Ruminal Degradation, Amino Acid Composition, and Intestinal Digestibility of the Residual Components of Five Protein Supplements[1]

HAROUNA A. MAIGA, DAVID J. SCHINGOETHE, and JUDY ELLISON HENSON
Dairy Science Department, South Dakota State University, Brookings 57007-0647

ABSTRACT

Two ruminally cannulated Holstein cows (~202 DIM) were used to determine the in situ degradability of five protein supplements: blood meal, meat and bone meal, corn gluten meal, expeller soybean meal, and solvent extracted soybean meal. Dacron bags containing 4 g of each supplement in duplicate were soaked in water and then incubated in the rumen for 0, 3, 6, 12, 18, and 24 h for 3 d. Four extra sample bags of each supplement were incubated in the rumen for 12 h to determine the in vitro intestinal digestibility and AA analysis of the residues. Protein supplements were also analyzed for their AA content. Ruminal degradability of individual supplements varied. Solvent soybean meal was the most degradable, and blood meal was the least degradable. Specific first-limiting essential AA were isoleucine for blood meal and meat and bone meal, lysine for corn gluten meal, and methionine for the soybean meals. The RUP fraction in solvent-extracted and expeller soybean meals tended to be more intestinally digestible than did the protein in blood meal and meat and bone meal. In general, all protein supplements, except solvent-extracted soybean meal, were high in RUP and had the potential to provide good quality AA to complement microbial AA for production.

(**Key words**: ruminal degradation, amino acid, residual intestinal digestibility, protein supplements)

Abbreviation key: **BM** = blood meal, **CGM** = corn gluten meal, **EAA** = essential AA, **ESBM** = expeller soybean meal, **MBM** = meat and bone meal, **SBM** = solvent-extracted soybean meal.

INTRODUCTION

Amino acids that are available for intestinal absorption by ruminants are supplied by microbial proteins that are synthesized in the rumen, by RUP, and by endogenous secretions into the digestive tract (19). Ruminal microbial protein is a high quality protein with a relatively constant AA content that is similar to that of milk protein (18, 19). To improve production, RUP must be digestible in the small intestine and must be as good as the quality of the ruminal microbial protein or must complement the AA deficiencies of the microbial protein (18). Dietary protein supplements that contain high amounts of limiting AA in their RUP are highly desirable to increase milk production and animal growth. Although ruminant animals have metabolic requirements for AA rather than for proteins per se (19), current feeding standards do not yet permit formulation of diets based on the AA composition of the feedstuffs. Such formulations require additional information, such as 1) the AA content of protein arriving at the duodenum relative to the total AA content of the feed, 2) the differential absorption of individual AA, and 3) differences of metabolic utilization (15). Considerable information is now available on the ruminal degradability of protein in many feeds, and the AA concentrations in the RUP fraction of some feeds were recently reported (3, 10). However, complete studies on ruminal degradability, intestinal digestibility, AA composition of nitrogenous feeds, efficiency of absorption, and utilization are limited. Values of RUP published by the NRC (13) for different feeds were mostly based on a few observations; therefore, more determinations of RUP, digestibility, and AA composition of common feedstuffs are needed.

The objective of this study was to contribute to the knowledge of the amount of RUP, the AA composition of the proteins in feedstuffs, the ruminally undegradable portion, and the residual digestibility of five common protein supplements.

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MATERIALS AND METHODS

Experimental Procedure

Two ruminally cannulated Holstein cows (~202 DIM) producing 24 kg/d of milk were used to determine the in situ ruminal degradability of five protein supplements: blood meal (**BM**), meat and bone meal (**MBM**), corn gluten meal (**CGM**), solvent-extracted soybean meal (**SBM**), and expeller SBM (**ESBM**; SoyPlus®; West Central, Ralston, IA). Cows were fed for ad libitum intake a TMR of 25% alfalfa hay, 25% corn silage, and 50% of a concentrate mix (DM basis) that contained the five protein supplements (Table 1). Cows were housed in individual pens that were equipped with feeders and clean water. Cows were fed once daily and were milked twice daily. In situ measurements were taken at 0, 3, 6, 12, 18, and 24 h for 3 d; there was a 1-d interval between each measurement day. Substrate samples of 4 g each were placed in 10- × 20-cm dacron bags (pore size, 53 ± 10 μ; Ankom Products, Fairport, NY) with heat-sealed seams. Each bag was sealed with a number 8 rubber stopper and two number 14 rubber bands. Duplicate sample bags of each feed were placed into a larger nylon mesh bag (36 × 42 cm) with a nylon zipper, soaked in 39°C water for 20 min, and then exposed to the rumen for 3, 6, 12, 18, and 24 h. Additionally, four extra samples of each feed were exposed to the rumen for 12 h for AA analysis of the residues. This time segment was selected because it might be representative of the residue that escapes ruminal degradation.

TABLE 1. Composition of basal diet fed to cows during the in situ experiment.[1]

Ingredient	(% of DM)
Alfalfa hay, chopped	25.00
Corn silage	25.00
Corn, shelled rolled	22.70
Soybean meal, 44% CP	8.25
Corn gluten meal	2.05
Blood meal	1.55
Meat and bone meal	2.55
Molasses	8.00
Tallow	2.50
Dicalcium phosphate	0.25
Limestone	0.50
Trace minerals	0.50
Sodium bicarbonate	0.75
Magnesium oxide	0.25
Vitamin premix[1]	0.15

[1]Provided 4400 IU of supplemental vitamin A, 880 IU of supplemental vitamin D, and 22 IU of supplemental vitamin E/kg of DM.

Samples that were to be exposed for 24 h were placed in the rumen first, at feeding, followed by the introduction of the remaining samples in reverse order of time exposure, such that the last samples (3-h incubation) were introduced 21 h after the introduction of 24-h samples (23). All mesh bags were placed in the middle of the rumen and were removed at the same time, 24 h after entry of the first set. The procedure for washing the bags has been described previously (3). Mesh bags were placed into 20-L buckets, gently agitated, and rinsed with tap water (~39°C) until the water ran clear. Individual dacron bags were further rinsed under running tap water at 39°C until all feed residues were rinsed to the bottom of the bag. Dacron bags then were allowed to drain for 3 to 5 h and were oven-dried at 55°C for 48 h. The same washing procedure was applied to the 0-h samples of each protein source that were not incubated to estimate the amount of water-soluble DM and CP. Two blank bags for each time exposure were incubated with the samples, and N of the blank samples was subtracted from the residual (16). Samples for AA analysis were lyophilized for 72 h to minimize N loss.

Intestinal digestibility of residues that remained after 12 h of ruminal exposure was determined as described by Calsamiglia and Stern (4).

Chemical Analysis and Estimation of Ruminal Degradability

Samples of supplements and TMR fed to the cows were obtained three times during the week of sampling and frozen at –20°C. Samples were combined, oven-dried at 55°C for 48 h, and ground through an ultracentrifuge mill (1-mm screen; Brinkman Instrument Co., Westbury, NY). All samples were analyzed for DM, CP, ether extract, and ash (2). The ADF, ADIN, and permanganate lignin were determined by the procedures of Robertson and Van Soest (17). Residues that resulted from ruminal incubation of the protein supplements were analyzed for DM and CP (2). The AA content of HCl hydrolyzates of the test feeds and residues was determined by HPLC separation (Spectra Physics Inc., San Francisco, CA) followed by postcolumn ninhydrin derivation (Pickering Laboratories Inc., Mountain View, CA) and colorometric quantification (2). Cystine and methionine contents were determined by performic acid oxidation followed by hydrazine reduction. The cystine and methionine contents then were quantified by the same procedure as the HCl hydrolizates (2).

Dry matter disappearance was calculated as the difference between the original test feed sample plus

TABLE 2. Chemical composition of protein supplements.[1]

Item	MBM	BM	ESBM	SBM	CGM
DM, %	95.5	95.1	88.6	90.7	92.0
			(% of DM)		
CP	51.8	92.0	45.9	49.9	68.4
Ether extract	10.96	0.71	5.54	1.49	1.15
ADF[2]	4.00	0.53	8.56	9.92	7.37
Ash	30.14	2.12	6.22	7.02	1.52
ADIN	0.39	0.15	0.28	0.34	1.00
ADIN, % of CP	4.70	1.02	3.51	4.62	9.14

[1]MBM = Meat and bone meal, BM = blood meal, ESBM = expeller soybean meal, SBM = solvent-extracted soybean meal, and CGM = corn gluten meal.

[2]Not corrected for ash.

the bag and the weight of the residue plus the bag. Disappearance of CP was calculated as the difference between the CP (grams) of the original sample and the CP (grams) of the residues. A linear regression model was fitted to the natural log-transformed model of DM and CP remaining in the residues to determine rates of disappearance, and the slope of the regression line was equal to the digestion rate. Ruminally available DM and CP were estimated by the procedures of Aldrich et al. (1) using the equation

$$\text{degradability percentage} = a + \{b \times [k_d/(k_d + k_p)]\}$$

where

- a = 100 – antilog intercept (amount soluble at 0 h),
- b = 100 – a,
- k_d = fractional digestion rate of b, and
- K_p = fractional passage rate (assumed to be 7%/h).

RESULTS AND DISCUSSION

The chemical compositions of the protein supplements (Table 2) were as expected and were similar to NRC (13) recommendations. Ether extract content was high (11%) in MBM and was low (0.7%) in BM. The MBM had high (30%) ash concentration, primarily because of the bone content. The ADIN content of all supplements was low.

Percentages of DM disappearance of the protein supplements are presented in Table 3. The SBM and ESBM exhibited the highest water solubilities. However, after 24 h of exposure in the rumen, 92% of SBM disappeared, and only 76% of ESBM disappeared. Disappearance of DM from SBM was similar to that reported previously (23). Rates of insoluble DM losses per hour for all protein supplements were higher during the first 12 h than during the latter 12 h, except for BM, which had a low rate of DM losses over 24 h of ruminal exposure.

Solubility of CP was highest in SBM and MBM (Table 4). Cozzi et al. (7) reported a similar CP

TABLE 3. Dry matter disappearance from polyester bags when protein supplements were incubated in the rumen of lactating dairy cows.[1]

	Ruminal exposure						Rate[3]		
Feed[2]	0 h	3 h	6 h	12 h	18 h	24 h	A	B	C
				(% of DM disappearance)					
MBM	18.7	28.8	34.3	41.2	43.7	46.1	1.87	0.41	1.14
BM	6.5	6.6	6.6	6.8	7.0	7.4	0.03	0.05	0.04
ESBM	33.2	38.9	48.3	57.2	65.6	75.7	2.00	1.54	1.77
SBM	34.2	46.4	56.9	73.3	84.0	92.2	3.56	1.58	2.42
CGM	13.5	21.7	26.9	33.0	37.8	41.6	1.62	0.72	1.17
SE	1.41	1.88	1.84	1.78	1.63	1.91	0.03	0.01	0.02

[1]Least squares means.

[2]MBM = Meat and bone meal, BM = blood meal, ESBM = expeller soybean meal, SBM = solvent-extracted soybean meal, and CGM = corn gluten meal.

[3]A = (percentage of 12-h disappearance – percentage of 0-h disappearance)/12, B = (percentage of 24-h disappearance – percentage of 12-h disappearance)/12, and C = (percentage of 24-h disappearance – percentage of 0-h disappearance)/24.

TABLE 4. Crude protein disappearance from polyester bags when protein supplements were incubated in the rumen of lactating dairy cows.[1]

	Ruminal exposure						Rate[3]		
Feed[2]	0 h	3 h	6 h	12 h	18 h	24 h	A	B	C
	(% of CP disappearance)								
MBM	17.0	33.3	39.5	49.5	48.1	51.7	2.71	0.19	1.45
BM	3.3	4.4	4.6	4.7	4.7	5.1	0.12	0.04	0.08
ESBM	9.1	16.1	17.5	26.5	38.7	55.8	1.46	2.44	1.95
SBM	19.5	30.5	39.1	61.2	79.1	90.3	3.47	2.43	2.95
CGM	5.6	9.8	9.0	11.6	15.8	19.9	0.49	0.69	0.59
SE	1.24	3.08	2.39	2.67	2.46	2.85	0.12	0.02	0.07

[1]Least squares means.

[2]MBM = Meat and bone meal, BM = blood meal, ESBM = expeller soybean meal, SBM = solvent-extracted soybean meal, and CGM = corn gluten meal.

[3]A = (percentage of 12-h disappearance – percentage of 0-h disappearance)/12, B = (percentage of 24-h disappearance – percentage of 12-h disappearance)/12, and C = (percentage of 24-h disappearance – percentage of 0-h disappearance)/24.

disappearance for SBM at 0 h. Cozzi and Polan (8) found a lower solubility (14.4%) for SBM, but Clark et al. (6) reported a higher value (24%), indicating a variation in the soluble fraction of CP in SBM. Soluble CP fractions of MBM, BM, and CGM were low, in agreement with values reported by Clark et al. (6). Percentages of CP disappearance were low for CGM and very low for BM. Cozzi and Polan (8) found very low CP disappearance for CGM. Degradability of CGM (Table 5) was low. Low degradability of CGM was attributed to the gelatinous nature and the lack of surface area for bacteria to adhere (21). The SBM showed the highest rate of CP degradation (9.3%/h), which agreed with the mean rate of degradation (10.2%/h) for SBM reported by Nocek and Russell (14). Blood meal was virtually undegraded in dacron bags. Considerable variation in CP degradability of BM was previously reported by Stern et al. (20). This variation in BM could be attributed to processing methods. During production of BM, heat may denature and coagulate the protein, making it insoluble. Ring-dried BM was more degradable than batch-dried BM (20). Decreased surface area for microbial attack and the reformation of chemical bonds might also make the protein more resistant to degradation (6).

Percentages of RUP for all supplements were within the ranges previously reported (20); SBM, BM, and CGM were at the higher end (Table 6). Estimated RUP for SBM in this study was 40.7% at a fractional passage rate of 7%/h and was within the

TABLE 5. Dry matter and CP degradation parameters as measured by in situ incubations.[1]

	DM			CP		
Feed[2]	Degradation rate[3]	Intercept[4]	Ruminally available[5]	Degradation rate[3]	Intercept[4]	Ruminally available[5]
	(/h)	(%)		(/h)	(%)	
MBM	0.016	75.3	38.7	0.020	72.4	43.7
BM	0.000	93.5	6.5	0.000	95.5	4.5
ESBM	0.042	68.3	57.4	0.029	95.0	32.9
SBM	0.093	72.0	69.1	0.093	94.9	59.3
CGM	0.016	82.8	32.6	0.006	93.8	13.9

[1]Least squares means.

[2]MBM = Meat and bone meal, BM = blood meal, ESBM = expeller soybean meal, SBM = solvent-extracted soybean meal, and CGM = corn gluten meal.

[3]Fractional degradation rate determined from the regression of the natural log of the percentage remaining in the residue after in situ incubation.

[4]Antilog of intercept from regression on time of natural log of fraction remaining undegraded.

[5]Extent of ruminal degradation estimated from in situ data at an assumed solid turnover rate of 0.07/h using the following equation: percentage of degradability = [100 – antilog of the intercept)] + antilog of the intercept × [degradation rate/(degradation rate) + solid turnover rate (0.07/h))].

range of NRC (13) recommendations. Values higher than 55% (13) for CGM were reported (7). Because the sticky, gelatinous, and hydrophobic nature of CGM may prevent microbial attachment, the in situ method may overestimate RUP values (7, 20). The RUP value of BM (95%) was higher than the NRC value (82%; n = 2). The ADIN content (as a percentage of CP) of BM was low (1.02%); therefore, BM should have been more degraded. Differences in degradation of BM might have been due to differences in handling and drying conditions (6). Results of intestinal digestibility and intestinally absorbable dietary protein of BM, MBM, CGM, and SBM (Table 6) agreed with those reported by Stern et al. (20).

Amino acid composition of the original feeds and of the residues after incubation for 12 h in the rumen are presented in Table 7. On a DM basis, residues of the protein supplements contained more CP and, therefore, more AA than their original feeds, except for MBM. When expressed per unit of CP, total essential AA (EAA) and individual EAA concentrations were similar in feed and feed residues for BM, CGM, and SBM (Table 7). Residues of MBM and ESBM contained more total EAA per gram of protein than did the feeds. The EAA profile of BM, CGM, and SBM agreed reasonably well with published values (15). Arginine was higher, and histidine was lower, in MBM than the values for these two AA as reported by Polan (15). Residues of MBM and ESBM also contained more total nonessential AA than did their original feeds. In some studies (22, 23), the AA profile of the residues in bags after ruminal exposure closely resembled that of the original feed. However, in other studies (7, 9), when the AA composition of RUP was corrected for microbial contamination, differences were found in the AA profile between SBM and its residues. Microbial AA contamination was not measured in this study; therefore, its presence is unknown. The AA profile of original feeds and of their residues was similar; however, this result was not an indication of the presence or absence of microbial contamination. More variation was observed in the nonessential AA profile of SBM residues than in the EAA profile of the original feed.

Apparent ranking of limiting EAA relative to milk protein is presented in Table 8. First-, second-, and third-limiting EAA were, respectively, isoleucine, methionine, and threonine for BM; lysine, tryptophan, and isoleucine for CGM; isoleucine, tryptophan, and valine and leucine for MBM; methionine, valine, and isoleucine for SBM; and methionine, lysine, and valine for ESBM. After 12 h of exposure to the rumen, all residues had the same first-limiting EAA as in their respective feeds; but the third- and sometimes the second-limiting EAA changed, except for BM, indicating that the AA composition of the RUP might differ from that of the original protein supplement. Schingoethe (18), using book values of AA in protein supplements, came up with a similar ranking of the three first-limiting EAA in BM and MBM. Isoleucine appeared to be the first-limiting EAA for milk protein synthesis in animal protein (BM and MBM), lysine in corn products (CGM), and methionine in SBM and ESBM. The first-limiting AA in these protein supplements is generally agreed upon (5 ,18), but there is less agreement as to the second- and third-limiting AA for the same feeds (5, 18). The AA composition of many feedstuffs tends to vary. Also, because of the hydrolytic analysis method, some AA, such as methionine, may not be recovered 100% in laboratory analysis (8). In a recent study, Meijer et al. (12) indicated that glutamine could be potentially limiting for milk protein synthesis in high producing dairy cows. The AA analysis procedure used in our study measured glutamate, a derivative of glutamine, and ϵ-amino N was included in the ammonia fraction. If it were considered to be a dietary EAA, glutamate ranked third-limiting in BM and its 12-h residue, and glutamate

TABLE 6. Crude protein, RUP, estimated intestinal digestibility (ID) after 12-h polyester bag incubation of protein sources in the rumen, and estimated intestinally absorbable dietary protein (IADP) of protein supplements.[1]

	MBM	BM	ESBM	SBM	CGM
CP, % of DM	51.9	92.0	45.9	49.9	68.4
RUP, % of CP[2]	56.3 (40–88)[3]	95.5 (76–98)	67.1 (38–53)	40.7 (22–29)	86.1 (82–85)
ID, % of RUP	54.0 (41–70)	53.0 (29–90)	88.0 (98–100)	85.0 (86–93)	84.0 (86–91)
IADP,[4] % of CP	30.4 (21–56)	52.7 (25–76)	59.0 (38–53)	34.6 (20–25)	72.3 (70–77)

[1]MBM = Meat and bone meal, BM = blood meal, ESBM = expeller soybean meal, SBM = solvent-extracted soybean meal, and CGM = corn gluten meal.

[2]Estimated RUP determined by in vitro three-step procedures of Calsamiglia and Stern (4).

[3]Values in parentheses were reported by Stern et al. (20) in a survey of several samples.

[4]IADP = RUP (percentage of CP) × intestinal CP digestion (percentage of RUP).

TABLE 7. Concentrations of AA of original protein supplements[1] (O) and their residues (R) remaining in polyester bags after 12 h of incubation in the rumen.

AA	MBM		BM		ESBM		SBM		CGM	
	O	R	O	R	O	R	O	R	O	R
	(% of CP)[2]									
Arginine	7.00	7.42	4.50	4.65	6.77	7.15	7.84	6.63	2.79	2.86
Histidine	1.81	1.80	7.10	7.11	2.39	2.61	2.67	2.63	1.80	1.77
Isoleucine	3.01	3.50	1.20	1.03	4.22	4.97	4.55	4.79	3.81	3.93
Leucine	6.25	7.10	13.92	13.85	7.46	8.77	8.00	8.71	16.66	16.67
Lysine	5.61	6.01	9.22	9.21	5.18	5.62	6.46	6.25	1.37	1.45
Methionine	2.99	2.98	0.77	0.76	1.41	1.34	1.32	1.48	1.91	1.99
Phenylalanine	3.45	3.81	6.95	7.05	4.70	5.67	5.40	5.49	6.02	5.91
Threonine	3.43	3.81	3.72	3.94	3.83	4.30	4.07	4.51	3.21	3.37
Tryptophan	0.81	1.31	1.64	1.41	1.39	1.18	1.18	1.45	0.66	0.56
Valine	4.24	4.85	9.25	8.57	4.42	5.25	4.89	5.27	4.28	4.37
Total EAA[3]	38.61	42.67	58.26	57.57	41.78	46.86	46.39	47.21	42.54	42.88
Alanine	7.66	7.67	8.25	8.35	4.18	4.78	4.41	4.96	8.70	8.69
Aspartate	7.68	8.34	12.28	12.65	10.90	12.44	12.11	11.78	6.02	5.99
Cysteine	0.83	1.04	1.13	1.04	1.17	1.09	1.28	1.48	1.49	1.46
Glutamate	12.84	13.53	9.94	10.05	17.71	19.54	19.37	16.40	21.49	21.31
Glycine	13.63	13.12	5.34	5.25	4.24	4.65	4.43	4.79	2.54	2.48
Proline	7.75	7.60	4.12	4.14	4.68	5.52	5.11	5.18	9.65	9.44
Serine	4.09	4.49	4.89	5.21	4.96	5.67	5.47	5.74	5.16	5.06
Tyrosine	2.39	2.77	2.84	2.71	3.57	4.13	3.77	4.17	5.04	5.12
Total NEAA[4]	56.88	58.57	48.79	49.40	51.38	57.71	55.98	54.50	60.01	59.54

[1]MBM = Meat and bone meal, BM = blood meal, ESBM = expeller soybean meal, SBM = solvent-extracted soybean meal, and CGM = corn gluten meal.

[2]Amino acids as a percentage of DM/CP as a percentage of DM × 100.

[3]Essential AA.

[4]Nonessential AA.

TABLE 8. Ranking of AA relative to milk protein limitation for protein supplements[1] and their residues after 12 h of incubation in the rumen.

AA	Total milk protein[2]	Protein supplement					Residue				
		MBM	BM	ESBM	SBM	CGM	MBM	BM	ESBM	SBM	CGM
	(g/100 g of CP)										
Arginine	3.6	10	6	10	10	8	10	6	10	10	8
Histidine	2.7	5	10	7	8	5	2	10	8	6	3
Isoleucine	5.9	1	1	4	3	3	1	1	4	4	5
Leucine	9.7	3	9	5	5	10	3	8	6	5	10
Lysine	8.1	6	4	2	4	1	5	5	2	2	1
Methionine	2.6	9	2	1	1	7	9	2	1	1	7
Phenylalanine	4.9	7	8	8	9	9	6	9	9	9	9
Threonine	4.6	8	3	6	7	6	7	3	7	7	6
Tryptophan	1.4	2	5	9	6	2	8	4	4	8	2
Valine	6.6	3	7	3	2	4	3	7	3	3	3
Tyrosine[3]	5.1	(1)	(4)	(4)	(2)	(10)	(1)	(4)	(4)	(5)	(10)
Glutamate[3]	21.9	(4)	(3)	(7)	(9)	(9)	(3)	(3)	(7)	(2)	(9)
MPS[4]	0.20	0.51	0.20	0.54	0.51	0.17	0.59	0.17	0.51	0.57	0.18

[1]MBM = Meat and bone meal, BM = blood meal, ESBM = expeller soybean meal, SBM = solvent-extracted soybean meal, and CGM = corn gluten meal.

[2]Jacobson et al. (11).

[3]Numbers in parentheses indicate the order that tyrosine and glutamine would rank if they were considered to be dietary essential AA.

[4]MPS = Milk protein score; (concentration of first-limiting AA in protein supplement or residue/AA concentration in milk protein).

was second- and third-limiting, respectively, in the 12-h residues of SBM and MBM.

CONCLUSIONS

The in situ method can be used to select protein supplements with different ruminal degradabilities and AA compositions. However, there are concerns that this method may underestimate protein degradability of CGM and, therefore, overestimate its RUP content. Protein supplements BM, MBM, CGM, and ESBM were high in RUP and had the potential to provide a good quality blend of AA to complement ruminal microbial AA to lactating dairy cows. In general, branched-chain AA (isoleucine and valine), lysine, and methionine or tryptophan tended to be low in these protein supplements. Specific first-limiting EAA were isoleucine for BM and MBM, lysine for CGM, and methionine for SBM and ESBM and remained the same in the RUP fractions of these protein supplements. With specific limitations, a protein supplement or a combination of protein supplements may be required to overcome AA deficiencies. The RUP fractions of SBM and ESBM tended to be more digestible than the RUP fractions of BM and MBM.

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