Lactational Evaluation of Protein Supplements of Varying Ruminal Degradabilities[1]

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ABSTRACT

Twelve lactating Holstein cows (9 multiparous and 3 primiparous) were used in a replicated 3 × 3 Latin square design with three periods of 4 wk each to evaluate diets containing three protein supplements that varied in ruminally undegradable protein and amino acid (AA) composition. Diets contained either 44% crude protein (CP) solvent-extracted soybean meal, expeller (mechanically extracted) soybean meal, or a blend of animal and vegetable proteins as the protein supplement. The animal and vegetable blend consisted of equal portions of protein from blood meal, corn gluten meal, meat and bone meal, and soybean meal. All diets contained 33.3% alfalfa haylage, 16.7% corn silage, and 50% of the respective concentrate mix (dry matter basis). Diets contained 17.4, 17.8, and 17.8% CP and 34, 45, and 45% of CP as ruminally undegradable protein, respectively. Dry matter intake, milk production and composition, and body weight were similar among treatments. Uptakes of AA by the mammary gland were similar among treatments. The apparent first-limiting AA for each diet was likely Met, but Lys and Phe were also potentially limiting. Varying degrees of protein degradability and AA composition within the range of this study did not affect lactational responses, indicating that all of these protein supplements were adequate to support milk production.
(**Key words**: protein, ruminal degradability, protein quality, lactating cows)

Abbreviation key: **AVB** = animal and vegetable blend, **BM** = blood meal, **CGM** = corn gluten meal, **ESBM** = expeller (mechanically extracted) soybean meal, **MBM** = meat and bone meal, **SBM** = solvent-extracted soybean meal.

INTRODUCTION

High producing dairy cows require an appropriate amount of good quality protein that possesses the desired amounts of essential AA to be presented to the lower digestive tract to sustain lactational and metabolic functions. Ruminal microorganisms are a good source of quality protein, but they cannot always supply sufficient amounts of metabolizable protein to support production and maintenance. Dietary RUP can substantially increase the amount of protein for digestion and flow of AA to the gastrointestinal tract for absorption.

Although many studies (4, 12, 17, 22, 24) have indicated that increasing the amounts of RUP in the diet boosted production of high producing cows, other studies (3, 10, 21) showed no improvement. These discrepancies might be due to one or more problems (24). Ruminally undegradable protein may be increased at the expense of ruminal microbial protein synthesis, which would cause no net change in the protein that is available to the cow; proteins that are undegraded in the rumen may also not be digested postruminally; and protein quality (i.e., the blend of AA presented for absorption from the gastrointestinal tract) may still contain insufficient amounts of limiting AA. Some concerns have arisen in the industry that animal by-products in diets decrease DMI, but research has not supported this theory.

Protein supplements that are less degradable in the rumen have been used to increase the amount of protein and AA available for digestion and absorption in the small intestine and to increase milk synthesis. The objective of this trial was to evaluate the lactational response of dairy cows to protein supplements that varied in ruminal degradability and AA composition in isonitrogenous diets that were designed to meet recommended dietary formulation guidelines (16).

MATERIALS AND METHODS

Experimental Plan

Twelve lactating Holstein cows (9 multiparous and 3 primiparous) were used in a 3 × 3 Latin square

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design (25) replicated four times to evaluate the response to three protein supplements that varied in RUP and AA composition. Cows were assigned to one of four replicates according to milk production, calving date, and lactation number (primiparous or multiparous); one cow from each replicate was then randomly assigned to one of the three treatment sequences. At the start of the experiment, mean milk production was 35.4 kg/d, and mean number of days postpartum was 57 (26 to 87). The initial week of each period was used for adjustment to the diets, and data were collected from wk 2 through 4.

Cows were allowed free access to diets containing either solvent-extracted soybean meal (**SBM**), expeller (mechanically extracted) soybean meal (**ESBM**), or a blend of animal and vegetable proteins (**AVB**) as the protein supplement (Table 1). The AVB consisted of equal portions of supplemental protein from each of the following: blood meal (**BM**), corn gluten meal (**CGM**), meat and bone meal (**MBM**), and SBM. Protein supplements SBM, ESBM, and AVB provided 35, 33, and 33%, respectively, of the total dietary CP intake. Tallow was added to diets at varying concentrations to make the fat content of all diets approximately equal. Mineral supplementation was more than required to meet recommended guidelines (16) and was kept the same for all diets. We did not attempt to compensate for the higher amounts of minerals supplied by MBM in the AVB diet. Total mixed diets contained (DM basis) 33.3% alfalfa haylage, 16.7% corn silage, and 50% of a concentrate mix containing the respective protein supplements described previously. Cows were housed in a free-stall barn, milked twice daily in a double-five herringbone parlor, and individually fed a total mixed diet once daily using Calan Broadbent feeding doors (American Calan Inc., Northwood, NH) with feeding by a Calan Data Ranger.

TABLE 1. Ingredient content of total mixed diet.

Ingredient	Diet[1]		
	SBM	ESBM	AVB
	(% of DM)		
Corn silage	16.70	16.70	16.70
Alfalfa haylage	33.30	33.30	33.30
Corn, ground shelled	29.60	29.70	33.00
Soybean meal, solvent	12.25	. . .	2.91
Soybean meal, expeller	. . .	12.65	. . .
Corn gluten meal	. . .	. . .	2.12
Blood meal	. . .	. . .	1.62
Meat and bone meal	. . .	. . .	2.68
Molasses	2.50	2.50	2.50
Tallow	2.50	2.00	2.00
Dicalcium phosphate	0.75	0.75	0.75
Limestone	0.75	0.75	0.75
Trace minerals	0.50	0.50	0.50
Sodium bicarbonate	0.75	0.75	0.75
Magnesium oxide	0.25	0.25	0.25
Vitamins A, D, and E premix[2]	0.1	0.1	0.1
Vitamin E premix[3]	0.05	0.05	0.05

[1]SBM = Solvent-extracted soybean meal, ESBM = expeller soybean meal, and AVB = animal and vegetable blend.

[2]Contained 4,400,000 IU of vitamin A, 880,000 IU of vitamin D, and 440 IU of vitamin E/kg of DM.

[3]Contained 44,000 IU of vitamin E/kg of DM.

Sample Collection and Analytical Procedures

Samples of grain mixes, corn silage, and alfalfa haylage were collected weekly and frozen at –20°C until processed for analysis. Samples were oven-dried at 55°C for 48 h and ground through a 2-mm screen of a standard Wiley mill (model number 3; Arthur H. Thomas Co., Philadelphia, PA). All samples were then reground through a 1-mm screen of an ultracentrifuge mill (Brinkman Instruments Co., Westbury, NY). Weekly feed samples were composited by period for analysis. Feed composites were corrected to a 100% DM basis after drying at 105°C. Crude protein, ether extract, ash, calcium, phosphorus, and magnesium content of the composite samples were determined according to AOAC methods (1). Acid detergent fiber and permanganate lignin were determined according to procedures by Robertson and Van Soest (20). Neutral detergent fiber was determined according to techniques reported by Van Soest et al. (27). Fatty acid composition of feeds was determined by GLC of methyl esters (26).

Milk samples were collected Monday night and Tuesday morning of wk 2 through 4 of each period and composited. Composite samples were analyzed for fat, protein, SNF, and lactose using the mid infrared spectroscopic method (Multispec; Foss Food Technology Corp., Eden Prairie, MN) according to AOAC methods (1). Somatic cell counts were determined using Fossomatic 90 (Foss Food Technology Corp.) according to AOAC procedures (1).

Ruminal degradability, AA composition, and digestibility of the RUP fractions of the various protein supplements were determined in situ (14). Those data were used to estimate amounts of AA presented to the intestinal tract when cows were fed the various diets.

The BW and body condition scores (28) of cows were recorded for 3 consecutive d at the start of the trial and the end of each period to evaluate changes in BW or body condition.

Ruminal fluid from each cow was collected 1 d during wk 4 of each period at 2 to 4 h after feeding via

an esophageal tube. Samples were placed on ice, analyzed for pH using a Corning ion analyzer 150 (Corning Inc., Corning, NY), and prepared (6) for determination of VFA (6, 18) and ammonia (7).

Samples of blood from jugular veins were collected into serum separation tubes (Becton Dickinson Vacutainer Systems, Rutherford, NJ) at the same time that ruminal fluid was sampled. Blood samples from jugular veins were immediately placed on ice until processed. Samples of blood plasma from a coccygeal vessel and the mammary vein were collected into heparinized tubes during wk 4 of each period and promptly cooled with ice. The samples from the coccygeal vessel were assumed to be arterial for purposes of calculating arteriovenous differences across the mammary gland. All blood samples were stored at –20°C until analyzed. Samples of jugular serum were analyzed for serum urea nitrogen (7). Samples of coccygeal and mammary plasma were analyzed for AA content using a high performance AA analyzer (model 6300; Beckman Instruments, Inc., Palo Alto, CA) (1). From these results, AA uptake, transfer efficiency, and extraction rates were calculated (5). Mammary blood flow was estimated from the ratio of output to uptake for Phe and Tyr as described by Cant et al. (5). The AA composition of milk protein was assumed to be similar to that reported by Jacobson et al. (11).

All data were analyzed using the general linear models procedure of SAS (23). Significance was declared at $P < 0.05$ unless otherwise noted. When treatment means differed at $P < 0.10$, a least squares means separation test (25) was used to determine whether treatments were significantly different from one another at $P < 0.05$.

RESULTS AND DISCUSSION

The chemical composition of the concentrate mixes, forages, and TMR are shown in Table 2. The ESBM and AVB diets contained approximately equal amounts of RUP and more RUP than did the SBM diet. All diets provided more than adequate amounts of RDP and sufficient energy (16). The ESBM, as well as the BM and CGM in the AVB diet, were on the high end of expected RUP contents (67, 95, and 86% of CP, respectively) (13), which is why these two diets contained slightly more RUP than anticipated. Fatty acid concentrations were lower than ether extract concentrations because other materials, such as waxes and chlorophyll, were extracted along with fatty acids during the ether extraction process. Fiber and mineral contents of the diets were more than adequate to meet NRC (16) recommended guidelines.

The quality of protein available for absorption from the intestinal tract when cows were fed each of the three diets was evaluated using two theoretical models. Milk protein scores (i.e., AA content of the most limiting AA that were estimated to be presented

TABLE 2. Chemical composition of concentrate mixes, forages, and total mixed diets.

	Concentrate mix[1]			Forage[2]		Total mixed diet[3]		
Nutrient	SBM	ESBM	AVB	CS	AH	SBM	ESBM	AVB
DM, %	87.4	87.7	87.8	29.2	46.0	53.9	54.6	54.6
	(% of DM)							
CP	17.5	18.2	18.2	9.0	21.6	17.4	17.8	17.8
RUP,[4] % of CP	. . .	. . .	. . .	. . .	. . .	33.7	45.4	45.4
Ether extract	7.2	8.0	7.6	3.2	4.1	5.8	5.8	6.0
Fatty acids	5.5	5.7	5.4	2.0	1.5	3.6	3.7	3.5
NE_L,[5] Mcal/kg of DM	. . .	. . .	. . .	. . .	. . .	1.6	1.5	1.5
NDF	16.7	20.1	20.1	43.5	47.0	35.6	36.7	32.9
ADF	4.7	5.0	5.0	23.6	36.5	22.5	22.0	21.4
Lignin	0.8	0.7	0.8	4.25	9.6	4.9	4.9	4.8
Ash	7.6	7.8	9.4	4.9	9.9	6.9	7.0	7.4
Ca	. . .	. . .	. . .	. . .	. . .	0.99	0.99	1.27
P	. . .	. . .	. . .	. . .	. . .	0.42	0.42	0.53
Mg	. . .	. . .	. . .	. . .	. . .	0.39	0.39	0.40

[1]SBM = Solvent-extracted soybean meal, ESBM = expeller soybean meal, and AVB = animal and vegetable blend.

[2]CS = Corn silage; AH = alfalfa haylage.

[3]Total mixed diets contained 50% concentrate mix, 16.7% CS, and 33.3% AH.

[4]Ruminally undegradable protein was determined for protein supplements (14) and was estimated for other feed ingredients (16).

[5]Estimated from NRC (16).

TABLE 3. Milk production and composition, DMI, BW, and body condition scores (BCS) for cows fed diets containing solvent-extracted soybean meal (SBM), expeller soybean meal (ESBM), and an animal and vegetable blend (AVB).

	Diet				
Item	SBM	ESBM	AVB	SE	*P*
Milk, kg/d	33.4	33.3	32.7	0.59	0.63
3.5 % FCM, kg/d	34.4	34.4	33.7	0.73	0.75
Milk fat					
%	3.74	3.77	3.73	0.08	0.94
kg/d	1.25	1.25	1.23	0.03	0.84
Milk protein					
%	2.99	2.94	2.94	0.03	0.57
kg/d	1.0	0.98	0.97	0.02	0.51
Milk lactose					
%	4.85	4.83	4.80	0.66	0.35
kg/d	1.94	1.61	1.57	0.18	0.31
Milk SCC, $\times 10^3$/ml	241.2	130.9	117.3	43.4	0.09
DMI, kg/d	22.9[a]	21.7[ab]	21.2[b]	0.54	0.09
BW, kg	606	608	608	9.0	0.99
BW Change, kg/28 d	9.24	9.25	6.58	2.02	0.83
BCS[1]	2.88	2.75	2.80	0.08	0.83
BCS Change	0.13	0.08	0.04	0.05	0.24

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1]Scored on a five-point scale where 1 = thin to 5 = fat (28).

to the intestinal tract relative to the AA content of milk protein) (24) for the three diets were 0.78, 0.76, and 0.80, respectively. Apparently, Met was the first-limiting AA in all cases followed by His and Val for the SBM and ESBM diets and by Ile and Val for the AVB diet. Correcting for the lower intestinal digestibility (14) of BM and MBM in the AVB diet would lower the milk protein score for that diet slightly. Using estimates of AA content of RUP portions of protein supplements reported by Maiga et al. (14), the Cornell Net Carbohydrate and Protein System (2) predicted that the SBM diet would be slightly deficient (97% of requirements) in Lys, the ESBM diet would be more than adequate in all AA (Lys was first-limiting at 103% of requirements), and the AVB diet would be slightly deficient (96 and 99% of requirements) in Ile and Lys, respectively; Met and His were predicted to be second- and third-limiting for the SBM and ESBM diets, and Met was predicted to be third-limiting for the AVB diet.

TABLE 4. Ruminal VFA, pH, ammonia, and plasma urea nitrogen concentrations for cows fed diets containing solvent-extracted soybean meal (SBM), expeller soybean meal (ESBM), and an animal and vegetable blend (AVB).

	Diet				
Measurement	SBM	ESBM	AVB	SE	*P*
VFA, mol/100 mol					
Acetate (A)	63.9[b]	66.2[a]	66.8[a]	0.53	<0.01
Propionate (P)	18.6[a]	17.1[b]	17.2[b]	0.43	0.04
Butyrate	12.5	12.1	11.3	0.58	0.34
Isobutyrate	1.0	1.0	1.0	0.12	0.96
Valerate	1.9	1.8	1.8	0.08	0.64
Isovalerate	2.1	1.8	2.0	0.13	0.21
A:P	3.5[b]	3.9[a]	3.9[a]	0.10	0.01
Total VFA, μmol/ml	78.5	67.7	73.4	5.70	0.30
pH	6.8	7.0	6.8	0.07	0.29
Ammonia, mg/dl	15.4	15.7	14.8	0.5	0.34
Serum urea, mg/dl	16.6	17.8	17.3	0.57	0.33

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

Milk production, composition, and SCC were similar ($P > 0.08$) for all diets (Table 3). The milk protein score system (24) predicted the highest production for cows fed the AVB diet, and the Cornell system (2) predicted the highest production for cows fed the ESBM diet; however, both prediction systems indicated that all diets were probably too similar in protein quality for differences in production to be detected. Results of this research agreed with those of Broderick (3), who observed similar milk production for cows fed ESBM and SBM diets. In another trial by Broderick et al. (4), milk production was higher for cows fed ESBM than for those fed SBM. When cows were fed a proportionately different blend of the same protein supplements that were used in the AVB diet of this study, milk production was similar to that of cows fed the SBM diet (13). In a study by Robinson et al. (21) using CGM, SBM, or a combination of the two, there was no difference in milk production or composition. Polan et al. (19) reported decreased milk production for cows fed CGM diets compared with that of cows fed the SBM diet because of a Lys deficiency in the CGM diets, but De Gracia et al. (8) reported similar milk production when cows were fed a CGM plus BM blend or SBM.

The DMI tended to differ ($P \leq 0.09$) among all treatments (Table 3); DMI of the AVB diet was lower ($P < 0.05$) than that of the SBM diet. Animal by-product blends did not affect DMI in a study by Mansfield et al. (15) that used a combination of MBM, feather meal, and BM, but DMI were lower than those of a SBM diet in a study by England et al. (9). Whether the trend toward DMI depression was caused by the hydrolyzed feather meal or by one of the animal by-products used in that trial cannot be determined. Diets that contain CGM are usually palatable (29). The DMI of dairy cows that consumed a different blend of the animal and vegetable proteins that were used in this study (13) were similar to the DMI of cows that consumed the SBM diet. The BW and body condition scores were similar ($P \leq 0.24$) for all treatments (Table 4).

Ruminal fermentation data are shown in Table 4. Molar percentages of acetate were lower ($P < 0.01$), and molar percentages of propionate were higher ($P < 0.05$), for cows fed the SBM diet; however, the biological significance of these relatively small differences might be questionable, and the total VFA concentrations were similar for all treatments. Ruminal pH

TABLE 5. Amino acid concentration in coccygeal artery plasma.

AA	Diet[1]			SE	*P*
	SBM	ESBM	AVB		
	(μmol/dl)				
Arg	9.1	9.5	8.5	0.58	0.47
His	3.4	3.8	4.0	0.20	0.15
Ile	13.0[ab]	15.0[a]	10.8[b]	0.87	0.01
Leu	16.3[b]	19.7[ab]	22.5[a]	1.09	<0.01
Lys	7.6	8.3	7.1	0.53	0.29
Met	1.9	1.7	1.8	0.13	0.40
Phe	3.8	4.2	4.3	0.23	0.41
Thr	9.6	8.5	8.1	0.59	0.23
Val	27.8[b]	32.7[a]	30.8[ab]	1.50	0.10
Total EAA[2]	92.5	103.4	97.9	. . .	. . .
Ala	31.0	27.2	28.4	2.10	0.46
Asp	1.2	1.2	1.1	0.08	0.65
Asn	4.0	3.6	3.5	0.32	0.50
Cys	0.1	0.2	0.1	0.03	0.35
Glu	9.2	8.4	8.5	0.32	0.19
Gln	40.5	37.6	38.3	2.40	0.69
Gly	30.4[a]	24.9[b]	28.7[ab]	1.60	0.07
Pro	12.3	12.6	14.0	0.99	0.43
Ser	9.1	7.8	8.6	0.57	0.25
Tyr	5.4	5.5	5.1	0.39	0.80
Total NEAA[3]	143.2	129.0	136.3	. . .	. . .

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1]SBM = Solvent-extracted soybean meal, ESBM = expeller soybean meal, and AVB = animal and vegetable blend.

[2]Total dietary essential AA.

[3]Total nonessential AA.

TABLE 6. Amino acid concentration in mammary vein plasma.

AA	Diet[1] SBM	ESBM	AVB	SE	*P*
	(μmol/dl)				
Arg	5.5	6.3	5.2	0.36	0.11
His	2.6[b]	3.1[a]	3.2[a]	0.13	0.01
Ile	8.1[a]	10.5[b]	6.6[a]	0.60	<0.01
Leu	9.3[b]	13.0[a]	14.8[a]	0.75	<0.01
Lys	2.8	3.5	2.7	0.35	0.29
Met	0.52	0.44	0.52	0.06	0.59
Phe	1.8	2.1	2.2	0.17	0.17
Thr	5.7	5.3	5.2	0.46	0.68
Val	21.1[b]	27.0[a]	24.7[a]	1.02	<0.01
Total EAA[2]	57.4	71.2	65.1	. . .	. . .
Ala	26.9	27.2	25.8	2.33	0.91
Asp	1.0	0.9	0.9	0.09	0.72
Asn	2.8	2.7	2.5	0.20	0.56
Cys	0.2	0.2	0.1	0.02	0.65
Glu	4.8	4.7	4.6	0.20	0.83
Gln	26.7	27.2	26.5	1.92	0.97
Gly	29.1	25.6	28.3	1.39	0.19
Pro	10.4	11.3	11.9	0.90	0.49
Ser	6.3	6.1	6.7	0.55	0.71
Tyr	3.0	3.5	3.1	0.28	0.44
Total NEAA[3]	111.2	109.4	110.4	. . .	. . .

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1]SBM = Solvent-extracted soybean meal, ESBM = expeller soybean meal, and AVB = animal and vegetable blend.

[2]Total dietary essential AA.

[3]Total nonessential AA.

TABLE 7. Differences in arteriovenous concentrations of AA.

AA	Diet[1] SBM	ESBM	AVB	SE	*P*
	(μmol/dl)				
Arg	3.6	3.8	3.3	0.34	0.62
His	0.8	0.8	0.8	0.13	0.98
Ile	4.9[ab]	5.3[a]	4.2[b]	0.35	0.09
Leu	7.0	8.0	7.7	0.50	0.40
Lys	4.8	5.1	4.4	0.30	0.25
Met	1.4	1.3	1.3	0.09	0.48
Phe	2.1	2.2	2.0	0.16	0.74
Thr	3.8[a]	3.5[ab]	2.9[b]	0.23	0.04
Val	6.7	7.3	6.1	0.56	0.31
Total EAA[2]	35.1	37.3	40.4	. . .	. . .
Ala	4.1	2.7	2.6	0.90	0.43
Asp	0.3	0.2	0.2	0.11	0.90
Asn	1.2	1.1	1.0	0.17	0.69
Glu	4.4	3.8	3.9	0.26	0.21
Gln	13.8	11.9	11.8	0.85	0.19
Gly	1.3	0.6	0.4	0.52	0.50
Pro	1.9	2.0	2.1	0.56	0.96
Ser	2.8	2.2	1.9	0.31	0.13
Tyr	2.3	2.3	2.0	0.18	0.37
Total NEAA[3]	32.1	26.8	25.9	. . .	. . .

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1]SBM = Solvent-extracted soybean meal, ESBM = expeller soybean meal, and AVB = animal and vegetable blend.

[2]Total dietary essential AA.

[3]Total nonessential AA.

TABLE 8. Extraction efficiency[1] of essential AA.

AA	Diet[2]			SE	*P*
	SBM	ESBM	AVB		
	(%)				
Arg	41.7	38.1	38.4	3.13	0.67
His	23.3	21.9	19.9	2.69	0.68
Ile	38.2	36.3	39.5	2.65	0.70
Leu	43.2[a]	41.4[a]	34.7[b]	2.01	0.02
Lys	62.9	63.4	62.3	3.58	0.98
Met	74.1[ab]	82.5[a]	70.5[b]	3.36	0.05
Phe	54.1	52.3	47.8	2.72	0.27
Thr	41.8	41.0	36.4	2.50	0.28
Val	24.4	23.1	19.7	1.80	0.18

[a,b]Means in the same row without a common superscript differ ($P < 0.05$).

[1](Arteriovenous difference ÷ AA concentration in artery) × 100.

[2]SBM = Solvent-extracted soybean meal, ESBM = expeller soybean meal, and AVB = animal and vegetable blend.

were similar among diets, but all values might have been elevated because of saliva contamination. Ruminal ammonia and serum urea nitrogen concentrations were similar and sufficiently high to indicate that all diets contained ample amounts of RDP. The relatively small differences in RDP content of diets (11.5, 9.7, and 9.7%, respectively) would not likely be great enough to reflect differences in ruminal ammonia, especially when all diets contained adequate amounts of RDP and fermentable energy.

Tail arterial (coccygeal vessel) concentrations of Ile were lower, and concentrations of Leu were higher, for cows fed the AVB diet (Table 5). Concentration of Val was lower, and concentration of Gly was higher, for cows fed the SBM diet than for cows fed the ESBM diet. This variation reflected differences in the AA concentration of the protein supplements and estimated RUP portions of the protein supplements used in these diets (14). Mammary vein concentrations of His, Leu, and Val were greater, and concentrations of Leu were lower, in cows fed the AVB diet than in cows fed the SBM diet because of the amounts of these AA in BM (Table 6). The concentration of Trp in blood was not determined in this study. Differences in arteriovenous concentrations of AA were similar ($P > 0.12$) among diets for all AA except for Thr, which was lower ($P \leq 0.04$) for cows fed the AVB diet than for cows fed the SBM diet (Table 7), and for Ile, which was lower ($P \leq 0.03$) for cows fed the AVB diet than for cows fed the ESBM diet. These small differences in uptake might be of questionable biological significance because milk protein yield was similar (Table 3) for all diets.

The ratio of uptake to output, transfer efficiency, and extraction efficiency of AA by the mammary gland are all methods used to estimate AA that limit milk protein synthesis (5, 24). All of these were calculated, but, for brevity, only extraction efficiency data are presented here (Table 8). Extraction efficiency of Met was highest for all diets, indicating that Met was the first-limiting AA in all diets. The extraction efficiency was higher ($P < 0.05$) for the ESBM diet, which was most deficient in Met according to the milk protein score (24), than for the AVB diet, which was most adequate in Met. Second- and third-limiting AA in all three diets were probably Lys and Phe using this method. Transfer efficiencies also indicated that Met was first-limiting in all three diets, and Phe or Lys was second- or third-limiting. However, AA ratios of uptake to output indicated that His, Phe, and Met were first-, second-, and third-limiting AA in all three diets, respectively. In all cases, when Tyr was considered to be an essential AA, it would have ranked as fourth-limiting; Gln would have been further down the list. Milk protein scores (24) for these diets indicated that Met was first-limiting in all three diets, which agreed with extraction and transfer efficiencies from blood by the mammary gland. The Cornell system (2) predicted Lys as being first-limiting for the SBM and ESBM diets and Ile as first-limiting for the AVB diet, but, if the blood data are correct, these predictions are incorrect.

CONCLUSIONS

This trial evaluated protein from SBM, ESBM, and an AVB consisting of BM, MBM, CGM, and SBM in

diets of lactating cows. Although ruminal degradability and AA composition varied with protein source, DMI, milk production, and milk composition were unaffected by the various protein supplements. This result was likely because the quality or AA composition of proteins ultimately presented to the lower digestive tract was not greatly altered. Varying degrees of protein degradability and quality within the range of this study did not affect milk production.

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