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ANIMAL

Effects of *Pediococcus pentosaceus* strains isolated from three different types of Kimchi in ICR mice infected with *Escherichia coli* or *Salmonella* Typhimurium

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Abstract

One hundred and twenty imprinting control region (ICR) mouse with initial body weights of 26 ± 2 g (5 weeks old) were assigned to six treatments for a two-week feeding trial to determine the effect of *Pediococcus pentosaceus* strains (*Pp*S) which were isolated from three different types of Kimchi in ICR mice infected with *Escherichia coli* (*Ec*) or *Salmonella* Typhimurium (*ST*). Six groups constituted a normal control group without *Ec* or *ST* orally administrated (NC-; n = 20), a normal control group (NC+; n = 20), a group for which *Lactobacillus plantarum* was orally administrated (LP; n = 20), a group for which *Pp*S A was orally administrated (PSA; n = 20), a group for which *Pp*S B was orally administrated (PSB; n = 20), and a group for which *Pp*S C was orally administrated (PSC; n = 20), the latter five groups constituted the *Ec* infected groups and the *ST* infected groups of 10 mice each. LP and PSC showed significantly ($p < 0.05$) improved growth performance compared to the other groups, except for NC- in the *Ec* infected mice group. NC+ showed significantly lower ($p < 0.05$) growth performance compared to the other groups, except for NC- in the *ST* infected mice groups. Regarding the *Ec* and *Salmonella* counts in the intestine, the LP and PSC groups had significantly lower ($p < 0.05$) counts than the NC+ and PSB groups. In conclusion, LP and PSC strains isolated from Kimchi can act as probiotics by inhibiting *Ec* and *ST*.

Key words: intestinal microorganisms, Kimchi, mouse, pathogen, probiotic

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Introduction

Probiotics are defined as microorganisms that can provide a beneficial effect on health when ingested in an appropriate amount. These effects include helping in achieving balance of the normal intestinal microflora, inhibiting the formation of harmful bacteria, preventing various diseases and

anticancer activity, enhancing the immune system and antioxidant activity, and lowering blood cholesterol (Homma, 1988). *Lactobacillus* spp. are one of the oldest probiotics and are generally used for farm animals these days (Silva et al., 1999; Jeong et al., 2017). Some previous studies reported that *Lactobacillus plantarum* has inhibitory ability against pathogenic bacteria. Yang et al. (2014) reported that feeding *L. plantarum* to young male piglets improved their growth performance by preventing diarrhea induced by *E. coli* K88 challenge and enhancing the function of the intestinal barrier. Fayol-Messaoudi et al. (2007) reported that intragastric administration of 200 μL of *L. plantarum* to *Salmonella* Typhimurium-infected conventional mice reduced the *S.* Typhimurium counts in intestinal tissues and intestinal contents. Murry et al. (2004) reported that *L. plantarum* inhibited the growth of *E. coli* and *S.* Typhimurium on normal starter and grower diets for intestinal tract of broiler chickens by reducing the pH level. Many probiotics are lactic acid bacteria and Lactobacillaceae are known for producing various bacteriocins and secondary metabolites with antibacterial activity (Skyttä et al., 1993; Asahara et al., 2004). *Pediococcus* is a group of lactic acid bacteria and belongs to the family Lactobacillaceae. *Pediococcus pentosaceus* strains can survive while passing through the digestive tract because they are capable of surviving in the stomach and are resistant to low pH, bile salt, and pepsin (Chiu et al., 2008; Osmanagaoglu et al., 2010; Xu et al., 2018; Park and Choi, 2021). *P. pentosaceus* strains showed intense inhibitory ability against *E. coli* and *Salmonella* (Silva et al., 2017). This ability might help the *P. pentosaceus* strains to reach the intestines safely and act as probiotics against pathogenic bacteria. There are many previous studies about the use of probiotic strains in infected animals to investigate their inhibitory ability against pathogenic bacteria; however, there are only a few studies about *P. pentosaceus* strains. This study was conducted to investigate the protective ability of *P. pentosaceus* strains, isolated from three different types of Kimchi, against *E. coli* and *S.* Typhimurium in *E. coli*-infected imprinting control region (ICR) mice and *S.* Typhimurium-infected ICR mice.

Materials and Methods

The experimental protocol for this study was reviewed and approved by the Institutional Animal Care and Use Committee of Chungbuk National University, Cheongju, Korea (approval #CBNUA-1427-20-02).

Microorganisms

E. coli and *S*. Typhimurium were received from Dankook University (Cheonan, Korea). *L. plantarum* was isolated from commercial probiotics supplement (Lactoplan, Genebiotech, Gongju, Korea). *P. pentosaceus* strain A was isolated from Cabbage Kimchi. *P. pentosaceus* strain B was isolated from Yeolmu Kimchi. *P. pentosaceus* strain C was isolated from Baek Kimchi. All of *P. pentosaceus* were received from Sookmyung Women's University (Seoul, Korea).

Animals and diets

One hundred twenty five weeks old male ICR mice, were purchased from Daehan BioLink (Eumseong, Korea), were housed under a 12 h light/12 h dark cycle in plastic cages with a temperature of 23 ± 3℃. Mice were fed with same diet (Table 1). Mice were divided into six groups based on the initial weight of mice (26 ± 2 g) on each *E. coli* infected group and *S.* Typhimurium infected group. Six groups were Normal control group without *E. coli* and *S.* Typhimurium orally administrated (NC-; n = 20), Normal control group with *E. coli* or *S.* Typhimurium orally administrated (NC+; n = 20), *L. plantarum* orally administrated group after *E. coli* or *S.* Typhimurium orally administrated (LP; n = 20), *P. pentosaceus* strain

A orally administrated group after *E. coli* or *S.* Typhimurium orally administrated (PSA; n = 20), *P. pentosaceus* strain B orally administrated group after *E. coli* or *S.* Typhimurium orally administrated (PSB; n = 20), *P. pentosaceus* strain C orally administrated group after *E. coli* or *S.* Typhimurium orally administrated (PSC; n = 20) on each *E. coli* infected groups and *S.* Typhimurium infected groups. They were fed standard mouse chow and saline for drinks. They were allowed free access to feed and drinks. All feed, bedding and water dispenser were sterilized.

Table 1. Compositions of the basal diets.

Item	Ingredient ($g \cdot kg^{-1}$)
Casein	210.00
L-cystine	3.00
Corn starch	280.00
Maltodextrin	50.00
Sucrose	325.00
Lard	20.00
Soybean oil	20.00
Cellulose	37.15
Mineral mix, AIN-93G-MX (94046)	35.00
Calcium phosphate, dibasic	2.00
Vitamin mix, AIN93-VX (94047)	15.00
Choline bitartrate	2.75
Yellow food color	0.10

Experimental design for growth performance

After 3 days of the acclimation period, 200 μL of *E. coli* (1.0×10^9 CFU·mL^{-1}) or *S.* Typhimurium (1.0×10^9 CFU·mL^{-1}) were orally administrated to NC+, LP, PSA, PSB and PSC on day 0 to make *E. coli* infected ICR mice groups and *S.* Typhimurium infected ICR mice groups. Same amount of PBS was administrated to NC-. 200 μL (1.0×10^8 CFU·mL^{-1}) of microorganisms were orally administrated to LP, PSA, PSB and PSC once every two days for 2 weeks while the same amount of PBS was administrated to NC- and NC+ groups. Body weight (BW) was recorded on day 0, 1, 7, and 14. BW was an important indicator of mice's health status during treatment administration. Body weight gain (BWG), feed intake (FI) and feed efficiency ratio (FER) were measured. All mice were monitored at least once a day to check the mortality rate.

Experimental design for change in the number of microorganisms

To confirm the change of *E. coli* counts or *S.* Typhimurium counts in the small intestine, two mouse in each group were dissected on day 0 (administrating *E. coli* and *S.* Typhimurium), day 1 and day 7 on each *E. coli* infected ICR mice groups and *S.* Typhimurium infected ICR mice groups. Four of mice were dissected on day 14. Intestine contents were isolated from ileum. Feces were collected on day 0, 1, 7, and 14 to confirm the change of *E. coli* counts or *S.* Typhimurium counts in large intestine. Intestine contents and feces were diluted in PBS and spread on Macconkey agar (MB cell, Seoul, Korea) or *Salmonella Shigella* agar (MB cell, Seoul, Korea) to measure CFU·mL^{-1} of *E. coli* or *S.* Typhimurium. Macconkey agar and *Salmonella Shigella* agar were incubated at the incubator for 24 hours and 48 hours, respectively.

Statistical analysis

SAS program (Statistical Analysis System 9.1, SAS Institute, Cary, NC, USA) was used to execute all statistical analyses. One-way ANOVA (SAS Institute, Cary, NC, USA) was used to analyze results statistically. Probability values ($p < 0.05$) were used to show statistical significance. Tukey's test was operated for comparison ($p < 0.05$) when variance was noticed among groups.

Results

Growth performance

Table 2 shows BW, BWG, FI and FER differences according to different treatments in *E. coli* infected mice group. On day 0 and day 1, there were no significant differences ($p > 0.05$) among groups in BW. On day 7 and day 14, NC- was the highest ($p < 0.05$) in BW. LP, PSA, PSB and PSC were significantly higher ($p < 0.05$) than NC+ while PSC had no significant difference ($p > 0.05$) with LP.

Table 2. Effects of various probiotics supplementation on growth performance in imprinting control region mice challenged by *E. coli*.

Item	Group							
	NC-	NC+	LP	PSA	PSB	PSC	SEM	p-value
BW (g)								
Day 0	26.89	26.88	26.87	26.90	26.89	26.87	0.060	0.968
Day 1	27.22	26.46	26.45	26.47	26.47	26.45	0.070	0.564
Day 7	29.81a	27.49c	27.68b	27.61b	27.68b	27.63b	0.070	0.032
Day 14	32.52a	28.71d	29.22b	28.99c	29.03c	29.18b	0.131	0.016
BWG ($g \cdot week^{-1} \cdot mouse^{-1}$)								
Week 1	2.59a	1.03d	1.25b	1.14c	1.17c	1.18bc	0.090	0.001
Week 2	2.51a	1.22d	1.53b	1.38c	1.39c	1.55b	0.074	0.001
FI ($g \cdot week^{-1} \cdot mouse^{-1}$)								
Week 1	32.14a	27.89c	30.11b	29.88b	30.12b	29.91b	0.212	0.043
Week 2	30.54a	26.48c	28.88b	28.91b	28.92b	28.74b	0.218	0.017
FER (per week)								
Week 1	0.081a	0.037b	0.042b	0.036b	0.036b	0.036b	0.004	0.001
Week 2	0.082a	0.052b	0.052b	0.046b	0.049b	0.055b	0.003	0.001
Mortality	-	2	-	1	-	-		

NC-, normal control group without *E. coli* orally administrated (n = 10); NC+, normal control group with *E. coli* orally administrated (n = 10); LP, *Lactobacillus plantarum* group (n = 10); PSA, *Pediococcus pentosaceus* strain A group (n = 10); PSB, *Pediococcus pentosaceus* strain B group (n = 10); PSC, *Pediococcus pentosaceus* strain C group (n = 10); SEM, standard error of mean; BW, body weight; BWG, body weight gain; FI, feed intake; FER, feed efficiency ratio.

a - c: Means different superscripts in same column are differ significantly ($p < 0.05$; n = 60).

On week 1 and week 2, NC- was the highest ($p < 0.05$) in BWG. LP, PSA, PSB and PSC were significantly higher ($p < 0.05$) than NC+ while PSC had no significant difference ($p > 0.05$) with LP in BWG. NC- was the highest ($p < 0.05$) in FI. LP, PSA, PSB and PSC were significantly higher ($p < 0.05$) than NC+ while there were no significant differences among NC+, LP, PSA, PSB and PSC in FI. NC- was the highest ($p < 0.05$) in FER. There were no significant differences ($p > 0.05$) displayed among NC+, LP, PSA, PSB and PSC in FER. Two and one mice have died in NC+ and PSA, respectively.

Table 3 shows BW, BWG, FI and FER differences according to different treatments in *S.* Typhimurium infected mice group. On day 0 and day 1, there were no significant differences ($p > 0.05$) among groups in BW. On day 7 and day 14, NC- was the highest ($p < 0.05$) in BW. LP, PSA, PSB and PSC were significantly higher ($p < 0.05$) than NC+ while there were no significant differences ($p > 0.05$) among LP, PSA, PSB and PSC.

Table 3. Effects of various probiotics supplementation on growth performance in imprinting control region mice challenged by *Salmonella* Typhimurium.

Item	Group							
	NC-	NC+	LP	PSA	PSB	PSC	SEM	p-value
BW (g)								
Day 0	26.88	26.86	26.90	26.89	26.88	26.88	0.04	0.898
Day 1	27.20	26.46	26.45	26.45	26.44	26.46	0.08	0.649
Day 7	29.83a	27.31c	27.54b	27.48b	27.47b	27.52b	0.094	0.031
Day 14	32.69a	28.39c	28.88b	28.80b	28.77b	28.85b	0.124	0.010
BWG ($g \cdot week^{-1} \cdot mouse^{-1}$)								
Week 1	2.63a	0.86c	1.09b	1.01bc	1.02b	1.06b	0.053	0.001
Week 2	2.86a	1.08c	1.35b	1.32b	1.29b	1.33b	0.069	0.001
FI ($g \cdot week^{-1} \cdot mouse^{-1}$)								
Week 1	32.58a	25.46c	27.21b	27.58b	27.32b	27.42b	0.155	0.001
Week 2	31.34a	24.84c	26.53b	26.26b	26.56b	26.47b	0.136	0.001
FER (per week)								
Week 1	0.080a	0.033c	0.041b	0.037b	0.035b	0.039b	0.003	0.001
Week 2	0.087a	0.043c	0.055b	0.050b	0.050b	0.050b	0.002	0.001
Mortality	-	1	-	-	-	-		

NC-, normal control group without *E. coli* orally administrated (n = 10); NC+, normal control group with *E. coli* orally administrated (n = 10); LP, *Lactobacillus plantarum* group (n = 10); PSA, *Pediococcus pentosaceus* strain A group (n = 10); PSB, *Pediococcus pentosaceus* strain B group (n = 10); PSC, *Pediococcus pentosaceus* strain C group (n = 10); SEM, standard error of mean; BW, body weight; BWG, body weight gain; FI, feed intake; FER, feed efficiency ratio.

a - c: Means different superscripts in same column are differ significantly ($p < 0.05$; n = 60).

On week 1 and week 2, NC- was the highest ($p < 0.05$) in BWG. LP, PSA, PSB and PSC were significantly higher ($p < 0.05$) than NC+ while there were no significant differences ($p > 0.05$) among LP, PSA, PSB and PSC in BWG. NC- was the highest ($p < 0.05$) in FI. LP, PSA, PSB and PSC were significantly higher ($p < 0.05$) than NC+ while there were no significant differences ($p > 0.05$) among LP, PSA, PSB and PSC in FI. NC- was the highest ($p < 0.05$) in FER. PSA, PSB and PSC were significantly higher ($p < 0.05$) than NC+ in FER. One of mice has died in NC+.

Microorganism counts change in intestines

Table 4 shows the change of *E. coli* in the large intestine and small intestine by different treatments. No significant differences ($p > 0.01$) were shown in the small intestine on day 0 and day 1. NC+ showed the highest ($p < 0.01$) counts on day 7 while NC- was the lowest ($p < 0.01$). PSC had no significant difference ($p > 0.01$) with LP on day 7. NC+ showed the highest ($p < 0.01$) counts on day 14 while NC-, LP and PSC were the lowest ($p < 0.01$). No significant differences ($p > 0.01$) were shown in the large intestine on day 0 and day 1. NC+ showed the highest ($p < 0.01$) counts on day 7 and day 14 while NC- was the lowest ($p < 0.01$). PSC had no significant difference ($p > 0.01$) with LP on day 7 and day 14.

Table 5 shows the change of *S.* Typhimurium in the large intestine and the small intestine by different treatments. No significant differences ($p > 0.01$) were shown in the small intestine on day 0 and day 1. NC+ showed the highest ($p < 0.01$) counts on day 7 while NC- was the lowest ($p < 0.01$). PSC had no significant difference ($p > 0.01$) with LP on day 7. NC+

showed the highest ($p < 0.01$) counts on day 14 while LP and PSC were the lowest ($p < 0.01$). PSC and LP were shown lower ($p < 0.01$) counts than NC- in the small intestine. No significant differences ($p > 0.01$) were shown in the large intestine on day 0 and day 1. NC+ showed the highest ($p < 0.01$) counts on day 7 while NC- was the lowest ($p < 0.01$). PSC had no significant difference ($p > 0.01$) with LP on day 7. NC+ showed the highest ($p < 0.01$) counts on day 14 while LP was the lowest ($p < 0.01$). PSC and PSA had no significant difference ($p > 0.01$) with NC- on day 14.

Table 4. Effects of various probiotics supplementation on change of intestinal and fecal microorganisms in imprinting control region mice challenged by *E. coli*.

Item	Group							
	NC-	NC+	LP	PSA	PSB	PSC	SE	p-value
Small intestine (log10 CFU·g^{-1})^{y}								
Day 0	3.27	3.25	3.25	3.28	3.26	3.25	0.08	0.849
Day 1	3.26	3.63	3.42	3.44	3.33	3.64	0.15	0.184
Day 7	3.27d	6.20a	5.45c	5.94b	6.01b	5.51c	0.13	0.001
Day 14	3.23c	5.84a	3.39c	4.10b	4.13b	3.35c	0.17	0.001
Large intestine (log10 CFU·g^{-1})^{z}								
Day 0	3.53	3.54	3.51	3.54	3.53	3.53	0.09	0.789
Day 1	3.51	3.71	3.85	3.69	3.57	3.60	0.17	0.194
Day 7	3.54d	6.33a	5.71c	6.11b	6.09b	5.75c	0.15	0.001
Day 14	3.53d	5.91a	4.23c	4.52b	3.37b	4.18c	0.12	0.009

NC-, normal control group without *E. coli* orally administrated (n = 10); NC+, normal control group with *E. coli* orally administrated (n = 10); LP, *Lactobacillus plantarum* group (n = 10); PSA, *Pediococcus pentosaceus* strain A group (n = 10); PSB, *Pediococcus pentosaceus* strain B group (n = 10); PSC, *Pediococcus pentosaceus* strain C group (n = 10); SE, standard error.

^{y} Samples from ileum.

^{z} Feces from excreted.

a - d: Means different superscripts in same column are differ significantly ($p < 0.01$; n = 60).

Table 5. Effects of various probiotics supplementation on change of intestinal and fecal microorganisms in imprinting control region mice challenged by *Salmonella* Typhimurium.

Item	Group							
	NC-	NC+	LP	PSA	PSB	PSC	SE	p-value
Small intestine (log10 CFU·g^{-1})^{y}								
Day 0	3.27	3.26	3.27	3.25	3.28	3.26	0.09	0.774
Day 1	3.28	3.69	3.48	3.70	3.61	3.59	0.19	0.346
Day 7	3.30d	4.73a	3.76c	4.23b	4.26b	3.91c	0.14	0.024
Day 14	3.26b	3.56a	2.73c	3.14b	3.12b	2.88c	0.11	0.037
Large intestine (log10 CFU·g^{-1})^{z}								
Day 0	3.29	3.28	3.28	3.29	3.29	3.28	0.08	0.917
Day 1	3.30	3.39	3.41	3.51	3.60	3.51	0.17	0.168
Day 7	3.29d	5.30a	4.25c	4.57b	4.56b	4.26c	0.13	0.001
Day 14	3.28c	4.17a	2.99d	3.32bc	3.37b	3.23c	0.17	0.003

NC-, normal control group without *E. coli* orally administrated (n = 10); NC+, normal control group with *E. coli* orally administrated (n = 10); LP, *Lactobacillus plantarum* group (n = 10); PSA, *Pediococcus pentosaceus* strain A group (n = 10); PSB, *Pediococcus pentosaceus* strain B group (n = 10); PSC, *Pediococcus pentosaceus* strain C group (n = 10); SE, standard error.

^{y} Samples from ileum.

^{z} Feces from excreted.

a - d: Means different superscripts in same column are differ significantly ($p < 0.01$; n = 60).

Discussion

In recent years, *E. coli* O157:H7 and *Salmonella* are the most common pathogens, which cause diarrhea and enteritis (Sung and Ho, 2003; Silva et al., 1999). *E. coli* O157:H7 is known as Shiga toxin-producing *E. coli,* which can cause infections even with a small amount (Lee et al., 2017). *Salmonella* can cause acute gastroenteritis (Sung and Ho, 2003). In this context, *E. coli* and *Salmonella* can cause reduction in BW, average daily gain (ADG), and FI by infections. Supplementing probiotics may balance the imbalanced intestinal microflora and improve the health performance (Giang et al., 2012). The main purpose of this research was to investigate the protective function of *P. pentosaceus* strains, isolated from Cabbage, Yeolmu, and Baek Kimchi, against *E. coli* and *S.* Typhimurium in *E. coli*-infected ICR mice and *S.* Typhimurium-infected ICR mice.

Growth performance

Research about an increase in growth performance by oral administration of *P. pentosaceus* has been reported in previous studies. Oral administration of 200 μL (3×10^9 CFU·mL^{-1}) of *P. pentosaceus* LI05 in *Clostridium difficile*-infected mice reduced weight loss than that in the normal control group (Xu et al., 2018). Oral administration of 1 ml (3×10^9 CFU·mL^{-1}) of *P. pentosaceus* LI05 in a liver cirrhosis model reduced weight loss compared to that in the normal control group by protecting the intestinal barrier in rats (Shi et al., 2017).

In *E. coli*-infected ICR mice groups, growth performance was significantly improved in PSA, PSB, and PSC than NC+ by increasing the BW, BWG, and FI. No significant differences were found in FER among groups. PSC showed no significant difference than LP in BW, BWG, FI, and FER. These results are supported by earlier studies. *L. plantarum* CJLP243 (T3) inhibited *E. coli* and improved average daily feed intake (ADFI), ADG, and FER (Lee et al., 2012). *L. Plantarum* B1 can inhibit *E. coli* K88 and promote growth performance (Wang et al., 2017). Feeding *P. acidilactici* (1×10^6 CFU·g^{-1}) and *P. pentosaceus* (1.3×10^6 CFU·g^{-1}) to lambs improved the BWG and FI (Saleem et al., 2017).

In *S.* Typhimurium-infected ICR mice groups, growth performance was significantly improved in PSA, PSB, and PSC than NC+ by increasing the BW, BWG, and FI. PSA, PSB, and PSC showed no significant difference than LP in BW, BWG, and FI. PSA, PSB, PSC, and LP were higher than NC+ at week 1 in terms of FER. PSA, PSB, and PSC were higher than NC+ and LP at week 2 in terms of FER. These results are supported by a previous study. Feeding *L. plantarum* CWBI-B659 with xylanase Belfeed B1100MP significantly increased the growth rate in *S*. Typhimurium-infected broilers (Vandeplas et al., 2009). The piglets fed lactic acid bateria (LAB) complex inclusive of *P. pentosaceus* D7 showed improved ADG and ADFI and lower feed conversion ratio (FCR) (Giang et al., 2012). Feeding *Pediococcus* spp to growing lambs through drinking water improved the BW, BWG, and FER (El-Katcha et al., 2016). Feeding 2×10^7 CFU·g^{-1} of *P. pentosaceus* with basal diet to SPF chickens improved the BW and ADG and lowered the FCR (Chen et al., 2017).

In both *E. coli*-infected ICR mice groups and *S.* Typhimurium-infected ICR mice groups PSA, PSB, and PSC showed higher growth performance than NC+.

P. pentosaceus showed a growth performance improvement effect by inhibiting the growth of *E.coli* and *S.* Typhimurium. These results are supported by previous studies. *P. pentosaceus* can inhibit *E. coli* and *S.* Typhimurium. *P. pentosaceus* MP12, *P. pentosaceus* MP-22, *P. pentosaceus* MP-36 isolated from pickled cabbage have been confirmed to have strong inhibitory activity against *E. coli* and *S.* Typhimurium (Chiu et al., 2008). *P. pentosaceus* M7-1 and *P. pentosaceus* DPC6006 have strong inhibitory ability against *E. coli* O157:H7 and *S*. Typhimurium (Casey et al., 2004).

In *E. coli*-infected ICR mice groups, two and one mice have died in NC and PSA, respectively. We consider that this occurred due to the low inhibitory ability of *P. pentosaceus* strain A against *E. coli*. The experimental results may vary depending on the amount of treatment and the number of samples. In *S*. Typhimurium- infected ICR mice groups, none of the mice have died in PSA, PSB, and PSC. It was a different result from the previous study. Pretreatment with *P. pentosaceus* 40 accelerated the infection and increased the number of deaths (Silva et al., 2017). The difference in experimental results depend on the pretreatment or not, number of test samples, environment, and diet composition.

Microorganism count change in intestines

Previous studies reported that weaned piglets fed LAB have lower *E. coli* count in the intestine (Tortuero et al., 1995; Huang et al., 2004; Mallo et al., 2010). Some strains of *P. pentosaceus* have shown outstanding antimicrobial activity against pathogenic bacteria, like *E. coli* and *Salmonella* (Xu et al., 2018; Lan et al., 2020). In this context, *P. pentosaceus* can reduce pathogenic bacterial counts in the intestine. A higher number of *E. coli* and *S.* Typhimurium were significantly reduced in PSA, PSB, and PSC than NC+ in the small intestine and the large intestine on day 7 and day 14. In terms of reduction of *E. coli*, PSC showed no significant difference than LP in the small intestine and the large intestine on day 7 and day 14, while it showed no significant difference than NC- in the small intestine on day 14. In the reduction of *S.* Typhimurium, PSC showed no significant difference than LP in the small intestine (on day 7 and day 14) and the large intestine (on day 7), while it showed no significant difference in NC- treatment in the large intestine on day 14. A higher number of *S.* Typhimurium was significantly reduced in PSC than NC- in the small intestine on day 14. This result is consistent with previous studies. *L. Plantarum* B1 reduced the *E. coli* count in the cecal content (Wang et al., 2017). *L. Plantarum* ZS2058 can inhibit *Salmonella* in a murine model (Liu et al., 2019). Feeding 2×10^7 CFU·g^{-1} of *P. pentosaceus* basal diet to SPF chickens decreased the number of *E. coli* in the cecal content. (Chen et al., 2017). *P. pentosaceus* MP12, *P. pentosaceus* MP-22, and *P. pentosaceus* MP-36 isolated from pickled cabbage significantly reduced the *Salmonella* count in the spleen and liver of mice (Chiu et al., 2008). We are in agreement with the results of (Lan et al., 2020), which suggested that the reduction in *E. coli* and *S.* Typhimurium in the intestines is due to *P. pentosaceus* expelled organic acid to lower the pH value and produce secondary metabolites, like a bacteriostatic toxin.

Conclusion

In conclusion, we considered that *P. pentosaceus* strains, isolated from three different types of Kimchi, can act as probiotics by inhibiting *E. coli* and *S.* Typhimurium. Among these three *P. pentosaceus* strains, *P. pentosaceus* strain C showed the highest inhibitory ability against *E. coli* and *S.* Typhimurium due to the highest growth performance and reduced the maximum number of *E. coli* and *S.* Typhimurium in the intestines; however, it showed no significant difference than *L. plantarum* (except for *S.* Typhimurium counts in the large intestine on day 14).

Conflict of Interests

No potential conflict of interest relevant to this article was reported.

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