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Evaluation of non-conventional feeds for ruminants using *in situ* nylon bag and the mobile bag technique

Youl-Chang Baek[1], Hyuck Choi[1,2*]
[1]**National Institute of Animal Science, Rural Development Administration**
[2]**Department of Dairy Science, Virginia Polytechnic Institute and State University**

In situ 나일론백 그리고 모바일백 방법을 이용한 국내 부존사료자원의 반추가축용 사료 가치 평가

백열창[1], 최혁[1,2*]
[1]농촌진흥청 국립축산과학원, [2]버지니아 폴리테크닉 주립대학교 낙농학과

Abstract This study was conducted to evaluate the chemical composition, digestibility, and energy value of 15 non-conventional feeds produced in South Korea as ruminant feeds. Three Hanwoo steers (body weight, 520 ± 20.20 kg) fitted with a permanent rumen cannula and duodenal cannula were housed individually in tie-stall barns, followed by a 14-day adaptation period and 3-day experimental period.Chemical composition analysis, in situ nylon bag, and mobile bag technique were used as experiments. As a result of the chemical composition analysis offeeds, crude protein (CP) contentsofmalt meal, perilla meal, soy sauce cake, and soymilk residue were greater than 30%. As a result of the degradability characteristics analysis of feeds using an in situ nylon bag, rumen undegraded protein (RUP) contents of beet pulp, brewer's grain, coffee meal, malt meal, milo bran, perilla meal, ramen residue, and soymilk residue were greater than 50%. Analysis of total digestible nutrient (TDN) values of feeds using an in situ mobile bag showed that TDN values of beet pulp, brewer's grain, makgeolli residue, milo bran, perilla meal, ramen residue, rice bran, soy sauce cake, soybean curd cake, soymilk residue, and wheat bran weregreater than 50%. In summary, these non-conventional feeds have high potential value as good feed resources to replace formulated feeds or roughage. Therefore, the chemical composition, digestibility, and energy value of non-conventional feeds obtained from this study can beused as base data for the manufacture of ruminant total mixed ration (TMR) with improved feed efficiency, reduced feed costs, and reduction of environmental pollution.

요 약 본 연구는 반추동물 사료로서 한국에서 생산된 부존사료자원 15종의 화학적 조성, 소화율 그리고 에너지 가를 평가하기 위하여 실시하였다. 반추위 그리고 십이지장 캐뉼라가 장착된 거세한우 3두(평균체중 520 ± 20.20 kg)를 개별 계류식우사에 공시한 후 14일의 순치기간과 3일간의 시험기간을 두었다. 실험 방법으로는 화학조성 분석법, *in situ* 나일론백과 모바일백 방법을 이용하였다. 사료 내 화학적 조성을 분석한 결과, 엿밥, 깻묵, 장유박 및 두유박의 조단백질 함량은 30% 이상이었다. *In situ* 나일론백을 이용한 사료의 분해 특성을 분석한 결과, 비트펄프, 맥주박, 커피박, 엿밥, 수수겨, 임자박, 라면박 및 두유박의 반추위 미분해 단백질 함량은 50% 이상이었다. *In situ* 모바일백을 이용한 사료 내 가소화 영양소총량(TDN)의 분석은 비트펄프, 맥주박, 막걸리박, 수수겨, 깻묵, 라면박, 미강, 장유박, 비지, 두유박 및 밀기울이 50% 이상인 것으로 관찰되었다. 요약하자면, 상기 부존사료자원은 배합사료 또는 조사료를 대체할 수 있는 훌륭한 사료자원으로서의 높은 잠재적 가치를 가지고 있음을 시사하고 있다. 따라서 본 연구에서 얻은 부존사료자원의 화학적 조성, 소화율 및 에너지 가를 반추동물 섬유질배합사료 제조를 위한 기초 자료로 활용하고 이를 통해 사료효율 향상, 사료비용 절감 및 환경오염 감소에 기여하고자 한다.

Keywords : Crude protein, Food by-products, Rumen undegraded protein, Total digestible nutrient, Total mixed ration

*Corresponding Author : Hyuck Choi(Virginia Polytechnic Institute and State University)
Tel: +82-63-238-7458 email: hchoi0504@gmail.com

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1. Introduction

The livestock industry in South Korea is suffering from increased feed costs and opening of global market. Feed is the single most expensive item in livestock production, accounting for 60%-70% of total costs [1, 2]. The grain harvest and trade conditions of importing countries are particularly important in South Korea, as almost all feed grain depends on imports. In addition, feed grain prices have risen due to rapid growth of ethanol production and corn prices in the United States [2]. Rising feed costs and associated higher costs for livestock production are reducing livestock production and increasing the retail price for livestock products, such as meat, milk, and eggs [3].

Many food by-products (referred to as non-conventional feed) are produced by the food industry (both agriculture and food processing sector), but most are incinerated or buried in landfills [4]. As a result, disposal of these food by-products increases processing costs and causes environmental problems, such as nitrate in soil and surface water eutrophication [5-7]. More than 6.265 million tons of food by-products are produced annually in South Korea, and 1.714 million tons of formulated feed would be replaced if half were collected and utilized for animal feed [8]. Cereal and legume crop residues as well as agricultural by-products have substantial potential value as animal feedstuffs [9]. In addition, some food by-products (e.g., soybean meal, distillers dried grains, and corn gluten feed) have long been used as important protein sources in ruminants feed, and they are no longer considered waste [10, 11]. Therefore, there has been increasing interest in the appropriate use of relatively inexpensive food by-products for animals feed [12-14]. Han et al. [15] reported the chemical composition and nutrient value of 100 non-conventional feeds collected from Southeast Asia and China. Moreover, Haile et al [16] showed that 8 different agro-industrial by-products differ in terms of chemical composition and nutritional value. However, the ingredient components, digestibility, and energy value data for non-conventional feeds produced in South Korea remain limited, making it difficult to use these components in ruminants feed. Furthermore, more accurate digestibility analysis of non-conventional feeds are required for use for ruminants feed. Therefore, present study used *in situ* mobile bag technique for analysis of the apparent digestibility of feeds.

The objective of this study was to evaluate the chemical composition, digestibility, and energy value of non-conventional feeds produced in South Korea as ruminants feed.

We hypothesized that the chemical composition and digestibility analyses of domestic non-conventional feeds would increase their usefulness as ruminants feed, thereby achieving a better balance of energy and reduced feed costs.

2. Materials and Methods

All experimental procedures were reviewed and approved by the Animal Care and Use Committee of the National Institute of Animal Science (NIAS), Korea (NO. NIAS 2015-673-2).

2.1 Animals and diet

Three Hanwoo steers (40 months old, 520 ± 20.20 kg of body weight) were fitted with permanent rumen cannula (Bar Diamond Inc., Parma ID, USA) and a T-shaped duodenal cannula (Bar Diamond). All steers were housed individually in tie-stall barns (127 × 250 × 200 cm) for the duration of the experiment. The tie-stall barn consisted of a rubber mat, individual feed bunk, and automatic water bowl. The steers were fed individually twice daily (0900 and 1700 h) equal parts of the daily diet, with water and free-choice minerals provided ad libitum. The diet consisted of 1.0 kg of rice straw with 5.0 kg of formulated concentrate mixture (as fed basis; Table 1). The basal diet was formulated to meet NRC requirements [10].

Table 1. Ingredient composition of formulated concentrate mixture.

Item	% of DM
Ground corn	47.9
Wheat bran	41.0
Soybean meal	5.0
Rapeseed meal	2.0
Molasses	2.0
Dicalcium phosphate	1.5
Salt	0.4
Vitamin-mineral premix[1]	0.2
Total	100.0

[1]Vitamin-mineral premix components: Vitamin A, 2,650,000 IU; Vitamin D_3, 530,000 IU; Vitamin E, 1,050 IU; Niacin, 10,000 mg; Mn, 4,400 mg; Fe, 13,200 mg; I, 440 mg; Co, 440 mg.

Each experimental period consisted of a 14-day adaptation period and a 3-day data collection period. Fig. 1. shows the s schematic experimental design in this study.

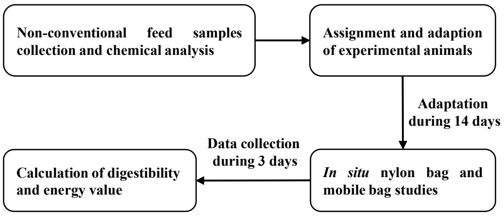

Fig. 1. Schematic diagram of experimental design.

2.2 Sample collection and chemical composition analysis

Fifteen non-conventional feed samples (pulp, brewer's grain, coffee meal, corn gluten feed, makgeolli residue, malt meal, milo bran, perilla meal, ramen residue, rice bran, soy sauce cake, soybean curd cake, soymilk residue, spent mushroom substrate from *Pleurotus eryngii* (SMSP), and wheat bran) were obtained from a local farm, and the NIAS in Wanju, Korea.

The feed samples were dried in a forced-air oven at 60°C for 48 h, and then milled to pass through a 2-mm mesh screen of a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ, USA) for the chemical composition analysis and *in situ* nylon bag and mobile bag studies. The Association of Official Analytical Chemists (AOAC) [17] methods were used to determine dry matter (DM), crude protein (CP), ether extract (EE), crude ash (CA), and crude fiber (CF) contents in the feed samples as described by procedures 930.15, 948.13, 920.39, 942.05, and 962.09, respectively. The nitrogen-free extract (NFE) was calculated as 100 – (CP + EE + CA + CF). Calcium (Ca) and phosphorus (P) were analyzed using inductively coupled plasma atomic emission spectroscopy (Optima 8300; Perkin Elmer, Inc., Waltham, MA, USA).

2.3 *In situ* nylon bag technique

In situ CP degradation measurements were performed using the nylon bag technique [18]. Nylon bags (made of polyamide, 8 × 15 cm; 45 µm pore size; sample size: surface area = 16.7 mg/cm^2) were filled with 5g of dry ground feed samples and were tightly sealed with a nylon string. The nylon bags were placed in larger polyester mesh bags (25 × 40 cm; 3 mm pore size) and tied with a rubber band. The nylon bags were presoaked in cold tap water for 15 min before rumen incubation. At 14:00 h, one polyester mesh bag (three replicates) per steer was inserted through the rumen cannula, positioned in the ventral sac, and incubated for 16 h. After 16 h, all nylon bags were removed from the rumen, gently rinsed with cold tap water, and then washed in a washing machine for 30 min, and dried in a forced-air oven at 60°C for 48 h until constant weight was achieved. Then, the residues were analyzed for CP according to AOAC methods [17]. Disappearance of CP was expressed relative to the original CP content in the sample.

CP degradation values in the rumen were calculated according to Ørskov and McDonald [18], with a passage rate of 5%/h [19].

The measured percent CP after the 16 h incubation in the rumen was calculated as the difference between the samples. The rumen degraded protein (RDP) and rumen undegraded protein (RUP) were determined according to the following two equations [10]:

RDP = A+ B[kd/(kd+kp)]
where:
RDP = RDP of the feedstuff, percentage of CP
A = Fraction A, percentage of CP
B = Fraction B, percentage of CP
Kd = rate of degradation of the B fraction, %/h
Kp = rate of passage from the rumen, %/h

RUP = B[Kp/(Kd + Kp)] + C
where:
RUP = RUP of the feedstuff, percentage of CP
B = Fraction B, percentage of CP
Kd = rate of degradation of the B fraction, %/h
Kp = rate of passage from the rumen, %/h
C = Fraction C, percentage of CP
The sum of RDP plus RUP equals 100%.

2.4 *In situ* mobile bag technique

Dry matter and CP degradability and digestibility using the *in situ* mobile bag technique were based on apparent disappearance from the rumen, abomasum, intestine, and the total gastrointestinal (GI) tract [20, 21]. The study period was divided into three incubation periods by anatomical parts (rumen, artificial abomasum, and lower intestine) to determine the degradability and digestibility of the feed samples. A 0.5 g sample of dry ground feed was weighed into a mobile bag (3 × 4.5 cm, 35 µm pore size; sample size: surface area = 37.04 mg/cm^2) for each sub-period and heat-sealed. The mobile bags were placed in a larger polyester mesh bag (25 × 40 cm; 3 mm pore size) and tied with a rubber band. The mobile bags were presoaked in cold tap water for 15 min before rumen incubation. At 14:00 h, three polyester mesh bags (three replicates) per steer were inserted through the rumen cannula, positioned in the ventral sac, and incubated for 16 h. The DM and CP disappearance trial consisted of the following. (1) Rumen degradation of DM and CP: After incubation in the rumen, all mobile bags were removed from the rumen, gently rinsed with cold tap water until the water ran clear, and then dried in a forced-air oven at 60°C for 48 h to constant weight. (2) Abomasum digestion of DM and CP: After removal from the rumen, the six remaining mobile bags were combined with 0.004 M HCl solution containing 1 g of pepsin/L (pH 2.4) at 39°C for 3 h to simulate digestion in the abomasum. The three mobile bags were washed with tap water until the wash water ran clear, and dried in a forced-air oven at 60°C for 48 h to constant weight. (3) Lower intestinal digestion of DM and CP: After simulating digestion in the abomasum, the remaining three mobile bags were inserted into the lower intestine through a simple T-shaped duodenal cannula at the evening feed time (17:00 h) at 5 min intervals [22]. The mobile bags were collected from the feces, washed with tap water until the water ran clear, and dried in a forced-air oven at 60°C for 48 h to constant weight. All bags were weighed, the digestibility of DM was determined and expressed on a DM basis, and the residues were analyzed for CP. Disappearance of CP was expressed relative to the original CP content of the feed samples.

2.5 Calculation of digestibility, digestible energy, and total digestible nutrients

Disappearance in the rumen was calculated as the differences between substrate weight before and after the 16 h incubation. Disappearance in the abomasum was calculated as the difference between the substrate weight after the 16 h incubation in the rumen and the portion remaining after 3 h that simulated abomasum digestion. Disappearance in the lower intestine and entire GI tract was calculated as the difference between the substrate weights after incubation and the portion remaining in samples recovered from feces. The total digestible nutrients (TDN) value was calculated according to NRC [10]: TDN (%) = tdCP + (tdEE × 2.25) + tdNFE + tdCF. The digestible energy (DE) value was calculated according to NRC [10]: DE (Mcal/kg) = 0.04409 × TDN (%). All data collected and recorded were calculated in Microsoft Excel (2013, Microsoft Inc., Redmond, WA, USA).

Table 2. Chemical composition of non-conventional feeds.

Ingredients	%, on a dry matter basis[1]							
	DM	CP	EE	CA	CF	NFE	Ca	P
Beet pulp	13.40	11.07	0.98	8.80	18.10	61.05	0.41	0.02
Brewer's grain	24.16	25.91	10.02	3.35	14.65	46.07	0.37	0.50
Coffee meal	21.35	11.18	27.07	0.79	51.57	9.39	0.12	0.02
Corn gluten feed	90.79	24.39	0.79	6.74	8.03	60.05	0.02	2.00
Makgeolli residue	16.66	19.63	2.64	1.32	9.30	67.11	0.18	0.24
Malt meal	59.29	47.56	13.57	3.74	3.33	31.80	1.32	0.62
Milo bran	10.63	8.91	8.46	3.17	9.07	70.38	0.05	0.45
Perilla meal	97.55	41.54	14.84	6.84	19.94	16.84	0.84	1.23
Ramen residue	87.99	7.97	16.29	1.95	10.26	63.54	0.10	0.25
Rice bran	88.06	16.59	22.78	11.42	9.73	39.48	0.12	2.27
Soy sauce cake	40.30	31.90	4.63	24.62	8.12	30.74	0.37	0.26
Soybean curd cake	17.46	16.61	0.52	2.12	9.45	71.30	0.17	0.17
Soymilk residue	90.88	36.37	11.89	4.46	10.77	36.50	0.15	0.60
SMSP[2]	43.81	9.66	1.21	7.26	33.51	48.35	1.89	1.98
Wheat residue	8.47	12.94	1.59	2.85	8.13	74.48	0.07	0.32

[1]DM, dry matter; CP, crude protein; EE, ether extract; CA, crude ash; CF, crude fiber; NFE, nitrogen free extract; Ca, calcium; P, phosphorus.
[2]SMSP, spent mushroom substrate from *Pleurotus eryngii*.

3. Results

3.1 Chemical composition of the feeds

The chemical composition of the non-conventional feeds are presented in Table 2.

DM varied between 97.55% for perilla meal to 8.47% for wheat residue. Malt meal, perilla meal, soy sauce cake, and soymilk residue were characterized by having greater CP content than 30%, followed by brewer’s grain, corn gluten feed, makgeolli residue, rice bran, and soybean curd cake, which had greater CP content than 15%. Among them, the malt meal recorded the greatest CP content at 47.56% while the least was recorded in ramen residue at 7.97%.

The brewer’s grain, coffee meal, malt meal, perilla meal, ramen residue, rice bran, and soymilk residue were characterized as having greater EE content than 10%. Overall, malt meal (47.56% and 13.57%), perilla meal (41.54% and 14.84%), and soymilk residue (36.37% and 11.89%) had the greatest CP and EE contents, respectively. The CA contents were generally lesser than 10% in all feeds except rice bran (11.42%) and soy sauce cake (24.62%). Ca content in non-conventional feeds was 1.89%-0.02% and was greatest in malt meal and SMSP at 1.32% and 1.89%, respectively, and was least in corn gluten feed at 0.02%. The P content varied between 2.00% for corn gluten feed to 0.02% for beet pulp and coffee meal. The P contents of corn gluten feed, perilla meal, rice bran, and SMSP were greater than 1.0%, and those of beet pulp and coffee meal were lesser than 0.1%.

3.2 Degradability characteristics

The respective values of the fractions A and B, the degradation rate of fraction B per hour (Kd), RDP, and RUP parameters varied among feeds (Table 3). The corn gluten feed, makgeolli residue, rice bran, soy sauce cake, soybean curd cake, and SMSP had a soluble A fraction of CP greater than 50%. Interestingly, coffee meal had no soluble A fraction of CP. In contrast, beet pulp, brewer’s grain, malt meal, ramen residue, soymilk residue, and wheat residue had a degradable fraction B of CP greater than 50%. The rates of degradation of fraction B were similar (0.01%-0.09%/h) among the feeds, except makgeolli residue (0.10%/h), rice bran (0.20%/h), and soy sauce cake (0.36%/h).

The RDP varied between 87.22% in makgeolli residue and 3.29% in coffee meal. The RDP content in corn gluten feed, makgeolli residue, rice bran, soy sauce cake, soybean curd cake, SMSP, and wheat residue was greater than 50% and that in brewer’s

Table 3. Crude protein fractions, rumen degradable protein and rumen undegraded protein of non-conventional feeds.

Item[1]	Ingredients, %, on a dry matter basis														
	Beet pulp	Brewer's grain	Coffee meal	Corn gluten feed	Makgeolli residue	Malt meal	Milo bran	Perilla meal	Ramen residue	Rice bran	Soy sauce cake	Soybean curd cake	Soymilk residue	SMSP[2]	Wheat residue
A (%)	13.20	6.38	0.00	51.70	72.04	10.00	2.70	11.22	2.00	48.84	41.70	61.12	21.50	54.90	14.10
B (%)	78.40	91.70	22.58	45.20	22.94	50.38	41.23	40.93	68.41	29.41	48.31	36.34	70.90	38.50	75.93
Kd (%/h)	0.027	0.040	0.010	0.033	0.100	0.010	0.040	0.020	0.025	0.200	0.360	0.070	0.027	0.048	0.090
RDP (%)	36.00	46.90	3.29	79.90	87.22	21.52	19.93	23.92	24.87	72.25	84.13	81.97	31.10	73.70	63.75
RUP (%)	64.00	53.10	96.71	20.10	12.78	78.48	80.07	76.08	75.13	27.75	15.87	18.03	68.90	26.30	36.25

[1]A, fraction A (% of CP); B, fraction B (% of CP); Kd, rate of degradation of the B fraction (%/h); RDP, rumen degradable protein (% of CP); RUP, rumen undegraded protein (% of CP).
[2]SMSP, spent mushroom substrate from *Pleurotus eryngii*.

grain, beet pulp, malt meal, perilla meal, ramen residue, and soymilk residue was greater than 20%.

In contrast, RUP varied from 96.71% in coffee meal to 12.78% in makgeolli residue. The RUP content in beet pulp, brewer’s grain, coffee meal, malt meal, milo bran, perilla meal, ramen residue, and soymilk residue was greater than 50%, and that in corn gluten feed, makgeolli residue, rice bran, soy sauce cake, soybean curd cake, SMSP, and wheat residue was greater than 20%.

Overall, the RDP content in makgeolli residue (87.22%) was the greatest and that in coffee meal (3.29%) was the least compared with the other feeds. In contrast, coffee meal (96.71%) showed the greatest RUP, and makgeolli residue (12.78%) has the least RUP among the feeds.

3.3 DM and CP degradability and digestibility

Degradability and digestibility of DM in the non-conventional feeds are presented in Table 4. There were wide variations in the degradability and digestibility of DM in the non-conventional feeds. Rumen degradability of DM was greater than 50% in corn gluten feed, makgeolli residue, ramen residue, and soy sauce cake, and that in coffee meal (2.14%) was the least among the feeds. Abomasum DM digestion of soy sauce cake (7.28%) and rice bran (4.40%) was the greatest compared with the other feeds, and corn gluten feed, soybean curd cake, and soymilk residue were not digested in the abomasum. Intestinal digestion of DM in brewer’s grain, malt meal, milo bran, perilla meal, ramen residue, soybean curd cake, soymilk residue, and wheat bran was greater than 20%, and that of coffee meal, soy sauce cake, and SMSP was lesser than 10%. The total GI tract digestion of DM in makgeolli residue, malt meal, ramen residue, rice bran, soy sauce cake, soymilk residue, and wheat residue was greater than 70%. Overall, total GI tract digestion of DM was the greatest in ramen residue (98.44%) and the least in coffee meal (12.66%) among the feeds.

Table 4. Dry matter degradability and digestibility of non-conventional feeds.

Ingredients	%, on a dry matter basis			
	Rumen	Abomasum	Lower intestine	Total tract
Beet pulp	38.30	1.22	17.95	57.47
Brewer's grain	19.68	0.86	37.53	58.07
Coffee meal	2.14	0.86	9.66	12.66
Corn gluten feed	54.44	0.00	13.40	67.84
Makgeolli residue	60.76	2.06	12.83	75.65
Malt meal	35.22	1.96	37.87	75.05
Milo bran	25.57	2.34	20.67	48.58
Perilla meal	20.82	0.46	45.19	66.47
Ramen residue	74.63	0.17	23.64	98.44
Rice bran	48.63	4.40	19.22	72.25
Soy sauce cake	64.08	7.28	9.02	80.38
Soybean curd cake	29.40	0.00	26.29	55.69
Soymilk residue	35.54	0.00	47.39	82.93
SMSP[1]	21.16	2.07	2.33	25.56
Wheat residue	39.18	2.98	35.40	77.56

[1]SMSP, spent mushroom substrate from *Pleurotus eryngii*.

Degradability and digestibility of CP in the non-conventional feeds are shown in Table 5. Degradability and digestibility of CP showed similar trends as digestibility of DM. Ruminal degradation of CP in corn gluten feed, makgeolli residue, rice bran, soy sauce cake, SMSP, and wheat bran was greater than 40%, and that in brewer's grain, coffee meal, and ramen residue was lesser than 10%. Abomasum digestion of CP was the greatest in wheat bran (17.41), followed by SMSP (5.59%), soy sauce cake (4.86%), rice bran (4.68%), beet pulp (3.04), makgeolli residue (2.27%), brewer's grain (0.58%), and malt meal (0.51%). Coffee meal, corn gluten feed, milo bran, perilla meal, ramen residue, soybean curd cake, and soymilk residue were not digested in the abomasum. More than 40% of the CP in brewer's grain, malt meal, perilla meal, ramen residue, and soymilk residue was digested in the intestines. Total GI tract digestion of CP in brewer's grain, corn gluten feed, makgeolli residue, malt meal, perilla meal, ramen residue, rice bran, soy sauce cake, soymilk residue, SMSP, and wheat residue was greater than 70%, that in beet pulp and soy sauce cake was greater than 40%, and that in coffee meal and milo bran was lesser than 40%. Overall, total GI tract digestion of CP in ramen residue (94.66%) was the greatest and that in coffee meal (19.88%) was the least among the feeds.

Table 5. Crude protein degradability and digestibility of non-conventional feeds.

Ingredients	%, on a dry matter basis			
	Rumen	Abomasum	Lower intestine	Total tract
Beet pulp	28.00	3.04	36.73	67.77
Brewer's grain	9.91	0.58	78.39	88.88
Coffee meal	0.00	0.00	19.88	19.88
Corn gluten feed	72.96	0.00	18.05	91.01
Makgeolli residue	58.54	2.27	14.21	75.02
Malt meal	15.31	0.51	58.94	74.76
Milo bran	16.21	0.00	20.19	36.40
Perilla meal	15.06	0.00	70.59	85.65
Ramen residue	9.56	0.00	85.10	94.66
Rice bran	43.30	4.68	31.95	79.93
Soy sauce cake	71.51	4.86	6.48	82.85
Soybean curd cake	29.07	0.00	30.88	59.95
Soymilk residue	35.54	0.00	47.40	82.94
SMSP[1]	59.56	5.59	10.51	75.66
Wheat residue	40.50	17.41	34.51	92.42

[1]SMSP, spent mushroom substrate from *Pleurotus eryngii*.

3.4 Energy values

The calculated DE and TDN values of the non-conventional feeds are presented in Table 6. The DE for beet pulp, brewer's grain, coffee meal, corn gluten feed, makgeolli residue, malt meal, milo bran, perilla meal, ramen residue, rice bran, soy sauce cake, soybean curd cake, soymilk residue, SMSP, and wheat bran were 2.30, 3.38, 0.51, 2.12, 4.09, 74.76, 2.26, 3.80, 3.90, 4.15, 3.02, 2.42, 3.33, 0.66, and 4.73 Mcal/kg, respectively. The TDN values were 52.08%, 76.70%, 15.51%, 48.13%, 92.98%, 3.35%, 51.37%, 86.29%, 88.53%, 94.36%, 68.60%, 55.04%, 75.51%, 15.02%, and 107.59%, respectively. Overall, the DE value was greatest in malt meal (74.76 Mcal/kg), and least in coffee meal (0.51 Mcal/kg) and SMSP (0.66 Mcal/kg) among the feeds. In addition, the TDN value of wheat bran (107.59%) was the greatest and that of malt meal (3.35%) was the least compared with the other feeds.

Table 6. Calculated digestible energy and total digestible nutrient value of non-conventional feeds.

Ingredients	Energy values[1]	
	DE	TDN
Beet pulp	2.30	52.08
Brewer's grain	3.38	76.70
Coffee meal	0.51	15.51
Corn gluten feed	2.12	48.13
Makgeolli residue	4.09	92.98
Malt meal	74.76	3.35
Milo bran	2.26	51.37
Perilla meal	3.80	86.29
Ramen residue	3.90	88.53
Rice bran	4.15	94.36
Soy sauce cake	3.02	68.60
Soybean curd cake	2.42	55.04
Soymilk residue	3.33	75.51
SMSP[2]	0.66	15.02
Wheat residue	4.73	107.59

[1]DE, digestible energy (Mcal/kg of dry matter basis); TDN, total digestible nutrient (% of dry matter basis).
[2]SMSP: spent mushroom substrate from *Pleurotus eryngii*.

4. Discussion

Great interest has emerged for utilizing non-conventional feeds by ruminants due to their reduced feed costs and potential benefit of mitigating environmental pollution [23, 24]. Several studies have reported the feasibility of using non-conventional feeds for ruminants [25-27]. However, few studies have evaluated non-conventional feeds for ruminants. This study provides information on the chemical composition, digestibility, and energy values of non-conventional feeds produced in South Korea.

4.1 Chemical composition

The alfalfa [10] was used as a standard reference for the non-conventional feeds in this study. As expected, chemical composition varied among the non-conventional feeds (Table 2). In particular, the CP and EE contents of brewer's grain, makgeolli residue, malt meal, perilla meal, soy sauce cake, and soymilk residue were greater than those of alfalfa (19.2%) [10]. The chemical compositions of beet pulp, brewer's grain, corn gluten feed, and rice bran were similar to those reported by the NRC [10]. Interestingly, CP and EE contents in ramen residue were greater than those in noodle waste (11.27% and 0.7%, respectively) [23]. Ca and P contents of the non-conventional feeds ranged from 1.89% to 0.02% and 2.0% to 0.002%, respectively. In particular, Ca and P contents in malt meal and SMSP were greater than those in alfalfa (1.47% and 0.28%, respectively) [10]. Ca (1.6%-2.0% of body weight) and P (0.9%-1.1% of body weight) are the most abundant minerals in the body, and the most important source of minerals for cattle comes from pasture and forage [10, 28]. These results suggest that non-conventional feeds provide superior quality nutrients when fed to ruminants, and that they can replace high-quality forage. In addition, the beet pulp, brewer's grain, coffee meal, perilla meal, and SMSP might be considered good quality feed sources that can supply Ca and P at the same time.

4.2 Degradability characteristics

Ruminal degradation of dietary feed CP is an important factor influencing ruminal fermentation and amino acids (AA) supply to cattle [10]. RDP and RUP are two components of dietary feed CP that have separate and distinct functions [10]. Table 3 shows variations in the CP fraction, RDP, and RUP of the non-conventional feeds. The soluble A fraction in makgeolli residue, rice bran, soybean curd cake, and SMSP was greater than that in alfalfa hay (immature; 42.5%), and that of corn gluten feed was similar to that reported by the NRC [10]. The degradable B fraction in beet pulp, brewer's grain, ramen residue, and soymilk residue was greater than that in alfalfa hay (immature; 51.0%) [10]. Interestingly, the Kd percentages of rice bran (0.200%/h) and soy sauce cake (0.360%/h) were greater than 0.100%/h among the feeds. These results indicate a higher proportion of protein degradation in the rumen. However, the Kd percentages in almost all feeds were smaller than that of alfalfa hay (immature; 17.8%) [10]. Beet pulp, brewer's grain, and wheat residue contents were slightly different compared to all CP fractions reported by the NRC [10]. As expected, the RUP content in coffee meal, malt meal, milo bran, perilla meal, and ramen residue was greater than that in alfalfa hay (immature; 75.0%) [10]. These variations in rumen degradation may originate from differences in physical properties (solubility, structure, etc.) and feed sources [29]. These results suggest that coffee meal, malt meal, milo bran, perilla meal, and ramen residue have high AA absorption potential in the small intestine. In addition, makgeolli residue, rice bran, soybean curd cake, and SMSP are good sources for microbial growth and synthesis of microbial proteins in the rumen.

4.3 Degradability and digestibility

Tables 4 and 5 shows the variations in degradability and digestibility of DM and CP in the non-conventional feeds. Differences in degradation rates of individual DM and CP components are related to different protein classes (albumin, globulin, prolamine, and glutelin), several types of nonprotein nitrogen (N), physical properties, and amount of cell wall in the feed [10, 29, 30]. Moreover, digestion in the lower intestine varies widely depending on the feed species and AA composition [31, 32]. Overall, these results indicate that brewer's grain, malt meal, perilla meal, ramen residue, and soymilk residue are good sources of RUP, which are mostly absorbed in the intestine. In particular, ramen residue had high degradability and digestibility among the feeds and is a valuable feed source for ruminants. We recommend further research on ramen by-products as feedstuff.

4.4 Energy values

Finally, Table 6 shows the variations in the calculated DE and TDN values of the non-conventional feeds. The TDN values of brewer's grain, makgeolli residue, perilla meal, ramen residue, rice bran, soy sauce cake, soymilk residue, and wheat bran were greater than that of alfalfa (56.4%) [10]. Interestingly, the TDN values of rice bran and wheat bran were greater than those reported by the NRC [10]. These results suggest that these feeds are potential energy sources for alternative formulated feed or roughage.

5. Conclusion

This study has provided vital information on the chemical composition and nutritive value of non-conventional feeds produced in South Korea. Almost all of the non-conventional feeds had high-quality nutrients and high potential to replace quality roughage. In addition, this study showed wide variations in rumen degradability characteristics, DM and CP digestibility, and TDN of the non-conventional feeds. These results will provide farmers with the flexibility to replace feed according to feed price. Therefore, these results provide useful base data for ruminant total mixed ration (TMR) to improve feed efficiency and reduce feed costs and environmental pollution.

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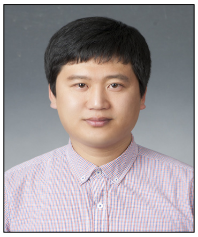
백 열 창(Youl-chang Baek) **[정회원]**

- 2010년 2월 : 충남대학교 낙농산업전공 (농학학사)
- 2014년 6월 : 충남대학교 낙농학과 (농학석사)
- 2010년 4월 ~ 현재 : 국립축산과학원 농업연구사

<관심분야>
동물영양, 가축사양

최 혁(Hyuck Choi) **[정회원]**



- 2006년 2월 : 전남대학교 농과대학 동물산업학과 (농학석사)
- 2011년 8월 : 전남대학교 농과대학 동물산업학과 (농학박사)
- 2015년 7월 ~ 2016년 10월 : 국립축산과학원 박사후 연구원
- 2016년 10월 ~ 현재 : 버지니아 폴리테크닉 주립대학교 낙농학과 방문과학자

<관심분야>
동물영양, 가축사양