Rumen Fermentation and Intestinal Supply of Nutrients in Dairy Cows Fed Rumen-Protected Soy Products

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ABSTRACT

Four multiparous lactating Holstein cows that were fistulated in the rumen and duodenum and that averaged 205 d in milk were used in a 4 × 4 Latin square design to evaluate the practical replacement of solvent-extracted soybean meal (SSBM) with soy protein products of reduced ruminal degradability. On a dry matter (DM) basis, diets contained 15% alfalfa silage, 25% corn silage, 34.3 to 36.9% corn grain, 19.4% soy products, 18.2% crude protein, 25.5% neutral detergent fiber, and 35.3% starch. In the experimental diets, SSBM was replaced with expeller soybean meal (ESBM); heated, xylose-treated soybean meal (NSBM); or whole roasted soybeans (WRSB) to supply 10.2% of the dietary DM. Intakes of DM (mean = 20.4 kg/d), organic matter, and starch were unaffected by the source of soy protein. Similarly, true ruminal fermentation of organic matter and apparent digestion of starch in the rumen and total tract were not altered by treatments. Intake of N ranged from 567 (WRSB) to 622 g/d (ESBM), but differences among soy protein supplements were not significant. Compared with SSBM, the ruminal outflow of nonammonia N was higher for NSBM, tended to be higher for ESBM, and was similar for WRSB. The intestinal supply of nonammonia nonmicrobial N was higher for NSBM and WRSB and tended to be higher for ESBM than for SSBM. However, no differences were detected among treatments when the flow to the duodenum of nonammonia nonmicrobial N was expressed as a percentage of N intake or nonammonia N flow. The ruminal outflow of microbial N, Met, and Lys was not altered by the source of soy protein. Data suggest that partially replacing SSBM with ESBM, NSBM, or WRSB may increase the quantity of feed protein that reaches the small intestines of dairy cows. However, significant improvements in the supply of previously reported limiting amino acids for milk production, particularly of Met, should not be expected.

(**Key words:** rumen-protected soy product, ruminal fermentation, intestinal supply of nutrients, dairy cow)

Abbreviation key: ESBM = expeller soybean meal; EAA = essential amino acids; NANMN = nonammonia nonmicrobial nitrogen; NEAA = nonessential amino acids; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; WRSB = whole roasted soybeans.

INTRODUCTION

Under conventional feeding conditions, an inadequate amount or pattern of essential amino acids (EAA) absorbed from the small intestine of dairy cows, particularly of Met, Lys, and His (NRC, 2001), may be partly responsible for creating or aggravating inefficiencies in the postabsorptive metabolism of N (Lobley, 2002). Selection of the proper source of supplemental CP for feeding offers an excellent opportunity for influencing the supply of AA to dairy cows. This is because the CP source modulates the intestinal supply of AA by affecting the passage of RUP and microbial N to the lower gastrointestinal tract (Clark et al., 1992). In addition, the contribution of RUP to the ruminal outflow of total protein and its AA composition impact the pattern of AA available for absorption in the small intestine (Rulquin and Vérité, 1993; NRC, 2001).

Solvent-extracted soybean meal (SSBM) and raw soybeans are excellent sources of RDP that can be used to supply ruminal microorganisms with the forms of N required for driving their growth (Stern et al., 1985; Tice et al., 1993). Although soy proteins are a good source of digestible Lys and His (Santos et al., 1998; NRC, 2001), they are low in Met (1.44 to 1.47% of CP) and can be extensively degraded (≥57.4 to 69.6%) by ruminal microbes (NRC, 2001), which may compromise their value for contributing quantitatively and (or) qualitatively to the supply of EAA in metabolizable protein. This limitation motivated the development of several methods for decreasing the ruminal degradability of proteins in SSBM and soybean seeds. Some of the most effective methods for this purpose that are

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approved for commercial use in the US involve the controlled administration of heat to soybeans (i.e., expeller processing and roasting of soybeans) or heat plus reducing sugars to SSBM [i.e., heated, xylose-treated soybean meal (**NSBM**); Cleale et al., 1987; Firkins and Fluharty, 2000; Grummer and Rabelo, 2000]. Estimations by the NRC (2001) for dairy cows consuming DM at 4% of BW in a 1:1 forage to concentrate ratio indicate that these methods can decrease ruminal degradability of proteins in raw soybeans by about 11% (roasting of whole seeds) and of proteins in soybean meal by about 62% (expeller processing) and 86% (heated, xylose treatment) without negatively affecting (Harstad and Prestlokken, 2000), and sometimes even improving (Tice et al., 1993), their intestinal digestibility.

Numerous studies have examined the lactational response of dairy cows to the feeding of heat-treated soybean seeds or soybean meal. Surprisingly, much less attention has been given to the effects of these treatments on the intestinal supply of N and AA (Santos et al., 1998; Ipharraguerre and Clark, 2005). Indeed, only a few studies with dairy cows have been undertaken, and a summary of 9 comparisons from those experiments (Ipharraguerre and Clark, 2005) showed that replacing SSBM with soy protein supplements of reduced ruminal degradability increased (25.2%) the passage to the duodenum of nonammonia nonmicrobial N (**NANMN**), but only improved marginally ($P > 0.05$) that of EAA (4.7%), Lys (3.9%), and Met (0.6%). Additionally, to our knowledge, the impact of heat-treated soy protein supplements on the ruminal outflow of N and starch has not been compared in the same study with lactating dairy cows. Therefore, it is likely that the paucity of data from in vivo experiments limits the use of current protein systems for predicting accurately the supply of AA to dairy cows fed diets containing rumen-protected soy protein supplements.

The objectives of this study were to compare the effects of partially replacing SSBM with expeller soybean meal (**ESBM**), NSBM, or whole roasted soybeans (**WRSB**) in the diet of lactating dairy cows on ruminal fermentation, passage of nutrients to the small intestine, and nutrient digestibility.

MATERIALS AND METHODS

Animals, Management, and Experimental Design

Four multiparous Holstein cows that averaged 205 DIM (range, 152 to 268 DIM) at the onset of the experiment were surgically fitted with ruminal and duodenal cannulas according to procedures approved by the University of Illinois Laboratory Animal Care Advisory Committee. The ruminal cannulas were constructed of soft plastic (Bar Diamond, Parma, ID) and measured

10.2 cm in diameter. The duodenal cannulas were an enclosed T-shaped design made of stainless steel (Borzins Vet Laboratory Ltd., Edmonton, Alberta, Canada). They were placed proximal to the common bile and pancreatic duct, about 10 cm distal to the pylorus. Cows were housed in individual stanchions equipped with water bowls and bedded with rubber mats and straw. With the exception of the last 3 d of each period when samples were being collected, cows were allowed to exercise in a dry lot from 0800 to 0900 h. Cows were fed a TMR at 0600 and 1700 h for ad libitum intake and were milked twice daily at the same time.

The experimental design was a 4×4 Latin square with 14-d periods. The first 7 d of each period were used to adapt the cows to treatments, and the remaining 7 d were used to collect data. Each cow was randomly assigned to one of 4 treatment sequences in which a treatment never followed the same treatment for all sequences. The control diet contained 40.07% forage; 40.51% corn, minerals, and vitamins; and 19.42% SSBM (Table 1). For the other 3 dietary treatments, SSBM was replaced with ESBM, NSBM, or WRSB to supply 10.20% of the dietary DM. All diets were formulated to contain 18% CP and to meet the NRC (2001) recommendations for all other nutrients. Diets were adjusted weekly to reflect changes in DM of forages and concentrate mixtures by drying each component overnight in an oven at 105°C.

Sampling, Measurements, and Analyses

Dry matter intake and orts were measured and recorded daily. Samples of individual feed ingredients, TMR, and orts were collected for the last 5 d of each period. Samples of individual feedstuffs and TMR were dried at 55°C in an oven for 72 h, ground through a 2-mm screen in a Wiley Mill (Arthur H. Thomas, Philadelphia, PA), composited on an equal weight basis by period, and ground through a 1-mm screen. Samples of orts were dried at 55°C in an oven for 72 h, ground through a 2-mm screen, composited by the amount and dry weight of the daily orts for each cow, and ground through a 1-mm screen. Samples of feeds, TMR, and orts were analyzed for DM, OM, Kjeldahl N (AOAC, 1990), ADF (Van Soest et al., 1991), NDF with heat-stable α -amylase (Thermamyl 120L; Novo Nordisk Biochem, Franklinton, NC), sodium sulfite (Van Soest et al., 1991), and starch (Kartchner and Theurer, 1981). Except for Met, samples of feeds and TMR were prepared for AA determination, except Met, which was determined by acid hydrolysis with 6 N HCl (McCarthy et al., 1989). For Met determination, samples were first oxidized with performic acid, lyophilized after dilution with water to remove excess performic acid (Overton

Table 1. Ingredient composition of the experimental diets (DM basis).

Ingredient	Treatment ¹			
	SSBM	ESBM	NSBM	WRSB
Alfalfa silage, %	15.01	15.01	15.01	15.01
Corn silage, %	25.06	25.06	25.06	25.06
Ground shelled corn, %	36.86	36.00	36.88	34.29
Soybean meal				
Solvent-extracted (49% CP), %	19.42	10.10	9.20	11.80
Expeller, ² %	...	10.20	...	...
Heated, xylose-treated, ³ %	...	...	10.20	...
Whole roasted soybeans, ⁴ %	...	...	...	10.20
Sodium bicarbonate, %	1.04	1.04	1.04	1.04
Dicalcium phosphate, %	0.47	0.47	0.47	0.47
Limestone, %	1.30	1.30	1.30	1.30
Mineral and vitamin mix, ⁵ %	0.26	0.26	0.26	0.26
Magnesium oxide, %	0.21	0.19	0.21	0.20
Sodium sulfate, %	0.37	0.37	0.37	0.37
Chemical				
DM, %	66.5	66.8	66.7	66.8
OM, %	92.7	92.5	92.4	93.0
CP, %	18.2	18.1	18.2	18.3
RUP, ⁶ %	6.8	8.2	8.8	6.6
RUP, ⁶ % of CP	37.4	45.2	48.3	36.1
RDP, ⁶ %	11.4	9.9	9.4	11.7
Metabolizable protein, ⁶ g/d				
Bacterial	1104	1189	1081	1105
RUP	1176	1570	1629	1097
Endogenous	93	101	99	92
NDF, %	24.2	25.4	27.1	26.5
ADF, %	13.3	13.3	13.3	13.8
Starch, %	35.3	34.8	35.8	33.7
Ether extract, ⁶ %	2.9	3.6	3.0	4.6
NE _L , ⁶ Mcal/kg of DM	1.67	1.67	1.66	1.73

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

²SoyPLUS (West Central Cooperative, Ralston, IA).

³Soy Pass (Ligno Tech USA, Inc., Rothschild, WI).

⁴Vita Plus Corp. (Madison, WI); protein dispersibility index = 8.96.

⁵Contained 5.0% Mg, 7.5% K, 10.0% S, 3.0% Zn, 3.0% Mn, 2.0% Fe, 0.5% Cu, 0.025% I, 0.015% Se, 0.004% Co, 2200 IU of vitamin A/g, 660 IU of vitamin D₃/g, and 8 IU of vitamin E/g.

⁶Calculated using NRC model (2001), the chemical composition of ingredients (Table 2), and least squares means for intakes for each treatment (Table 3).

et al., 1995), and hydrolyzed with 6 N HCl as outlined by Moore (1963). Individual AA were then separated by ion exchange chromatography on a Beckman 126AA AA analyzer equipped with a Beckman 12-cm column (Beckman Instruments Inc., Palo Alto, CA).

Samples of ruminal fluid and duodenal digesta were collected every 3 h during the last 3 d of each period. The sampling time was adjusted ahead 1 h daily so that a sample was obtained for each 1-h interval of the day (24 total samples). Ruminal fluid samples were taken from multiple sites in the rumen, and pH of ruminal fluid was measured immediately by glass electrode. After measurement of pH, a subsample of 50 mL was acidified to pH < 2 with 50% H₂SO₄ (vol/vol), centrifuged at 27,000 × g for 10 min at 4°C, and the supernatant was frozen at -20°C for later analyses. Following removal of the cap of the duodenal cannula, accumulated digesta

was discarded, and when the flow appeared normal, 500 mL of duodenal contents were collected. Samples were pooled by cow and stored frozen in 20-L buckets at -20°C until analyses.

Ruminal fluid samples taken at 0, 1, 2, 3, 5, 7, 9, and 10 h after the morning feeding and at 0, 1, 2, 3, 5, 7, 9, 11, and 12 h after the afternoon feeding (17 total samples) were thawed, centrifuged at 27,000 × g for 20 min at 4°C, and an aliquot of 4 mL was diluted with 25% metaphosphoric acid (4:1). These subsamples were assayed with a gas chromatograph (model 5890 Series II; Hewlett-Packard, Avondale, PA) equipped with a 1.8-m glass column packed with 10% SP 1200/1% H₃PO₄ on 80/100 chromosorb W AW (Supelco, 1975) to determine the concentration of VFA. Nitrogen was the carrier gas, and the temperature of the injection port and column was 175°C and 125°C, respectively. Ruminal

NH₃N was determined according to the procedures outlined by Chaney and Marbach (1962) as modified by Cotta and Russell (1982).

Duodenal samples were thawed and homogenized for 5 min using a propeller-type mixer set at high speed. During continuous stirring, a representative subsample (1000 mL) of digesta was collected by vacuum. Samples then were poured into shallow pans, lyophilized, ground through a 1-mm screen, and analyzed for DM, OM, Kjeldhal N, starch, and AA as described above. The concentration of NH₃N in duodenal digesta was determined by steam distillation with MgO (Bremner and Keeney, 1965), and purines, used as a bacterial marker, were measured by the method of Zinn and Owens (1986).

Ruminal bacteria were isolated from samples (1000 mL) of whole ruminal contents obtained from the reticulum near the reticulo-omasal orifice at 6 separate post-feeding times (0, 2, 4, 6, 8, and 10 h) during the last 3 d of each period. Ruminal contents were blended in a Waring blender (Waring Products Division, New Hartford, CT) for 1 min at low speed and strained through 6 layers of cheesecloth; the effluents were used to prepare a bacteria-rich sample by differential centrifugation (Overton et al., 1995). Bacterial samples were pooled by cow within period and frozen at -20°C. These samples were lyophilized and analyzed for DM, OM, Kjeldahl N, AA, and purines by the methods described above.

During the last 6 d of each period, fecal grab samples were collected twice daily at 12-h intervals. The sampling time was adjusted ahead 2 h daily so that a sample was obtained for each 2-h interval of the day (12 total samples). Samples were composited on an equal wet weight basis, dried at 55°C, ground through a 1-mm screen, and assayed for DM, OM, Kjeldahl N, and starch as described above.

Chromic oxide was used as an indigestible marker to assess the passage of digesta to the duodenum and fecal excretion by the cows. Gelatin capsules that contained 10 g of Cr₂O₃ powder were administered via the ruminal cannula at 0800 and 2000 h during the last 10 d of each period. Concentration of Cr in duodenal and fecal samples was quantified by atomic absorption spectroscopy (air plus acetylene flame; Perkin-Elmer, Norwalk, CT) after preparation of samples by the procedure of Williams et al. (1962).

Passage of microbial N and OM to the duodenum was calculated from the passage of DM and from the proportion of N or OM of bacterial origin, respectively. These proportions were estimated by dividing the N to purine ratio or the OM to purine ratio of isolated bacteria by the N to purine ratio or the OM to purine ratio of duodenal digesta. Passage of NANMN to the duodenum

was calculated by subtracting passage of microbial N from passage of total NAN. Apparent digestibility of OM in the rumen was corrected for the passage of microbial OM to the duodenum to establish the amount of OM truly digested in the rumen.

Milk weights were recorded at each milking during the last 7 d of each period. Milk samples were taken at each milking during the last 7 d of each period, preserved with 2-bromo-2-nitropropane-1,3-diol, and stored at 4°C. Samples were sent to Dairy One Cooperative Inc. (Ithaca, NY) for analyses of fat, CP, true protein, TS, and urea N by infrared procedures (AOAC, 1990; Foss 4000; Foss North America, Eden Prairie, MN).

Statistical Analyses

Data were analyzed as a 4 × 4 Latin square using PROC MIXED of SAS (2000), with cow treated as a random variable and according to the following model:

$$Y_{ijk} = \mu + C_i + P_j + T_k + \varepsilon_{ijk}$$

where

Y_{ijk} = dependent variable,

μ = overall mean,

C_i = effect of cow i ($i = 1, 2, 3, 4$),

P_j = effect of period j ($j = 1, 2, 3, 4$),

T_k = effect of the treatment k ($k = 1, 2, 3, 4$), and

ε_{ijk} = residual error.

A multiple comparison test (protected Fisher's least square difference) was used to separate least squares means into significant main effects.

Ruminal VFA, NH₃ N, and pH data were analyzed as repeated measures in time using PROC MIXED of SAS (Littell et al., 1996) and according to the following model:

$$Y_{ijkl} = \mu + C_i + P_j + T_k + \varepsilon_{ijk} + H_l + TH_{kl} + \omega_{ijkl}$$

where

Y_{ijkl} = dependent variable,

μ = overall mean,

C_i = effect of cow i ($i = 1, 2, 3, 4$),

P_j = effect of period j ($j = 1, 2, 3, 4$),

T_k = effect of the treatment k ($k = 1, 2, 3, 4$),

ε_{ijk} = whole plot error,

H_l = effect of the sampling time l ($l = 1, 2, \dots, 17$),

TH_{kl} = interaction between treatment k and sampling time l , and

ω_{ijkl} = split plot error.

Table 2. Chemical composition of forages and protein supplements.

Item	Silages		Protein supplement ¹			
	Alfalfa	Corn	SSBM	ESBM	NSBM	WRSB ²
OM, %	89.4	95.7	93.9	92.6	93.1	94.7
NDF, %	46.0	39.5	7.0	16.7	30.4	21.4
ADF, %	35.5	23.4	6.0	8.0	7.1	11.4
Starch, %	1.1	28.9	1.3	0.9	4.3	3.8
CP, %	19.0	7.6	53.2	48.8	51.0	41.6
EAA, ³ % of CP						
Arg	3.03	2.38	7.67	6.67	6.80	7.49
His	1.66	1.85	2.78	2.54	2.61	2.79
Ile	4.88	3.73	5.30	4.89	5.11	5.36
Leu	7.66	9.50	8.39	7.74	8.13	8.36
Lys	4.87	2.64	6.83	5.88	5.62	6.63
Met	1.37	2.24	1.26	1.37	1.31	1.18
Phe	4.91	4.01	5.43	4.97	5.17	5.45
Thr	3.90	2.93	3.87	3.23	3.55	3.72
Val	6.24	4.95	5.70	5.24	5.51	5.64
Lys, % of total EAA	12.66	7.72	14.45	13.81	12.84	14.22
Met, % of total EAA	3.56	6.54	2.67	3.22	3.00	2.52

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

²Protein dispersibility index = 8.96.

³EAA = Essential amino acids.

The smallest value for the Akaike's information criterion was used to select the most appropriate covariance structure (Littell et al., 1996). Because the treatment $\times$ hour interaction was not significant ($P > 0.05$) for the ruminal parameters measured, treatment effects were compared across treatment sampling times using the procedure described above.

Differences among treatments were considered to be significant when $P < 0.05$, whereas when $P > 0.05$ but < 0.10 differences were considered to indicate a trend toward a significant effect.

RESULTS AND DISCUSSION

Chemical Composition of Diets and Feed Ingredients

The percentage of dietary CP averaged 18.2 for all diets (Table 1). The retrospective evaluation of the diets using the NRC (2001) model as outlined in Table 1 indicated that replacing SSBM with ESBM or NSBM, but not with WRSB, increased the percentage of dietary DM and CP supplied as RUP. As expected, variation in the percentage of NDF (SD = 1.30), ADF (SD = 0.40), and starch (SD = 1.25) among diets was small.

The chemical composition of the protein supplements and forages (Table 2) was within the range reported in the literature (Miller and Hoover, 1998; NRC, 2001). With the exception of Met, ESBM and NSBM contained less EAA per unit of CP than SSBM and WRSB, which suggests that a larger proportion of EAA, especially Lys, might have been irreversibly bound to carbonyl

groups in ESBM and NSBM than in SSBM and WRSB, impeding their release during the acid hydrolysis performed prior to analysis (Firkins and Fluharty, 2000). Alternatively, differences in the AA composition among sources of soybeans used to manufacture the soy products evaluated in this experiment might have contributed to these findings. Other researchers have reported similar variability for the concentration of EAA between SSBM and ESBM (Maiga et al., 1996) or NSBM (Harstad and Prestlokken, 2000).

Intakes and Digestibilities of DM, OM, and Starch

The intakes of DM and OM were not significantly affected by treatments and averaged 20.4 and 18.8 kg/d, respectively (Table 3). Other researchers also reported that replacing SSBM with ESBM (Reynal and Broderick, 2003), NSBM (Mansfield and Stern, 1994), or WRSB (Knapp et al., 1991) to provide varying proportions of the dietary DM did not affect DMI of lactating cows. In some experiments, however, feeding WRSB depressed DMI when compared with SSBM (Mohamed et al., 1988; Pires et al., 1996).

The amount and proportion of DM apparently digested in the total tract were unaffected by the soy protein supplements. Similarly, the amount and proportion of OM digested in the rumen (apparent and true digestion) and total tract as well as the amount of OM that passed to and was digested in the intestines was not different among treatments. Previous work also showed a lack of changes in these parameters in re-

Table 3. Least square means for intakes and digestibilities of DM and OM in various segments of the gastrointestinal tract of lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
DM						
Intake, kg/d	19.8	21.4	20.9	19.4	1.8	0.24
ADTT ²						
kg/d	14.0	15.3	15.1	13.9	1.4	0.30
%	70.7	71.5	72.2	71.5	0.9	0.60
OM						
Intake, kg/d	18.3	19.7	19.2	18.0	1.7	0.28
Apparently digested in the rumen						
kg/d	7.5	8.5	7.2	7.3	1.5	0.65
% of intake	39.5	42.0	36.9	39.6	5.1	0.67
Truly digested in the rumen						
kg/d	10.1	10.1	9.8	9.6	1.7	0.62
% of intake	53.7	55.2	50.7	52.7	5.1	0.76
Passage to duodenum, kg/d	10.8	11.1	11.8	10.7	0.3	0.12
Apparently digested postruminally						
kg/d	5.7	5.8	6.5	5.8	0.3	0.16
% of intake	32.7	30.6	35.5	33.3	4.9	0.55
% of passage to duodenum	53.1	52.1	55.4	54.9	3.5	0.53
ADTT						
kg/d	13.2	14.4	14.1	13.1	1.3	0.36
%	72.2	73.1	73.4	72.9	0.9	0.76

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

²ADTT = Apparently digested in the total gastrointestinal tract.

sponse to the supplementation of diets for dairy cows (Mansfield and Stern, 1994; Reynal and Broderick, 2003) or steers (Cleale et al., 1987; Ludden et al., 1995) with the same treated soy supplements.

Intake, apparent ruminal and total tract digestibility (amount and percentage), flow to duodenum, and the apparent postruminal digestibility (amounts and proportions) of starch were not significantly influenced by treatments (Table 4). In relation to numerical trends,

feeding WRSB tended to decrease the quantity of starch that was apparently digested in the total digestive tract compared with ESBM and NSBM. Because the percentage of starch that was digested in the total tract did not follow the same trend, this response can be attributed to the numerically smaller amount of starch consumed by cows fed WRSB, which probably arose from small variations in both DMI and starch content of the diet (smaller proportion of corn grain in the WRSB diet).

Table 4. Least square means for intake and digestibility of starch in various segments of the gastrointestinal tract of lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
Starch						
Intake, kg/d	7.0	7.7	7.4	6.4	0.7	0.11
Apparently digested in the rumen						
kg/d	4.0	4.7	4.2	4.0	0.7	0.37
% of intake	55.6	59.7	57.2	61.3	5.7	0.59
Passage to duodenum, kg/d	3.0	2.8	3.0	2.4	0.3	0.46
Apparently digested postruminally						
kg/d	2.8	2.6	2.8	2.2	0.3	0.38
% of intake	41.2	37.0	39.5	36.0	5.9	0.59
% of passage to duodenum	91.9	91.6	92.4	92.0	2.5	0.97
ADTT ²						
kg/d	6.7	7.4	7.1	6.2	0.6	0.10
%	96.7	96.5	96.3	97.3	0.8	0.43

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

²ADTT = Apparently digested in the total gastrointestinal tract.

Table 5. Least square means for ruminal fermentation parameters of lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
pH	5.82	5.86	5.83	5.74	0.05	0.12
Total VFA, mM	123.9 ^a	115.4 ^b	125.5 ^a	123.2 ^a	4.07	0.02
Acetate, mol/100 mol	61.2 ^b	62.6 ^a	62.0 ^a	61.2 ^b	0.82	0.007
Propionate, mol/100 mol	23.9 ^a	22.3 ^b	22.2 ^b	24.1 ^a	0.58	0.001
Isobutyrate, mol/100 mol	1.1 ^a	0.9 ^b	0.9 ^b	1.0 ^b	0.06	0.003
Butyrate, mol/100 mol	10.2 ^c	10.9 ^b	10.6 ^a	10.7 ^b	0.28	0.001
Isovalerate, mol/100 mol	1.8 ^a	1.8 ^a	1.6 ^b	1.5 ^c	0.09	0.001
Valerate, mol/100 mol	1.8 ^a	1.6 ^b	1.5 ^b	1.6 ^b	0.11	0.001
NH ₃ N, mg/dL	24.5 ^a	20.4 ^b	21.2 ^b	23.5 ^a	1.39	0.001

^{a,b,c}Values within the same row with uncommon superscripts are different ($P < 0.05$). Pairwise comparisons were calculated using the appropriate standard error.

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

To our knowledge, few studies with dairy cows have examined the impact that soy protein supplements have on the extent and site of starch digestion. Mansfield and Stern (1994) reported that the use of SSBM or lignosulfonate-treated SSBM (approximately 16.5% of the dietary DM) as the sole source of supplemental CP resulted in similar intake and digestibility (rumen and total tract) of nonstructural carbohydrates. Similarly, in another experiment, the complete replacement of SSBM with lignosulfonate- or xylose-treated SSBM (17% of the dietary DM) did not influence the ruminal fermentation of NSC or fiber fractions (Windschitl and Stern, 1988). Based on these data, it seems reasonable to speculate that alterations in the extent and site of starch digestion should not be expected when ESBM, NSBM, or WRSB are used to increase the RUP content of SSBM-based diets fed to dairy cows, unless they are overheated.

Ruminal Fermentation

The source of soy protein did not affect the mean ruminal pH, which averaged 5.81 for all treatments (Table 5). Similar results were obtained in other studies with dairy cows (Knapp et al., 1991; Reynal and Broderick, 2003) or steers (Ludden and Cecava, 1995; Orias et al., 2002) in which heat-treated soy products were compared with SSBM or raw soybeans.

The concentration of VFA in ruminal fluid decreased when ESBM, but not NSBM or WRSB, replaced SSBM in the diet (Table 5). The molar proportion of acetate was higher for ESBM and NSBM than for SSBM and WRSB, whereas the opposite was observed for the molar percentage of propionate. The percentage of butyrate was highest for ESBM and WRSB, intermediate for NSBM, and lowest for SSBM. Although not always significant, similar changes in the molar proportion of ace-

tate and (or) propionate have been reported in a number of studies in which SSBM was compared with ESBM (Ludden and Cecava, 1995; Reynal and Broderick, 2003) or NSBM (Windschitl and Stern, 1988). Similarly, results reported here agree with data from other experiments, indicating that the replacement of SSBM with roasted (Mohamed et al., 1988; Knapp et al., 1991) or extruded (Stern et al., 1985) soybeans has generally failed to alter the relative concentration of these VFA in ruminal fluid. Windschitl and Stern (1988) explained these changes in the molar proportions of acetate and propionate by suggesting that increasing the availability of true protein in the rumen by feeding more degradable protein sources stimulates the production of propionate more than acetate. Because the intake and ruminal fermentation of OM and starch were similar among treatments, this response might also be explained by a more rapid rate of degradation of OM and protein in SSBM than in ESBM and NSBM as well as by the lower fat content in the SSBM diet compared with the WRSB diet. To some extent, these observations are supported by data from experiments showing that the in situ rate of protein degradation of SSBM was significantly faster than that of ESBM (Maiga et al., 1996) or NSBM (Harsstad and Prestlokken, 2000) and by the well-documented effects of lipids on the molar proportion of acetate and propionate (Jenkins, 1993).

The molar concentrations of isobutyrate and valerate were highest for SSBM and did not differ among the rumen-protected soy supplements. The percentage of isovalerate was highest for SSBM and ESBM, intermediate for NSBM, and lowest for WRSB. Because these VFA are the end products of the oxidative deamination and decarboxylation of branched-chain AA (Allison, 1978), it is likely that less feed protein was degraded in the rumen when SSBM was replaced with the other soy protein supplements in the diet. Some support for

Table 6. Least square means for intake and digestibility of N in various segments of the gastrointestinal tract of lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	<i>P</i> > <i>F</i>
	SSBM	ESBM	NSBM	WRSB		
N intake, g/d	579	622	613	567	51.0	0.22
Passage to duodenum						
Total N						
g/d	502	543	590	529	31.4	0.08
% of N intake	87.9	90.1	100.4	93.7	6.1	0.38
NAN						
g/d	467 ^b	514 ^{ab}	564 ^a	498 ^b	5.1	0.05
% of N intake	81.6	85.2	95.8	88.1	5.5	0.28
NANMN ²						
g/d	222 ^b	283 ^{ab}	323 ^a	289 ^a	21.6	0.05
% of NAN	48.4	56.0	58.5	57.9	3.5	0.15
% of N intake	40.0	47.4	56.0	51.0	5.1	0.16
Microbial N						
g/d	245	227	236	209	25.1	0.42
% of NAN	51.6	43.9	41.5	42.1	3.5	0.15
g/kg of OMAD ³	35.4	30.7	35.6	30.3	5.5	0.49
g/kg of OMTD ⁴	25.4	22.2	25.2	22.4	2.9	0.42
g/kg of OMADTT ⁵	18.2	16.4	17.3	16.1	1.3	0.50
N digested postruminally						
g/d	344	372	409	354	25.7	0.23
% of N intake	60.2	62.4	70.8	62.6	6.0	0.50
% of N passage to duodenum	68.5	69.1	70.6	66.9	2.4	0.68
N ADTT ⁶						
g/d	421	450	440	393	43.1	0.33
%	72.3	72.8	71.9	69.0	1.7	0.32

^{a,b}Values within the same row with uncommon superscripts are different (*P* < 0.05). Pairwise comparisons were calculated using the appropriate standard error.

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

²NANMN = Nonammonia nonmicrobial N.

³OMAD = OM Apparently digested in the rumen.

⁴OMTD = OM Truly digested in the rumen.

⁵OMADTT = OM Apparently digested in the total gastrointestinal tract.

⁶ADTT = Apparently digested in the total gastrointestinal tract.

this hypothesis is provided by the finding that the NH₃N concentration in the rumen was highest for SSBM and WRSB and lowest for ESBM and NSBM. Previous work also showed that the replacement of SSBM with NSBM (from 13.8 to 17% of the dietary DM) decreased the molar proportion of branched-chain VFA and the concentration of NH₃N in ruminal fluid (Windschitl and Stern, 1988; Mansfield and Stern, 1994). Also, in agreement with our results, the substitution of WRSB for SSBM to supply 12 to 24% of the dietary DM decreased the percentage of isobutyrate (Mohamed et al., 1988) or valerate (Knapp et al., 1991) without altering the ruminal NH₃N concentration (Mohamed et al., 1988). However, changes in the concentration of isoacids and (or) NH₃N in response to the replacement of SSBM or raw soybeans with heat-treated soy supplements have not always been observed (Ludden and Cecava, 1995; Reynal and Broderick, 2003).

Intake and Ruminal Outflow of Nitrogen

The intake of N ranged from 567 to 622 g/d, but differences among treatments were not significant (Table 6). The amount of total N that passed to the duodenum tended to be greater for NSBM than for SSBM and WRSB. This trend, however, was not evident when passage of N was expressed as a percentage of N intake. Compared with SSBM, the ruminal outflow of NAN was higher for NSBM (+20.8%), tended (*P* < 0.09) to be higher for ESBM (+10.1%), and was similar for WRSB. These increases in ruminal outflow of NAN were the results of the intestinal supply of NANMN being higher for NSBM (+44.5%) and WRSB (+30.2%) and tending (*P* < 0.08) to be higher for ESBM (+27.5%). Among rumen-protected soy products, ruminal escape of NAN was higher for NSBM than for WRSB. Conversely, the source of soy protein did not affect the passage of microbial N to the small intestine (expressed as g/d or per-

Table 7. Least square means for intakes of AA by lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
	(g/d)					
Essential						
Arg	212 ^b	256 ^a	223 ^b	262 ^a	21.9	0.02
His	94 ^b	115 ^a	100 ^b	88 ^b	9.3	0.02
Ile	167 ^c	209 ^a	190 ^{ab}	168 ^{bc}	17.1	0.03
Leu	340 ^{bc}	390 ^a	359 ^{ab}	313 ^c	32.4	0.04
Lys	206 ^b	241 ^a	206 ^b	189 ^b	19.7	0.04
Met	60	66	64	57	5.5	0.11
Phe	192 ^{bc}	225 ^a	205 ^{ab}	180 ^c	18.6	0.04
Thr	153 ^a	161 ^a	144 ^a	126 ^b	13.6	0.03
Val	189 ^b	243 ^a	222 ^a	194 ^b	19.8	0.02
Total	1613	1908	1711	1577	159.1	0.07
Nonessential						
Ala	217 ^{ab}	246 ^a	226 ^a	196 ^b	20.6	0.04
Asp	417 ^{bc}	481 ^a	432 ^{ab}	379 ^c	39.6	0.04
Glu	663 ^{bc}	774 ^a	699 ^{ab}	604 ^c	63.4	0.03
Gly	172 ^{bc}	200 ^a	180 ^{ab}	157 ^c	16.5	0.04
Pro	252 ^{ab}	286 ^a	264 ^a	231 ^b	23.7	0.05
Ser	190 ^a	171 ^{ab}	149 ^b	128 ^c	15.1	0.003
Tyr	92 ^{bc}	114 ^a	102 ^{ab}	87 ^c	9.2	0.02
Total	2004 ^{ab}	2270 ^a	2052 ^a	1782 ^b	187.9	0.04
Total AA	3617 ^b	4178 ^a	3764 ^{ab}	3359 ^b	345.2	0.05

^{a,b,c}Values within the same row with uncommon superscripts are different ($P < 0.05$). Pairwise comparisons were calculated using the appropriate standard error.

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

centage of NAN flow) or the efficiency of microbial growth.

These results agree with those from a meta-analysis of 9 treatment comparisons (Ipharraguerre and Clark, 2005), showing that the replacement of SSBM with rumen-protected soy products in the diet of lactating cows did not influence the intestinal supply of microbial N but increased the outflow from the rumen of NAN (range = 3.7 to 17.5%) and NANMN (range = 10 to 42.5%). In this experiment, no differences were detected among SSBM and the rumen-protected soy supplements when the flow to duodenum of NAN and NANMN were expressed as percentage of N intake (or percentage of NAN flow), suggesting that variation in the intake of DM and N might have accounted for the increased intestinal supply of NAN and NANMN elicited by NSBM and ESBM. Similarly, Mansfield and Stern (1994) and Reynal and Broderick (2003) did not detect improvements in the proportional contribution of NANMN to the ruminal outflow of NAN in dairy cows fed NSBM or ESBM, respectively.

Apparent N digestion in the intestines and total tract was unaltered by treatments (Table 6). Similar to results from this experiment, other researchers have reported no change in intestinal and (or) total tract digestibility of N when heated SSBM (Mabjeesh et al., 1996), NSBM (Cleale et al., 1987; Mansfield and Stern, 1994),

or ESBM (Ludden and Cecava, 1995) were compared with SSBM.

Intake and Ruminal Outflow of AA

With the exception of Met, Thr, Ala, Pro, Ser, and total nonessential AA (NEAA), replacing SSBM with ESBM increased the intake of individual EAA and NEAA, total EAA ($P < 0.07$), and total AA (Table 7). These differences were less pronounced when NSBM or WRSB were compared with SSBM. That is, NSBM increased the intake of Ile and Val and decreased the intake of Ser; WRSB enhanced the intake of Arg but depressed that of Thr and Ser. Among rumen-protected soy supplements, the intakes of His, Lys, and total EAA ($P < 0.07$) were largest for ESBM and those of Leu, Phe, Thr, Val, and NEAA (i.e., individual and total) were lowest for WRSB. Because the source of supplemental CP was essentially the only ingredient that varied in the diets, these results can be attributed to variations in DMI (Table 3) and in the AA composition of the soy protein supplements (Table 2). In other trials, the replacement of SSBM with heated SSBM (Mabjeesh et al., 1996), NSBM (Windschitl and Stern, 1988), or extruded soybeans (Stern et al., 1985) also altered AA intake.

Table 8. Least square means for passage of microbial AA to the duodenum of lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
	(g/d)					
Essential						
Arg	67	56	60	54	8.6	0.48
His	27	22	24	22	3.6	0.55
Ile	80	71	73	67	10.6	0.64
Leu	110	94	99	89	13.9	0.53
Lys	105	89	93	85	13.0	0.48
Met	32	33	30	28	5.5	0.85
Phe	69	60	63	57	9.0	0.59
Thr	69	57	60	54	7.5	0.29
Val	91	80	82	76	12.5	0.62
Total	651	563	583	533	82.8	0.54
Nonessential						
Ala	105	89	92	85	13.1	0.50
Asp	164	139	145	132	19.8	0.46
Glu	174	149	154	140	21.4	0.49
Gly	87	77	79	72	11.9	0.64
Pro	51	43	44	40	6.4	0.48
Ser	49	38	43	37	5.0	0.18
Tyr	52	44	47	42	6.0	0.38
Total	682	579	604	549	82.7	0.46
Total AA	1333	1141	1188	1081	165.5	0.50

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

The source of soy protein did not influence the ruminal outflow of individual AA, total EAA, total NEAA, and total AA of microbial origin (Table 8), but affected markedly the ruminal escape of AA in the NANMN (Table 9) and NAN fractions (Table 10). With the exception of Met, Ser, and Tyr, partially replacing SSBM with NSBM improved or tended to improve (i.e., Ile, Lys, Val, and Gly) the intestinal supply of all other EAA and NEAA (Table 10). Similar improvements in the amount of AA that reached the small intestines of lactating cows were observed when heated and unheated SSBM were compared (Mabjeesh et al., 1996). However, Windschitl and Stern (1988) reported that only the passage to the duodenum of Glu and Pro increased when SSBM was replaced with xylose- or lignosulfonate-treated SSBM in the diet of dairy cows. In another experiment (Mansfield and Stern, 1994), the amount of AA delivered to the lower digestive tract of dairy cows did not change when SSBM was totally replaced with lignosulfonate-treated SSBM. In comparison with SSBM, supplementing the diet with WRSB increased the passage to duodenum of Arg, His, Ile ($P < 0.06$), Leu, Lys ($P < 0.06$), Phe, Val ($P < 0.06$), Asp, Glu, Gly ($P < 0.07$), Pro, total NEAA, and total AA (Table 10). Previous work showed that the postruminal supply of most EAA and NEAA was not enhanced when extruded soybeans were compared with SSBM (Stern et al., 1985). Apart from Glu and Pro, the partial re-

placement of SSBM with ESBM did not alter the amount of AA that passed to the lower digestive tract (Table 10). Other researchers also found that diets supplemented with either SSBM or ESBM resulted in similar amounts of AA delivered to the small intestine of dairy cows (Reynal et al., 2003) and steers (Ludden and Cecava, 1995). Among the rumen-protected soy products, the ruminal outflow of Leu, Thr, Ala, Asp, Glu, Pro, and total AA was highest for NSBM (Table 10). In comparison with ESBM, feeding NSBM and WRSB tended to increase postruminal supplies of Arg ($P < 0.05$), Ile, Lys, Val, and Gly. None of these RUP sources enhanced the amount of Met that reached the small intestine when compared with each other or with SSBM.

In agreement with results reported here, a meta-analytic review of 6 treatment comparisons (Ipharraguerre and Clark, 2005) indicated that replacing SSBM with rumen-protected soy products in the diet of lactating dairy cows increased numerically ($P > 0.05$) the intestinal supply of Lys and Met by 3.9 and 0.6%, respectively. Additionally, the magnitude of the numerical improvement in the ruminal outflow of Lys that was elicited by NSBM (18.7%) and WRSB (12%) in this trial was within or slightly outside of the mean response range (−5.5 to 14.3%) reported in that review. Regression analyses conducted by Rulquin and Vérité (1993) and the NRC (2001) showed that most of the variation

Table 9. Least square means for passage of nonammonia nonmicrobial AA to the duodenum of lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
	(g/d)					
Essential						
Arg	54 ^b	67 ^b	95 ^a	87 ^a	6.2	0.004
His	29 ^c	34 ^{bc}	45 ^a	40 ^{ab}	2.4	0.006
Ile	58 ^c	63 ^{bc}	93 ^a	84 ^{ab}	7.9	0.03
Leu	119	140	176	156	10.9	0.06
Lys	61 ^b	75 ^{ab}	103 ^a	100 ^a	9.1	0.03
Met	26	26	34	33	6.1	0.60
Phe	58 ^c	69 ^{bc}	93 ^a	84 ^{ab}	5.7	0.02
Thr	43 ^b	60 ^a	71 ^a	66 ^a	4.8	0.02
Val	64 ^b	70 ^{ab}	101 ^a	95 ^a	9.7	0.05
Total	512 ^c	602 ^{bc}	812 ^a	746 ^{ab}	56.7	0.02
Nonessential						
Ala	66	80	103	97	9.6	0.06
Asp	99 ^c	129 ^{bc}	183 ^a	162 ^{ab}	13.7	0.008
Glu	181 ^c	235 ^{bc}	311 ^a	259 ^{ab}	17.5	0.03
Gly	61 ^b	68 ^b	95 ^a	94 ^a	8.2	0.02
Pro	73 ^b	91 ^{ab}	112 ^a	94 ^a	6.0	0.03
Ser	40	65	68	62	8.1	0.11
Tyr	24 ^b	31 ^b	44 ^a	45 ^a	3.4	0.004
Total	545 ^c	695 ^{bc}	914 ^a	812 ^{ab}	56.8	0.007
Total AA	1057 ^c	1297 ^{bc}	1726 ^{ab}	1559 ^{ab}	111.3	0.009

^{a,b,c}Values within the same row with uncommon superscripts are different ($P < 0.05$). Pairwise comparisons were calculated using the appropriate standard error.

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

Table 10. Least square means for passage of AA to the duodenum of lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
	(g/d)					
Essential						
Arg	121 ^b	124 ^b	155 ^a	141 ^a	7.5	0.04
His	55 ^c	57 ^{bc}	69 ^a	61 ^{ab}	2.4	0.006
Ile	139	135	167	151	7.9	0.06
Leu	229 ^c	240 ^{bc}	280 ^a	245 ^b	10.9	0.003
Lys	166	164	197	186	9.0	0.06
Met	58	59	64	61	4.7	0.76
Phe	127 ^c	132 ^{bc}	159 ^a	141 ^{ab}	5.8	0.01
Thr	112 ^b	118 ^b	133 ^a	121 ^b	5.6	0.03
Val	155	151	185	171	9.7	0.06
Total	1163 ^b	1179 ^b	1409 ^a	1279 ^{ab}	55.1	0.02
Nonessential						
Ala	171 ^b	173 ^b	200 ^a	182 ^b	8.5	0.03
Asp	262 ^c	273 ^{bc}	334 ^a	294 ^b	13.5	0.009
Glu	355 ^c	393 ^b	475 ^a	399 ^b	17.6	0.001
Gly	148	144	174	166	8.5	0.07
Pro	124 ^c	136 ^b	158 ^a	134 ^b	5.7	0.001
Ser	90	104	112	99	8.0	0.17
Tyr	77	75	91	87	7.0	0.11
Total	1226 ^c	1299 ^{bc}	1544 ^a	1361 ^{ab}	59.0	0.004
Total AA	2390 ^c	2478 ^{bc}	2953 ^a	2640 ^b	112.4	0.01

^{a,b,c}Values within the same row with uncommon superscripts are different ($P < 0.05$). Pairwise comparisons were calculated using the appropriate standard error.

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

Table 11. Least square means for production and composition of milk from lactating dairy cows fed diets containing different rumen-protected soy products.

Item	Treatment ¹				SEM	P > F
	SSBM	ESBM	NSBM	WRSB		
Milk, kg/d	20.5 ^b	22.6 ^{ab}	25.0 ^a	22.5 ^{ab}	2.0	0.04
3.5% FCM, ² kg/d	22.2 ^c	25.2 ^b	28.3 ^a	24.2 ^b	2.0	0.04
Fat						
%	4.04	4.24	4.36	4.05	0.38	0.51
kg/d	0.82 ^c	0.94 ^b	1.08 ^a	0.90 ^b	0.06	0.001
CP						
%	3.62	3.63	3.65	3.46	0.12	0.21
kg/d	0.74 ^c	0.81 ^b	0.90 ^a	0.78 ^c	18.6	0.04
True protein						
%	3.43	3.44	3.47	3.28	0.13	0.23
kg/d	0.70 ^b	0.77 ^b	0.86 ^a	0.73 ^b	0.06	0.005
TS						
%	13.2	13.2	13.5	12.9	0.42	0.21
kg/d	2.71 ^b	2.96 ^b	3.38 ^a	2.89 ^b	0.23	0.01
MUN, ³ mg/dL	16.7	16.4	16.1	16.7	2.40	0.94

^{a,b,c}Values within the same row with uncommon superscripts are different ($P < 0.05$). Pairwise comparisons were calculated using the appropriate standard error.

¹ESBM = Expeller soybean meal; NSBM = heated, xylose-treated soybean meal; SSBM = solvent-extracted soybean meal; and WRSB = whole roasted soybeans.

²3.5% FCM = 0.4324 (kilograms of milk) + 16.216 (kilograms of fat).

in the profile of EAA that exit the rumen is accounted for by the individual EAA content of RUP and the contribution of RUP to the intestinal supply of NAN. Because differences in the EAA composition among soy protein sources were small (Table 2), it is reasonable to expect that significant improvements in the intestinal supply of EAA, particularly of Lys and Met, would be achieved only if the contribution of NANMN to the passage of NAN to the duodenum is remarkably increased. As previously indicated, the proportion of the ruminal outflow of NAN contributed by NANMN was not affected significantly by treatments, which provides an explanation for the lack of significant responses in the postruminal supply of Lys and Met in response to the addition of ESBM, NSBM, or WRSB to the SSBM-based diet.

Production of Milk and Milk Composition

Yields of milk and 3.5% FCM were highest for NSBM, intermediate for ESBM and WRSB, and lowest for SSBM, although differences in milk production were significant only between SSBM and NSBM (Table 11). The concentration of fat, CP, true protein, TS, and urea N were not affected by the source of soy protein. The yield of milk components, however, paralleled changes in milk production. That is, the yield of fat, CP, true protein, and TS were highest for NSBM, intermediate for ESBM and WRSB, and lowest for SSBM. However, differences in the daily output of true protein and TS were not significant among SSBM, ESBM, and WRSB.

In a summary of 37 comparisons (Ipharraguerre and Clark, 2005), it was estimated that replacing SSBM with rumen-protected soy products significantly increased the yield of milk but did not affect the production of CP and fat. It should be noted, however, that the magnitude of the response in milk output (+2.7%) that was estimated in that review was 12 to 4 times smaller than the responses obtained in this experiment (i.e., +21.9, 10.3, and 9.8% for NSBM, ESBM, and WRSB, respectively). In another summary of the literature, Santos et al. (1998) reported that increasing the RUP content of SSBM-based diets with rumen-protected soy products significantly increased milk yield in 6 of 29 comparisons but significantly decreased milk protein percentage in 8 of the 29 comparisons. Using data from 13 treatment comparisons between SSBM and WRSB, Grummer and Rabelo (2000) estimated that feeding WRSB to dairy cows in research trials increased the yields of milk and FCM on average by 1.5 and 2.3 kg/d but decreased milk protein content by 0.10 percentage units. Similar lactational responses were estimated by these authors for 12 comparisons between SSBM and extruded soybeans. Although the positive milk and FCM responses elicited by rumen-protected soy products in this experiment are consistent with previous research, the magnitude of these effects was considerably larger than expected. For this reason, and because of the limited number of cows that were involved in this study, caution is recommended in extrapolating these data to other situations.

CONCLUSIONS

Replacing SSBM with rumen-protected soy products in the diet of lactating dairy cows sustained DMI and did not alter the extent, percentage, and site of OM and starch digestion. Compared with SSBM, soy supplements of reduced rumen degradability decreased the molar proportion of isobutyrate and valerate as well as the concentration of NH_3N (ESBM and NSBM) in ruminal fluid. The NSBM and WRSB treatments increased, and ESBM tended to increase, the intestinal supply of NANMN without depressing the ruminal outflow of microbial N. However, increases in the ruminal outflow of NANMN elicited by these RUP sources were not sufficiently large to result in significant improvements in the postruminal supply of Met and Lys.

These results suggest that replacing a portion of SSBM with ESBM, NSBM, or WRSB may increase the quantity of feed protein that reaches the small intestines of dairy cows. However, significant improvements in the supply of previously reported limiting AA for milk production, particularly of Met, should not be expected. To accomplish this goal, it seems that these rumen-protected soy products must be combined with other RUP sources and (or) rumen-protected AA that complement their EAA profile.

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