A Pelleted Combination of Raw Soyhulls and Condensed Corn Steep Liquor for Lactating Dairy Cows¹

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ABSTRACT

An experiment was conducted to evaluate the effect of a pelleted combination of raw soyhulls and condensed corn steep liquor on performance and plasma metabolites when fed to replace a portion of the grain and forage in diets for lactating dairy cows. The raw soybean hull-corn steep liquor pellet (SHSL) contained 24.2% crude protein, 8.7% rumen undegradable protein, 28.9% acid detergent fiber, 36.7% neutral detergent fiber, and 2.5% ether extract (% of dry matter, [DM]). Eighteen multiparous Holstein cows were assigned to one of three diets in a replicated 3 × 3 Latin square design with 28-d periods. Cows were blocked by pretreatment body weight and energy-corrected milk (ECM) and assigned to control, SHSL (20.7% of diet DM), or pelleted raw soybean hulls ([PSH] 14.3% of diet DM). The SHSL product replaced 6.2% alfalfa hay, 3.7% corn silage, 6.6% corn, and 3.3% soybean meal (SBM), and 1.7% expeller SBM replaced solvent SBM in order to maintain dietary levels of rumen undegradable protein. PSH replaced 6.2% alfalfa hay, 3.7% corn silage, and 5.1% corn. Diet crude protein (%) and energy density (Mcal/kg NE_L) were 16.6 and 1.64, 16.3 and 1.65, 17.1 and 1.63 for control, SHSL, and PSH, respectively. Cows fed PSH consumed more DM than cows fed control, with the intake of cows fed SHSL being intermediate. SHSL and PSH increased ECM, milk protein, and solids-notfat and showed higher concentrations of milk and plasma urea N and total alpha-amino N in plasma than the control diet. Furthermore, feeding SHSL tended to improve the ratio of ECM to DM intake. There was no effect of diet on concentrations of total essential and nonessential amino acids in plasma. These production data suggest SHSL can replace a portion of

the forage, grain, and SBM in diets for lactating dairy cows without decreasing lactational performance.

(**Key words:** soybean hull, corn steep liquor, byproduct, dairy cattle)

Abbreviation key: CSL = condensed corn steep liquor, ECM = energy-corrected milk, MUN = milk urea nitrogen, NFC = nonfiber carbohydrate, PSH = pelleted raw soybean hulls, PUN = plasma urea nitrogen, RSH = raw soybean hulls, SBM = soybean meal, SHSL = raw soybean hull-condensed corn steep liquor pellet, SNF = solids-notfat, TAAN = total α -amino nitrogen.

INTRODUCTION

Research continues to show the usefulness of byproduct feedstuffs in dairy cattle diets. Mowrey and Spain (1999) found that 20% of lactating dairy cattle diets contain byproduct feedstuffs in the Midwest United States. Incorporating byproducts into diets for dairy cattle often improves ration quality and reduces feed costs. Some negative factors associated with byproducts include local availability, seasonal supply, shipping costs, storage life, and variability in chemical composition.

Survey data from Mowrey and Spain (1999) indicate most (63%) of the grain and oilseed processing byproducts fed to lactating dairy cows in the Midwest United States originate from corn, wheat, and soybeans. According to Mowrey and Spain (1999), nearly 25% of lactating dairy cows are fed soybean hulls. Raw soybean hulls (RSH) contain a highly digestible source of fiber (Garleb et al., 1988). Previous research with soybean hulls in dairy diets suggests they possess an energetic value similar to corn (Nakamura and Owen, 1989), whereas others have described their ability to replace forage fiber (Grant, 1997). Condensed corn steep liquor (CSL), a byproduct of the wet corn milling industry, contains a mixture of carbohydrates, amino acids, peptides, organic compounds, heavy metals, inorganic ions, and myo-inositol phosphates (Hull et al., 1996). Corn steep liquor has improved BW and body condition when used as a protein supplement for beef cattle grazing dormant native range (Wagner et al., 1983), and in vitro work by Filho (1999)

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indicated CSL increases starch digestion but decreases cellulose digestion. Combining RSH and CSL into a dry pellet form could potentially provide a transportable product that is compatible with the nutritional needs of lactating dairy cows.

Our laboratory has developed a pelleted feedstuff of raw soybean hull-corn steep liquor (**SHSL**), containing 75% raw soybean hulls and 25% CSL (DM basis). A preliminary, short-term feeding experiment using cows in late lactation indicated SHSL is palatable, high in fiber and protein, and suitable for lactating dairy cattle diets (DeFraire et al., 2001). The objective of the present work was to evaluate the effect of SHSL on performance and plasma metabolites when fed to replace a portion of the grain and forage in diets for lactating dairy cows.

MATERIALS AND METHODS

Animal care and handling was in accordance with a protocol approved by the Kansas State University Institutional Animal Care and Use Committee.

Production of SHSL

The CSL used to produce SHSL contained equal proportions of byproducts from starch extraction and ethanol production facilities (Minnesota Corn Processors, LLC, Columbus, NE). RSH were obtained from a soybean meal production facility in Northeast Kansas (Bunge, Inc., Emporia, KS). The pelleted combination of RSH and CSL (SHSL) was manufactured at the Kansas State University (Manhattan, KS) pilot feed mill using a 30-hp California Pellet Mill 1000 series "Master HD" model, (Crawfordsville, IN) equipped with a standard conditioner and a 4.76×31.75 mm (hole diameter $\times$ effective die thickness) die. A liquid pump (Robins and Myers, Inc., Springfield, OH) was used to propel CSL into the pellet mill conditioner. Conditioning speed and temperature remained constant at 28 rpm and 66°C, respectively. All pellets were conveyed to a California Pellet Mill horizontal cooler, equipped with a steam heat exchanger that generated a temperature of 104°C to assist in drying of the pellets. The pellets remained in the California Pellet Mill horizontal cooler for approximately 6.5 min, after which they were conveyed by bucket elevator to a sack-off bin, packaged into paper bags (approx. 18 kg), placed on pallets, and shipped to the Kansas State University Dairy Teaching and Research Center, Manhattan, KS.

The pellet mill feeder was calibrated by incrementally increasing the flow rate of RSH and recording the respective rpm using a photo/contact digital tachometer (Model 05-028-23; Fisher Scientific, Pittsburgh, PA). Throughput was recorded in 10-s intervals, in triplicate, at four different feeder-screw speeds. A linear trend line

was established by regressing throughput on rpm of the feeder screw. This model was used to predict flow rates of RSH to the pellet mill conditioner at speeds within the linear range.

The liquid pump was calibrated in the same manner to determine the flow rate of CSL to the pellet mill conditioner. CSL liquor was pumped into a tared weigh bucket at various pump speeds. The rpm of the liquid pump and CSL output (kg/10 s) was recorded in triplicate at various rpm, and a trend line was fit to the data, which allowed the model to predict flow rates at pump speeds within the linear range.

These procedures were used to produce the final product, containing 75% RSH and 25% CSL (DM basis). Predicted and analyzed nutrient composition of RSH, CSL, and SHSL are shown in Table 1. Differences between predicted and analyzed values suggest the ratio of RSH:CSL was lower than our anticipated ratio of 75:25 (DM basis).

Animals, Diets, and Sampling

Eighteen multiparous Holstein cows averaging 148 ± 35 DIM and 41.5 kg/d energy-corrected milk (**ECM** = $(0.327 \times \text{milk yield}) + (12.95 \times \text{fat yield}) + (7.2 \times \text{protein yield})$; Orth, 1992) were used in six replicated 3×3 Latin squares (all possible dietary treatment sequences were represented equally within the experimental design) with 28-d periods. All cows were injected with bST (Posilac; Monsanto Co., St. Louis, MO) at 14-d intervals throughout the study. Cows were housed and individually fed in tie-stall facilities at the Kansas State University Dairy Teaching and Research Center. Experimental diets (Table 2) were control, SHSL (20.7% of diet DM), or pelleted RSH (**PSH**) 14.3% of diet DM). The PSH diet was formulated to provide RSH at a level equal to the RSH contained in the SHSL diet. Experimental diets were formulated to be isonitrogenous and meet NRC (1989) guidelines for 40 kg/d milk production with similar amounts of NDF, ADF, and RUP. All diets contained similar levels of menhaden fish meal and blood meal, and expeller soybean meal (**SBM**) replaced a portion of the solvent SBM in the SHSL diet to equalize diet RUP.

One week prior to initiation of treatments, cows were moved into the tie-stall facility and fed a common diet consisting primarily of alfalfa hay, corn silage, and corn grain. Pretreatment ECM and BW were used to assign cows to squares. Diets were mixed and offered twice daily for ad libitum consumption as a TMR at 0600 and 1700 h. Orts were removed and weighed once daily, and TMR offered was adjusted to ensure 10% feed refusal. Samples of TMR, Orts, and corn silage were collected weekly and dried at 105°C for DM determination. Samples of alfalfa hay, corn silage, SHSL, and PSH were collected weekly

Table 1. Nutrient composition of raw soybean hulls, condensed corn steep liquor (CSL), and a pellet containing 75% raw soybean hulls, 25% condensed corn steep liquor (SHSL [DM basis]).

Item	Raw soyhulls	Condensed CSL	SHSL	
			Predicted ¹	Analyzed
DM, %	91.0	52.5	81.4	87.0
CP, %	13.5	44.2	21.2	24.2
Soluble protein, % of CP	32.0	92.0	47.0	39.8
RUP, % of CP	44.0	9.0	35.3	36.0
ADF, %	43.3	0.7	32.7	28.9
NDF, %	58.7	2.3	44.6	36.7
NFC, ² %	19.5	42.4	25.2	28.2
Ether extract, %	2.9	0.8	2.4	2.5
Ash, %	5.4	10.5	6.7	7.5
Ca, %	0.68	0.08	0.53	0.45
P, %	0.18	2.04	0.65	0.75
Mg, %	0.27	0.75	0.39	0.44
K, %	1.42	2.89	1.79	1.96
Na, %	0.04	0.17	0.07	0.18
S, %	0.12	1.90	0.57	0.48
Fe, mg/kg	592	119	473	402
Zn, mg/kg	44	101	58	68
Mn, mg/kg	30	40	33	36
Cu, mg/kg	11	6	10	9

¹Predicted = [(0.75 × raw soyhulls) + (0.25 × condensed corn steep liquor)].

²Nonfiber carbohydrate = 100 – (% CP + % NDF + % ether extract + % ash).

and composited by period. Fish meal and blood meal were sampled at the beginning of the trial, and cottonseed was sampled by load. Grain mixes were sampled by batch and composited by period.

Cows were milked twice daily at 0530 and 1630 h, and milk yield was recorded. Milk samples (a.m., p.m. composite) were obtained weekly and analyzed for protein, fat, lactose, solids-notfat (SNF), milk urea nitrogen (MUN), and SCC. Cows were weighed immediately after the p.m. milking on two consecutive days at the beginning of the study and the end of each period. Averages of the two weights were used for analysis. Body condition was scored according to Wildman et al. (1982) at the beginning of the study and the end of each period. Urine and fecal samples were collected on d 6 of each week and immediately analyzed for pH using a portable pH meter equipped with a combination electrode. Weekly blood samples (~15 ml) were collected from the coccygeal vein into evacuated tubes (Becton Dickinson and Co., Franklin Lakes, NJ) containing EDTA approximately 3 h after feeding and immediately placed on ice for transport to the laboratory. Blood was centrifuged, and plasma was harvested and stored at –20°C until further analysis. At the end of each 28-d period, a separate blood sample was collected from the jugular vein into evacuated tubes containing sodium heparin, plasma was harvested, and concentrations of individual amino acids were measured following the procedures outlined by Campbell et al. (1997).

Laboratory Analysis

Dietary components (alfalfa hay, corn silage, whole cottonseed, concentrate, SHSL, and PSH) were analyzed by Northeast DHI Forage Testing Laboratory, Ithaca, NY. CP was measured as Kjeldahl N × 6.25. *Streptomyces griseus* enzymatic technique was used to measure protein degradability using the method of Roe and Sniffen (1990) for concentrates and the method of Coblenz et al. (1999) for forages. In addition, NDF, ADF, and lignin were measured using the ANKOM A200 (ANKOM Technology Corp., Fairport, NY) filter bag technique. Ether extract was measured using the automated Tecator Soxtec System HT6 (FOSS North America, Eden Prairie, MN). Nonfiber carbohydrate (NFC) was calculated by difference using the equation $\text{NFC (\%)} = 100 - (\% \text{CP} + \% \text{NDF} + \% \text{ether extract} + \% \text{ash})$. Diet NE_L values were calculated and reported using the computer software package provided by NRC (2001). The analyzed nutrient composition of SHSL (Table 1) was substituted for the default values listed for soybean hulls displayed within the byproduct/other feeds category of the software program.

Heart of America DHI Laboratory, Manhattan, KS, conducted milk compositional analysis. Milk true protein, fat, and lactose were determined using near-infrared spectroscopy (Bentley 2000 Infrared Milk Analyzer; Bentley Instruments, Chaska, MN). Concentration of MUN was determined using chemical methodology

Table 2. Ingredient and nutrient composition of experimental diets.

Item	Diet		
	Control	SHSL ¹	PSH ²
	% of DM		
Ingredient			
Alfalfa hay	29.7	23.8	24.3
Corn silage	16.0	11.0	11.2
Whole cottonseed	9.3	9.1	9.3
Corn grain, ground	33.5	27.2	29.2
Soybean meal, 48% CP	5.0	...	5.1
Expeller soybean meal	...	1.7	...
SHSL	...	20.7	...
Soybean hulls, pelleted	...	...	14.3
Wet molasses	1.0	1.0	1.0
Fish meal	1.9	1.9	2.0
Blood meal	0.50	0.50	0.50
Dicalcium phosphate	.42	0.16	0.50
Limestone	1.38	1.59	1.30
Sodium bicarbonate	0.66	0.66	0.67
Magnesium oxide	0.21	0.21	0.21
Trace mineralized salt ³	0.32	0.32	0.32
Vitamin ADE premix ⁴	0.13	0.13	0.13
Sodium selenite premix ⁵	0.013	0.014	0.014
Nutrient			
CP, %	16.6	16.3	17.1
RUP, % of CP	44.1	50.3	45.1
NE _L , ⁷ Mcal/kg	1.64	1.65	1.63
Ether extract, %	5.92	5.07	5.72
NDF, %	26.9	27.5	31.6
ADF, %	19.1	20.6	23.1
NFC, ⁷ %	44.0	44.4	37.7
Ash, %	6.61	6.74	7.86
Ca, %	1.10	1.20	0.96
P, %	0.47	0.45	0.52
Na, %	0.34	0.34	0.34
K, %	1.48	1.56	1.46
Cl, %	0.36	0.33	0.34
S, %	0.20	0.26	0.19
DCAD, ⁸ meq/kg of DM	302	289	307

¹Pellet containing 75% raw soybean hulls and 25% condensed corn steep liquor (DM basis).

²Pelleted raw soybean hulls.

³Composition: not less than 95.5% NaCl, 0.24% Mn, 0.24% Fe, 0.05% Mg, 0.032% Cu, 0.032% Zn, 0.007% I, 0.004% Co.

⁴Contributed 5,733 IU vitamin A, 2,866 IU vitamin D, and 17 IU vitamin E per kg diet DM.

⁵Contained 600 mg Se per kg premix.

⁶Estimated from NRC (2001).

⁷Nonfiber carbohydrate = 100 - (% NDF + % CP + % ether extract + % ash).

⁸DCAD as [(Na + K) - (Cl + S)] in milliequivalents per kg of DM.

based on a modified Berthelot reaction (ChemSpec 150 Analyzer; Bentley Instruments, Chaska, MN), and somatic cells were counted using a flow cytometer laser (Somacount 500; Bentley Instruments, Chaska, MN).

Coccygeal plasma samples were thawed, and concentrations of glucose, plasma urea N (**PUN**), and total α -amino N (**TAAN**) were measured using a Technicon AutoAnalyzer III (Technicon Industrial Systems, Tarrytown, NY). A peroxidase indicator reaction with glucose oxidase (Technicon industrial method no. SE-4-0036FJ4) was used to determine plasma glucose concentrations, based on procedures of Gochman and

Schmitz (1972). **PUN** was measured by a diacetyl-mon ozime assay (Technicon industrial method no. 339-01), according to methods of Marsh et al. (1965), and **TAAN** was determined by a trinitrobenzenesulfonic acid assay (Technicon industrial method no. 512-77T), based on the method of Palmer and Peters (1969). Plasma NEFA concentrations were measured using a colorimetric assay (NEFA-C kit; Wako Chemicals, Richmond, VA), as modified by Eisemann et al. (1988). A colorimetric assay (Infinity Triglycerides Reagent procedure no. 343; Sigma Diagnostics, St. Louis, MO) was used to measure the concentration of plasma triacylglycerides.

Statistical Analysis

ANOVA was conducted using the MIXED procedure (Littell et al., 1996) of SAS (1990). Observations from one cow were omitted due to reasons not related to dietary treatment. Cow served as the experimental unit. Data collected daily (milk production and DMI) and weekly (milk composition and plasma metabolites) were analyzed as split plots, with the main plot as Latin squares and week as the subplot. The model included cow, period, treatment, week, and the week $\times$ treatment interaction, and animal $\times$ period $\times$ treatment was included as a random variable to serve as the main plot error term. Data collected once per period (BW, BCS, and plasma amino acid profiles) were analyzed using the MIXED procedure with cow, period, and treatment in the model. Treatment means were separated using the PDIFF option for all comparisons among means when the *F*-test for treatment was significant ($P < 0.05$). Tendencies were defined as such when $P < 0.10$.

RESULTS AND DISCUSSION

General Observations

Ingredient and chemical composition of experimental diets are shown in Table 2. Diet CP concentrations (%) were 16.6, 16.3, and 17.1, and calculated energy densities (Mcal NE_L/kg) were 1.64, 1.65, and 1.63 for control, SHSL, and PSH, respectively. A higher-than-expected CP content of the formulated grain mix resulted in the higher CP content of PSH. All diets were formulated to contain 40% RUP, based on NRC (1989) values and an analyzed value for SHSL (32% RUP). The differences between formulated and analyzed RUP content of the diets resulted from higher-than-expected RUP content of dietary ingredients, particularly SHSL. Diet forage NDF was 18.1, 13.8, and 14.0% for control, SHSL and PSH, respectively.

Cow Performance

Production responses to experimental diets are presented in Table 3. Cows fed PSH consumed more ($P < 0.05$) DM than cows fed control, with the intake of cows fed SHSL being intermediate. Research conducted by Kertz et al. (1981), using component-fed diets, found pelleting of concentrates increased the rate of consumption. Weidner and Grant (1994) reported a 14% increase in DMI when soybean hulls were fed with coarsely chopped hay; they postulated that soybean hulls increase DMI because they reduce dietary particle size. This hypothesis was based upon earlier studies with cows fed soybean mill run (MacGregor et al., 1976) and soybean hulls (Bernard and McNeill, 1991). MacGregor et al. (1976) sug-

gested that the particle size of soybean hulls facilitates higher rates of passage, allowing for higher levels of DMI. Bernard and McNeill (1991) speculated the higher level of DMI resulted from the higher level of palatability and digestibility of soybean hulls. In general, soybean hulls minimally affected DMI when used to replace forage (Sarwar et al., 1991) or concentrates (Nakamura and Owen, 1989). One exception is the work of Bernard and McNeill (1991), who reported higher intakes when ground corn was replaced by soybean hulls at 23% of diet DM. In our study, lower levels of forage NDF in cows fed SHSL and PSH likely contributed to the higher levels of DMI because forage NDF is negatively related to DMI ($r = -0.31$ [Armentano and Pereira, 1997]).

Cows fed SHSL or PSH produced more milk and ECM ($P < 0.05$) than cows fed control. Diets formulated to partially replace concentrates with soybean hulls have resulted in minimal effects on milk production (Bernard and McNeill, 1991; Cunningham et al., 1993). Likewise, others have replaced a mix of alfalfa and corn silage with soybean hulls and reported no significant effects on milk production (Sarwar et al., 1992; Pantoja et al., 1994). In our study, soybean hulls replaced a combination of forage and concentrate, which reduced the content of the top and bottom box of the Penn State Particle Separator and increased the content of the middle box (data not shown). Perhaps this combination of feedstuffs provided sufficient effective NDF and improved DM digestibility, thereby resulting in higher milk yields from cows fed SHSL and PSH. Efficiency of ECM production (ECM/DMI) was similar among cows fed control and PSH and tended ($P = 0.06$) to be higher for cows fed SHSL. Because the SHSL and PSH contained similar amounts of soybean hulls (~15% of diet DM), the CSL addition, particularly the CP and NFC of CSL, may be responsible for improved diet digestibility, as previously reported by Johnson et al. (1962).

Effects of experimental diets on milk composition are presented in Table 3. Milk protein percentage was not affected by diet, but feeding SHSL and PSH increased ($P < 0.05$) milk protein yield. The increase in milk protein yield was directly related to the observed increase in milk yield for cows fed SHSL and PSH. The ratio of CP output in milk to calculated CP intake was highest ($P < 0.05$) for cows fed SHSL and similar for those fed PSH and control. Intakes of CP were 4.3, 4.3, and 4.6 kg/d for control, SHSL, and PSH, respectively. Because milk protein yield and TAAN were similar for SHSL and PSH, but higher than for cows fed control, differences in protein efficiencies (CP output in milk/CP intake) were likely a result of differences in dietary CP content, which exceeded requirements (NRC, 2001) in all diets. Milk fat percentage and SCC were similar for cows fed SHSL and PSH but lower ($P < 0.05$) than those fed control. However,

Table 3. DMI, milk yield, milk composition, milk SCC, BW, and BCS of cows fed control, a pelleted combination of 75% raw soybean hulls and 25% condensed corn steep liquor (SHSL [DM basis]), or pelleted raw soybean hulls (PSH).

Item	Diets			SEM
	Control	SHSL ¹	PSH ²	
DMI, kg/d	26.0 ^b	26.7 ^{ab}	27.3 ^a	0.3
Milk, kg/d	33.9 ^b	36.3 ^a	36.6 ^a	0.5
ECM ³ , kg/d	36.5 ^b	38.4 ^a	38.3 ^a	0.6
ECM/DMI	1.33	1.39	1.35	0.02
Milk fat, %	4.11 ^a	3.93 ^b	3.89 ^b	0.06
Milk fat, kg/d	1.38	1.42	1.40	0.03
Milk CP, %	3.12	3.14	3.13	0.02
Milk CP, kg/d	1.05 ^b	1.13 ^a	1.14 ^a	0.02
Milk SNF ⁴ , %	8.65 ^b	8.78 ^a	8.78 ^a	0.03
Milk SNF, kg/d	2.94 ^b	3.18 ^a	3.22 ^a	0.05
Milk lactose, %	4.64 ^b	4.75 ^a	4.75 ^a	0.03
Milk lactose, kg/d	1.59 ^b	1.72 ^a	1.75 ^a	0.03
SCC × 10 ³ /ml	221 ^a	128 ^b	129 ^b	31
Milk urea N, mg/dl	15.2 ^b	16.8 ^a	16.4 ^a	0.3
CP efficiency ⁵ , %	24.8 ^b	26.3 ^a	24.5 ^b	0.3
BW, kg	663	663	660	5
BCS ⁶	2.66	2.68	2.65	0.04
Urine pH	8.32 ^{ab}	8.30 ^b	8.33 ^a	0.01
Fecal pH	6.49 ^c	6.65 ^a	6.58 ^b	0.03

^{a,b}Means within a row not bearing common superscript differ ($P < 0.05$).

¹Pellet containing 75% raw soybean hulls and 25% condensed corn steep liquor (DM basis).

²Pelleted raw soybean hulls.

³Energy-corrected milk (Orth, 1992).

⁴Solids nonfat.

⁵CP output in milk (kg/d)/dietary CP intake (kg/d) × 100%.

⁶1 = emaciated and 5 = overly fat (Wildman et al., 1982).

fat yields were similar among treatments, suggesting that the lower milk fat percentage was a result of dilution, rather than a depression in fat synthesis. The importance of supplying adequate effective fiber to maintain ruminal pH and optimal milk fat production has been outlined by Allen (1997). More specifically, the value of effective fiber in diets containing soybean hulls was illustrated by Weidner and Grant (1994), who fed soybean hulls at 25% of diet DM with and without 20% alfalfa hay and reported improvements in yields of milk fat and protein and DM digestibility when soybean hulls were fed in combination with alfalfa hay. The level of alfalfa hay in the SHSL and PSH diets were similar (24% of diet DM) to those of Weidner and Grant (1994). In general, milk fat production has not been affected when soybean hulls are substituted for portions of concentrates (Nakamura and Owen, 1989; Bernard and McNeill, 1991) or forages (Cunningham et al., 1993). In our study, the ability to maintain milk fat yield and increase milk protein yield by cows fed SHSL or PSH may be attributed to adequate levels of effective fiber, in general agreement with the work of Weidner and Grant (1994). However, the substitution of SHSL and PSH for portions of both forage and concentrate resulted in differences in diet NDF and NFC, confounding responses to source and level

of carbohydrates in our treatments, as outlined by Arm-entano and Pereira (1997).

In agreement with Broderick and Clayton (1997), MUN and PUN (Tables 3 and 4, respectively) responded similarly. Concentrations of urea N in both milk and plasma were higher ($P < 0.05$) for cows fed SHSL and PSH than those fed control. Because diet CP (% of DM) and diet CP per unit of dietary NE_L are highly correlated with MUN (Broderick and Clayton, 1997), higher urea N concentrations would be expected for cows receiving PSH. Diet CP and diet CP per unit of dietary energy (Mcal/kg) of cows fed SHSL were similar to those fed control, yet MUN and PUN of cows fed SHSL were similar to MUN and PUN of cows fed PSH. This suggests the protein in SHSL may be more ruminally degradable than indicated by laboratory analysis.

Dietary treatments resulted in minor differences in urine pH (Table 3). These differences were perhaps due to the sulfur content of SHSL. Corn wet-milling byproducts, such as corn steep liquor, are typically high in sulfur (1.9% DM basis) because of the addition of sulfur dioxide during the steeping process. The sulfur of SHSL was largely responsible for the reduction in the dietary cation-anion difference (Table 2). Fecal pH was highest in cows fed SHSL and lowest in those fed control. Ireland-Perry

Table 4. Effects of diet on plasma metabolites.

Plasma	Diet			SEM
	Control	SHSL ¹	PSH ²	
Urea N, mg/dl	16.1 ^b	17.3 ^a	17.2 ^a	0.3
Total α -amino N, mM	2.30 ^b	2.47 ^a	2.53 ^a	0.03
Glucose, mg/dl	71.8	72.0	71.9	0.4
Triacylglycerol, mg/dl	12.0	12.6	12.2	0.3
NEFA, mM	105	106	93	8
Essential amino acids, μ M				
Lys	85.0	89.3	80.8	3.6
His	65.0 ^{ab}	67.3 ^a	61.0 ^b	1.8
Arg	87.0	87.4	81.5	3.0
Thr	91.5	90.2	90.1	4.9
Val	288	308	282	10
Met	24.8	23.8	22.8	0.9
Ile	142	149	134	5
Leu	186	185	170	7
Phe	58.1	55.5	53.0	1.9
Trp	39.6	41.4	41.2	1.1
Total essential	1068	1099	1018	34
Nonessential amino acids, μ M				
Asp	9.7	10.6	10.5	0.5
Ser	69.8	71.7	68.0	2.7
Glu	54.4	53.3	50.8	1.6
Gly	197	207	209	6.5
Ala	240	237	240	7.6
Asn	39.3	41.1	37.4	2.0
Gln	230	231	216	7.9
Tyr	61.8 ^a	57.7 ^{ab}	52.8 ^b	2.6
Total nonessential	902	911	886	26
Total amino acids, μ M	1971	2011	1904	55

^{a,b}Means within a row not bearing common superscript differ ($P < 0.05$).

¹Pellet containing 75% raw soybean hulls and 25% condensed corn steep liquor (DM basis).

²Pelleted raw soybean hulls.

and Stallings (1993) found fecal starch content to be negatively correlated to fecal pH ($r = -0.55$). Although fecal starch content was not measured in our study, differences in fecal pH were possibly due to differences in dietary starch because soybean hulls, in both SHSL and PSH diets, partially replaced ground corn in the control diet. The higher fecal pH observed in cows fed SHSL could also be attributed to the higher level of limestone in the diet. Brinke et al. (1984) found that increasing the level of limestone from 0.8 to 1.7% of diet DM resulted in a significant ($P < 0.01$) increase in fecal pH of steers fed corn-based diets. BW and body condition were not influenced by diet and remained relatively constant throughout the study.

Plasma Constituents

Effects of experimental diets on plasma metabolites are presented in Table 4. Concentrations of glucose, NEFA, and triacylglycerol in plasma were not influenced by diet. Milk yields and concentrations of glucose in plasma observed in our study were higher than those of MacGregor et al. (1976), who also reported no treatment differences when soybean mill run was used to replace

corn at 0, 27, and 49% of diet DM. The higher ($P < 0.05$) TAAN in plasma of cows fed SHSL and PSH likely contributed to the higher milk protein yields. Although differences in TAAN in plasma existed, the sum of individual amino acids was similar among treatments. Concentrations of plasma His in cows fed control were similar to those fed SHSL and PSH, but plasma His levels were higher ($P < 0.05$) for cows fed SHSL than those fed PSH. Vanhatalo et al. (1999) found His to be the first limiting essential amino acid using multiparous cows in mid- to late lactation (90 to 120 DIM) fed grass-silage-based diets. Because milk yields were similar for cows fed SHSL and PSH, His was likely not limiting in our study. The only nonessential amino acid affected by the experimental diets was Tyr, which was highest for cows fed control and lowest for those fed PSH.

CONCLUSIONS

Feeding mid-lactation dairy cows diets containing 20.7% SHSL or 14.3% PSH (DM basis) increased the yield of milk and milk CP, SNF, lactose, and urea N. The tendency for an improvement in the efficiency of ECM production suggests SHSL has the potential to im-

prove diet digestibility. Although further research with SHSL is warranted, our investigations indicate SHSL is a useful alternative feedstuff for lactating dairy cow diets when fed to replace a portion of the forage, grain, and SBM.

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