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Effects of full-fat soybean diet on performance, carcass characteristics, and fatty acid composition of Hanwoo steers

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Abstract: The effect of dietary full-fat soybean on performance and carcass characteristics of Hanwoo steers was investigated. Thirty steers (653 ± 52.96 kg) were allotted to control and full-fat soybean groups with a 210-day comparative feedlot trial. Steers were fed either the basal finishing diet (control) or control plus 5% full-fat soybean, using Calan gates for individual intake measurement. There was no difference in BW, feed intake, carcass weight, backfat thickness, loin muscle area, or meat color between groups. The average daily gain was greater ($P < 0.05$) in the soybean group compared to the control group. Steers fed soybean showed a lower feed conversion ratio than the controls. Marbling in the soybean group was greater ($P < 0.05$) than that in the control group. Supplementary full-fat soybean increased ($P < 0.05$) crude fat but decreased ($P < 0.05$) crude protein content in the longissimus muscle. Full-fat soybean increased ($P < 0.05$) total unsaturated fatty acids, including the levels of oleic, linoleic, and linolenic acid but, consequently, decreased ($P < 0.05$) total saturated fatty acids. Levels of conjugated linoleic acid, and its major precursor trans-vaccenic acid, were significantly increased by soybean supplementation. Our results demonstrate that full-fat soybeans may offer a better way to produce healthier beef with increased unsaturated fatty acids.

Key words: Full-fat soybean, linoleic acid, conjugated linoleic acid, Hanwoo steers

1. Introduction

Consumer preferences for meat products have recently focused on health-related functionality rather than marbling score in terms of meat quality (1). Due to its beneficial effects in lowering the risk of metabolic disorders including diabetes, arteriosclerosis, and cancer, conjugated linoleic acid (CLA) has been the subject of beef product research (2). CLA is found predominantly in the milk and meat of ruminants and originates from the process of microbial hydrogenation of either $C_{18:2}$ (linoleic acid) or $C_{18:3}$ (linolenic acid) into $C_{18:0}$ (stearic acid) (3). The total amount of CLA in animal products varies greatly depending on what animals eat; supplementation of ruminant rations with vegetable oils rich in linoleic and linolenic acids increases the CLA content in their meat (4). Soybean, the most widely used feed ingredient, is rich in protein and fat and provides the essential amino acids and fatty acids, especially unsaturated fatty acids (5). Enhanced ruminal CLA content was observed through supplementation with either linseed or fish oil (6). Feeding cattle with high-oil corn (7) or soybean oil (8) had no effect on CLA production. Administration of extruded full-fat soybean increased CLA content in the fat tissues of steers (9). Therefore, we hypothesized that full-fat soybean, which is rich in unsaturated fatty acids and high-quality amino acids, would increase the CLA content in Hanwoo beef. The objective of this study was to evaluate the effect of a full-fat soybean diet on performance, carcass characteristics, and CLA content of loin muscle in Hanwoo steers.

2. Materials and methods

2.1. Animals, diets, and management

The experiment was conducted at an experimental cattle farm in Gyeongbuk, Korea. Experimental animals were handled according to the guidelines of the National Institute of Animal Science, Korea. Thirty Hanwoo steers (BW: 653 ± 52.96 kg, age: 23.7 ± 0.2 months) were stratified by BW and age and randomly assigned to control or full-fat soybean diet groups. Steers were fed using Calan gates for individual intake measurement; diets consisted of a basal corn-based finishing diet (control) or control diet plus 5% full-fat soybean, which was replaced with 3% soybean meal and 2% coconut meal. Steers were kept

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in 4.5 × 9.0 m pens (5 animals per pen) under treatment for 210 days, excluding a 15-day adjustment period. All animals were fed twice per day and had free access to water. Feed intake was recorded daily, and animals were weighed monthly. Animal diets were formulated following the Korean Feeding Standard (10). The chemical and fatty acid composition of full-fat soybean is shown in Table 1. Chemical composition of experimental diets, including concentrates and straw, is shown in Table 2. The formula of feed ingredients is shown in Table 3.

2.2. Sampling and analysis

2.2.1. Carcass assessment

Steers were fasted for 24 h and slaughtered at a local commercial abattoir. Carcass yield and quality were graded by meat graders using criteria provided by Livestock Quality Assessment (11). Dry matter and ash content was determined according to AOAC (12). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed by standard methods (13). Total crude fat content of M. longissimus dorsi (LD) muscle samples obtained from the 12th and 13th rib sections was determined using the Soxhlet extraction method according to AOAC (12). The crude fiber content was estimated by acid–base digestion method (12). Crude protein content was determined by the Kjeldahl method (12). Briefly, 0.5 g of loin samples was digested at 450 °C for 5 h, distilled by the addition of 50% NaOH, and titrated with HCl; then the total amount was calculated by multiplying %N by the converting factor of 6.25.

2.2.2. Meat color

The meat color attributes Hunter L (lightness), a (redness), and b (yellowness) and CIE L*, a*, and b* were determined

Table 1. Chemical and fatty acid composition of full-fat soybean in experimental diets.

Items	Full-fat soybean
Chemical composition, %DM	
Moisture	6.16 ± 0.13[1)]
Crude protein	38.62 ± 0.89
Crude fat	14.63 ± 0.71
Crude ash	4.82 ± 0.02
Fatty acids, % of total fatty acid	
$C_{16:0}$	9.28 ± 0.34
$C_{16:1}$	0.43 ± 0.05
$C_{18:0}$	2.84 ± 0.17
$C_{18:1n9}$	31.92 ± 3.52
$C_{18:2n6}$	38.91 ± 1.98
$C_{18:3n3}$	15.63 ± 0.18
$C_{20:0}$	0.82 ± 0.19
$C_{20:3n3}$	0.04 ± 0.01
$C_{20:4n6}$	0.09 ± 0.01
SFA[2)]	13.15 ± 0.62
UFA[3)]	86.94 ± 0.52
MUFA[4)]	32.37 ± 3.54
PUFA[5)]	54.67 ± 2.21
U/S[6)]	6.61 ± 0.47

[1)] Mean ± SD, [2)] saturated fatty acids, [3)] unsaturated fatty acids,
[4)] monounsaturated fatty acids, [5)] polyunsaturated fatty acids,
[6)] unsaturated fatty acids/saturated fatty acids.

Table 2. Chemical composition of concentrates and rice straw in the experimental diet.

Items	Concentrates		Rice straw
	Control	Full-fat soybean[1)]	
Chemical composition, %DM			
Moisture	12.25	12.10	11.23
Crude protein	13.47	13.89	5.61
Crude fat	3.83	4.12	0.34
NDF	27.64	26.22	64.11
ADF	13.41	10.13	47.85
Crude ash	6.00	5.24	11.26
Ca	1.02	0.76	0.20
P	0.44	0.57	0.20

[1)] Contained 5% full-fat soybean in diet .

Table 3. Formula of concentrates.

Item	Concentrates	
	Control	Full-fat soybean
	As-fed basis, %	
Ingredient		
Corn grain	30.50	30.50
Wheat	4.00	4.00
Full-fat soybean	-	5.00
Wheat bran	15.50	15.50
Corn gluten feed	13.00	13.00
Soybean meal	4.50	1.50
Palm kernel meal	8.00	8.00
Coconut meal	10.00	8.00
Cottonseed meal	5.50	5.50
Molasses	5.00	5.00
Salt, dehydrated	0.50	0.50
Limestone	1.50	1.50
Vitamin premix[1)]	1.00	1.00
Mineral premix[2)]	1.00	1.00
Total	100	100

[1)] Contains the following ingredients per kg: vitamin A: 2,000,000 IU; vitamin D_3: 500,000 IU; vitamin B_1: 150 mg; vitamin B_{12}: 1500 mg.
[2)] Contains the following ingredients per kg: Fe: 5000 mg; Zn: 2000 mg; Mn: 3500 mg; Cu: 500 mg; Co: 100 mg; Mg: 250 mg.

by chroma meter (CR-10; Minolta Corporation, Japan). Each sample was measured at 5 different locations on the muscle surface, and an average score was taken.

2.3. Fatty acid composition analysis by gas chromatography

Fatty acid methyl esters (FAMEs) were prepared as modified methods described by Lepage and Roy (14) and Choi et al. (15). Briefly, approximately 3 g of samples were pulverized in liquid nitrogen, homogenized in a Polytron (PT-MR-2100, Switzerland) with chloroform:methanol (2:1, vol/vol), and filtered. Extracted FAMEs were then mixed with 2 mL of methanol:benzene (4:1, vol/vol), 200 µL of acetyl chloride, 1 mL of isooctane, and 8 mL of 6% potassium carbonate and centrifuged at 1500 rpm for 10 min. Supernatant was analyzed by gas chromatography (Clarus 500; PerkinElmer, Shelton, CT, USA) using a fused silica capillary column (Supleco SP-2560; 0.25 mm I.D.). One microliter of sample was injected with the split ratio of 100:1 at 250 °C, and a flame ionization detector detected the signal at 270 °C. The oven temperature was set at 170 °C for 5 min and then increased to 220 °C (2 °C/min) and held for 40 min.

2.4. Statistical analysis

Variance analysis was carried out in accordance with the general linear model. Data were represented as least squares (mean ± SE) and compared using Student's t-test of SAS (16). Statistical significance was established at $P < 0.05$.

3. Results

3.1. Growth performance

Growth performance including BW and average daily gain (ADG) is shown in Table 4. Although not statistically significant, steers fed full-fat soybean showed higher BW (784.13 kg) than the control group (752.07 kg). The full-fat soybean treatment group had greater ($P < 0.05$) ADG than the control group (0.61 kg vs. 0.48 kg) but tended to have a lower intake of concentrate diet. Steers fed full-fat soybean showed a lower feed conversion ratio compared to the control group (by 23.47%). In general, high dietary fat content in feed leads to a decrease in feed intake (17). Roasted soybean, which is known to improve fat digestibility, is a good source of high quality protein and, thereby, improves the nutritional values of feed ingredients (18). Felton and Kerley (19) showed that high-fat diets supplemented with soybean improve both feed efficiency and meat quality in steers. Our previous study also showed that dietary roasted soybean decreased the feed requirement in steers (1). Concomitant with these results, our current study confirms that administration of full-fat soybean improves daily gains and feed efficiency in Hanwoo steers.

3.2. Carcass characteristics

Carcass weight, backfat thickness, LD muscle area, marbling score, and meat color in Hanwoo steers are shown in Table 5. Steers fed a full-fat soybean-supplemented diet tended to have greater ($P = 0.06$) carcass weight than the control

Table 4. Performance of finishing Hanwoo steers fed full-fat soybean supplemented diet.

Items	Control	Full-fat soybean[1)]	t-test[2)]
Initial age, day	712.70 ± 9.33[3)]	732.57 ± 10.04	0.2357
Final age, day	922.70 ± 9.33	942.57 ± 10.04	0.2357
Duration, days	210	210	
Body weight gain, kg/hd			
Initial weight	651.03 ± 61.67	656.03 ± 44.25	0.4290
Final weight	752.07 ± 31.66	784.13 ± 42.46	0.0916
Total weight gain	101.07 ± 18.82	128.10 ± 22.83	0.0450
Daily gain	0.48 ± 0.22	0.61 ± 0.52	0.0363
Feed intake, kg/hd			
Concentrate	1745.13 (8.03)[4)]	1645.40 (7.83)	0.224
Rice straw	210.40 (1.01)	218.42 (1.14)	0.321
Feed conversion, kg/kg			
Concentrate	16.73	12.84	0.021
Roughage	2.10	1.86	0.094

[1)] Contained 5% of fed full-fat soybean in diet; [2)] Probability of the t-test.
[3)] Mean ± SD; [4)] Values in parentheses represent intake per head per day.

Table 5. Carcass yield and quality grades of Hanwoo steers fed full-fat soybean supplemented diets.

Items	Control	Full-fat soybean[1)]	t-test
Cold carcass weight, kg	448.48 ± 30.41[2)]	469.02 ± 32.60	0.0621
Yield traits:			
Backfat thickness, mm	14.27 ± 6.82	16.64 ± 5.37	0.1749
M. longissimus dorsi area, cm^2	92.93 ± 11.39	98.73 ± 9.06	0.2255
Yield index	62.44 ± 5.09	63.14 ± 4.76	0.6032
Quality traits:			
Marbling score[3)]	5.98 ± 1.22	7.01 ± 1.43	0.0429
Meat color[4)]	4.70 ± 1.06	4.96 ± 0.36	0.8734
Fat color[5)]	2.93 ± 0.26	2.93 ± 0.27	0.5987
Texture[6)]	1.00 ± 0.00	1.07 ± 0.27	0.1632
Maturity[7)]	2.00 ± 0.00	2.00 ± 0.00	1.0000

[1)] Contained 5% of fed full-fat soybean in diet.
[2)] Mean ± SD.
[3)] 9 = Most abundant, 1 = devoid.
[4)] 7 = Dark red, 1 = bright.
[5)] 7 = Yellowish, 1 = white.
[6)] 3 = Coarse, 1 = fine.
[7)] 9 = Mature, 1 = youthful.

group. There was no difference in backfat thickness, LD area, or meat color between control and treatment groups. Feed ingredients included in diets, as well as feeding strategy during the fattening period, are determinants of economic traits, including backfat thickness, LD area, and marbling score in steers (20). Felton and Kerley (19) showed an increase in marbling scores of steers fed a diet supplemented with soybean. Concomitant with these results, our current and previous (1) studies showed that feeding roasted soybeans or full-fat soybean during the fattening period increased the marbling score ($P < 0.05$), suggesting that dietary soybean treatment has a beneficial effect on meat quality grade in Hanwoo steers.

3.3. Physicochemical characteristics of the carcass

Effects of dietary full-fat soybean on the physicochemical characteristics of LD muscles from Hanwoo steers are shown in Table 6. Moisture level was not significantly different between the control and full-fat soybean groups (63.73% and 61.05%, respectively). Crude fat content in the full-fat soybean group (19.01%) was greater ($P < 0.05$) than that in the control group (15.73%). Crude protein content of the full-fat soybean group (13.15%) was lower than that of the control group (18.77%). The overall range of measured CIE values, including L (lightness), b (yellowness), and h (color), was not different between the experimental groups. The amount and nutrient composition of diet affect the absorption rate and subsequent partitioning of nutrients toward body fat or protein (21). Meat quality grade increases with increased crude fat content, which is negatively correlated with moisture content (22,23). In agreement with these data associating feed nutrients with meat quality constituents, supplemental full-fat soybean changed the body composition of Hanwoo steers, allowing them a higher fat content in our current study. Further study will be necessary to specify the mechanisms by which feeding full-fat soybean modulates nutrient conversion (or energy repartitioning) in muscle and fat biosynthesis.

3.4. Fatty acid composition of M. longissimus dorsi

Supplementation of 5% full-fat soybean decreased ($P < 0.05$) the total saturated fatty acids (SFAs) level but increased the total unsaturated fatty acids (UFAs) level in LD muscle of Hanwoo steers (Table 7). More specifically, full-fat soybean supplementation decreased ($P < 0.05$) palmitic acid ($C_{16:0}$) among SFAs and increased ($P < 0.05$) oleic acid ($C_{18:1}$), linoleic acid ($C_{18:2}$), and linolenic acid ($C_{18:3}$) among UFAs. Consumers are aware of the impact of saturated fat consumption on their health. Their concern results in closer scrutiny of the fatty acid composition of ruminant products. Level of SFAs is mainly affected by palmitic acid ($C_{16:0}$) and stearic acid ($C_{18:0}$), and UFAs concentration is related to the oleic acid ($C_{18:1}$) content in beef (20). Lee et al. (24) reported a result obtained from a rumen dry matter and fatty acid degradability experiment indicating that supplementary full-fat soybean increased ($P < 0.05$) oleic acid levels. Later, Felton and Kerley (19) reported that 16% supplemental soybean decreased SFA levels in whole body fat of steers. Plant oil is not a common supplement in ruminant feed since the large amounts of

Table 6. Physicochemical characteristics of carcasses of Hanwoo steers fed full-fat soybean supplemented diets.

Items	Control	Full-fat soybean[1)]	t-test
Moisture, %	63.73 ± 2.79[2)]	61.05 ± 4.77	0.0621
Crude fat, %	15.73 ± 4.14	19.01 ± 5.93	0.0234
Crude protein, %	18.77 ± 0.95	13.15 ± 1.55	0.0474
Crude ash, %	0.84 ± 0.12	0.86 ± 0.07	0.2255
CIE value[3)]:			
L	37.67 ± 2.15	38.41 ± 3.63	0.8997
A	23.94 ± 2.43	21.98 ± 2.06	0.2829
B	10.35 ± 1.71	10.98 ± 1.67	0.8934
Chroma	25.98 ± 2.89	26.16 ± 2.49	0.6987
Hue	22.85 ± 1.99	22.11 ± 2.07	0.3632

[1)] Contained 5% of fed full-fat soybean in diet; [2)] Mean ± SD; [3)] L = Lightness, a = redness, b = yellowness.

Table 7. Fatty acid composition of M. longissimus dorsi of Hanwoo steers fed full-fat soybean supplemented diets.

Items	Control	Full-fat soybean[1)]	t-test
Percentage (%)			
$C_{12:0}$	0.10 ± 0.03[2)]	0.12 ± 0.02	0.8451
$C_{14:0}$	3.81 ± 0.80	3.22 ± 0.69	0.1247
$C_{14:1}$	0.35 ± 0.04	0.20 ± 0.04	0.0721
$C_{15:0}$	1.37 ± 0.28	1.26 ± 0.36	0.2146
$C_{15:1}$	0.15 ± 0.01	0.08 ± 0.01	0.0612
$C_{16:0}$	26.97 ± 2.21	21.69 ± 1.73	0.0458
$C_{16:1}$	6.74 ± 1.18	6.42 ± 0.92	0.7587
$C_{17:0}$	0.18 ± 0.03	0.16 ± 0.04	0.3257
$C_{18:0}$	9.10 ± 0.73	9.89 ± 0.68	0.0913
$C_{18:1}$	48.29 ± 3.39	51.03 ± 2.98	0.0420
$C_{18:2}$	1.68 ± 0.37	1.98 ± 0.43	0.0321
$C_{18:3}$	0.27 ± 0.13	0.30 ± 0.12	0.0265
$C_{20:0}$	0.44 ± 0.03	0.42 ± 0.02	0.6528
SFA[3)]	41.97 ± 2.32	36.76 ± 2.68	0.0115
UFA[4)]	57.48 ± 2.76	60.01 ± 2.09	0.0314
MUFA[5)]	55.53 ± 2.37	57.73 ± 2.53	0.0645
PUFA[6)]	1.95 ± 0.21	2.28 ± 0.39	0.1284
U/S[7)]	1.37	1.63	0.0457

[1)] Contained 5% of fed full-fat soybean in diet; [2)] mean ± SD; [3)] saturated fatty acid; [4)] unsaturated fatty acid; [5)] monounsaturated fatty acid; [6)] polyunsaturated fatty acid; [7)] unsaturated fatty acid/saturated fatty acid.

Table 8. Composition conjugated linoleic acid (CLA) and trans-vaccenic acid (TVA) of Hanwoo steers fed full-fat soybean supplemented diets.

Items	Control	Full-fat soybean[1)]	t-test
	c9, t11 CLA, %		
M. longissimus dorsi	0.22 ± 0.06	0.43 ± 0.07	0.0223
	t11 TVA, %		
M. longissimus dorsi	1.31 ± 0.27	1.82 ± 0.23	0.0441

[1)] Contained 5% of fed full-fat soybean in diet.

polyunsaturated fatty acids (PUFAs) in this oil can be toxic to rumen microbes, which may lower ruminal fermentation and animal productivity. An alternative approach, and one used in our current study, is to feed steers supplemental full-fat soybean containing high levels of poly UFAs (Table 2), which allows the oil source to become gradually available for microbial fermentation, thus minimizing the adverse effects on microbial growth. This approach markedly increased UFAs, especially the oleic acid and mono UFAs, in LD muscle of Hanwoo steers. Therefore, supplementation with dietary full-fat soybean could be a better way to modulate the nutritional profile, in particular fatty acid composition, of beef products.

4. Discussion

About 30% of the consumer intake of CLA is from beef products (25). The concentration of CLA in milk and meat is affected by animal breed, age, diet, and feeding regime (26). Biomedical studies with animal models demonstrated that an increase in the CLA content of milk and meat has the potential to raise the nutritive and therapeutic values of dairy and beef products (2). Administration of full-fat soybean markedly increased the CLA in milk fat, but only a few studies have investigated these effects in beef products. Therefore, our main objective was to examine the effects of dietary supplementation of full-fat soybeans on the CLA level in LD muscle of Hanwoo steers. When compared with the control diet, a full-fat soybean diet increased ($P < 0.05$) the levels of CLA and trans-vaccenic acid (TVA) in LD muscles of Hanwoo steers (Table 8). The cis-9, trans-11 isomer is the principal dietary form of CLA (about 72%), but the concentration of these isomers in beef varies depending on the diets fed to steers (3). Feedings with 3%–6% roasted soybean increased the CLA content in loin beef (27). Vegetable oils such as sunflower and linseed oils, as well as flaxseed and soybean treatment, decreased marbling but increased CLA content in beef (28). The cis-9 CLA and trans-11 TVA levels in the soybean supplemented group were about 0.21% and 0.51%, respectively, greater than those in the control group (Table 8). The trans-9 TVA was also detected, but data are not shown due to the negligible amount. Full-fat soybean supplementation provides polyunsaturated fatty acids, especially linoleic acid and linolenic acid, which are key substrates in rumen biohydrogenation (4). This, in turn, increases ruminal production of cis-9 CLA and trans-11 CLA as well as TVA, which is converted into CLA by Δ^9desaturase (29). TVA, which is a major precursor of CLA, is responsible for about 78% of CLA production in milk (30). Concomitant with these data, our results showed that full-fat soybean increased the level of CLA and TVA in LD muscle of Hanwoo steers. Since consumer and end-use preferences for meat are changing, the current feeding strategy is to modify the fatty acid composition of meat. In this regard, dietary full-fat soybeans provide an opportunity for beef producers to improve the healthiness of meat while lowering feed costs without any detrimental effects on productivity.

In conclusion, administration of a full-fat soybean diet has beneficial effects on ADG, feed conversion ratio, and marbling score. In particular, it increases UFA and decreases SFA. In addition it improves the content of CLA, which is gaining attention due to its health benefits, which include fighting cancer and diabetes, boosting fat loss, and building lean muscle. Taken together, administration of full-fat soybean has beneficial effects on growth performance and the formation of healthier fatty acid composition in loin muscle of Hanwoo steers.

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