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Growth performance, carcass characteristics and meat quality of Hanwoo steers fed fermented liquid whey inoculated with lactic acid bacteria

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The present study was conducted to evaluate the effects of liquid whey fermented with lactic acid bacteria on the growth performance, carcass characteristics, meat composition, fatty acid profile and meat oxidative stability of Korean Hanwoo steers. Twenty-four homogenous Hanwoo steers (22-months-old) were randomly distributed into two dietary treatments with four replications of three steers per treatments. Basal diet was supplemented with 0.2% fermented liquid whey (FLW) and its effects were compared with those of a control. At the end of feeding trial, steers were slaughtered and graded for quality and yield factors by a trained carcass evaluator. Overall, dietary supplementation with 0.2% FLW increased the body weight, average daily gain and gain to feed ratio (P<0.05) of Hanwoo steers. None of the carcass characteristics were affected by dietary FLW. The ether extract and ash contents of loin eye meat were reduced, whereas the calcium and iron contents were increased in response to dietary FLW supplementation (P<0.05). At fresh state, the malondialdihyde (MDA) value of meat was reduced in response to FLW supplementation (P=0.003), whereas no difference was observed at week 1. During weeks 2 and 3, dietary FLW tended to reduce the MDA value of loin eye meat (P<0.10). Dietary supplementation with FLW increased the concentration of linoleic acid, sum of polyunsaturated fatty acids (PUFAs) and n-6 PUFAs (P<0.05). Overall, supplementation of diet with 0.2% FLW exerted beneficial effects on growth performance, meat composition and meat oxidative stability without affecting carcass characteristics, indicating that it can be used as a feed additive in finishing beef cattle.

Key words: Liquid whey, lactic acid bacteria, growth performance, meat composition, oxidative stability, Hanwoo steers.

INTRODUCTION

The potential removal of antibiotic growth promoters (AGPs) from the beef cattle industry has created renewed interest in the use of probiotics. Lactic acid bacteria (LAB), which are the most common types of microorganisms used as probiotics in animal nutrition, are mainly administered after freeze-drying in the form of tablets, paste or powder directly or by mixing with feed. An alternative to delivering large numbers of LABs is the use of fermented feed, in which LABs are present as viable cells with metabolites produced during the fermentation process (Amezcua et al., 2007). A number of scientific studies have demonstrated that fermentation with LAB occurs more rapidly, with greater control and less production of undesirable fermentation products (Demecková et al., 2002; Lawlor et al., 2002); therefore, it is considered a biosafe method for fermenting animal feed

(Kobashi et al., 2008). Liquid feeds fermented with specific strains of LAB exhibit probiotic properties and can tolerate the acidic conditions in the stomach and bile acids in the small intestine (Geary et al., 1999; Alvarez-Olmos and Oberhelman, 2001). Therefore, fermented liquid feeding is considered to be an alternative to anti-microbial growth promoters.

Utilization of liquid feeds in animals has created an opportunity for recycling of liquid co-products from the human food industry. Whey, a valuable co-product of cheese, curds and casein, is a slightly acidic, yellow-green liquid that remains after the coagulation of milk by rennet or by the reduction of its pH (Green, 1977). Liquid whey is composed of lactose (5%), water (93%), proteins (0.85%), minerals (0.53%), a minimum amount of fat (0.36%), and some non-protein nitrogen (Pescuma et al., 2008). The primary whey proteins are β-lactoglobulin (58%) and α-lactalbumin (13%), whereas immunoglobulin, serum albumins and protease peptones are present to a lesser extent (Pescuma et al., 2008) and afford a number of beneficial effects. Whey protein can improve protein synthesis and mineral absorption, whereas reducing blood sugars and blood lipids and improving insulin sensitivity (Pal et al., 2010; Pilvi et al., 2007). Considerable amount of whey is disposed of as waste, causing serious environmental problems. Owing to the nutritional value of whey, significant efforts have been made over the past few years to identify new outlets for whey utilization and reduce environmental pollution. Among the proposed solutions, the utilization of whey as animal feed is by far the most promising. For ruminants, whey is mainly used as a silage additive to improve the quality of low grade forage or agro-industrial by-products. It is evident that adult ruminants are able to use whey or derived products more efficiently than poultry, pigs or rats (Schingoethe, 1976).

Fermentation of whey by LAB has been shown to result in the production of organic acids, mainly lactic acid (Weiberg, 2003), as well as other metabolites such as aroma compounds that contribute to the flavor and texture of fermented feed (Mauriello et al., 2001). The production of ammonium lactates as a source of crude protein (defined as total N × 6.25) for cattle by fermentation of cheese whey have been described by Reddy et al. (1976). The proteolytic enzymes of the lactic acid bacteria contributed in the formation of amino acids and vitamins in fermented whey (Law and Haandrikman, 1997) and thereby may increase the availability of amino acid for rumen microorganism. The fermented whey had its lactose, which could also serve as an energy source for rumen microorganisms. In addition, LABs itself can interact with rumen microorganisms in such a way that their activity is enhanced and fiber degradability is improved (Weinberg, 2003). A limited number of animal experiments have been conducted using fermented liquid whey as feed additives (Amezcua et al., 2007; de Oliveira et al., 2012). This study was aimed to investigate the effects of fermented liquid whey (FLW) on the growth performance, carcass quality, meat composition and fatty acid profile and meat oxidative stability of finishing Hanwoo (Korean native cattle) cattle.

MATERIALS AND METHODS

Fermentation of whey by lactic acid bacteria

A commercially available freeze-dried probiotic starter culture, YO-MIX^{TM} 211, was used for the fermentation of whey (Danisco Culture Co., Denmark). YO-MIX^{TM} 211 contains a mixture of *Streptococcus thermophilus*, *Lactobacillus delbreuckii* subspecies *bulgaricus*, *Lactobacillus acidophilus* and *Bifidobacterium lactis.* The cheese whey was obtained from the Dairy Microbiology Laboratory of the Department of Animal Science and Technology, Sunchon National University, Korea. Before fermentation, the whey was sterilized at 63°C for 30 min, after which it was cooled to 37°C using a water bath. After cooling, 1.5% YO-MIX^{TM} 211 was added to the whey and was fermented for 3 to 4 h at 37°C and pH 4.7 to 4.8. After fermentation, the fermented product was stored in the refrigerator until added to the feed. The fermented liquid whey (FLW) contained approximately 1 × 10^8 cfu/mL lactic acid bacteria, 6.5% dry matter, 19.2% crude protein, 0.12% ether extract and 27.21% SNF.

Experimental design, animals and diets

A total of 24 homogenous Hanwoo steers (22-months-old; 599.58 ± 19.39 kg body weight) were randomly distributed into two dietary treatments with twelve steers per treatments in a completely randomized design. A group of three steers was considered as one replication. Experimental diets consisted of a control (basal diet) and a diet supplemented with 0.2% FLW. The feeding trial was carried out at the Sunchon National University experimental farm and continued for 6 month (up to 26 month of age). The steers were housed individually in well ventilated clean shed having individual feeding and watering arrangements. A commercially available total mixed ration (TMR) feed was used as the basal diet (Table 1). The experimental feed was supplied twice per day in the morning and evening at a rate of 10.87 kg/steer/day on DM basis. The fermented whey was sprayed directly onto the basal diet before each feeding period. Water was available *ad libitum*. Lighting and other management methods were carried out in accordance with general practice. All experimental procedures used in this study were approved by the Animal Care and Use Committee of Sunchon National University.

Samples of the basal and FLW diet were ground through a 1 mm

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Abbreviations: FLW, Fermented liquid whey; **LAB,** lactic acid bacteria; **MDA,** malondialdihyde, **MUFA,** monounsaturated fatty acid; **PUFA,** polyunsaturated fatty acid; **SFA,** saturated fatty acid; **TBARS,** thiobarbituric acid reactive substance.

Table 1. Feed ingredients and chemical composition of TMR diet.

Item	Control	FLW 0.2%
Ingredient (%, DM basis)		
Corn grain	43.33	43.33
Wheat	10.50	10.50
Tapioca	3.45	3.45
Corn gluten feed	11.78	11.78
Wheat flour	2.00	2.00
Soybean meal	0.50	0.50
Rapeseed meal	2.00	2.00
Coconut meal	8.23	8.23
Palm kernel expeller	9.00	9.00
Lupin	6.00	6.00
Molasses	3.00	2.80
Liquid fermented whey	0.00	0.20
Vitamin mineral premix[a]	0.21	0.21
Analysed chemical composition		
Dry matter (% of natural matter)	83.26	78.56
Crude protein (% DM)	12.62	15.24
Ether extract (% DM)	3.63	6.52
Crude fiber (% DM)	16.68	17.58
Crude ash (% DM)	5.48	5.83
Calcium (% DM)	0.82	1.10
Phosphorus (% DM)	0.38	0.50
NDF(% DM)	21.70	22.15
ADF (% DM)	10.70	10.25
Calculated composition (Mcal/kg DM)		
Net energy for maintenance (NEm)	1.99	2.01
Net energy for gain (NEg)	1.34	1.35

[a]Premix provided the following nutrients per kg of diet: Vitamin (Vit) A, 9,000,000 IU; Vit. D_3, 2,100,000 IU; Vit. E, 15,000 IU; Vit. K, 2,000 mg; Vit. B_1, 1,500 mg; Vit. B_2, 4,000 mg; Vit. B_6, 3,000 mg; Vit. B_{12}, 15 mg; Pan-Acid-Ca, 8500 mg; Niacin, 20,000 mg; Biotin, 110 mg; Folic-Acid, 600 mg; Co, 300 mg; Cu, 3,500 mg; Mn, 55,000 mg; Zn, 40,000 mg; I, 600 mg; Se, 130 mg.

screen to analyze the chemical composition. Crude protein (988.05), ether extract (991.36), crude ash (942.05) and crude fibre (962.09) contents were analyzed according to procedures from the Association of official Analytical Chemists (AOAC, 2000). Calcium and phosphorus were analyzed using an Atomic Absorption Spectrophotometer (AA-6200, Korea). The neutral detergent fiber (NDF) and Acid Detergent Fiber (ADF) were determined according to Van Soest et al. (1991). The ADF values were used to predict DE (digestible energy) values of the ration using the equation TDN% = 88.936 – 0.653 ADF (for TMRs and miscellaneous mixed feeds) and 1 kg TDN = 4.4 Mcal DE (NRC, 1996). The calculated DE values of the feed were used to predict the net energy for maintenance (NEm) and net energy for gain (NEg) of the diet using calculated metabolizable energy (ME = DE × 0.82) values according to the following formula (NRC 1996):

$$NEm = 1.37ME – 0.138\ ME^2 + 0.0105ME^3 – 1.12$$

$$NEg = 1.42ME – 0.174\ ME^2 + 0.0122ME^3 – 1.65$$

Measurements and analyses

Body weights were taken before feeding and watering using a platform scale at 3-month intervals from the onset of the experiment until the end. Feed bunks were cleaned and residues were collected daily and weighed at intervals corresponding to weigh dates throughout the trial. The feed intake was calculated on DM basis. Feed efficiency (gain/feed) was calculated as the ratio between average body weight gain and feed intake on DM basis.

All steers were slaughtered in a commercial packing facility of Suncheon City and graded for quality and yield factors by a trained carcass evaluator. Grading of carcasses was carried out in accordance with Korean beef carcass grading standards (KAPE, 2012). Each beef carcass was assigned one of five quality grades (1++, 1+, 1, 2 or 3). Grades were primarily based on marbling score and additionally adjusted according to meat color, fat color, texture of lean meat and maturity. One of three yield grades (A, B or C) was determined by assessing the live weight, carcass weight, back fat thickness and longissimus muscle area.

Table 2. Effect of dietary supplementation with fermented liquid whey (FLW) on growth performance of Hanwoo steers from 22 to 28 months of age.

Item	Treatment		SEM	P-value
	Control	FLW 0.2%		
Initial body weight (kg)	603.42	595.75	19.39	0.79
Final body weight (kg)	764.50[b]	818.00[a]	13.81	0.04
Average daily gain (kg/day)	0.90[b]	1.24[a]	0.04	0.001
Average daily feed intake of DM (kg/day)	10.83	10.83	0.07	0.98
Feed efficiency (gain/feed)	0.08[b]	0.11[a]	0.01	0.001

For each treatment, data are presented as the mean value of four replicate groups with three steers per replication (n = 12). Within a row, means without a common letter differ significantly (P<0.05).

To investigate the meat composition, loin eye meats from selected Hanwoo steers were excised and ground with a meat grinder. The moisture (934.01), crude protein (988.05), ether extract (991.36) and crude ash (942.05) contents of the samples were then determined using the methods described by AOAC (2000). The calcium (Ca), iron (Fe) and magnesium (Mg) contents of carcasses were determined using an atomic absorption spectrophotometer (AA-6200, Korea).

To determine the cholesterol content, 1 g of each meat sample was mixed with reference material (100 µg of 5 α-cholesterol) and homogenized with 0.5 N KOH (aq) and 22 mL of ethanol, after which it was subjected to saponification at 23°C for 6 h. The total cholesterol was subsequently extracted with hexane and analyzed by gas chromatography (DS 6200, Donam Co., Seongnam, Gyeonggi-do, Korea) using a gas chromatograph equipped with a flame ionization detector and a Hewlett Packard HP-5 capillary column (J&W Scientific, USA) 30 m in length with a 0.32 mm internal diameter and 0.25 µm polyethylene glycol-film thickness. Nitrogen was used as the carrier gas. The initial oven temperature was held at 250°C for 2 min, increased by 15°C/min to 290°C (held for 10 min), and then by 10°C/min to a final temperature of 310°C (held for 10 min). The other chromatographic conditions were as follows: injector and detector temperatures, 280°C; split ratio, 50:1; sample volume injected, 2 µL. Cholesterol content was expressed as mg/100g meat.

Meat fatty acids were determined by the methyl ester extraction methods according to Yang et al. (2003) and analyzed by gas chromatography using a DS 6200 gas chromatograph (described above) equipped with a flame ionization detector and a Hewlett Packard HP-5 capillary column (J&W Scientific, USA) 30 m in length with a 0.32 mm internal diameter and 0.25 µm polyethylene glycol-film thickness. Samples were injected by an auto-sampler. During analysis, the injector temperature was maintained at 250°C and the detector temperature was maintained at 270°C. The initial oven temperature was held at 140°C for 1 min, after which was increased by 10°C/min to 220°C, which was held for 2 min, then further increased by 2°C/min to 240°C, which was held for 9 min. Nitrogen was applied at 1.0 mL/min as the carrier gas and hydrogen was applied at 30 mL/min as the makeup gas. Individual fatty acids were identified by comparing their retention times with those of an authenticated standard fatty acid mix (Supelco 37; Sigma Chemical Co. Ltd., Poole, UK). Individual fatty acids were corrected by their relative response factors using the value of the internal standard and expressed as g/100 g of total fatty acids identified. Fatty acids were grouped as saturated (SFA), monounsaturated (MUFA) or polyunsaturated (PUFA), and the ratios of PUFA:SFA and n-6/n-3 were calculated.

To determine the oxidative stability, meat samples were preserved in a refrigerator at 4.5°C and the thiobarbituric acid reactive substance (TBARS) values were assayed when fresh as well as at 1, 2 and 3 weeks according to the method described by Sarker and Yang (2011). Color value was determined using a Vis-Spectrophotometer (Model 20D+, Milton Roy, USA) based on the absorbance at 530 nm, and TBARS values are expressed as micromoles of malondialdehyde (MDA) per 100 g of meat sample.

Statistical analysis

All data were analyzed as a completely randomized design using the GLM procedure of the Statistical Analysis System (version 9.1; SAS Ins. Inc., Cary, NC, USA, 2003) based on the statistical model:

$Yij = \mu + Ti + eij$

Where Yij = dependent variable of the j^{th} animal on the i^{th} treatment; µ = overall mean; Ti = the fixed effect of i^{th} treatment effect (I = 1, 2); Eij = random residual (error) associated with the dependent variable from the j^{th} animal on the i^{th} treatment.

A group of three steers served as the experimental unit for all parameters. Model included the effects of diets. Variability in data was expressed as the standard error of the means (SEM) and Duncan's multiple range tests were used to examine significant differences among treatment means. A P≤0.05 was considered to indicate statistical significance, whereas 0.5<P≤0.10 was considered to indicate trends.

RESULTS

There was no differences in the initial body weight of the steers (P>0.79) between dietary treatments (Table 2). Steers fed 0.2% FLW supplemented diet showed higher final body weight (P<0.04) and average daily gain relative to the control (P=0.001). Steers in both treatment groups had similar feed intakes; however, the gain/feed ratio was higher in the 0.2% FLW supplemented group (P=0.001). None of the measured carcass characteristics were affected by dietary supplementation with FLW (Table 3).

The effects of FLW on meat composition, cholesterol and trace mineral content of Hanwoo carcasses are shown in Table 4. Moisture and crude protein contents of loin meat were unaffected by FLW dietary treatment (P>0.97); however, ether extract (P<0.05) and ash (P<0.04) contents were reduced in the loin eye meat of steers fed the diet supplemented with 0.2% FLW. There was no difference among treatments in the cholesterol

Table 3. Effects of dietary supplementation with fermented liquid whey (FLW) on carcass characteristics of Hanwoo steers.

Item	Treatment		SEM	P-value
	Control	FLW 0.2%		
Live weight (kg)	764.50	818.00	21.10	0.12
Hot carcass weight (kg)	432.50	463.00	14.07	0.18
Dressing percent (%)	56.55	56.59	0.37	0.95
Carcass yield grade	3.00	2.75	0.28	0.58
Carcass quality grade	1.75	1.25	0.20	0.13

The carcass yields are graded as 3, grade A; 2, grade B; and 1, grade C. The carcass quality are graded as 5 (1++), 4 (1+), 3 (1), 2 (2), and 1 (3) (According to KAPE, 2012). Data are presented as the mean value of four replicate groups with three steers per replication (n = 12).

Table 4. Effects of dietary supplementation with fermented liquid whey (FLW) on meat composition, cholesterol and trace mineral content of Hanwoo carcasses.

Item	Treatment		SEM	*P*-value
	Control	FLW 0.2%		
Moisture (%)	68.44	69.92	0.73	0.21
Crude protein (%)	22.12	22.16	0.64	0.97
Ether extract (%)	8.3[a]	7.00[b]	0.36	0.05
Crude ash (%)	1.11[a]	0.93[b]	0.05	0.04
Cholesterol (mg/100 g meat)	25.09	27.06	1.36	0.36
Ca (mg/100 g)	0.25[b]	0.35[a]	0.02	0.02
Fe (mg/100 g)	0.40[b]	0.49[a]	0.02	0.05
Mg (mg/100 g)	2.39	2.20	0.08	0.21

Data are presented as the mean value of four replicate groups with three steers per replication (n = 12). Within a row, means without a common letter differ significantly (P<0.05).

content of meat (P>0.36). Dietary supplementation with 0.2% FLW increased the Ca (P<0.02) and Fe (P<0.05) contents of loin meat, whereas the Mg content remained unaffected (P>0.21).

The effects of dietary FLW on the fatty acid composition of Hanwoo steer loin eye meat are presented in Table 5. Dietary supplementation of FLW increased the linoleic acid concentration (P<0.03) of the loin eye meat of Hanwoo steers. The sum of PUFAs (P<0.04) and n-6 PUFAs (P<0.05) were also elevated in response to FLW supplementation.

In the fresh state, the MDA value was lower in the FLW-supplemented group than in the control (P=0.003; Figure 1), whereas it did not differ from the control group during week 1 (P>0.33). During weeks 2 and 3, a reducing tendency (P<0.10) was found in the MDA value of loin meat obtained from the FLW-supplemented group.

DISCUSSION

Utilization of whey in feed provided to ruminants constitutes one of the newest and most rapidly exploitable means of application because it is inexpensive, easy to put into practice and offers a good method of utilizing non-protein nitrogen sources for ruminants. Whey fermented by LAB can improve ruminant performance by synchronizing rumen fermentation, being a source of organic acid and living bacteria (de Oliveira et al., 2012). The results showed significant improvements in body weight, average daily gain and feed efficiency (gain/feed) in steers fed 0.2% FLW diets versus the control. Manipulation of ruminal fermentation has been one of the methods used to increase ruminant productivity (de Oliveira et al., 2012). The low protein and high rapidly degradable carbohydrate (lactose) content of whey led to the assumption that this by-product would help synchronize rumen fermentation, thereby improving performance. Fermentation of whey with LAB produces a considerable amount of lactic acid through metabolism of whey lactose. Dietary addition of fermented whey can continue the lactose fermentation process, as well as that of other carbohydrates that reduce the pH of the rumen and stimulate the growth of lactate utilizing bacteria (Krehbiel et al., 2003). Once lactate utilizing bacteria concentrations increase, the ability to metabolize lactate

Table 5. Effects of dietary supplementation with fermented liquid whey (FLW) on meat fatty acid profile of Hanwoo steers.

Fatty acid (% of total fatty acid)	Treatment		SEM	P-value
	Control	ACP 0.5%		
Myristic acid (C14:0)	4.50	4.17	0.45	0.62
Palmitic acid (C16:0)	31.52	32.96	2.09	0.69
Stearic acid (C18:0)	0.05	0.02	0.02	0.27
Palmitoleic acid (C16:1n-7)	3.73	4.42	0.90	0.67
Oleic acid (C18:1n-9)	48.84	45.74	3.15	0.58
Linoleic acid (C18:2n-6)	9.27^{b}	10.51^{a}	0.30	0.03
Linolenic acid (C18:3n-6)	0.51	0.48	0.06	0.82
α-Linolenic acid (C18:3n-3)	0.09	0.10	0.01	0.77
Eicosenoic acid (C20:1n-9)	0.15	0.13	0.02	0.48
Arachidonic acid (C20:4n-6)	0.62	0.72	0.16	0.72
Eicosapentaenoic acid (C20:5n-3)	0.34	0.35	0.03	0.70
Adrenic acid (C22:4n-6)	0.27	0.25	0.04	0.86
Docosahexaenoic acid (C22:6n-3)	0.14	0.17	0.03	0.58
∑ Saturated fatty acid (SFA)	39.75	41.54	3.04	0.73
∑ Monounsaturated fatty acid (MUFA)	49.04	45.88	3.13	0.57
∑ Poly unsaturated fatty acids (PUFA)	11.22^{b}	12.58^{a}	0.36	0.04
∑ Unsaturated fatty acids (UFA)	60.25	58.46	3.04	0.73
∑n-3 PUFA	0.56	0.62	0.03	0.30
∑n-6 PUFA	10.66^{b}	11.96^{a}	0.35	0.05
MUFA/SFA	1.24	1.19	0.15	0.82
PUFA/SFA	0.29	0.31	0.02	0.45
UFA/SFA	1.52	1.50	0.17	0.92
n-6/n-3	19.24	19.71	1.39	0.82

Data are presented as the mean value of four replicate groups with three steers per replication (n = 12). Within a row, means without a common letter differ significantly ($P<0.05$).

to volatile fatty acid (primarily propionic acid) also increases (Counotte et al., 1983). If propionic acid production is both energetically enhanced and proportionately increased, then it is likely that the energy available to the animal also increases, thereby increasing growth performance. Another possibility is that LABs produce bacteriocins in the FLW, which might inhibit detrimental microorganisms (*Escherichia coli*) in the rumen, resulting in improved fiber digestibility (Ramaswami et al., 2005). The beneficial effects of LABs to improve feed efficiency and daily gain of feedlot cattle were also reported by Swinney-Floyd et al. (1999) and Galyean et al. (2000), however no differences were reported for carcass characteristics. Krehbiel et al. (2003) also reviewed that, LAB did not affect the dressing percentage, USDA yield grade, USDA quality grade and marbling score of beef cattle, which is consistent with our findings.

Ether extract refers to the crude mixture of fat-soluble material present in a sample and includes glycerides (mono-, di-, tri-), phospholipids, steroids, free fatty acids, fat soluble vitamins, and cholesterol. Stimulation of the lipolytic activity in adipose tissue or inhibition of fat synthesis is one method of reducing ether extract content in animal tissue. A number of scientific studies have confirmed the lipolytic activity of LABs through the production of lipases and esterases (Meyers et al., 1996). According to Medina et al. (2004), LABs can hydrolyze triglycerides, releasing most short and medium chain, and essential fatty acids, which are valuable to health conscious consumers. LABs also exhibit anti-lipogenic activity to inhibit fat synthesis by reducing the expression of sterol regulatory element-binding proteins (SREBP), which controls the lipid composition of animal cells (Sakai et al., 1998). Yonejima et al. (2013) reported that the administration of *Lactobacillus* fermented soymilk and soy yogurt reduced the expression of SREBP and hepatic lipogenesis in rats. Furthermore, whey is reported to contain substantial amount of branched-chain amino acid, leucine, which is able to promote muscle protein synthesis, instead of fat storage in the adipose tissue (Pilvi et al., 2007). In the present study, the reduction in ether extract contents in the loin eye meat of Hanwoo steers was likely due to the synergistic effects of whey protein and LABs.

Dietary supplementation of FLW increased the Ca and

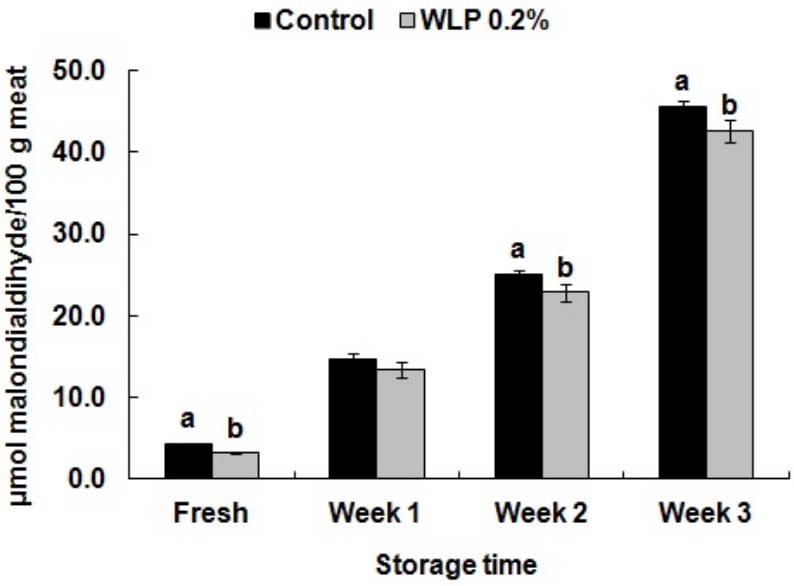

Figure 1. Effects of dietary fermented liquid whey (FLW) on thiobarbituric acid reactive substance (TBARS) values in loin eye meats of Hanwoo beef. TBARS values are expressed as micromoles of malondialdehyde (MDA) per 100 g of meat. Data are presented as the mean ± S.E. Bars at a particular time point without a common letter indicate a significant difference ($P<0.05$).

Fe content of beef. Whey itself is a good source of calcium, magnesium, phosphorus, iron and zinc with high purity and bioavailability. Fermentation of whey by LABs produces lactic acid by using lactose, which reduces the pH of the rumen and the digesta pH in the lower tract and therefore may stimulate dietary Ca and Fe absorption by slowing the gastric emptying rate (Chonan et al., 1998). Low pH also increases the buffering capacity, which keeps the Fe in a bioavailable form (Hallberg and Rossander, 1982).

The consumption quality of meat largely depends on its fatty acid composition (Wood et al., 1999). Consumers are increasingly demanding products with higher PUFA content because of their beneficial effects in preventing cardiovascular disease (Ander et al., 2003). In this experiment, dietary supplementation with FLW signify-cantly increased the proportion of linoleic acid, total PUFAs and total n-6 PUFAs in Hanwoo beef without affecting the SFA, and the proportion of n-6/n-3 PUFA indicates its positive effects on meat quality. A previous study conducted by Ross et al. (2012) reported that dietary supplementation of *Lactobacillus amylovorus* and *Enterococcus faecium* can increase the concentration of linoleic acid and total PUFAs in pig muscles. One possible explanation for this is that LABs may reduce the oxidation of PUFAs by scavenging free radicals (Virtanen et al., 2007) or degrading the superoxide anion and hydrogen peroxide (Kullisaar et al., 2002).

Malondialdehyde, a product of lipid oxidation, is determined by the TBARS test as an estimate of the development of rancidity in meat products. The rate of lipid oxidation can be effectively retarded by the use of antioxidants, and the antioxidative potential of LAB has been previously reported (Virtanen et al., 2007). Lactic acid bacteria strains exhibit antioxidative activity in varying ways, which makes it very difficult to identify individual mechanisms or compounds responsible for its antioxidative activity. Kaizu et al. (1993) reported that LABs are able to decrease the risk of accumulation of reactive oxygen species (ROS). Furthermore, Korpela et al. (1997) and Kullisaar et al. (2002) reported the superoxide anion and hydrogen peroxide degradation capacity of LABs. In addition, several studies have described the antioxidant potential of whey protein (Chen et al., 2003; Virtanen et al., 2007). Previous studies conducted by Osuntoki and Korie (2010) revealed the development of antioxidant activity in fermented milk whey inoculated with *Lactobacillus* species. Virtanen et al. (2007) reported that milk fermented with mixed cultures of LAB resulted in higher radical scavenging activity than milk fermented with single bacterial strains. In this study, dietary supplementation of FLW significantly reduced the MDA value of Hanwoo beef, which was ascribed to a synergistic effect of whey protein and LABs.

In conclusion, dietary supplementation with 0.2% fermented liquid whey (FLW) can improve the growth performance and meat composition of finishing Hanwoo steers without affecting the carcass characteristics. In addition, feeding on FLW was also found to be beneficial to improve meat storage quality by reducing the oxidative

rancidity of beef. Therefore, these results suggest FLW at 0.2% level as a functional feed additive for finishing beef cattle. Further investigation with different dose level is suggested to justify the results.

Conflict of interests

The author(s) have not declared any conflict of interests.

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REFERENCES

Alvarez-Olmos MI, Oberhelman RA (2001). Probiotic agents and infectious diseases: A modern perspective on a traditional therapy. Clin. Infect. Dis. 32:1567-1576.

Amezcua MDR, Friendship R, Dewey C, Weese S, de Lange CFM, Reid G (2007). Effects on growth performance, feed efficiency, and health of weanling pigs fed fermented liquid whey inoculated with lactic acid bacteria that inhibit *Escherichia coli in vitro*. J. Swine Health Prod.15:320-329.

Ander BP, Dupasquier CMC, Prociuk MA, Pierce GN (2003). Ployunsaturated fatty acids and their effects on cardiovascular disease. Exp. Clin. Cardiol. 8:164-172.

AOAC (2000). Official Methods of Analysis, 934.01. 17th edn. Vol. 1. Association of Official Analytical Chemist: Maryland, USA.

Chen J, Lindmark-Månsson H, Gorton L, Åkesson B (2003). Antioxidant capacity of bovine milk as assayed by spectrophotometric and amperometric methods. Int. Dairy J. 13:927-935.

Chonan O, Takahashi R, Yasui H, Watanuki M (1998). Effect of L-lactic acid on calcium absorption in rats fed omeprazole. J. Nutr. Sci. Vitaminol. 44:473-481.

Counotte GHM, Lankhorst A, Prins RA (1983). Role of DL-lactic acid as an intermediate in rumen metabolism of dairy cows. J. Anim. Sci. 56(5):1222-1235.

de Oliveira JS, de Queiroz AC, Mantovani HC, Bayão GFV, Detmann E, Santos EM, da Silva TC (2012). Evaluation of whey fermented by *Enterococcus faecium* in consortium with *Veilonella parvula* in ruminant feeding. R. Bras. Zootec. 41:172-180.

Demecková V, Kelly D, Coutts AGP, Brooks PH, Campbell A (2002). The effect of fermented liquid feeding on the faecal microbiology and colostrums quality of farrowing sows. Int. J. Food Microbiol. 79:85-97.

Galyean ML, Nunnery GA, Defoor PJ, Salyer GB, Parsons CH (2000). Effects of live cultures of *Lactobacillus acidophilus* (Strains 45 and 51) and *Propionibacterium freudenreichii* PF-24 on performance and carcass characteristics of finishing beef steers. Available: http://www.asft.ttu.edu/burnettcenter/progressreports/bc8.pdf. Accessed June 27, 2002.

Geary TM, Brooks PH, Beal JD, Campbell A (1999). Effect on weaner pig performance and diet microbiology of feeding a liquid diet acidified to pH 4 with either lactic acid or through fermentation with *Pediococcus acidilactici*. J. Sci. Food Agric. 79:633-640.

Green ML (1977). Review of the progress of dairy science: Milk coagulants. J. Dairy Res. 44:159-188.

Hallberg L, Rossander L (1982). Absorption of iron from western-type lunch and dinner meals. Am. J. Clin. Nutr. 35:502-509.

Kaizu H, Sasaki M, Nakajima H, Suzuki Y (1993). Effect of antioxidative lactic acid bacteria on rats fed a diet deficient in vitamin E. J. Dairy Sci. 76:2493-2499.

KAPE (2012). The beef carcass grading [Online]. (Korea Institute for Animal products quality evaluation). Available at: http://www.ekape.or.kr/view/eng/system/beef.asp (Accessed 15 May 2012)

Kobashi Y, Ohmori H, Tajima K, Kawashima T, Uchiyama H (2008). Reduction of chlortetracycline-resistant *Escherichia coli* in weaned piglets fed fermented liquid feed. Anaerobe 14:201-204.

Korpela R, Lähteenmäki T, Sievi E, Saxelin M, Vapaatalo H (1997). Lactobacillus rhamnosus GG shows antioxidative properties in vascular endothelial cell cultures. Milchwissenschaft 52:503-505.

Krehbiel CR, Rust SR, Zhang G, Gilliland SE (2003). Bacterial direct-fed microbials in ruminant diets: Performance response and mode of action. J. Anim. Sci. 81:E120-E132.

Kullisaar T, Zilmer M, Mikelsaar M, Vihalemm T, Annuk H, Kairane C, Kilk A (2002). Two antioxidative lactobacilli strains as promising probiotics. Int. J. Food Microbiol. 72:215-224.

Law J, Haandrikmaan A (1997). Proteolytic enzymes of lactic acid bacteria. Int. Dairy J. 7:1-11.

Lawlor PG, Lynch PB, Gardiner GE, Caffrey PJ, O'Doherty JV (2002). Effect of liquid feeding weaned pigs on growth performance to harvest. J. Anim. Sci. 80:1725-1735.

Mauriello G, Moio L, Moschetti G, Piombino P, Addeo F, Coppola S, (2001). Characterization of lactic acid bacteria strains on the basis of neutral volatile compounds produced in whey. J. Appl. Microbiol. 90:928-942.

Medina RB, Katz MB, González S, Oliver G (2004). Determination of the esterolytic and lipolytic activities of lactic acid bacteria. Public Health Microbiol. 268:465-470.

Meyers SA, Cuppett SL, Hutkins RW (1996). Lipase production by lactic acid bacteria and activity on butter oil. Food Microbiol. 13:383-389.

NRC (1996). Nutrient requirements of beef cattle. 7th ed. National Academy Press, Washington, DC.

Osuntoki A, Korie I (2010). Antioxidant activity of whey from milk fermented with *Lactobacillus* species isolated from Nigerian fermented foods. Food Technol. Biotechnol. 48:505-511.

Pal S, Ellis V, Ho S (2010). Acute effects of whey protein isolate on cardiovascular risk factors in overweight, post-menopausal women. Atherosclerosis 212:339-344.

Pescuma M, Hébert EM, Mozzi F, de Valdez GF (2008). Whey fermentation by thermophilic lactic acid bacteria: Evolution of carbohydrate and protein content. Food Microbiol. 25:442-451.

Pilvi TK, Korpela R, Huttunen M, Vapaatalo H, Mervaala EM (2007). High-calcium diet with whey protein attenuates body-weight gain in high-fat-fed C57Bl/6J mice. Br. J. Nutr. 98:900-907.

Ramaswami N, Chaidhary LC, Agarwal N, Kamra DN (2005). Effect of lactic acid producing bacteria on the performance of male crossbred calves fed roughage based diet. Asian-Aust. J. Anim. Sci. 18:1110-1115.

Reddy CA, Henderson HE, Erdman MD (1976). Bacterial fermentation of cheese whey for production of a ruminant feed supplement rich in crude protein. Appl. Environ. Microbiol. 32:769-776.

Ross GR, Van Nieuwenhove CP, González SN (2012). Fatty acid profile of pig meat after probiotic administration. J. Agric. Food Chem. 60:5974-5978.

Sakai J, Rawson RB, Espenshade PJ, Cheng D, Seegmiller AC, Goldstein JL, Brown MS (1998). Molecular identification of the sterol-regulated luminal protease that cleaves SREBPs and controls lipid composition of animal cells. Mol. Cell 2:505-514.

Sarker MSK, Yang CJ (2011). Eosungcho (*Houttuynia cordata*) with multi strain probiotics as alternative to antibiotic for broiler production. J. Med. Plants Res. 5:4411-4417.

Schingoethe DJ (1976). Whey utilization in animal feeding: a summary and evaluation. J. Dairy Sci. 59:556-570.

Swinney-Floyd D, Gardner BA, Owens FN, Rehberger T, Parrott T (1999). Effect of inoculation with either strain P-63 alone or in combination with *Lactobacillus acidophilus* LA53545 on performance of feedlot cattle. J. Anim. Sci. 77(Suppl. 1):77.

Van Soest PJ, Robertson JB, Lewis BA (1991). Methods for dietary fibre, neutral detergent fibre and nonstrach polysaccharides in relation to

animal nutrition. J. Dairy Sci. 74:3583-3597.
Virtanen T, Pihlanto A, Akkanen S, Korhonen H (2007). Development of antioxidant activity in milk whey during fermentation with lactic acid bacteria. J. Appl. Microbiol. 102:106-115.
Weinberg ZG (2003). Effect of Lactic acid bacteria on animal performance. Indian J. Biotechnol. 2:378-381.
Wood JD, Enser M, Fisher AV, Nute GR, Richardson RI, Sheard PR (1999). Manipulating meat quality and composition. Proc. Nutr. Soc. 58:1-8.
Yang CJ, Yang IY, Oh DH, Bae IH, Cho SG, Kong IG, Uuganbayar D, Nou IS, Choi KS (2003) Effect of green tea by-product on performance and body composition in broiler chicks. Asian-Aust. J. Anim. Sci. 16:867-872.
Yonejima Y, Ushida K, Mori Y (2013). Effect of lactic acid on lipid metabolism and fat synthesis in mice fed a high-fat diet. Biosci. Microbiota Food Health 32:51-58.