The Response of Lactating Dairy Cows to Increasing Levels of Whole Roasted Soybeans

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ABSTRACT

Twenty-four Holstein cows, including four primiparous and four ruminally cannulated, were in replicated 4 × 4 Latin squares with 21-d periods to determine the effects of feeding level of whole roasted soybeans on lactation performance and rumen function. Cows were fed rations containing a 50:50 forage:concentrate ratio with 0, 12, 18, or 24% of diet DM as whole roasted soybeans. Rations contained 16.8, 16.9, 18.6, and 19.7% CP and 1.68, 1.71, 1.72, and 1.74 Mcal NE_L/kg DM, respectively. Milk production and milk fat percentages for diets containing 0, 12, 18, or 24% whole roasted soybeans were 34.9, 37.5, 38.5, and 38.8 kg/d and 3.23, 3.20, 3.32, and 3.37%, respectively. Milk protein percentage was depressed at all levels of whole roasted soybeans. Ruminal pH, VFA molar percentages except valerate, and DM disappearance of forage from dacron bags did not differ among treatments. Responses were similar among primiparous and multiparous cows. Results suggest benefit from feeding whole roasted soybeans at levels up to 18% of ration DM without adversely affecting DMI, milk fat, or rumen fermentation.

(Key words: whole roasted soybeans, lactating cows, rumen function)

Abbreviation key: AD = apparent total tract nutrient digestibility, DCP = direct current plasma emission spectroscopy, EE = ether extract, SBM = soybean meal, UIP = undegraded intake protein, WRSB = whole roasted soybeans.

INTRODUCTION

Use of whole roasted soybeans (WRSB) in diets for lactating dairy cattle is increasing among dairy producers in the Midwest. Inclusion of WRSB containing 20% ether extract [EE;(15)] is a means of increasing the energy density of diets fed to lactating cows without compromising the proportion forage in the diet. Feeding WRSB that contains 42% CP (15), of which 40 to 60% is resistant to ruminal degradation, may be an effective method of supplying adequate undegraded intake protein (UIP) to the small intestine of high producing dairy cows (20, 30).

Extension specialists and nutrition consultants commonly recommend that WRSB be fed at levels of 2.7 to 3.6 kg/d per cow (9). A major concern with feeding WRSB at higher levels is possible negative effects of polyunsaturated oil contained in WRSB on rumen function. Polyunsaturated soy oil fed independently of the oilseed has been shown to alter rumen fermentation and reduce milk fat percentage (11, 13).

Previous studies have shown favorable lactation responses when diets formulated with WRSB or popped soybeans were fed in comparison with those formulated with soybean meal [SBM;(20, 30)]. Intake of popped or WRSB in these studies did not exceed the 3.6-kg/d limit commonly recommended. Another study found no differences in milk production between primiparous cows fed diets containing 19% (3.6 kg/d) or 33% (6.9 kg/d) popped soybeans or 19 or 33% raw whole soybeans (12): average total VFA concentrations and acetate:propionate did not differ among diets. Although no production responses were observed, data indicated that levels of popped soybeans exceeding recommendations could be fed without adversely affecting rumen function in primiparous cows. A dose-response curve to WRSB for multiparous cows has been determined (25). In their

TABLE 1. Ingredient composition of diets containing different levels of whole roasted soybeans (WRSB).

Ingredient	WRSB, % DM basis			
	0	12	18	24
Alfalfa haylage	35.0	35.0	35.0	35.0
Corn silage	15.0	15.0	15.0	15.0
Ground corn	39.3	35.4	29.4	23.4
Soybean meal, 44% CP	8.1	0	0	0
WRSB	0	12.0	18.0	24.0
Calcium phosphate, dibasic	.3	.3	.3	.3
CaCO₃	1.5	1.5	1.5	1.5
MgO	.2	.2	.2	.2
Trace-mineralized salt	.5	.5	.5	.5
Vitamin premix[1]	.1	.1	.1	.1

[1]Vitamin premix provided vitamins (IU/kg diet DM) A, 3168; D, 600; and E, .6.

study, DMI was low, averaging 16.7 kg/d, and the highest intake of WRSB was only 3.3 kg/d.

Objectives of our study were to examine the response of lactating dairy cows fed diets containing WRSB at or above concentrations exceeding current recommendations and to examine effects of soy oil on rumen fermentation when increasing levels of WRSB were included in the diet.

MATERIALS AND METHODS

Twenty-four lactating Holstein cows were allocated to six replicated 4 × 4 Latin squares with 21-d periods. Days 1 to 14 or each experimental period served as an adaptation period, and all sample and data collection occurred during d 15 to 21. Cows were assigned to squares as follows: square 1, primiparous cows 100 ± 10 d postpartum producing 30 ± 1.5 kg/ d milk; square 2, ruminally cannulated cows 142 ± 64 d postpartum producing 36 ± 7.0 kg/ d milk; squares 3 and 4, high producing multiparous cows 63 ± 25 d postpartum producing 43 ± 2.7 kg/d milk; and squares 5 and 6, low producing multiparous cows 65 ± 34 d postpartum producing 38 ± 1.0 kg/d of milk. Multiparous cows in squares 3 to 6 were assigned to either high or low production groups based on actual milk production 1 wk prior to the start of the trial. Cows within squares were assigned randomly to dietary treatments of either 0, 12, 18, or 24% of diet DM as WRSB. Data collected during period 4 on one multiparous nonfistulated cow were not included in statistical analyses due to severe mastitis.

Diets (Table 1) were formulated to contain a 50:50 forage:concentrate ratio and were fed for ad libitum intake allowing for 10% feed refusals. Forage was fed four times daily at 0400, 1000, 1400, and 2200 h. Concentrate was thoroughly mixed with the forage during 1000- and 2200-h feedings. Forage consisted of 70% alfalfa haylage and 30% corn silage, DM basis. Nutrient composition of the modified TMR is in Table 2. The commercially obtained WRSB were roasted in a Gem roaster (Gem Roaster, Winona, MN) for 2 min at 300.2°F 149°C. Beans were rolled after roasting, resulting in splitting of beans into halves and quarters. Beans were not steeped after roasting. The WRSB contained 38% CP, of which 49.5% was determined to be resistant to ruminal degradation (3). Fatty acid composition of the WRSB was 14.5, 3.1, 21.6, 53.2, and 7.6% $C_{16:0}$, $C_{18:0}$, $C_{18:1}$, $C_{18:2}$, and $C_{18:3}$, respectively, as determined by GLC of methyl esters (27).

Feed offered and refused was measured daily. Feed refusals were sampled and composited on individual cows for d 15 to 18 of each period. Forages were sampled weekly for DM determination, and as-fed forage:concentrate ratios were adjusted accordingly. Concentrate mixes were sampled with each new batch mixed at the feed mill. Concentrate and forage samples were obtained during wk 3 of each period, and orts were dried for 48 h at 60°C in a forced-air oven, ground through a 1-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA), and duplicate samples were analyzed for absolute DM (1), OM (1), CP (1), NDF (19), and $C_{16:0}$ to $C_{18:3}$ fatty acids (27).

TABLE 2. Nutrient composition of diets containing different levels of whole roasted soybeans (WRSB).

Nutrient	WRSB, % DM basis			
	0	12	18	24
CP, %	16.8	16.9	18.6	19.7
UIP,[1,2] %	5.6	6.3	7.2	8.1
NDF, %	26.4	26.4	26.7	27.0
Fatty acids,[3] %	3.0	5.1	6.4	7.0
Ca, %	1.2	1.2	1.2	1.2
P, %	.4	.4	.4	.4
Mg, %	.3	.3	.3	.3
NE_L,[2] Mcal/kg	1.68	1.71	1.72	1.74

[1]UIP = Undegraded intake protein.

[2]Calculated using NRC values (15).

[3]$C_{16:0}$ to $C_{18:3}$ fatty acids.

Fatty acids were determined using GLC (Varian 2100, Sunnyvale, CA) with GP 10% SP-2330 Chromasorb W AW column packing (Supelco, Inc., Bellefonte, PA). Mineral and NE_L content of diets were calculated using published values (15).

Milk yield was recorded on d 15 to 21 of each period. Milk samples from a.m. and p.m. milkings were taken on d 17 to 20 for fat and protein analyses by infrared procedures (Wisconsin DHI laboratory, Appleton, WI).

Rumen fluid samples from fistulated cows were drawn on d 21 of each period via rumen cannulas at 0, 3, and 6 h postfeeding (1000 h). Rumen pH was determined immediately on a fresh aliquot. A second aliquot was acidified with .6 ml of 50% (vol/vol) H_2SO_4 and frozen until analyzed. Twelve nonfistulated, multiparous cows were rumen sampled via an esophageal tube on d 21 at 3 h postfeeding (1000 h). Rumen fluid samples for VFA analysis were preserved as previously described. No pH determination was made on samples obtained via esophageal tube due to possible contamination with saliva. Molar percentages of VFA were determined on all rumen fluid samples using GLC (Varian 2100, Sunnyvale, CA) with GP 10% SP-1200/1% H_3PO_4 on 80/100 Chromasorb W AW column packing (Supelco, Inc., Bellefonte, PA) as described in the Supelco bulletin (28) and modified by Brotz and Schaefer (4).

Gelatin capsules containing ytterbium chloride (61 mg Yb/capsule) mixed with SBM were given twice daily (0900 and 2100 h) on d 12 to 21 of each period to 16 nonfistulated multiparous cows. On d 18 to 21 of each period, fecal grab samples were taken twice daily at 12-h intervals and frozen immediately. Upon thawing, fecal samples were composited on an individual cow basis, dried at 60°C in a forced-air oven, and ground through a 1-mm screen in a Wiley mill. Duplicate fecal samples were analyzed as described for feeds. Dried, ground fecal samples also were wet ashed using a nitric acid digestion and analyzed for Yb concentrations by direct current plasma emission spectroscopy [DCP; (6)]. Apparent total tract nutrient digestibilities (AD) were calculated from intake data and DCP results as AD = 100 - [100 × ([Md]/[Mf]) × ([Nf]/[Nd])], where [Md] is marker concentration in the diet, [Mf] is marker concentration in the feces, [Nf] is nutrient concentration in the feces, and [Nd] is the nutrient concentration in the diet.

Fistulated cows were used to determine forage DM disappearance from dacron bags in situ on d 19 to 21 of each period. Duplicate dacron bags with a finished area of 9 × 12 cm and a pore size of approximately 50 μm were ruminally incubated for 0, 6, 12, 24, 36, 48, and 72 h. A dried, ground (2-mm screen), 2-g sample of forage (70% alfalfa haylage and 30% corn silage) was placed in each dacron bag. After incubation, bags were removed from the rumen, immediately placed in an ice bath to reduce microbial activity, and then washed until rinse water was clear. Bags were dried for 48 h at 60°C in a forced-air oven and weighed to determine forage DM loss.

Data were examined by ANOVA using the general linear models procedure of SAS (21). The statistical model employed was

$$Y_{ijkm} = \mu + S_i + C_j(S)_i + P_k + D_m$$
$$+ (S \times D)_{im} + (S \times P)_{ik}$$
$$+ (P \times D)_{km} + E_{ijkm}$$

where

Y_{ijkm} = dependent variable;

μ = overall mean of the population;

S_i = average effect of square i;

$C_j(S)_i$ = average effect of cow j nested within square i;

P_k = average effect of period k;

D_m = average effect of diet m;

$(S \times D)_{im}$ = interaction of square i and diet m;

$(S \times P)_{ik}$ = interaction of square i and period k;

$(P \times D)_{km}$ = interaction of diet m and period p; and

E_{ijkm} = unexplained residual error, assumed normally and independently distributed.

Average effect of square was tested using cow(square) as the error term. All other terms were tested using the residual mean square. Terms of the model that were not significant ($P > .05$, square × diet interactions and square × period interactions) were dropped from the model and pooled with the residual term. Differences among diets were determined by comparing individual diet least squares means using the protected significance difference test (26). Lactation performance and DMI data for square 1 (primiparous cows), square 2 (fistulated cows), squares 3 and 4 (high producing multiparous cows), and squares 5 and 6 (low producing multiparous cows) also were analyzed separately. All data involving samples taken over time (dacron bag data and rumen pH and VFA data from fistulated cows) were analyzed using split-plot over time. The model used was

$$Y_{ijkm} = \mu + C_i + P_j + D_k + (C \times P \times D)_{ijk}$$
$$+ H_m + (H \times C)_{mi} + (H \times P)_{mj}$$
$$+ (H \times D)_{mk} + E_{ijkm},$$

where

Y_{ijkm} = dependent variable;

μ = overall mean of the population;

C_i = average effect of cow i;

P_j = average effect of period j;

D_k = average effect of diet k;

$(C \times P \times D)_{ijk}$ = interaction of cow i, period j, and diet k;

H_m = average effect of hour m;

$(H \times C)_{mi}$ = interaction of hour m and cow i;

$(H \times P)_{mj}$ = interaction of hour m and period j;

$(H \times D)_{mk}$ = interaction of hour m and diet k; and

E_{ijkm} = unexplained residual error, assumed normally and independently distributed.

Cow, period, and diet effects were tested using the mean square for cow × period × diet as the error term. All other terms were tested using the residual mean square. Terms of the model that were not significant ($P > .05$, hour × period interaction) were dropped from the model and pooled with the residual term. Due to nonsignificant diet × hour interactions for rumen VFA samples, data from the 3-h sampling time point for fistulated animals were pooled with data from the 16 multiparous, nonfistulated animals for analysis. Significance was declared at $P < .05$ unless otherwise noted.

RESULTS AND DISCUSSION

Intakes of DM and selected nutrients are in Table 3. Dry matter intake averaged 24.9 kg/d 55.9lbs/d across all diets and was not different among diets. Estimated intakes of WRSB based on DMI were 0, 3, 4.5 or 6 kg/d for cows receiv- 6.6, 9.9, or 13.2lbs/d ing diets containing 0, 12, 18, or 24% WRSB. Others have observed that DMI of lactating cows fed diets containing WRSB or popped soybeans was similar to that of diets containing SBM (20, 30). No differences in DMI were significant when diets formulated to contain 0, 1.1, 2.2, or 3.3 kg/d of WRSB were fed to lactating cows (25). In contrast, one study (13) has reported that DMI was depressed 9.5% when WRSB (1.9 kg/d) replaced SBM in the diet of lactating cows.

TABLE 3. Intakes of DM and selected nutrients.[1]

Variable	WRSB, % DM basis			
	0	12	18	24
DMI,[2,3] kg/d	24.6 (.2)	24.9 (.2)	25.0 (.2)	24.9 (.2)
Fatty acids,[4] kg/d	.7	1.2	1.5	1.7
UIP,[5,6] kg/d	1.4	1.6	1.8	2.0
NE_L,[7] Mcal/d	41.3	42.6	43.0	43.3

[1] DMI statistically analyzed; other nutrients calculated and not statistically analyzed.

[2] Least squares means are not significantly different $(P > .05)$.

[3] SEM are shown in parentheses.

[4] $C_{16:0}$ to $C_{18:3}$ fatty acids.

[5] UIP = Undegraded intake protein.

[6] The UIP of WRSB determined by an in vitro procedure (3). The UIP of other feeds obtained from NRC (15).

[7] Calculated using NRC values (15).

The absence of a depression in DMI as WRSB were increased in the diet in our study provides indirect evidence that increasing levels of soy oil from WRSB did not depress fiber digestion. Cows receiving 24% of their diet DM as WRSB were consuming 6 kg/d of WRSB. This is approximately twice the quantity commonly recommended. Total fatty acid intake ($C_{16:0}$ to $C_{18:3}$) of cows consuming diets containing 0 to 24% WRSB were .7 and 1.7 kg/d, respectively. Therefore, cows receiving the highest concentration of WRSB were consuming 1 kg/d of fatty acids from soy oil (53.2% $C_{18:2}$) within WRSB. This equals 4% of diet DM being comprised of highly unsaturated long-chain fatty acids from WRSB. Dry matter intake has been affected negatively in other studies when similar or lesser amounts of soy oil were fed in the free form (13).

As the level of WRSB in the diet increased, consumption of UIP also was increased. Energy intake, calculated using NRC (15) values, increased from 41.3 Mcal NE_L/d with control diet to 43.3 Mcal NE_L/d when diets contained 24% of the DM as WRSB. Chandler (5) speculated that the energy value of 2.18 Mcal NE_L/kg assigned to WRSB by NRC (15) is undervalued by as much as 24%. Therefore, differences in energy intake among diets may have been greater than those calculated from NRC (15) values.

Milk production (Table 4) increased 2.6 kg/d when WRSB were increased from 0 to 12% of diet DM. A second increase in milk production of 1.3 kg/d occurred when WRSB increased from 12 to 18% of the DM. Increases in milk production when WRSB or popped soybeans replaced SBM in lactation diets have been observed (20, 30). Others have observed no differences in milk production between cows consuming diets with or without WRSB (13, 25).

Milk fat percentage (Table 4) was similar among cows fed control diet and cows fed

TABLE 4. Production and composition of milk from cows fed different levels of whole roasted soybeans (WRSB).

Variable	WRSB, % DM basis				SEM
	0	12	18	24	
Milk, kg/d	34.9^c	37.5^b	38.8^a	38.8^a	.4
Milk fat, %	3.23^b	3.20^b	3.32^a	3.37^a	.03
Milk fat, kg/d	1.12^c	1.19^a	1.16^b	1.17^b	.02
Milk protein, %	3.11^a	3.03^b	3.00^b	3.01^b	.01
Milk protein, kg/d	1.08^c	1.13^b	1.16^a	1.17^a	.01

[a,b,c] Least squares means in same row with different superscripts differ $(P \leq .05)$.

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TABLE 5. Responses in 3.5% FCM to different levels of whole roasted soybeans (WRSB) by high and low producing multiparous cows, primiparous cows, and fistulated cows.[1]

| Variable | WRSB, % DM basis | | | | SEM |
	0	12	18	24	
Overall	33.3[c]	35.5[b]	37.5[a]	37.8[a]	.4
High producing multiparous (63 ± 25 DIM)[2]	36.9[c]	40.0[b]	41.2[ab]	41.8[a]	1.5
Low producing multiparous (65 ± 34 DIM)	33.2[b]	35.1[b]	37.9[a]	38.1[a]	1.2
Primiparous (100 ± 10 DIM)	28.6[b]	32.0[a]	32.6[a]	33.1[a]	1.3
Fistulated (142 ± 64 DIM)	30.5[b]	30.7[b]	34.0[a]	34.0[a]	1.9

[a,b,c]Least squares means in same row with different superscripts differ ($P \leq .05$).

[1]Square by diet and square by period interactions were not significant ($P > .05$).

[2]Mean ± SD of DIM at start of the trial.

12% of the DM as WRSB but was increased .12 percentage unit when WRSB were increased from 12 to 18% of the DM. Milk fat production followed the same trend as milk production. Milk fat percentage has been observed to increase when cows were fed WRSB or popped soybeans compared with SBM in some (20, 30) but not all studies (13). Milk fat percentages were similar among cows consuming 0, 1.1, 2.2, or 3.3 kg/d of WRSB (25). Primiparous Holstein cows fed diets containing 33% WRSB (1.2 kg/d of soy oil) supported milk fat at 4.05% (12); however, a control diet without WRSB was not fed in this trial. Milk fat percentage was depressed when cows were fed diets supplemented with similar or lesser quantities of free soy oil compared with control diets containing SBM (11, 13). The lack of a depression in milk fat percentage when WRSB were substituted for SBM in lactation diets or fed at high levels provides additional evidence that soy oil encapsulated within the seed does not interfere with rumen fermentation. Protection of the soy oil by the seed and slow release of the encapsulated oil in the rumen also may reduce the formation of trans-$C_{18:1}$, which has been shown to play a role in milk fat depression (24, 29). Increased milk fat percentages observed in our study may have been due to increased dietary fatty acids being taken up by the mammary gland for milk fat synthesis.

Milk protein percentage (Table 4) was depressed approximately .1 percentage unit when cows were fed diets containing WRSB regardless of level of WRSB in the diet. Although milk protein percentage was depressed, actual milk protein production increased by .05 kg/d when WRSB were fed at 12% of diet DM. A second increase of .03 kg/d was observed when WRSB increased from 12 to 18% of the DM. The observed depressions in milk protein percentage when WRSB replaced SBM in the diet concur with the findings of some (13, 30) but not all studies (20). Milk protein percentage also did not differ among cows consuming no WRSB and cows consuming 1.1, 2.2, or 3.3 kg/d WRSB. Depressions in milk protein percentage frequently occur when diets formulated with supplemental fat are fed to lactating cows (16).

Production of 3.5% FCM (Table 5) was increased 2.2 kg/d when WRSB were added at 12% of the diet DM and further increased by 2.0 kg/d when WRSB were increased to 18% of the diet DM. No further improvements were observed when WRSB were increased from 18 to 24% of ration DM. Values for 3.5% FCM for the various production groups are presented in Table 5. Square × diet interactions were not significant for any lactation parameter, indicating that lactation performance was enhanced with addition of WRSB at either 12 to 18% of diet DM regardless of level of production,

TABLE 6. Rumen pH and VFA molar percentages in lactating cows fed different levels of whole roasted soybeans (WRSB).

Variable	WRSB, % DM basis				SEM
	0	12	18	24	
pH[1]	6.24	6.22	6.22	6.27	.04
	(mol/100 mol)				
VFA[2]					
Acetate	63.0	63.0	63.2	64.0	<.1
Propionate	20.9	21.2	20.9	20.5	<.1
Butyrate	12.5	12.2	12.2	11.9	<.1
Isobutyrate	1.0	1.0	1.0	1.0	<.1
Valerate	2.9[a]	1.4[b]	1.5[b]	1.4[b]	<.1
Isovalerate	1.0	.9	1.0	1.0	<.1

[a,b]Least squares means in same row with different superscripts differ ($P \leq .05$).

[1]pH = Average of 0-, 3-, and 6-h postfeeding samples (fistulated cows).

[2]VFA = 3-h postfeeding sample (nonfistulated and fistulated cows).

parity, or stage of lactation of cows. The present study agrees with previous work that demonstrated that late lactation cows respond favorably to supplemental fat feeding (7, 8). Others have reported that responses to fat supplementation (ruminally inert fats or popped soybeans) are less favorable with primiparous cows than with mature cows (12, 22). Diets were not consistent in UIP or NE_L content; therefore, it was not possible to determine whether improved energy or protein status was responsible for improved lactation performance when feeding 12 or 18% WRSB. However, both UIP and NE_L intakes by cows on control diets were adequate according to NRC (15) to support levels of 3.5% FCM production (Table 5) obtained when WRSB comprised 12% of the diet DM. These results indicate that nutrients other than UIP or energy may have been limiting in the control diet or that nutrient requirements or UIP and NE_L content of feeds cited by NRC (15) are in error.

The effects of feeding increasing levels of WRSB on rumen function is of interest because of the high levels of polyunsaturated oil (20% EE) contained within WRSB. As previously discussed, feeding free polyunsaturated oils can affect rumen fermentation adversely and reduce fiber digestion. In the present study, no diet effects or diet × hour interactions were significant for rumen pH, indicating that pH and rumen fermentation were unaffected by increasing additions of WRSB to the diet (Table 6). These results agree with others

who have observed no differences in rumen pH when comparing diets containing WRSB or popped soybeans with diets containing SBM, raw full fat soybeans, extruded full fat soybeans, or free soy oil (13, 20, 23).

Molar percentages of VFA (Table 6) were unaffected by increasing levels of WRSB with the exception of a depression in valerate. Acetate:propionate ratio likewise was unaffected. These results lend support to the theory that encapsulation of the soy oil within the seed coat and gradual release of soy oil from the whole seed prevent many of the negative effects on rumen fermentation associated with feeding polyunsaturated oils in free form (13). However, not all studies have indicated an effect of free polyunsaturated oils on acetate: propionate ratio (2, 11). Mohamed et al. (13), feeding lactating cows, compared SBM with WRSB and observed a depression only in isobutyrate concentration and no change in acetate:propionate when the WRSB were fed. No differences in ruminal acetate:propionate ratio or VFA concentrations were observed when popped soybeans were fed at 19 or 33% of diet DM [(13); .7 vs. 1.2 kg soy oil/d]. Feeding diets containing WRSB or extruded soybeans resulted in significant increases in acetate:propionate ratio compared with raw full fat soybeans (23).

Increasing levels of soy oil from WRSB had no adverse effect on ruminal fiber digestion as evidenced by lack of significant differences among diets in forage DM disappearance

TABLE 7. Total tract apparent nutrient digestibilities of diets containing different levels of whole roasted soybeans (WRSB) fed to lactating cows.

Variable	WRSB, % DM basis				SEM
	0	12	18	24	
DM, %	63.1	62.7	64.3	63.5	.69
CP, %	61.5[ab]	59.9[b]	63.4[a]	63.3[a]	.84
NDF, %	43.6	43.9	45.9	44.6	1.19
Fatty acids,[1] %	73.4[a]	65.8[c]	70.9[ab]	66.8[bc]	1.3
$C_{16:0}$, %	72.7	73.8	75.0	73.7	1.1
$C_{16:1}$, %	87.4	92.3	91.6	86.7	2.1
$C_{18:0}$, %	−498.1	−560.1	−441.1	−544.4	35.4
$C_{18:1}$, %	74.6[a]	49.9[b]	55.1[b]	47.8[b]	3.4
$C_{18:2}$, %	93.4[a]	90.4[b]	92.5[ab]	94.7[a]	1.0
$C_{18:3}$, %	96.5[b]	97.0[ab]	98.3[a]	97.6[ab]	.5

[a,b,c]Least squares means in same row with different superscripts differ ($P < .05$).

[1]$C_{16:0}$ to $C_{18:3}$ fatty acids.

from dacron bags in situ (Figure 1). Again, this indicates that polyunsaturated oil within WRSB did not interfere with ruminal fermentation. Scott et al. (23) observed no differences in fractional rates of digestion of alfalfa DM or NDF from dacron bags in situ when diets containing roasted, raw, or extruded full fat soybeans were fed.

The AD of DM and NDF (Table 7) were unaffected by feeding diets formulated with increasing levels of WRSB. These results agree with Shriver et al. (25) in which diets containing 0, 1.1, 2.2, or 3.3 kg/d of WRSB did not differ in AD of DM or NDF. The AD of DM tended to be lower with diets containing WRSB than with diets containing SBM (13). Scott et al. (23) observed lower AD of DM and NDF when diets containing WRSB were fed compared with diets containing raw whole soybeans, but diets containing extruded full fat soybeans had AD of DM and NDF similar to that of diets with WRSB.

The AD of CP (Table 7) was lower when WRSB comprised 12% of the DM vs. 18 or 24% of the DM but was similar to the diet containing no WRSB (Table 7). Diets containing 18 or 24% WRSB also did not differ from the control diet (0% WRSB) in AD of CP. Scott et al. (23) reported that AD of CP was lower for diets containing WRSB than for diets containing either extruded or raw full fat soybeans.

The AD of fatty acid ($C_{16:0}$ to $C_{18:3}$; Table 7) was lower when WRSB were at 12% of the diet DM than when WRSB comprised either 0

or 18% of the DM but was similar to WRSB at 24% of diet DM; fatty acid digestibility of diets containing 24% WRSB was similar to that of diets containing 12 or 18% WRSB. A similar depression in fatty acid digestibility was reported when cows were consuming 3.3 kg/d of WRSB compared with 0, 1.1, or 2.2 kg/d (25). Scott et al. (23) also noted a depression in fatty acid apparent digestibility when feeding WRSB compared with feeding raw or extruded full fat soybeans. Typically, EE digestibility of the diet is increased when supplemental fat is fed (17). In contrast with
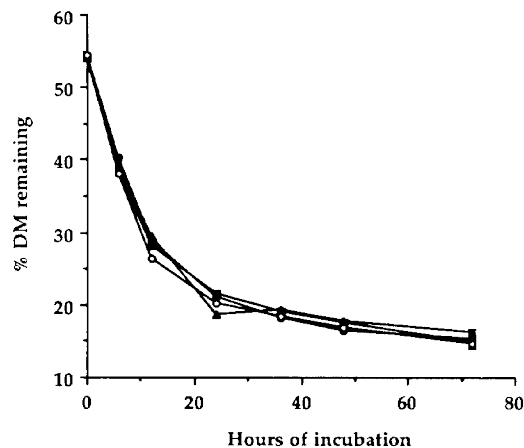

Figure 1. Effect of increasing levels of whole roasted soybeans (WRSB), 0% (■), 12% (▲), 18% (●), and 24% (○), on forage DM disappearance from dacron bags in situ.

measurement of fatty acids, measurement of EE in forage-based diets includes considerable nondigestible waxes and pigments. Consequently, it is likely that EE digestibility would be increased when supplementing diets with oils that are relatively well digested compared with waxes and pigments.

Digestibilities of individual fatty acids are presented in Table 7. Addition of increasing levels of WRSB did not significantly affect digestibility of $C_{16:0}$, $C_{16:1}$, or $C_{18:0}$. Digestion coefficients for $C_{18:0}$ were negative, reflecting extensive ruminal biohydrogentation of unsaturated 18 carbon fatty acids. Digestion coefficients for $C_{18:1}$ were low relative to other reports (10, 14) and were significantly decreased by the addition of WRSB to the diets. Reduced $C_{18:1}$ digestibility may reflect a reduction in hydrogenation and indicate that oilseeds or heat treatment of oilseeds or both may "protect" fatty acids from microbial metabolism. In contrast, digestibility of $C_{18:2}$ and $C_{18:3}$ was extensive across treatments. However, because conversion of $C_{18:1}$ to $C_{18:0}$ is the rate-limiting step in hydrogenation of polyunsaturated fatty acids, one might speculate that effects of feeding oils as part of an oilseed or heat-treated oilseed on hydrogenation would be most easily detected for $C_{18:1}$.

True digestibilities for CP and total fatty acids in the total digestive tract were estimated using the formula $TD_n = (I_n - [F_n - E_n]/I_n) \times 100$ where TD is true digestibility of nutrient, I_n is total intake of nutrient, F_n is fecal excretion of nutrient, and E_n is endogenous secretion of nutrient. Fecal excretion of nutrients was estimated by solving for fecal excretion of the nutrient from the following equation: $AD = ((I_n - F_n)/I_n) \times 100$. Endogenous secretion of protein was estimated using the equation IDM $\times$ .09 (15) where IDM is indigestible DMI. Endogenous secretion of total fatty acids was estimated at 55.9 g/d (18). True total tract digestibilities were estimated from treatment means and were 81.5, 79.9, 80.7, and 80.0% for CP and 83.2, 72.9, 77.2, and 72.8% for fatty acids in diets containing 0, 12, 18, and 24% WRSB, respectively.

CONCLUSIONS

Results from our study indicate that lactation performance can be enhanced by feeding

WRSB at concentrations higher than commonly recommended. Yield of FCM was improved by supplementing WRSB at 12 or 18% of total diet DM, but additional benefits were not realized when WRSB were increased to 24% of diet DM. Data indicate that soy oil within WRSB did not interfere with ruminal fermentation when WRSB were blended with concentrate and forage at levels up to 24% of diet DM. Results from this trial may not apply to feeding situations in which WRSB are top-dressed.

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REFERENCES

1 Association of Official Analytical Chemists. 1980. Official methods of analysis. 13th ed. AOAC, Washington, DC.

2 Beitz, D. C., and C. L. Davis. 1964. Relationship of certain milk fat depressing diets to changes in the proportion of the volatile fatty acids produced in the rumen. J. Dairy Sci. 47:1213.

3 Broderick, G. A. 1987. Determination of protein degradation rates using a rumen in vitro system containing inhibitors of microbial nitrogen metabolism. Br. J. Nutr. 58:463.

4 Brotz, P. G., and D. M. Schaefer. 1987. Simultaneous determination of lactic and volatile fatty acids in microbial fermentation extracts by gas-liquid chromatography. J. Microbiol. Methods 6:139.

5 Chandler, P. 1990. Energy prediction of feeds by forage testing explored. Feedstuffs 62:12.

6 Combs, D. K. 1985. An evaluation of markers and techniques used to measure nutrient digestion in ruminants. Ph.D. Diss., Univ. Wisconsin, Madison.

7 DePeters, E. J., S. J. Taylor, A. A. Franke, and A. Aguirre. 1985. Effects of feeding whole cottonseed on composition of milk. J. Dairy Sci. 68:897.

8 Grummer, R. R. 1988. Influence of prilled fat and calcium salt of palm oil fatty acids on ruminal fermentation and nutrient digestibility. J. Dairy Sci. 71:117.

9 Hutjens, M. F. 1990. Feeding soybeans to dairy cattle. Page 308.2 in 1990 Dairy management manual, Vol. 1. Western Regional Publication Committee, Urbana, IL.

10 Jenkins, T. C., and B. F. Jenny. 1989. Effect of hydrogenated fat on feed intake, nutrient digestibili-

ties, and lactation performance of dairy cows. J. Dairy Sci. 72:2316.

11 Larson, S. A., and L. H. Schultz. 1970. Effects of soybeans compared to soybean oil and meal in the rations of dairy cows. J. Dairy Sci. 53:1233.

12 Leonard, M., and E. Block. 1988. Effect of ration protein content and solubility on milk production of primiparous Holstein heifers. J. Dairy Sci. 71:2709.

13 Mohamed, O. E., L. D. Satter, R. R. Grummer, and F. R. Ehle. 1988. Influence of dietary cottonseed and soybean on milk production and composition. J. Dairy Sci. 71:2677.

14 Murphy, M., P. Uden, D. L. Palmquist, and H. Wiktorsson. 1987. Rumen and total tract diet digestibilities in lactating cows fed diets containing full-fat rapeseed. J. Dairy Sci. 70:1572.

15 National Research Council. 1989. Nutrient requirements of dairy cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.

16 Palmquist, D. L. 1988. The feeding value of fats. Page 293 in Feed science. E. R. Orskov, ed. Elsevier Sci. Publ., BV, Amsterdam, Neth.

17 Palmquist, D. L., and T. C. Jenkins. 1980. Fat in lactation rations: review. J. Dairy Sci. 63:1.

18 Palmquist, D. L., A. Kelby, and D. Kinsey. 1989. Digestibility by lactating cows of diets containing two levels of several commercial fats. J. Dairy Sci. 72(Suppl. 1):572.(Abstr.)

19 Robertson, J. B., and P. J. Van Soest. 1981. The detergent system of analysis and its application to human foods. Page 123 in The analysis of dietary fibres in foods. W.P.T. James and O. Theander, ed. Marcell Dekker, New York, NY.

20 Ruegseggar, G. J., and L. H. Schultz. 1985. Response of high producing dairy cows in early lactation to the feeding of heat-treated whole soybeans. J. Dairy Sci. 68:3272.

21 SAS® User's Guide: Statistics, Version 5 Edition. 1985. SAS Inst., Inc., Cary, NC.

22 Schneider, P., D. Sklan, W. Chalupa, and D. S. Kronfeld. 1988. Feeding calcium salts of fatty acids to lactating cows. J. Dairy Sci. 71:173.

23 Scott, T. A., D. K. Combs, and R. R. Grummer. 1991. Effects of roasting, extrusion, and particle size on the feeding value of soybeans for dairy cows. J. Dairy Sci. 74:2555.

24 Selner, D. R., and L. H. Schultz. 1980. Effects of feeding oleic acids or hydrogenated vegetable oils to lactating cows. J. Dairy Sci. 63:1235.

25 Shriver, B. J., D. L. Palmquist, and D. J. Kinsey. 1985. Digestibility of dairy rations with various levels of whole roasted soybeans. J. Dairy Sci. 68(Suppl. 1): 162.(Abstr.)

26 Steele, R.G.D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York, NY.

27 Sukhija, P. S., and D. L. Palmquist. 1988. Rapid method for determination of total fatty acid content and composition of feedstuffs and feces. J. Agric. Food Chem. 36:1202.

28 Supelco. 1975. GC separation of VFA C2–C5. Bulletin 749B, Supelco, Inc., Bellefonte, PA.

29 Teter, B. B., P. J. Gaynor, J. Sampugna, M. Keeney, R. A. Erdman, and D. R. Waldo. 1980. Diet induced bovine milk fat depression is associated with increased trans fatty acid level in milk. J. Dairy Sci. 72: 549.

30 Voss, V. L., D. Stehr, L. D. Satter, and G. A. Broderick. 1988. Feeding lactating dairy cows proteins resistant to ruminal degradation. J. Dairy Sci. 71:2428.