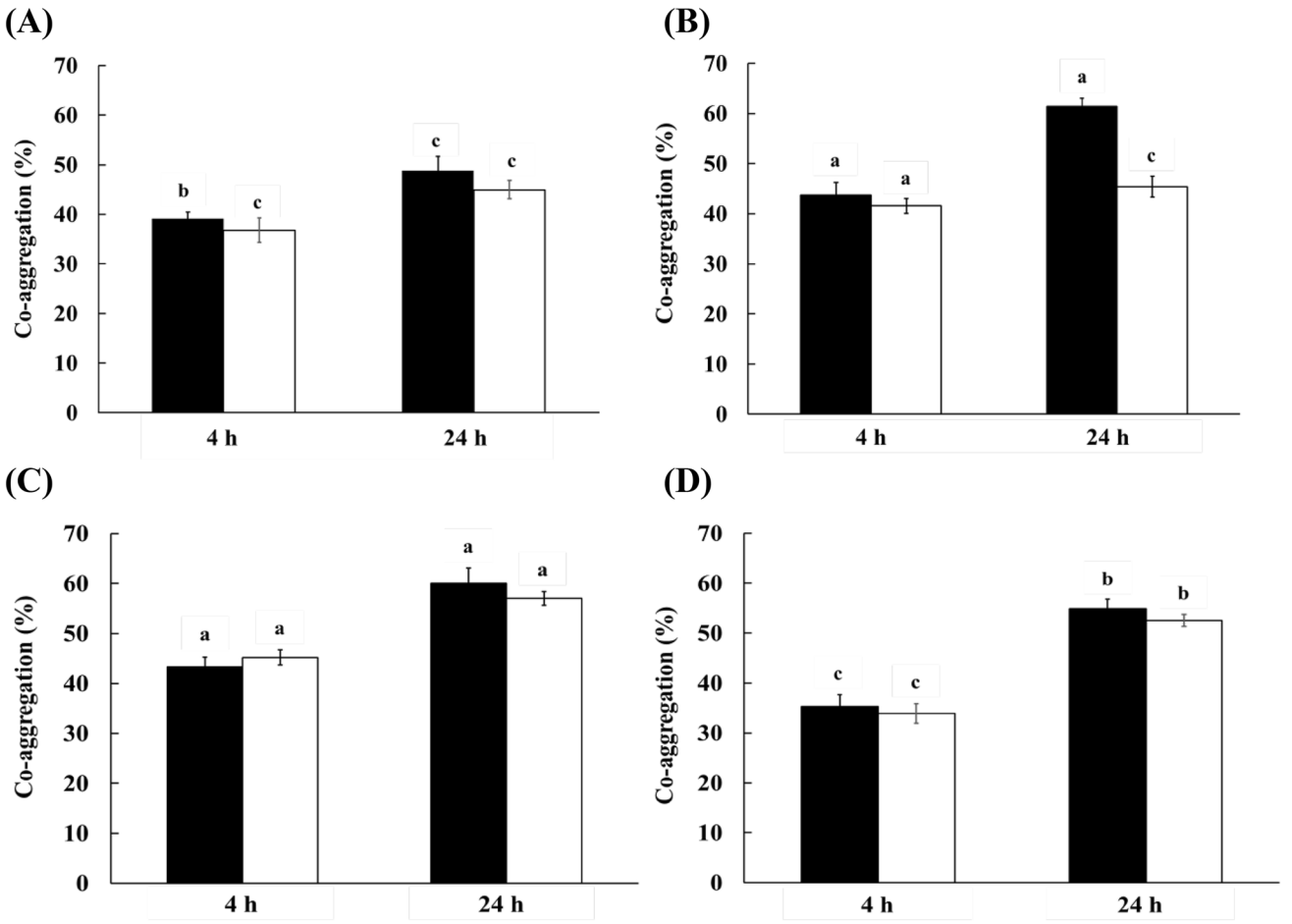

Fig. 2 Co-aggregation activities of LGG and *L. brevis* KU15153 with pathogens. (**A**) LAB with *Listeria monocytogenes* ATCC 15313, (**B**) LAB with *Salmonella* Typhimurium P99, (**C**) LAB with *Escherichia coli* ATCC 25922, and (**D**) LAB with *Staphylococcus aureus* KCCM 11335. Filled square, LGG (*L. rhamnosus* GG); open square, *L. brevis* KU15153. Each value represents the mean ± standard deviation and different letters on each bar represent significant difference between values ($p < 0.05$)

Table 4 Antioxidant activities of LGG and *L. brevis* KU15153 with different mechanisms

Microorganisms	Antioxidant activity (%)	
	DPPH radical scavenging activity	β-Carotene bleaching inhibitory activity
LGG	19.21 ± 2.92[a]	64.25 ± 6.27[a]
L. brevis KU15153	44.14 ± 0.23[b]	71.62 ± 6.87[a]

LGG, *L. rhamnosus* GG

All values are mean ± standard deviation

[a–b]The superscript letters in the same row indicate statistical differences ($p < 0.05$)

can modify the intestinal microflora by inhibiting adhesion of pathogens to the intestines.

Auto-aggregation and co-aggregation

Auto-aggregation and co-aggregation were evaluated to assess colonization of bacteria on intestinal cells (Fig. 2). At 4 h incubation, *L. brevis* KU15153 and LGG showed 21.44% and 22.68% auto-aggregation abilities, respectively. After 24 h incubation, auto-aggregation of *L. brevis* KU15153 (52.55%) was higher than that of LGG (44.70%). The co-aggregation activity of *L. brevis* KU15153 with pathogens was 40-55% after 24 h of incubation. Co-aggregation of *L. brevis* KU15153 with pathogens showed a lower coaggregation ability than LGG. In another study, co-aggregation of *L. lactis* KC24 with pathogens (*L. monocytogenes* and *S. aureus*) was the 29.28–74.11%. These auto-aggregation and co-aggregation abilities of *L. brevis* KU15153 suggest that this strain helps to prevent colonization or modification under the conditions of the intestine (Lee et al., 2015).

Antioxidant activity

The antioxidant activity of LAB strains plays an important role in the protection from free radicals (Ren et al., 2014). The antioxidant activity of *L. brevis* KU15153 was measured by DPPH radical scavenging and β-carotene bleaching assays (Table 4). The DPPH radical scavenging and β-carotene bleaching inhibitory activities of *L. brevis* KU15153 were higher than those of LGG. *L. brevis* KU15153 and LGG showed DPPH radical scavenging activities of 44.14% and 19.21% at 10^7 CFU/mL, respectively. The β-carotene bleaching activities of *L. brevis* KU15153 and LGG were 71.62% and 64.25%, respectively. Aarti et al. (2017) reported that the DPPH radical scavenging activity of *L. brevis* LAP2 increased in a concentration-dependent manner (18.8–68.35% at 10^8–10^9 CFU/mL). Some *L. brevis* strains (O-9 and LSe) showed low DPPH radical scavenging activities with values of 0% and 9.3% (Shakibaie et al., 2017; Uugantsetseg and Batjargal, 2014). These antioxidant effects were reported to be strain-specific based on the cell wall composition, enzyme, metabolite production, etc. (Oh et al., 2018).

In conclusion, *L. brevis* KU15153 isolated from kimchi showed potential probiotic properties such as stability under gastric conditions and adherence to intestinal cells. Additionally, *L. brevis* KU15153 showed antibiotic susceptibility and hemolytic activity, and thus appears to be safe. *L. brevis* KU15153 may have modified the intestinal conditions by inhibiting pathogenic strains and adhering pathogens to intestinal cell. Its antioxidant activity was higher than that of LGG in DPPH radical scavenging and β-carotene bleaching inhibitory activities. Therefore, *L. brevis* KU15153 may be useful as a probiotic organism and can be applied in the functional food industry as a safe food additive.

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Compliance with ethical standards

Conflict of interest Jang, Lee, and Paik declare that they have no conflict of interest.

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