Food Sci. Biotechnol. 26(2): 441-446 (2017)
DOI 10.1007/s10068-017-0060-z

Food Science and Biotechnology

Changes in antioxidant activities and volatile compounds of mixed berry juice through fermentation by lactic acid bacteria

Jae-Bum Park, Seung-Hee Lim[1], Hyun-Su Sim[2], Joong-Hee Park, Hun-Joo Kwon[2], Hee Sop Nam[3], Myoung-Dong Kim[2], Hyung-Hee Baek[1], and Suk-Jin Ha*

Department of Bioengineering and Technology, Kangwon National University, Chuncheon, Gangwon 24341, Korea
[1]*Department of Food Engineering, Dankook University, Cheonan, Chungnam 31116, Korea*
[2]*Department of Food Science and Biotechnology, Kangwon National University, Chuncheon, Gangwon 24341, Korea*
[3]*Research & Development Center, Dongwon F&B, Seongnam, Gyeonggi 13207, Korea*

Received July 28, 2016
Revised December 26, 2016
Accepted January 2, 2017
Published online April 30, 2017

*Corresponding Author
Tel: +82-33-250-6278
Fax: +82-33-243-6350
E-mail: sjha@kangwon.ac.kr

pISSN 1226-7708
eISSN 2092-6456

Abstract The objectives of this study were to analyze antioxidant activities and identify volatile compounds in mixed berry juice after fermentation by lactic acid bacteria (LAB). Antioxidant activity of the mixed berry juice increased significantly from 209.57±2.93 to 268.30±1.75 μmol TE/g after 24 h of fermentation. After LAB fermentation, 34 volatile compounds were identified. Among them, three compounds—benzoic acid, benzaldehyde, and vitispirane—showed significant changes in their concentrations. Peak areas of benzoic acid and benzaldehyde, which are known to possess antioxidant activities, increased by 64 and 188%, respectively, after fermentation. However, the peak area of vitispirane, which is the most abundant terpene compound in berry juices, decreased by 92% after fermentation.

Keywords: berry, fermentation, antioxidant activity, volatile compound, GC-MS

Introduction

Various foods or beverages were recently developed using different berries such as the acai berry, blue berry, black berry, raspberry, aronia, and cranberry (1). Berries show positive influences on various lifestyle-related diseases, including obesity, hypertension, cerebrovascular diseases, arteriosclerosis, myocardial infarction, cancers, or rheumatoid arthritis (2-4). Therefore, there is high demand for berry-based products from consumers. Berries are also known as natural antioxidants that are capable of eliminating reactive oxygen species (ROS) like hydroxyl, peroxide radicals, and radicals of other reactive forms of oxygen (5). The U.S. Department of Agriculture selected 12 foods containing high amounts of antioxidants, and six among these include berries (6).

There have been many reports regarding the antioxidant activities of blackberry, raspberry, cranberry, and blueberry, and recently, several studies were performed using the acai berry, which shows high antioxidant activity (1,6-12). Berries contain high contents of vitamin C and polyphenols, mainly anthocyanins, phenolic acids, flavanols, and tannins, which are known natural antioxidants (13,14). Vitamin C and polyphenols are known to exist as glycosides in berries (15,16). When glucose was removed from glycoside in berries by enzyme glycoside hydrolase, antioxidant activities of berries improved (9,17). Antioxidants activities from natural compounds increased after fermentation by fungi, yeasts, or lactic acid bacteria (LAB) (10,18). A highly active β-1,4-xylosidase, one of the glycoside hydrolase enzymes, was reported from *Leuconostoc* spp. (7,19).

Several studies investigated volatile compounds of various berries such as the blackberry, raspberry, cranberry, blueberry, acai berry, and aronia (20-25). Kraujalyte *et al.* (20) reported that ester compounds such as ethyl-2-methylbutanoate, ethyl-3-methylbutanoate, and ethyl decanoate play an important role in the aroma of aronia. It is known that 1-(*p*-hydroxyphenyl)-3-butanone, or raspberry ketone, primarily imparts the characteristic aroma to raspberries (21). Recently, β-damascenone, *trans*-linalool oxide, (Z)-3-hexenol, and 2-phenylethanol were reported as aroma-active compounds in acai berries (22).

Recently, we found that the antioxidant activities of acai berry or blackberry juices were enhanced by 31 or 15%, respectively, after fermentation by LAB (26). In this study, we investigated the following properties of mixed berry juice: solid content, pH, sugar content, and antioxidant activity. After fermentation of the mixed berry juice by *Lactobacillus plantarum* LP-115, changes in the antioxidant activities were analyzed by oxygen radical absorbance capacity (ORAC). In addition, volatile compounds were analyzed by solid phase micro-extraction (SPME) and gas chromatography-mass spectrometry (GC-MS).

Materials and Methods

Materials and strain The mixed berry juice was supplied by Dongwon F&B Co., Ltd. (Seongnam, Korea). It comprised 73% of acai berry, 17% of aronia, and 10% of cranberry. All chemicals used in this study were purchased from Sigma-Aldrich (St. Louis, MO, USA). For the fermentation of the mixed berry juice, *L. plantarum* LP-115 (Danisco USA Inc., Madison, WI, USA) was used.

Analysis of physiochemical properties of the mixed berry juice The solid content of the mixed berry juice was analyzed by the freeze-drying method (27). The sugar content was analyzed using a Brix meter (Atago, Tokyo, Japan). Concentrations of glucose and xylose were determined by high-performance liquid chromatography (HPLC 1200 Series; Agilent Technologies, Santa Clara, CA, USA) using a Rezex ROA-Organic Acid column (Phenomenex Inc., Torrance, CA, USA) equipped with a refractive index detector. The column was eluted with 0.005 N H_2SO_4 at a flow rate of 0.6 mL/min at 50°C.

Analysis of antioxidant activity of the mixed berry juice Antioxidant activity was analyzed using ORAC assay kit (Cell Biolabs, San Diego, CA, USA) according to the manufacturer's instructions (28). Briefly, the sample (25 μL) and 150 μL of fluorescein solution were added in a 96-well immune plate and incubated at 37°C for 10 min. After 10 min, 25 μL free radical initiator was added. Fluorescence was detected every minute for 60 min using a Microplate fluorometer (Thermo Fisher Scientific, Waltham, MA, USA) at 480 nm excitation and 520 nm emission. Trolox (Cell Biolabs) was used as reference, and the standard calibration curve was used for quantitative analysis. Antioxidant capacity measured by ORAC assay was expressed as μmol TE/g of the sample.

Fermentation of the mixed berry juice by *L. plantarum* LP-115 pH of the mixed berry juice was adjusted from pH 3.2 to pH 7.0, using 5 M NaOH solution, for optimum growth of LAB, and 1 g/L of freeze-dried *L. plantarum* LP-115 was inoculated in the juice. Fermentations were performed using a 500-mL flask with 100 mL of working volume at 37°C and shaking at 200 rpm for 36 h.

Extraction of volatile compounds from the mixed berry juice Volatile compounds were extracted from the mixed berry juice by the SPME method (29-31). The mixed berry juice (10 mL) was placed in a 20-mL teflon-capped headspace vial and allowed to equilibrate at 40°C for 30 min. Volatile compounds were extracted at 40°C for 30 min using an SPME fiber (50/30 μm divinylbenzene/carboxene/polydimethylsiloxane). The fiber was then retracted and immediately injected into the injection port of gas chromatography (200°C) for 1 min to desorb volatile compounds.

Analysis of volatile compounds by GC-MS GC-MS was performed to analyze the volatile compounds from mixed berry juice. Agilent 6890N GC/Agilent 5973 mass selective detector (Agilent Technologies) was used with a DB-wax column (60 mm length×0.25 mm i.d.×0.25 μm film thickness; J & W Scientific, Folsom, CA, USA). Operation conditions were as follows: injection port temperature, 200°C; detector temperature, 250°C; capillary direct interface temperature, 280°C; ionization voltage, 70 eV; mass range, 33–350 amu; flow rate of helium, 1.0 mL/min. Oven temperature was maintained at 40°C for 5 min, increased to 200°C with increments of 5°C/min, and maintained at 200°C for 20 min.

Identification of volatile compounds from the mixed berry juice Positive identification was based on the comparison of retention indices and mass spectra of unknowns with those of authentic standard compounds. Tentative identification was based on matching the mass spectra of unknowns with those in the Wiley/7n mass spectral database (Agilent Technologies) and previous reports (25,26).

Statistical analysis All experiments were performed in triplicate and error bars indicate standard deviation. Statistical analyses were performed using the statistical package for the social sciences (SPSS) (21.0 version, IBM, Armonk, NY, USA), and Scheffe's multiple range test was performed for testing the significance of the differences (32).

Results and Discussion

Physiochemical properties of the mixed berry juice The mixed berry juice comprised the acai berry, aronia, and cranberry. After freeze drying, the solid content, pH, and sugar content of the mixed berry juice were 0.10±0.00 g/mL, 3.22±0.01, and 8.67±0.06 Brix, respectively. HPLC analysis showed that the mixed berry juice contained 34.96±0.01 g/L of glucose and 22.69±0.01 g/L of xylose. In addition, the mixed berry juice showed 251.43±0.53 μmol TE/g of antioxidant activity by ORAC assay. In general, acai berries showed much higher antioxidant activity than other berries such as raspberries, blackberries, cranberries, and blueberries (26). As the mixed berry juice contained 73% acai berry, the antioxidant activity of the mixed berry juice was much higher than those of raspberry (159.40±3.72 μmol TE/g), blackberry (125.85±10.23 μmol TE/g), cranberry (103.27±2.68 μmol TE/g), or blueberry (101.40±2.06 μmol TE/g) (26).

Improved antioxidant activities of the mixed berry juice after fermentation by *L. plantarum* LP-115 In this study, *L. plantarum* LP-115 was selected to improve the antioxidant activity of the mixed berry juice containing 73% of acai berry, based on previous reports that *L. plantarum* LP-115 showed 20–30% increase in the antioxidant activity of acai berry juice after fermentation (26). To ferment the mixed berry juice by *L. plantarum* LP-115, the pH of the mixed berry

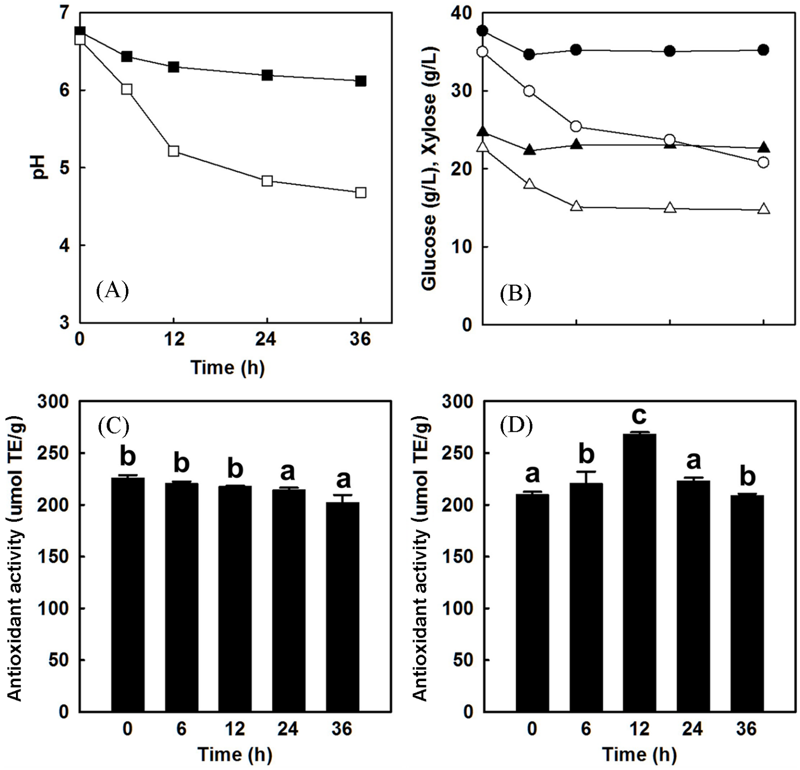

Fig. 1. Fermentation results of the mixed berry juice by *L. plantarum* LP-115. (A) Time profile of pH without *L. plantarum* LP-115 inoculation (closed square) or with *L. plantarum* LP-115 inoculation (open square). (B) Time profiles of glucose (circles) and xylose (triangles) consumptions without (closed symbols) or with (open symbols) *L. plantarum* LP-115 inoculation. (C) Changes in antioxidant activities without *L. plantarum* LP-115 inoculation. (D) Changes in antioxidant activities with *L. plantarum* LP-115 inoculation.

juice was adjusted to 7.0, using NaOH solution, prior to bacterial inoculation. During the fermentation, 14.21 g/L of glucose and 7.97 g/L of xylose were consumed, 28 g/L of lactic acid was produced, and the pH decreased drastically from 6.65 to 4.68 after 36 h of fermentation. The negative control without *L. plantarum* LP-115 inoculation showed no sugar consumption and a slight change in pH (Fig. 1A and 1B). Without *L. plantarum* LP-115 inoculation, the antioxidant activity of the mixed berry juice showed a 10% decrease from 225.58±2.98 to 202.00±7.51 μmol TE/g (Fig. 1C). However, the antioxidant activity of the mixed berry juice increased significantly from 209.57±2.93 to 268.30±1.75 μmol TE/g after 24 h of fermentation (Fig. 1D). The antioxidant activity of the mixed berry juice improved by about 28% after fermentation by *L. plantarum* LP-115. These results suggested that glycoside hydrolase or other metabolites from *L. plantarum* LP-115 may improve the antioxidant activity of the mixed berry juice during fermentation. Similar phenomena were reported using fungi, yeasts, or LAB (10,18). After 24 h of fermentation, the antioxidant activity decreased.

Changes in volatile compounds in the mixed berry juice during fermentation by *L. plantarum* LP-115 During fermentation of the mixed berry juice by *L. plantarum* LP-115, volatile compounds were extracted by the SPME method and identified by GC-MS. As shown in Table 1, 34 compounds were identified, apart from three unknown compounds, from the mixed berry juice during fermentation: seven alcohols, eleven terpene compounds, three ketones, four acids, three aldehydes, two esters, one lactone, one phenol, and one miscellaneous. The 34 identified compounds were classified into 8 groups: acid, aldehyde, alcohol, terpene, ketone, ester, furan, and phenol. The sum of peak areas of acid and aldehyde groups increased (47 and 122%, respectively), and the peak area of terpene decreased (64%) significantly during fermentation by *L. plantarum* LP-115.

Among acidic compounds, the peak area of benzoic acid increased significantly from 102.65×10^6 to 168.84×10^6 after 12 h of fermentation (Fig. 2A) and remained unchanged thereafter. Benzoic acid is generally used as a preservative in the food industry because of its antimicrobial activity (33). In addition, it was reported that benzoic acid and its derivatives showed antioxidant properties against different types of free radicals (34). Among aldehydes, the peak area of benzaldehyde increased sharply (191%) from 17.89×10^6 to 52.06×10^6 after 24 h of fermentation (Fig. 2B). Benzaldehyde produced from *Photorhabdus temperata* M1021 exhibited high antioxidant activity, determined by the DPPH method, as well as antimicrobial and insecticidal activity (35). The peak area of 2,6,6-trimethyl-10-methylidene-1-oxaspiro[4.5]dec-8-ene (vitispirane), which is the most abundant terpene compound in the mixed berry juice, decreased drastically (92%) from 143.87×10^6 to 12.30×10^6 after 12 h of

Table 1. Changes in the volatile compounds of the mixed berry juice during fermentation by *Lactobacillus plantarum* LP-115

No	RI[1)]	Compound name	Peak area (×10⁶)[2)]				
			0 h	6 h	12 h	24 h	36 h
		Alcohol					
1	1384	1-Hexanol	2.77±0.04	2.60±0.06	1.89±0.01	2.04±0.05	1.95±0.02
2	1387	(Z)-3-Hexenol	36.22±1.00	34.56±0.62	24.20±0.02	26.50±0.61	24.82±0.08
3	1492	2-Ethyl-1-hexanol	2.42±0.31	1.85±0.00	1.71±0.01	1.86±0.04	1.64±0.08
4	1560	1-Octanol	2.14±0.26	1.43±0.11	1.49±0.08	1.49±0.10	1.29±0.03
5	1898	Benzyl alcohol	2.68±0.09	2.75±0.05	3.05±0.06	2.72±0.01	2.90±0.07
6	1934	2-Phenyl ethanol	3.81±0.23	3.69±0.06	4.57±0.38	3.64±0.13	3.90±0.10
7	1970	1-Dodecanol	11.99±1.49	3.57±0.31	8.59±1.33	5.61±0.23	4.03±0.07
		Total	62.03±1.86	50.45±0.71	45.50±1.39	43.86±0.68	40.53±0.18
		Terpene					
8	1169	Isocineole	7.77±0.78	5.62±0.46	tr[3)]	3.25±0.25	tr
9	1213	1,8-Cineole	3.39±0.41	4.40±0.31	1.36±0.16	3.66±0.24	tr
10	1458	*Trans*-linalool oxide	21.73±1.17	21.74±0.57	20.31±0.08	20.60±0.10	22.11±0.42
11	1485	*Cis*-linalool oxide	7.69±0.26	7.87±0.44	8.18±0.04	7.56±0.08	9.43±0.30
12	1548	2,6,6-Trimethyl-10-methylidene-1-oxaspiro[4.5]dec-8-ene	143.87±2.20	106.17±7.63	2.86±0.42	12.30±0.75	1.73±0.13
13	1550	Linalool	13.48±1.48	12.88±0.24	11.02±0.22	12.22±0.21	11.60±0.10
14	1584	1-Terpineol	2.49±0.10	2.46±0.06	2.23±0.24	2.23±0.00	2.16±0.03
15	1615	4-Terpineol	4.66±0.37	4.08±0.08	3.69±0.18	3.96±0.09	3.87±0.16
16	1641	β-Terpinol	6.70±0.29	5.71±0.09	4.53±0.04	4.50±0.11	4.77±0.15
17	1711	α-Terpineol	36.46±1.33	36.91±0.91	32.85±0.43	32.67±0.30	35.34±0.65
18	1713	γ-Terpineol	7.02±0.26	7.09±0.19	6.12±0.02	5.89±0.05	6.49±0.07
		Total	255.26±5.13	214.93±7.74	93.15±0.74	108.84±0.92	97.50±0.88
		Ketone					
19	1139	3-Penten-2-one	321.23±7.71	323.65±3.69	292.24±5.14	332.41±4.90	321.88±0.43
20	1478	4-Hydroxy-2-pentanone	1.24±0.17	1.16±0.09	1.43±0.05	1.38±0.07	1.43±0.09
21	1845	β-Damascenone	4.01±0.33	3.51±0.15	3.16±0.15	3.54±0.14	2.52±0.28
22	2179	γ-Decalactone	1.82±0.09	2.64±0.32	1.50±0.01	ND[4)]	ND
		Total	329.82±7.72	332.26±3.71	299.76±5.14	338.67±4.90	327.13±0.52
		Acid					
23	1468	Acetic acid	21.43±2.07	19.49±1.14	20.80±1.14	19.30±0.23	20.05±0.07
24	1677	2-Methylbutanoic acid	17.76±0.51	18.73±1.12	18.58±0.36	18.26±0.48	20.41±0.55
25	2171	Nonanoic acid	1.40±0.55	0.50±0.02	1.97±0.30	tr	tr
26	>2200	Benzoic acid	102.65±8.60	135.32±9.40	168.84±0.28	158.18±11.31	154.69±11.53
		Total	143.24±8.87	174.04±9.53	210.19±1.26	195.74±11.32	195.15±11.54
		Aldehyde					
27	1489	Furfural	4.77±0.23	4.16±0.15	3.47±0.02	4.26±0.14	3.83±0.06
28	1545	Benzaldehyde	17.89±0.41	17.93±0.15	25.03±2.64	52.06±0.14	28.09±1.31
29	1703	α-4-Dimethyl-3-cyclohexene-1-acetaldehyde	4.55±0.11	4.63±0.04	4.04±0.06	4.22±0.00	4.34±0.08
		Total	27.21±0.48	26.72±0.21	32.54±2.64	60.54±0.19	36.26±1.31
		Ester					
30	1594	Methyl-2-furoate	6.06±0.26	5.60±0.17	6.01±0.51	5.57±0.14	5.66±0.10
31	1748	Benzyl acetate	11.14±3.34	4.07±0.50	6.19±0.53	5.35±0.31	3.59±0.13
		Total	17.2±3.35	3.67±0.52	12.20±0.73	10.92±0.34	9.25±0.16
		Furan					
32	1529	3,9-Epoxy-1-*p*-menthene	1.83±0.06	1.77±0.07	1.36±0.07	1.71±0.02	1.56±0.03
		Total	1.83±0.06	1.77±0.07	1.36±0.07	1.71±0.02	1.56±0.03
		Phenol					
33	1881	Guaiacol	0.69±0.01	0.46±0.00	0.43±0.01	0.65±0.00	0.40±0.02
		Total	0.69±0.01	0.46±0.00	0.43±0.01	0.65±0.00	0.40±0.02
		Miscellaneous					
34	1112	2-Ethenyltetrahydro-2,6,6-trimethyl-2H-pyran	22.01±0.61	6.84±0.58	ND	ND	ND
		Total	22.01±0.61	6.84±0.58	ND	ND	ND
		Unknown					
35	1203	Unknown	29.16±0.15	16.44±1.33	ND	7.54±0.57	tr
36	1211	Unknown	33.30±0.81	19.25±0.76	tr	5.98±0.18	tr
37	1540	Unknown	16.94±0.83	16.14±0.33	9.05±0.07	12.78±0.12	8.16±0.23
		Total	79.40±1.17	51.83±1.56	9.05±0.07	26.30±0.61	8.16±0.48

[1)]Retention indices were determined on DB-wax using C8-C22 as the external reference.
[2)]Mean±standard deviation.
[3)]tr, trace.
[4)]ND, not detected.

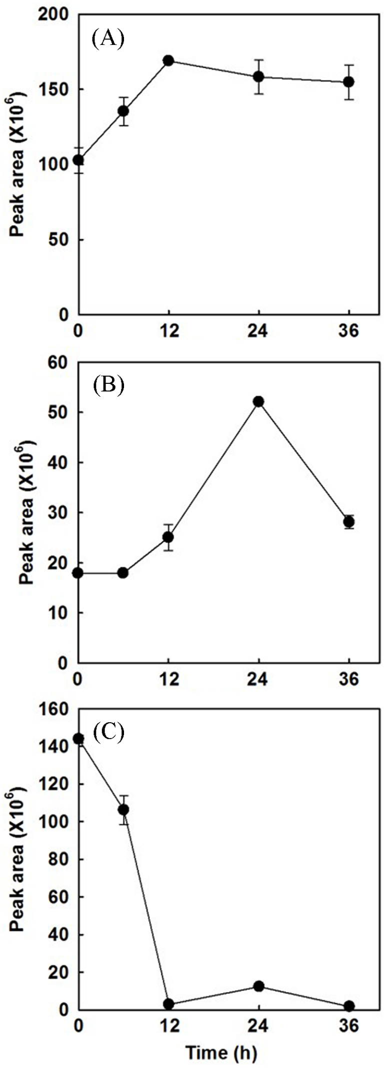

Fig. 2. Peak area changes in benzoic acid (A), benzaldehyde (B), and vitispirane (C) from the mixed berry juice during fermentation by *L. plantarum* LP-115.

fermentation (Fig. 2C). Vitispirane was one of the major nor-isoprenoids found in wines, having an important sensorial impact on wine aroma, and the concentration of vitispirane increases with aging (36). As shown in Fig. 3, the peak areas of vitispirane and benzoic acid changed significantly, whereas that of other volatile compounds did not change significantly during fermentation. The peak area of benzaldehyde was relatively smaller than those of vitispirane and benzoic acid, as shown in Table 1. Therefore, it is not easy to indicate benzaldehyde in Fig. 3, although the peak area of benzaldehyde increased by 191%. Recent reports showed that the quality of prickly pears juice was enhanced after fermentation by *L. fermentum* ATCC 9338 (37). Similar to the results in this study, risky compounds such as furan or furfural decreased during the fermentation of the mixed berry juice by *L. plantarum* LP-115. In conclusion, we showed that the antioxidant activity of mixed berry juice increased significantly after fermentation by *L. plantarum* LP-115. For further understanding of the improved antioxidant activity of the mixed berry juice, 34 volatile compounds were identified by SPME and GC-MS. Among them, the peak areas of benzoic acid and benzaldehyde, known to possess antioxidant activities, increased greatly. However, the peak area of vitispirane, which is the most abundant terpene compound in the mixed berry juice, decreased drastically after fermentation.

Acknowledgments This work was supported by the Korean Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries (IPET) through (High Value-added Food Technology Development Program), funded by the Ministry of Agriculture, Food and Rural Affairs (MAFRA) (313-034-03).

Disclosure The authors declare no conflict of interest.

References

1. Park HM, Yang SJ, Kang J, Lee DH, Kim DI, Hong JH. Quality characteristics and granule manufacture of mulberry and blueberry fruit extracts. Korean J. Food Cook. Sci. 28: 375-382 (2012)
2. Dröge W. Free radicals in the physiological control of cell function. Physiol. Rev. 82: 47-95 (2002)
3. Park SH, Hwang HS, Han JH. Development of drink from composition with medicinal plants and evaluation of its physiological function. J. Nutr. Health 37: 364-372 (2004)
4. Rocha A, Wang L, Penichet M, Martins-Green M. Pomegranate juice and specific components inhibit cell and molecular processes critical for metastasis of breast cancer. Breast Cancer Res. Tr. 136: 647-658 (2012)
5. Castro L, Freeman BA. Reactive oxygen species in human health and disease. Nutrition 17: 161-165 (2001)
6. Peìrez-Jimeìnez J, Neveu V, Vos F, Scalbert A. Systematic analysis of the content of 502 polyphenols in 452 foods and beverages: an application of the phenol-explorer database. J. Agr. Food Chem. 58: 4959-4969 (2010)
7. Jang MH, Kim MD. β-1,4-Xylosidase activity of *Leuconostoc* lactic acid bacteria isolated from kimchi. Korean J. Food Sci. Technol. 43: 169-175 (2011)
8. Kang J, Li Z, Wu T, Jensen GS, Schauss AG, Wu X. Anti-oxidant capacities of flavonoid compounds isolated from acai pulp (*Euterpe oleracea* Mart.). Food Chem. 122: 610-617 (2010)
9. Lindroth RL. Hydrolysis of phenolic glycosides by midgut β-glucosidases in *Papilio glaucus subspecies*. Insect Biochem. 18: 789-792 (1988)
10. Kang OJ. Production of fermented tea with *Rhodotorula* yeast and comparison of its antioxidant effects to those of unfermented tea. Korean J. Food Cook. Sci. 26: 422-427 (2010)
11. Park SJ, Kim ES, Choi YS, Kim JD. Effects of sophorae fructus on antioxidative activities and lipid levels in rats. Prev. Nutr. Food Sci. 37: 1120-1125 (2008)
12. Suh J, Paek OJ, Kang Y, Ahn JE, Yun J, Oh K-S, An Y-S, Park S-H, Lee S-J. Study on theantioxidant activity in the various vegetables. J. Food Hyg. Safety 28: 337-341 (2013)
13. Balogh E, Hegedûs A, Stefanovits-Bányai É. Application of and correlation among antioxidant and antiradical assays for characterizing antioxidant capacity of berries. Sci. Hortic.-Amsterdam 125: 332-336 (2010)
14. Kim HY, Woo KS, Hwang IG, Lee YR, Jeong HS. Effects of heat treatments on the antioxidant activities of fruits and vegetables. Korean J. Food Sci. Technol. 40: 166-170 (2008)
15. Cho MJ, Howard LR, Prior RL, Clark JR. Flavonoid glycosides and antioxidant capacity of various blackberry, blueberry and red grape genotypes determined by highperformance liquid chromatography/mass spectrometry. J. Sci. Food Agr. 84: 1771-1782 (2004)
16. Zhu N, Sheng S, Li D, LaVoie EJ, Karwe MV, Rosen RT, Ho CT. Antioxidative flavonoid glycosides from quinoa seeds (*Chenopodium quinoa* Willd). J. Food Lipids 8: 37-44 (2001)
17. Bokkenheuser VD, Shackleton C, Winter J. Hydrolysis of dietary flavonoid glycosides by strains of intestinal Bacteroides from humans. Biochem. J. 248: 953-956 (1987)
18. Ohara H, Owaki M, Sonomoto K. Xylooligosaccharide fermentation with *Leuconostoc lactis*. J. Biosci. Bioeng. 101: 415-420 (2006)

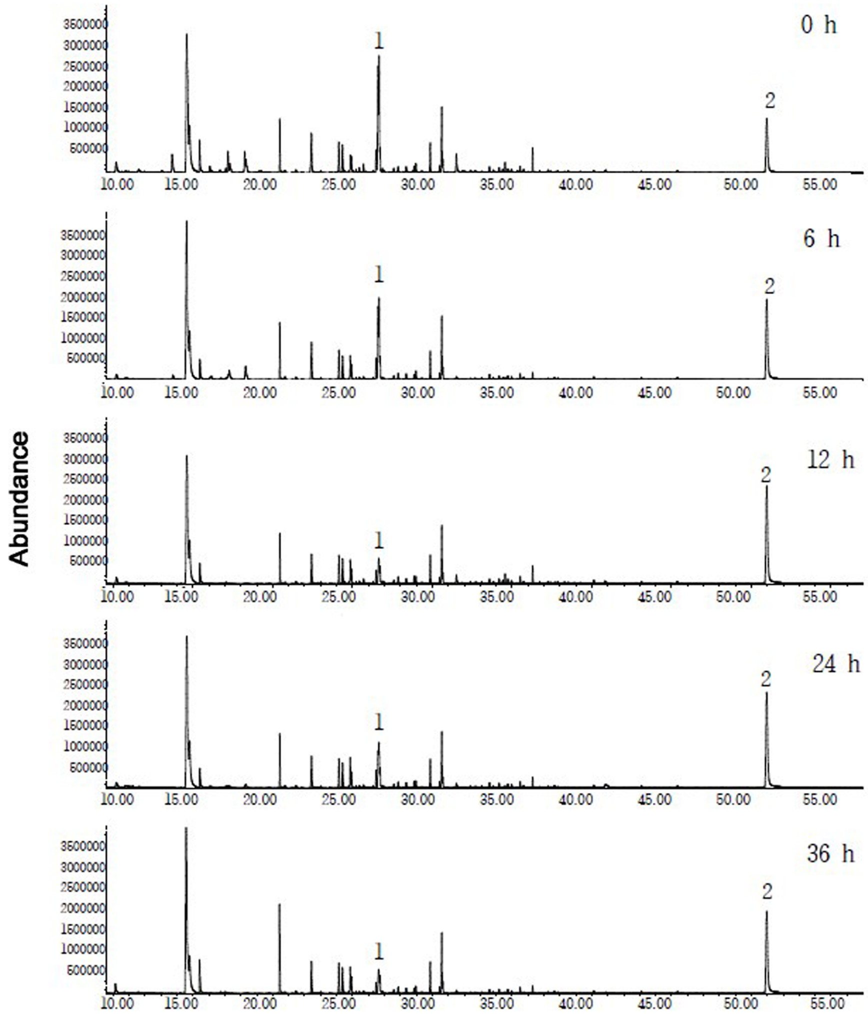

Fig. 3. Total ion chromatograms of the mixed berry juice by solid phase microextraction and gas chromatography-mass spectrometry during fermentation by *L. plantarum* LP-115. 1: vitispirane, 2: benzoic acid.

19. Yang HS, Choi YJ, Oh HH, Moon JS, Jung HK, Kim KJ, Choi BS, Lee JW, Huh CK. Antioxidative activity of mushroom water extracts fermented by lactic acid bacteria. Prev. Nutr. Food Sci. 43: 80-85 (2014)
20. Kraujalyte V, Leitner E, Venskutonis PR. Characterization of *Aronia melanocarpa* volatiles by headspace-solid-phase microextraction (HS-SPME), simultaneous distillation/extraction (SDE), and gas chromatography-olfactometry (GC-O) methods. J. Agr. Food Chem. 61: 4728-4736 (2013)
21. Belitz HD, Grosch W. Food Chemistry. 2nd ed. Springer, Heidelberg, Germany. pp. 806-861 (2004)
22. Lim SH, Nam H, Baek HH. Aroma characteristics of acai berry. Food Sci. Biotechnol. 48: 122-127 (2016)
23. Nile SH, Park SW. Edible berries: Bioactive components and their effect on human health. Nutrition 30: 134-144 (2014)
24. Hirvi T, Honkanen E, Pyysalo T. The aroma of cranberries. Eur. Food Res. Technol. 172: 365-367 (1981)
25. D'Agostino M, Sanz J, Sanz M, Giuffrè A, Sicari V, Soria AC. Optimization of a solid-phase microextraction method for the gas chromatography–mass spectrometry analysis of blackberry (*Rubus ulmifolius* Schott) fruit volatiles. Food Chem. 178: 10-17 (2015)
26. Park JB, Sim HS, Ha SJ, Kim MD. Enhancement of antioxidative activities of berry or vegetable juices through fermentation by lactic acid bacteria. Microbiol. Biotechnol. Lett. 43: 291-295 (2015)
27. Lee S, Kim JK. Quality characteristics of *Aronia melanocarpa* by different drying method. Korean J. Food Preserv. 22: 56-62 (2015)
28. Ungvari Z, Ridgway I, Philipp EE, Campbell CM, McQuary P, Chow T, Coelho M, Didier ES, Gelino S, Holmbeck MA. Extreme longevity is associated with increased resistance to oxidative stress in *Arctica islandica*, the longest-living non-colonial animal. J. Gerontol. A Biol. Sci. Med. Sci. 66: 741-750 (2011)
29. Arthur CL, Pawliszyn J. Solid phase microextraction with thermal desorption using fused silica optical fibers. Anal. Chem. 62: 2145-2148 (1990)
30. Zhang Z, Yang MJ, Pawliszyn J. Solid-phase microextraction. A solvent-free alternative for sample preparation. Anal. Chem. 66: 844A-853A (1994)
31. Tiitinen K, Hakala M, Kallio H. Headspace volatiles from frozen berries of sea buckthorn (*Hippophae rhamnoides* L.) varieties. Eur. Food Res. Technol. 223: 455-460 (2006)
32. Harter HL. Critical values for Duncan's new multiple range test. Biometrics 671-685 (1960)
33. Sieber R, Bütikofer U, Bosset J. Benzoic acid as a natural compound in cultured dairy products and cheese. Int. Dairy J. 5: 227-246 (1995)
34. Velika B, Kron I. Antioxidant properties of benzoic acid derivatives against superoxide radical. Free Radical. Antioxid. 2: 62-67 (2012)
35. Ullah I, Khan AL, Ali L, Khan AR, Waqas M, Hussain J, Lee IJ, Shin JH. Benzaldehyde as an insecticidal, antimicrobial, and antioxidant compound produced by *Photorhabdus temperata* M1021. J. Microbiol. 53: 127-133 (2015)
36. Ferreira ACS, de Pinho PG. Nor-isoprenoids profile during port wine ageing-influence of some technological parameters. Anal. Chim. Acta 513: 169-176 (2004)
37. Panda SK, Behera SK, Qaku XW, Sekar S, Ndinteh DT, Nanjundaswamy H, Ray RC, Kayitesi E. Quality enhancement of prickly pears (*Opuntia* sp.) juice through probiotic fermentation using *Lactobacillus fermentum*-ATCC 9338. LWT-Food Sci. Technol. 75: 453-459 (2017)