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ARTICLE

Comprehensive Evaluation of Microbiological and Physicochemical Properties of Commercial Drinking Yogurts in Korea

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Abstract Most consumers consider yogurt to be a healthy food because it contains probiotic microorganisms. Although a plethora of commercially produced yogurts exists, nutritional and functional aspects of the commercial yogurts have not been well characterized. In this study, the microbiological and physicochemical properties of popular drinking yogurts in Korea were extensively characterized. The viability of lactic acid bacteria, including lactobacilli and bifidobacteria, varied between yogurt samples. These lactobacilli and bifidobacteria showed effective antimicrobial activities against foodborne pathogenic bacteria. Unlike the titratable acidity and pH, the soluble solids content varied between yogurt samples. All the yogurt samples contained high levels of potassium (average 143.53 mg/100 g) and calcium (average 133.92 mg/100 g), as well as phosphorus and sodium. Lactose, fructose, and glucose were the major sugar components in most yogurt samples, whereas the levels of sucrose and maltose were relatively low. Among several organic acids analyzed in the yogurt samples, lactic acid (average 767.67 mg/100 g) and citric acid (average 170.91 mg/100 g) were the most predominant. Taken together, this study provides preliminary information about the nutritional and functional characteristics of commercially available drinking yogurts.

Keywords commercial drinking yogurt, antimicrobial activity, physicochemical properties

Introduction

Fermented milk products are the most popular fermented foods in the world (Zare et al., 2011). As the processing technologies and competition in the food markets have developed, the interest in nutritious foods with appealing flavor properties has increased. Yogurt, one of the fermented milk products, is considered the most frequently used food matrices containing probiotic bacteria due to its nutritional and

health benefits (Hamann and Marth, 1984). It is defined as a coagulated milk product resulting from the fermentation of lactic acid by *Lactobacillus* and *Streptococcus* (Bourlioux and Pochart, 1988). Other bacterial species, including *Bifidobacterium*, are also frequently employed to provide the unique characteristics of the final products (Perez-Cornago et al., 2016).

In addition to the nutritional and health benefits of yogurts, the composition, physicochemical properties, sensory attributes, and textural aspects are important factors that influence acceptance and choices for consumers (Isleten and Karagul-Yuceer, 2006; Zare et al., 2011). During fermentation of milk, lactose is converted by starter cultures into lactic acid, which provides a mildly sour taste, acts as a bio-preservative for the products, influences the physical and chemical properties, and enhances the digestibility and absorptivity (Hekmat and Reid, 2006). Therefore, the alteration of process conditions, the addition of ingredients, and the use of different starter cultures can affect the quality of yogurt.

Among the different food product sectors, the dairy food division has undergone substantial change regarding health claims (Bayarri et al., 2011). Although a plethora of commercially produced yogurts exists, the market of drinking yogurts offers products of similar appearance, starter cultures, color, and texture as each other, as well as the same type of packaging, with limited comparative data to characterize their microbiological and physicochemical properties. Since yogurt can be perceived by consumers to be a healthy food, dairy food manufacturers should keep pace with consumer attitudes and behaviors toward foods that can promote health by continuing to assist consumers as they include these products in their diets. Therefore, in this study, we investigated the microbiological and physicochemical characteristics of commercially available drinking yogurts in Korea.

Materials and Methods

Yogurt samples

The top six best-selling brands of plain-flavored drinking yogurts from the year 2017 in Korea, were purchased from local supermarkets within 1 wk after production and analyzed within 2 d after purchase. Detailed information and nutrition facts about the samples used in this study can be found in Table 1 and 2.

Microbiological analyses

Escherichia coli KCTC1039 and *Salmonella* Typhimurium KCTC 1925 were obtained from the Korea Collection for Type Cultures (Jeongup, Korea), and *Staphylococcus aureus* ATCC 29213 and *Listeria monocytogenes* ATCC 3569 were purchased from the American Type Culture Collection (Manassas, VA, USA). The foodborne pathogenic bacteria were grown in brain heart infusion medium (BD Biosciences, Franklin Lakes, NJ, USA) at 37°C. Serial dilutions of yogurt samples were made in 0.85% (w/w) NaCl solution (saline) and then spread-plated in triplicate on modified plate count agar (Hardy Diagnostics, Santa Maria, CA, USA) for the enumeration of lactic acid bacteria by aerobically incubating at 37°C for 48 h or Bifidus Selective Medium (BSM; Sigma-Aldrich, St. Louis, MO, USA) agar for the enumeration of *Bifidobacterium* by anaerobically incubating at 37°C for 48 h in the anaerobic jar. To enumerate viable bacteria, bacterial cultures were appropriately incubated at 37°C between 48 to 72 h. Viable cell counts were performed by plating on appropriate agar.

Antimicrobial activities of supernatants from isolated lactic acid bacteria and bifidobacteria against the foodborne pathogenic bacteria were determined in 96-well microtiter plates, as previously described (Sambanthamoorthy et al., 2014) with minor modification. Briefly, randomly selected lactobacilli and bifidobacteria of the isolates from yogurt samples were grown in de Man Rogosa, and Sharpe broth (BD Biosciences) and BSM broth (Sigma-Aldrich) at 37°C for 24 h, respectively.

Table 1. Information on commercial drinking yogurt samples tested in this study

Samples	Ingredient list
1	Fluid milk 70%, non-fat dried milk, distilled water, high fructose corn syrup, isomaltooligosaccharide, acacia fiber, nutriose, fibosol-2, bifidus-enhancer, flavor extract, *Salicornia europaea* extract, kelp extract, pectin, lactase, natural vanilla flavoring, fruit-based lactic acid bacteria, LAB mixture 10^8 CFU/mL, *Bifidobacterium* spp., *L. fermentum* PL 9988, lemon juice concentrate.
2	Fluid milk, plain syrup 12.5%, apple juice concentrate 2.858%, lemon juice concentrate 0.4%, non-fat dried milk, LAB 0.00015%, probiotics-LAB 0.00029%.
3	Fluid milk, mixed non-fat dried milk, distilled water, fructooligosaccharide 1.5%, whey protein powder, *Bifidus actregularis* 10^8 CFU/mL, lactase.
4	Fluid milk, distilled water, plain syrup 10%, mixed non-fact dried milk, sugar, isomaltooligosaccharide, L-GG LAB 250×10^8 CFU/mL.
5	Fluid milk 73%, distilled water, high fructose corn syrup, indigestible maltodextrin, chicory fiber, mixed non-fat dried milk, isomalto oligosaccharide, lactrose, xylooligosaccharide, pectin, mixed LAB 150×10^8 CFU/mL, LP299V 15×10^8 CFU/mL.
6	Fluid milk 6.513%, distilled water, high fructose corn syrup, isomaltooligosaccharide, chicory fiber, whey protein powder, fructooligosaccharide, salt-free whey-milk protein powder mix, pear juice concentrate, Japanese apricot juice concentrate, egg-processed product 0.5%, chajogi extract 0.05%, egg yolk powder, artificial flavorings (Japanese apricot flavor, creamy flavor), Tangja citrus extract 0.003%, Mugwort extract 0.003%, broccoli extract 0.003%, cabbage concentrate powder 0.001%, freeze-dried aloe gel powder 0.01%, lactase, enzyme-treated ste3via, citrus concentrate, LAB (*S. thermophilus,* Lactobacilli, Bifidobacteria) 10^8 CFU/mL, Lactobacilli (HP7) 10^8 CFU/mL.

Table 2. Nutrition facts of sample (per 100 g)

Nutrition facts	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Calories (kcal)	96.7	76.7	63.1	76	100	93.3
Total carbohydrate (g)	13.3	10	7.7	11.2	17.3	14
Sugar (g)	6.7	7.3	6.9	9.6	8	8.7
Dietary fiber (g)	0.8	NI	NI	NI	5	2
Total fat (g)	3.3	2.7	2.2	1.8	3	3.3
Trans fat (g)	0	<0.1	0	0	0	0
Saturated fat (g)	2.1	2	1.3	1.2	1.9	1.8
Cholesterol (mg)	13.3	13.3	7.7	8	6.7	16.7
Protein (g)	3.3	3.3	3.1	3.2	3.3	3.3
Calcium (mg)	100	80	103.8	112	100	96.7
Sodium (mg)	60	60	53.8	64	53.3	60

NI, not indicated.

After incubation, cell-free supernatants (CFS) were obtained by filtration (0.2-μm pore size). Indicator foodborne pathogenic bacteria were grown under the appropriate conditions and adjusted to 0.05 optical density at 595 nm wavelength (OD_{595}) and then the bacterial suspensions (100 μL) were transferred to a 96-well microtiter plate. Subsequently, 100 μL of the CFS was added to each well and mixed with the suspension of indicator foodborne pathogenic bacteria. The suspensions of indicator foodborne pathogenic bacteria mixed with fresh media were used as controls. Following the 24-h incubation, the inhibition of indicator foodborne pathogenic bacteria was determined using a microplate reader at OD_{595}.

Physicochemical analyses

Chemical reagents

Methanol and acetonitrile were supplied by Fisher Scientific (Pittsburgh, PA, USA). Deionized water (18.2 MΩ) used for high-performance liquid chromatography (HPLC) elution was purified using an ultra-pure water system (OmniaTap6, Stakpure, Niederahr, Germany). The liquid chromatography solvents were filtered through HVLP filters (47 mm diameter, 0.45 μm pore size; Millipore, Burlington, MA, USA), while the analyte solutions were filtered through regenerated cellulose membrane filters (15 mm diameter, using 0.2 μm pore size; Sartorius, Gottingen, Germany). The reference standards, which contained sugars (glucose, fructose, sucrose, lactose, and maltose) and organic acids (oxalic acid, malic acid, citric acid, fumaric acid, acetic acid, tartaric acid, succinic acid, and lactic acid), were supplied by Sigma-Aldrich.

Analyses of soluble solids content (SSC), titratable acidity (TA), and pH

The SSC, TA, and pH were measured in yogurt samples. The SSC was determined at 20℃ by using a refractometer (Rx-500α, Atago Co. Ltd., Tokyo, Japan). TA was measured in yogurt samples diluted in distilled water by titration with 0.1N NaOH, using phenolphthalein indicator. The pH level was measured using a pH meter (Starter 2100 pH meter, Ohaus, Parsippany, NJ, USA) previously calibrated with pH 4.0 and 7.0 buffer solutions. The color quality of yogurt samples was determined using a colorimeter (NE-6000, Nippon Denshoku, Tokyo, Japan), as described by Akgun et al. (2016), to record the CIE L*a*b* color parameters, representing whiteness(+)/blackness(–), redness(+)/greenness(–), and yellowness(+)/blueness(–), respectively. Prior to color measurements, the colorimeter was calibrated against a white reference tile. Triplicate measurements were recorded for all samples.

Analysis of mineral composition

For the analysis of the mineral composition of yogurt samples, 1.0 g of a sample was digested in 7 mL of concentrated 69% HNO_3 (Dongwoo Fine Chemical, Iksan, Korea) in a Teflon digestion vessel. The samples were digested for 40 min while heating to 1,000 W with pressure increasing incrementally, using a Milestone Ethos 1 microwave digestion system (Sorisole, Italy). The sample digests were diluted with distilled water into 50-mL flasks and analyzed by using an Activa Horiba Jobin Yvon inductively coupled plasma optical emission spectrometer (Longjumeau, France) running through an argon gas flow (plasma flow 13 L/min, sheath flow 1.5 L/min). The following minerals were detected at the indicated absorption wavelengths (nm): calcium (Ca, 317.933 nm), potassium (K, 766.490 nm), sodium (Na, 589.592 nm), and phosphorus (P, 213.618 nm). A mixed multi-element standard solution was used for calibration and quantification. Data were expressed as mg/100 g of sample.

Analysis of sugar contents

Sugar contents were quantified using the method given by Vidal-Valverde et al. (1984) with some modifications. Before HPLC analyses, yogurt samples were diluted 20-fold in distilled water and filtered through a 0.2-μm syringe filter. Chromatographic separation was achieved using an UltiMate 3000 HPLC system (Thermo Fisher Scientific, MA, USA) equipped with a refractive index detector and a carbohydrate high-performance column (250×4.6 mm id., 4 μm; Waters, Milford, MA, USA) at 30℃. The mobile phase consisted of 79% acetonitrile and 21% distilled water with a 1.0 mL/min flow rate. The injection volume was 10 μL Three different concentrations of the standard solutions were analyzed to construct the calibration curves, and results were expressed as g/100 g of sample.

Analysis of organic acids

Organic acids were analyzed using the method stated by Bordonaba and Terry (2010) with some modifications. Yogurt samples were diluted 20-fold in distilled water and then filtered through a 0.2-μm syringe filter. For individual organic acid separation, HPLC was carried out at 25°C using an Agilent 1100 Series (Santa Clara, CA, USA) installed with a diode array detector and Prevail™ organic acid column (250×4.6 mm id., 5 μm; Alltech, Deerfield, IL, USA). The HPLC mobile phase was 25 mM KH_2PO_4 adjusted to pH 2.1 using H_3PO_4, and the detection wavelength was set at 210 nm. Flow rate and the injection volume were 1.0 mL/min and 3 μL, respectively. Calibration curves were constructed as described above but using the organic acid standards. Data were expressed as mg/100 g of yogurt sample.

Statistical analysis

Physiochemical data were analyzed using the general linear model approach to the analysis of variance, followed by Duncan's multiple range test with $p<0.05$. All statistical analyses were performed using SAS version 9.3 (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Enumeration of lactobacilli and bifidobacteria in commercial drinking yogurts

Viable counts of lactobacilli and bifidobacteria in the six yogurt samples are shown in Table 3. All yogurt samples were evaluated for the viability of lactobacilli and bifidobacteria during refrigerated storage at 4°C. Lactobacilli were present in all samples, with levels in the range of 6.12–8.13 Log CFU/mL. The approximate 2-log unit difference in lactobacilli counts depended on the sample tested. Bifidobacteria tended to be present in lower numbers than lactobacilli, ranging from 4.54 to 7.93 Log CFU/mL. These results suggested that the lactobacilli and bifidobacteria populations differed between each product. Since an essential factor for the yogurt quality is the survival of probiotic bacteria during shelf life, the viability and activity of the bacteria are important considerations (Kailasapathy and Chin, 2000). It has been suggested that a probiotic product should contain at least 10^6 CFU/mL at the expiry date (Gueimonde et al., 2004; Kailasapathy and Chin, 2000). Although four of the six yogurt samples contained less than 6 Log CFU/mL of bifidobacteria, all samples showed a high number of lactobacilli (>6 Log CFU/mL). Our observation indicated that commercial drinking yogurts tested in this study had different numbers of viable probiotic bacteria. It can be assumed that the variation in viable bacteria between the products may be attributed to the refrigerated storage and duration (Dave and Shah, 1997; Gilliland et al., 2002).

Antimicrobial activities of lactobacilli and bifidobacteria isolated from commercial drinking yogurts

Table 3. Viable cell count of *Lactobacillus* and *Bifidobacterium* in commercial drinking yogurts

Strains	Viable cell counts (Log CFU/mL)					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Lactobacillus spp.	7.30±0.02^{b}	6.52±0.31^{c}	7.25±0.05^{b}	8.13±0.42^{a}	6.95±0.10^{b}	6.12±0.05^{d}
Bifidobacterium spp.	7.30±0.05^{b,c}	4.77±1.32^{d}	4.54±0.05^{d}	7.93±0.27^{b}	5.03±1.84^{d}	5.76±0.94^{c,d}

Data are expressed as mean±SD from triplicates and different letters in a column are significantly different at $p<0.05$.
Detailed information and nutrition facts about the samples used in this study can be found in Table 1 and 2.

The antimicrobial effect of lactobacilli and bifidobacteria isolated from yogurt samples against foodborne pathogenic bacteria was determined *in vitro*, as shown in Fig. 1. Lactobacilli isolated from the products significantly inhibited the growth of *E. coli* (92.1%–93.4% inhibition) (Fig. 1A), *S.* Typhimurium (85.4%–88.2% inhibition) (Fig. 1B), and *S. aureus* (87.9%–91.3% inhibition) (Fig. 1C). However, lactobacilli did not seem to effectively inhibit the growth of *L. monocytogenes* (Fig. 1D). The growth of *L. monocytogenes* was strongly inhibited (>75% inhibition) by samples 4, 5, and 6 compared with samples 2 and 3 (41.7% and 32.8% inhibition, respectively), while it was moderately inhibited (68.5% inhibition) by Sample 1. Harris et al. (1989) reported that not all *Lactobacillus* spp. exhibited effective inhibition toward *Listeria* spp. *Lactobacillus acidophilus*, which is widely used as a yogurt starter culture, did not show any antagonistic effect on the growth of *Listeria* spp. In addition, *Lactobacillus helveticus* and *Lactobacillus plantarum* did not display an inhibitory activity toward *Listeria* spp. In contrast, *Lactobacillus curvatus* and *Lactobacillus sakei* exhibited antilisterial activity (Hartmann et al., 2011), indicating that the antimicrobial activities of lactobacilli may be species- and strain-specific.

Fig. 1E–H shows that the bifidobacteria effectively inhibited the growth of the foodborne pathogenic bacteria. All bifidobacteria reduced the growth of *E. coli* (>90% inhibition) (Fig. 1E), *S.* Typhimurium (>80% inhibition) (Fig. 1F), *S. aureus* (>80% inhibition) (Fig. 1G), and *L. monocytogenes* (>70% inhibition) (Fig. 1H), suggesting that the antimicrobial activities of bifidobacteria isolated from yogurt samples were more effective than lactobacilli for inhibiting foodborne pathogenic bacteria, including *L. monocytogenes*. It is known that lactobacilli and bifidobacteria produce substantial amounts

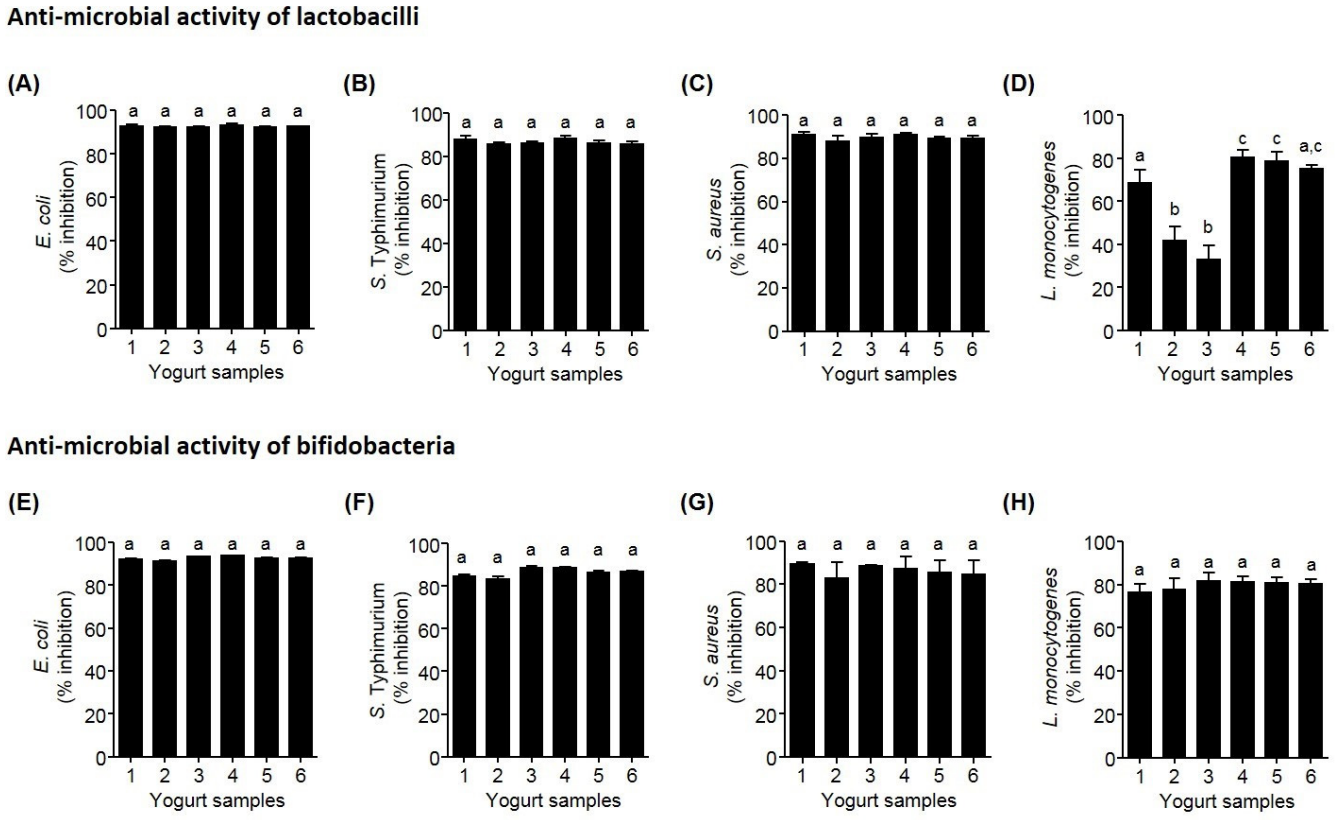

Fig. 1. Anti-microbial activity of lactobacilli and bifidobacteria isolated from commercial drinking yogurts against foodborne pathogenic bacteria. *E. coli* (A), *S.* Typhimurium (B), *S. aureus* (C), or *L. monocytogenes* (D) were incubated with the cell-free supernatants of lactobacilli for 24 h at 37℃. Similarly, *E. coli* (E), *S.* Typhimurium (F), *S. aureus* (G), or *L. monocytogenes* (H) were incubated with the cell-free supernatants of bifidobacteria for 24 h at 37℃. After incubation, the growth of each pathogen was measured at OD_{595}.

of antimicrobial substances, such as bacteriocins, organic acids, CO_2, and H_2O_2 (Cheikhyoussef et al., 2008; Patel et al., 2014). In accordance with previous observations, it can be assumed that lactobacilli and bifidobacteria isolated from commercial drinking yogurts exerted antagonistic activities against foodborne pathogenic bacteria by secreting antimicrobial substances.

Characteristics of SSC, TA, pH, color, and mineral contents in commercial drinking yogurts

Table 4 reveals the SSC, TA, pH, color, and mineral contents of the yogurt samples. The SSC, TA, and pH ranges were 10.13–18.36°Bx, 0.52%–0.64%, and 4.10–4.52, respectively. The average SSC, TA, and pH of yogurt samples were 15.00±3.20°Bx, 0.58±0.05% and 4.27±0.15, respectively. The maximum SSC (18.36±0.09°Bx) was significantly high ($p<0.05$) among the samples. The SSC varied widely due to the various sugar-derived ingredients added during the manufacturing process.

Granata and Morr (1996) reported that pH values between 4.0 and 4.4 are considered as necessary for flavor and texture in good-quality yogurts. The six yogurt samples tested in this study showed average pH values between 4.0 and 4.4, indicating that these yogurts are good quality. Regarding TA and pH, the results were slightly different among yogurt samples.

Besides the CIE L*a*b* data, the color difference (ΔE) values were computed, where $\Delta E=[(L_1^*-L_2^*)^2+(a_1^*-a_2^*)^2+(b_1^*-b_2^*)^2]^{1/2}$). Between the highest L* value (Sample 1) and the lowest L* value (Sample 6), ΔE was 3.7, which denotes an obvious color difference since ΔE values above 3.0 can be easily detected by the naked eye (Mezquita et al., 2015). Among the other samples, ΔE was less than 2.0.

A possible explanation for the variations in SSC, TA, pH, and color between yogurt samples is the different compositions, such as sugars and organic acids. In addition, the storage conditions, such as refrigeration temperature, influence the pH and TA (Hassan and Amjad, 2010). Sichani et al. (2014) observed an increase in the TA of yogurts stored under refrigeration condition with increased storage duration. Furthermore, the continuation of post-acidification by bacteria in the yogurts could contribute to the changes in SSC, TA, and pH during storage.

Table 4. Physiochemical properties and mineral contents of commercial drinking yogurts

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Mean±SD
Soluble solids content (°Bx)	17.68±0.21^{b}	12.47±0.08^{d}	10.13±0.07^{e}	13.61±0.03^{c}	17.72±0.02^{b}	18.36±0.09^{a}	15.00±3.20
Titratable acidity (%)	0.64±0.01^{a}	0.52±0.02^{c}	0.55±0.01^{c}	0.64±0.02^{a}	0.59±0.02^{b}	0.55±0.02^{c}	0.58±0.05
pH	4.20±0.01^{c}	4.34±0.01^{b}	4.34±0.01^{b}	4.12±0.01^{d}	4.10±0.01^{e}	4.52±0.01^{a}	4.27±0.15
Color measurements							
L*	92.02±0.03^{a}	91.76±0.01^{c}	91.96±0.01^{b}	91.05±0.02^{d}	90.60±0.03^{e}	88.88±0.01^{f}	91.05±1.13
a*	–2.93±0.01^{b}	–3.03±0.01^{c}	–3.44±0.01^{e}	–3.44±0.01^{e}	–3.22±0.01^{d}	–2.51±0.01^{a}	–3.10±0.33
b*	7.87±0.02^{e}	6.67±0.03^{f}	8.07±0.03^{c}	7.96±0.02^{d}	8.39±0.02^{b}	9.79±0.01^{a}	8.12±0.95
Mineral contents (mg/100 g)							
Ca	148.39±10.3^{a}	130.51±6.83^{b,c}	142.06±1.95^{a}	121.83±6.93^{c}	121.42±4.29^{c}	139.29±2.65^{a,b}	133.92±11.67
K	157.23±0.95^{a}	141.43±0.12^{c}	148.78±0.61^{b}	134.32±0.26^{d}	123.01±2.59^{e}	156.41±1.18^{a}	143.53±12.59
Na	46.74±0.07^{a}	38.63±0.27^{e}	39.77±0.28^{d}	40.91±0.36^{c}	34.34±0.58^{f}	44.78±0.12^{b}	40.86± 4.18
P	100.70±3.82^{b}	87.63±3.48^{c}	97.46±0.48^{b}	87.45±3.71^{c}	84.03±1.76^{c}	112.28±0.39^{a}	94.93±10.27

Data are expressed as mean±SD from triplicates and different letters in a row are significantly different at $p<0.05$.
Detailed information and nutrition facts about the samples used in this study can be found in Table 1 and 2.

Among the macro-minerals (Ca, K, Na, and P) analyzed, the contents decreased in the trend K>Ca>P>Na, although all were plentiful in each of the six yogurt samples (Table 4). It is well known that yogurt contains several other minerals, such as zinc and magnesium. However, the mineral contents are hardly changed during the milk fermentation process (Buttriss, 1997). Hernandez and Park (2014) reported that Na is a major mineral in commercial goat milk yogurt. In the current study, although the concentration of Na was lower than that of the other minerals, Na was detected as a major mineral in the commercial yogurts tested in this study.

Content of sugars in commercial drinking yogurts

Quantification of the fructose, glucose, sucrose, maltose, and lactose contents in the yogurt samples (Table 5) revealed lactose was the main sugar, except in samples 1 and 6, which contained fructose and glucose as the predominant sugars, while sucrose was abundant in Sample 4. Maltose was either not detected or negligible. Interestingly, the sucrose content of Sample 4, which listed white sugar on the food label, was significantly higher in comparison to the other samples ($p<0.05$). As a result, the average sugar content of Sample 4 was higher (9.83 g versus 5.54–6.68 g/100 g). Cow's milk contains less than 5% (w/v) lactose, and this value is decreased dramatically by fermentation (Alm, 1982). However, our observation indicates that the lactose concentration of the six yogurt samples was in the range of 0.18%–4.41%, but it was not detected in Sample 6. This wide variation in the lactose concentration of the yogurt samples could arise from the addition of milk powder in the formulation to standardize the quantity of solids required in yogurt (Peng et al., 2009).

Content of organic acids in commercial drinking yogurts

Among the organic acids (oxalic acid, malic acid, citric acid, fumaric acid, acetic acid, tartaric acid, succinic acid, and lactic acid) quantified in the yogurt samples (Table 6), lactic acid and citric acid were the most predominant. Lactic acid is a strong indicator of the activity of the bacterial culture (e.g., *Streptococcus thermophilus*, *Lactobacillus bulgaricus*, *Lactobacillus acidophilus*) and is influenced by the quality of the milk (Batista et al., 2015). Lactate, citrate, and acetate were found at levels of 671.87–858.85, 137.27–214.86, and 17.98–42.59 mg/100 g, respectively, with corresponding average contents of 767.67±68.14, 170.91±24.22, and 31.92±9.14 mg/100 g. Citric acid is derived from the citric acid or citrus syrup contained in the product. During the fermentation of yogurt, the metabolic activity of starter cultures on lactose in the milk leads to produce several organic acids, such as citric, acetic, butyric, pyruvic, and formic acids (Venica et al., 2014). In

Table 5. Individual sugar contents in commercial drinking yogurts (g/100 g)

Samples	Fructose	Glucose	Sucrose	Maltose	Lactose	Total sum
Sample 1	2.32±0.18^{a}	2.70±0.08^{b}	0.16±0.12^{c}	0.19±0.14^{a}	0.18±0.07^{c}	5.54±0.21^{d}
Sample 2	1.30±0.17^{c}	1.32±0.12^{c}	ND	ND	3.33±0.12^{b}	5.96±0.18^{c,d}
Sample 3	1.69±0.19^{b}	ND	ND	ND	4.41±0.20^{a}	6.09±0.01^{c,d}
Sample 4	0.32±0.05^{d}	0.66±0.08^{d}	5.40±0.13^{a}	0.07±0.07^{b}	3.38±0.35^{b}	9.83±0.48^{a}
Sample 5	1.86±0.05^{b}	1.47±0.22^{c}	ND	ND	3.11±0.25^{b}	6.44±0.45^{b,c}
Sample 6	2.41±0.16^{a}	3.92±0.07^{a}	0.34±0.05^{b}	ND	ND	6.68±0.17^{b}
Mean±SD	1.65±0.73	1.68±1.33	0.98±2.03	0.04±0.09	2.40±1.74	6.76±1.48

Data are expressed as mean±SD from triplicates and different letters in a column are significantly different at $p<0.05$.
Detailed information and nutrition facts about the samples used in this study can be found in Table 1 and 2.
ND; not detected below LOD (glucose 0.04/100 g, sucrose 0.04/100 g, maltose 0.05/100 g, and lactose 0.05/100 g).

Table 6. **Individual organic acid contents in the drinking yogurts** (mg/100 g)

Samples	Lactic acid	Citric acid	Acetic acid	Total sum
Sample 1	848.85±25.90^{a}	214.86±8.31^{a}	42.59±0.94^{a}	1,106.30±33.95^{a}
Sample 2	773.66±15.80^{b}	169.40±1.91^{b,c}	33.67±0.62^{b}	976.74±15.82^{b,c}
Sample 3	697.36±14.55^{c}	167.13±1.80^{c}	41.89±1.65^{a}	906.38±17.32^{d,e}
Sample 4	827.53±30.54^{a}	160.02±6.12^{c}	31.11±0.35^{b,c}	1,018.66±36.67^{b}
Sample 5	786.72±12.40^{b}	137.27±2.21^{d}	17.98±0.67^{c,d}	941.97±14.83^{c,d}
Sample 6	671.87±14.43^{c}	176.80±4.23^{b}	24.26±1.08^{d}	872.94±19.14^{e}
Mean±SD	767.67±68.14	170.91±24.22	31.92±9.14	970.49±81.53

Data are expressed as mean±SD from triplicates and different letters in a column are significantly different at $p<0.05$.
Detailed information and nutrition facts about the samples used in this study can be found in Table 1 and 2.

accordance with Venica et al. (2014), high levels of lactic, citric, and acetic acids were also found in the commercial yogurts tested in this study.

Conclusions

This work provides information about the microbiological and physicochemical characteristics of some commercial drinking yogurts. In addition, as a probiotic drink, the antibacterial activities of yogurts against foodborne pathogenic bacteria are also demonstrated. It is assumed that the microbiological and physicochemical properties are largely affected by the formulation and storage time. The commercial drinking yogurts display a wide range of carbohydrate contents, but they show similar physicochemical and microbiological characteristics. Although more research is needed to emphasize the nutritional and functional values, the current study provides preliminary information regarding several popular drinking yogurts commercialized in Korea.

Conflict of interest

The authors declare no potential conflict of interest.

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Author Contributions

Conceptualization: Kang SS, Kim MK, Kim YJ. Data curation: Kang SS, Kim MK, Kim YJ. Formal analysis: Kang SS, Kim YJ. Methodology: Kang SS, Kim YJ. Software: Kang SS, Kim YJ. Validation: Kang SS, Kim YJ. Investigation: Kang SS, Kim YJ. Writing - original draft: Kang SS, Kim MK, Kim YJ. Writing - review & editing: Kang SS, Kim MK, Kim YJ.

Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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