Particle Size of Roasted Soybeans and the Effect on Milk Production of Dairy Cows[1,2]

T. R. DHIMAN,*[,3] A. C. KOREVAAR,†[,4] and L. D. SATTER*[,†,5]
*Department of Dairy Science, University of Wisconsin and
†US Dairy Forage Research Center, USDA,
Agricultural Research Service,
Madison 53706

ABSTRACT

Fifteen cows were used in an experiment with a 5 × 5 replicated Latin square design to quantify the effect of particle size of roasted soybeans on milk production and fecal excretion of soybeans. The five experimental periods were each 2 wk long. Diets contained (percentage of dry matter) 33% alfalfa silage, 17% corn silage, 30.6% high moisture ear corn, 18% soybeans, and 1.4% mineral supplement. The five dietary treatments included raw whole soybeans or roasted soybeans in four particle sizes (whole and half, half and quarter, quarter and smaller, and coarsely ground). Mean particle sizes of the raw soybeans and of the roasted soybeans in whole and half sizes were >4.75 mm. Mean particle sizes of the roasted soybeans in half and quarter, quarter and smaller, and coarsely ground roasted soybeans were 2.92, 2.01, and 1.59, respectively. During the normal handling of roasted soybeans, a large number of seeds was broken into halves in the treatment with whole and half sizes (36%, wt/wt basis). Production of 3.5% fat-corrected milk was 35.4, 37.7, 37.2, 35.1, and 35.4 kg/d for cows fed raw soybeans; roasted soybeans in whole and half, half and quarter, and quarter and smaller sizes; and ground roasted soybeans, respectively. Cows that were fed raw soybeans excreted the largest amount of visible soybean particles in feces, and cows that were fed ground roasted soybeans had the least amount of soybeans in the feces (61.3 vs. 10.6 g of soybeans/kg of fecal dry matter). Roasted soybeans in half and quarter sizes are optimal for milk production.
(**Key words**: cows, roasted soybeans, particle size, milk)

Abbreviation key: **RSBCG** = coarsely ground roasted SB, **RSBHQ** = roasted SB in half and quarter sizes, **RSBQQ** = roasted SB in quarter and small sizes, **RSBWH** = roasted SB in whole and half sizes, **RWSB** = raw whole SB, **SB** = soybeans.

INTRODUCTION

Soybeans (**SB**) contain (dry basis) 19% fat and 43% CP (17) and are an economical and convenient source of dietary fat and protein. Heat-treated SB can increase the amount of soy protein escaping microbial degradation in the rumen (3, 9). Reduction of protein degradation occurs because of Maillard type reactions between sugar aldehyde groups and free amino groups (8).

Properly heated SB can be used as a source of RUP for high producing dairy cows, especially during early lactation (19). Optimal heat treatment of SB has resulted in a mean increase in milk production of 1.5 kg/d (19). Recently, the quality of commercial heat-processed SB has improved because of the availability of procedures to measure the extent of heat treatment (12).

The use of heat-processed SB in the diets of dairy cows has increased rapidly (20). The question remains, however, as to the optimal particle size of roasted SB. The protein in small particles is likely to be degraded more rapidly than the protein in large particles because of the larger surface area of small particles. Recently, Tice et al. (23), using midlactation dairy cows fitted with ruminal and duodenal cannulas, observed a trend toward greater protein degradation in the rumen and lower milk production as particle size of roasted SB was reduced. The objective of the present experiment was to quantify the effect of particle size of roasted SB on milk production, DM digestibility, and fecal excretion of SB in high producing dairy cows.

Received August 19, 1996.
Accepted December 12, 1996.
[1]Trade names and the names of commercial companies are used in this report to provide specific information. Mention of a trade name or manufacturer does not constitute a guarantee or warranty of the product by the USDA or an endorsement over products not mentioned.
[2]This is a contributing project to USDA North Central Regional Research Project 185 titled "Metabolic relationships in supply of nutrients for lactating cows".
[3]Present address: Department of Animal, Dairy and Veterinary Science, Utah State University, Logan 84322.
[4]Present address: Christian Agricultural College, De Drieslag 1, 8251 JZ Dronten, The Netherlands.
[5]Corresponding author.

MATERIALS AND METHODS

Cows and Treatments

Fifteen multiparous Holstein dairy cows were used in an experiment with a 5 × 5 Latin square design. During the first 2 wk of the experiment, cows were fed a pretrial diet. At the end of the pretrial period, cows were blocked according to milk production and were assigned randomly to three squares of 5 cows each. Within squares, cows were assigned randomly to one of the five treatments. Each experimental period was 2 wk long. The 1st wk of each period was used for adaptation, and measurements were made during the 2nd wk of each period. At the beginning of the experimental period, cows were between 126 and 171 DIM, and, during the last week of the pretrial period, cows were producing between 35.1 and 51.3 kg/d of milk. The ingredient composition of the experimental diets is presented in Table 1. The five dietary SB treatments included 1) raw whole SB (**RWSB**), 2) roasted SB in whole and half sizes (**RSBWH**), 3) roasted SB in half and quarter sizes (**RSBHQ**), 4) roasted SB in quarter and smaller sizes (**RSBQQ**), and 5) coarsely ground roasted SB (**RSBCG**). Roasted soybeans were heated to 146°C in a commercial roaster (Jet-Pro roaster®; Jet-Pro Co., Springfield, OH) and steeped for approximately 30 min before cooling. Roasted SB that were not milled were included in the RSBWH treatment. To prepare RSBHQ and RSBQQ, roasted SB were passed through a roller mill and were then screened using a Hi-Cap grain cleaner (model 44; David Manufacturing Co. Inc., Mason City, IA). Soybeans in the RSBCG treatment were prepared by passing the SB through a hammer mill (Meter/Mill; Clay Equipment Corp., Cedar Falls, IA) using a 0.95-cm screen. Diets were fed as a TMR once daily. Feed was offered at 105 to 110% of the ad libitum intake of the previous day on an as-fed basis. Cows were allotted into two groups of 7 and 8 each and were injected with 500 mg of a slow-release formulation of recombinant bST (Sometribove Zinc; Monsanto, St. Louis, MO) every 2 wk. This protocol resulted in the injection of one group during adaptation and injection of the other group during the measurement week in each period. This procedure did not introduce a treatment bias because all cows were subjected to all treatments. The mean BW of cows at the beginning and end of the experiment were 609 kg (range, 501 to 675 kg) and 626 kg (range, 549 to 687 kg), respectively.

TABLE 1. Ingredient composition of treatment diets.[1]

Ingredient	
	(%, DM basis)
Alfalfa silage	33.0
Corn silage	17.0
High moisture ear corn	30.5
Soybeans[1]	18.0
Dicalcium phosphate	0.6
Limestone	0.3
Trace-mineralized salt[2]	0.5
Vitamin A, D, and E premix[3]	0.1

[1]The five dietary soybean (SB) treatments included in the experiment were raw whole SB and heated SB with four different particle sizes (whole and half, half and quarter, quarter and smaller, and coarsely ground). The SB were heated at 146°C in a commercial roaster (Jet-Pro roaster®; Jet-Pro Co., Springfield, OH) and steeped for approximately 30 min before cooling.

[2]Trace-mineralized salt contained 94 to 96% NaCl, not less than 0.55% Zn, 0.55% Mn, 0.35% Fe, 0.14% Cu, 0.008% I, 0.006% Se, and 0.002% Co.

[3]Vitamin supplement was added to provide 148,500 IU of vitamin A, 49,500 IU of vitamin D, and 405 IU of vitamin E/d per cow.

Sampling, Laboratory Analysis, and Calculations

Feed offered and orts for individual cows were weighed daily. Daily samples of silage and orts were frozen, and composite samples from each week were used for chemical analysis. Samples of individual dietary ingredients were taken once weekly. The DM content of feed ingredients was determined by drying 100 to 150 g of representative sample in a forced-air oven for 48 h at 60°C. Dietary formulations were adjusted weekly (if necessary) to account for small changes in the DM content of the ingredients. Dried feed samples were ground through a Wiley mill (1-mm screen; Arthur H. Thomas, Philadelphia, PA). Ground samples were analyzed for CP by the Kjeldahl procedure (7), for NDF (24), and for ADF (11). During analysis, the samples were dried further at 105°C to determine absolute DM, and chemical analyses were expressed on this final DM. Water extracts of alfalfa silage and corn silage were prepared from samples collected during the measurement period of each week (16). The pH of silage extracts was determined immediately. Alfalfa silage and corn silage had a pH of 4.78 (±0.08 SD) and 3.76 (±0.1 SD), respectively.

Chemical composition of the diets was calculated from chemical analyses of the individual ingredients. The NE_L and RUP contents of each diet were estimated by using NE_L and RUP values of the NRC (17) for individual dietary ingredients. The RUP value for SB was from the research of Faldet et al.

(10). The NE_L and RUP values used for alfalfa silage, corn silage, high moisture ear corn, SB, and roasted SB were 1.35, 1.60, 1.91, 2.11, and 2.18 Mcal of NE_L/kg of DM and 23, 31, 50, 26, and 50% RUP as a percentage of total CP, respectively. The diets were formulated to be isocaloric and isonitrogenous. Calculated NE_L contents of the diets were 1.68 and 1.69 Mcal/kg of DM in RWSB and roasted SB treatments, respectively. Dietary CP contents in treatments 1 through 5 using actual analysis were 17.3, 17.6, 17.6, 17.6, and 17.6% (DM basis), respectively. The calculated RUP contents of the diets were 5.01, 6.77, 6.79, 6.83, and 6.79% (DM basis) for treatments 1 through 5, respectively. However, actual RUP content of the SB treatments was likely to change as particle size changed.

Cows were weighed for 2 consecutive d at the beginning and end of the experiment. Milk weights were recorded daily. During the last 2 d of each period, milk samples were collected from two consecutive a.m. and p.m. milkings and analyzed for fat, protein, lactose, and SNF by the National Cooperative DHIA (Wisconsin DHIA Laboratory, Appleton) using near infrared procedures and a Fossomatic-605 (B filter; Foss Electric, Hillerød, Denmark). Final milk composition was expressed on weighted milk production of a.m. and p.m. samples.

Feed DM digestibility was determined using acid detergent lignin as an internal marker. During the last week of each period, six fecal grab samples were collected within 48 h from each of 2 cows in each treatment. Fecal samples were dried at 60°C and ground through a Wiley mill (1-mm screen). Composite fecal samples from each cow and samples of dietary ingredients during each period were analyzed for acid detergent lignin (11). Feed DM digestibility (percentage) for individual cows was calculated using the following relationship: 1 – (concentration of acid detergent lignin in DM consumed/concentration of acid detergent lignin in the fecal sample of the cow) × 100. During the last week of each period, a fecal grab sample (approximately 500 g, wet weight basis) from each cow was washed with water through different screens (4.75, 3.35, 1.18, and 0.6 mm) to collect SB particles. Residue that was retained on each screen was dried at 60°C, and visible SB particles were separated manually. Soybean particles were expressed as grams of visible SB particles excreted per kilogram of fecal DM and as a percentage of daily SB intake.

During the last day of each period, blood samples (15 ml) were collected in heparinized vacutainers from the coccygeal vein or artery at 5 h postfeeding. To separate plasma, blood samples were centrifuged on the same day at 2200 × *g* for 15 min at 4°C. Blood plasma was stored at –20°C for further analysis. Glucose and urea concentrations were determined colorimetrically in deproteinized blood plasma samples using industrial method numbers 120-71A and 856-87T, respectively, on an Autoanalyzer II (Bran + Luebbe Inc., Buffalo Grove, IL).

Experimental Design and Analysis

Data were analyzed by nested ANOVA using the general linear models procedures of SAS (18). The model included square, cow within square, period, treatment, period by treatment interaction, and square by treatment interaction. The error term for square was cow within square. Results are expressed as least squares means because four data points for blood plasma glucose and urea and two data points for fecal SB excretion were missing. Significance was declared at $P < 0.05$ unless otherwise noted.

RESULTS AND DISCUSSION

Cows were fed diets containing 50% forage and 50% grain. Results of chemical analyses of dietary feed ingredients are presented in Table 2. The DM content of the diets containing treatments 1 through 5 ranged from 49.6 to 50.1%. The alfalfa silage and corn silage used in the experiment were of good quality as was indicated by contents of CP, NDF, and ADF. The high moisture ear corn contained 8% cob (DM basis) and was coarsely ground. Soybeans provided 18% of the DM and contributed 40% of total protein to the diet. The CP contents of roasted SB were slightly higher than those of RWSB, which might have been because raw and roasted SB were from two different lots. Also, some SB hulls, which contain less protein than do the seeds, might have been lost during roasting and handling. Dietary RUP contents were higher in roasted SB treatments than in the RWSB treatment. Most other nutrients were similar or slightly in excess of NRC (17) recommendations in all treatments. The ADIN of SB was 3.2, 2.0, 2.0, 2.5, and 2.5% of total N for RWSB, RSBWH, RSBHQ, RSBQQ, and RSBCG, respectively. The protein dispersibility index of SB was 92.5 and 10.6 for RWSB and roasted SB, respectively. The recommended protein dispersibility index value is 9 to 11 for optimally heated SB, 11 to 14 for marginally heated SB, and >14 for underheated SB (19). Based on this rating, the roasted SB were optimally heated.

Distribution of particle size of SB is presented in Table 3. After dry-sieving (4), the mean particle size

TABLE 2. Chemical composition of feed ingredients.[1]

Ingredient	DM		CP		NDF		ADF	
	(%)		(% of DM)					
	X̄	SD	X̄	SD	X̄	SD	X̄	SD
Alfalfa silage	36.6	6.5	20.1	1.2	45.4	2.3	38.8	1.6
Corn silage	38.3	2.6	6.9	0.4	41.8	2.5	25.2	1.9
High moisture ear corn	70.2	1.7	9.1	0.2	11.9	1.6	3.0	0.7
Raw soybeans	89.5	0.5	36.9	0.4	ND[2]		ND	
Heated soybeans[3]								
Whole and half sizes	98.7	1.0	38.7	0.3	ND		ND	
Half and quarter sizes	98.4	2.1	39.0	0.6	ND		ND	
Quarter and smaller sizes	99.2	0.4	39.3	0.3	ND		ND	
Coarsely ground	98.8	0.3	38.9	0.4	ND		ND	

[1]Represents a mean chemical composition for the entire experiment.

[2]Not determined.

[3]Soybeans were heated at 146°C in a commercial roaster (Jet-Pro roaster®; Jet-Pro Co., Springfield, OH) and steeped for approximately 30 min before cooling.

was determined to be >4.75 mm for RWSB and RSBWH (<8.4% of the sample passed through the 4.75-mm screen), 2.92 mm for RSBHQ, 2.01 mm for RSBQQ, and 1.59 mm for RSBCG treatments. During normal handling of roasted SB, a large number of seeds in the RSBWH treatment was broken into halves (36%, wt/wt basis).

Cow performance data are summarized in Table 4. Daily feed intake did not differ among treatments, which is similar to previous research (5, 6, 9, 21) in which DMI was not affected by supplementation of RWSB or roasted SB. Reducing the particle size of heated SB did not alter feed intake. Scott et al. (21) observed no change in DMI when raw SB were fed whole or ground. After cows had fully adjusted to their respective diets, Tice et al. (23) observed no difference in DMI caused by a reduction in particle size of roasted SB. The mean DMI in the present study was 23.9 kg/d. Intakes of CP were similar for cows fed all treatments because all diets had similar protein contents.

Cows fed the RSBWH treatment produced more milk (1.9 kg/d) and 3.5% FCM (2.3 kg/d) than did cows fed the RWSB treatment (Table 4). Among the different particle size treatments, cows fed the RSBHQ treatment had higher milk production than did cows fed the RSBQQ and RSBCG treatments. The 3.5% FCM production was higher for cows fed the RSBWH treatment than that for cows fed the RSBQQ and RSBCG treatments. Milk production did not differ between cows fed the RSBWH and RSBHQ treatments. In fact, a trend for decreased 3.5% FCM production occurred for cows fed the RSBQQ and RSBCG treatments. In another study, Tice et al. (23) reported no improvement in milk production because of a reduction in particle size of whole roasted SB.

Milk fat and protein percentages were similar across treatments (Table 4). These results are in

TABLE 3. Particle size distribution of different soybean (SB) treatments.

Screen size	Treatment[1] RWSB	RSBWH	RSBHQ	RSBQQ	RSBCG
	(% retained on screen)				
4.75 mm	92.6	90.6	21.2	30.5	5.1
3.35 mm	6.1	8.0	36.9	21.1	10.4
2.36 mm	0.9	0.8	23.9	17.7	23.5
1.18 mm	0.3	0.3	10.7	16.7	32.1
Pan	0.07	0.3	7.3	14.0	28.9

[1]RWSB = Raw whole SB, RSBWH = roasted SB in whole and half sizes, RSBHQ = roasted SB in half and quarter sizes, RSBQQ = roasted SB in quarter and smaller sizes, and RSBCG = coarsely ground roasted SB. The SB were heated at 146°C in a commercial roaster (Jet-Pro roaster®; Jet-Pro Co., Springfield, OH) and steeped 30 min before cooling.

TABLE 4. Dry matter intake, milk production, feed digestibility, and blood plasma urea and glucose concentrations of cows fed soybeans (SB) of different particle sizes.

	Treatment[1]						
Measurement	RWSB	RSBWH	RSBHQ	RSBQQ	RSBCG	SEM	*P*
DMI, kg/d	24.3	24.0	23.7	23.6	23.9	0.5	0.9
CP Intake, kg/d	4.24	4.25	4.24	4.22	4.26	0.09	0.9
Milk, kg/d	36.2[b]	38.1[ab]	38.7[a]	37.4[bc]	37.0[bc]	0.4	0.003
3.5% FCM,[2] kg/d	35.4[bc]	37.7[a]	37.2[ab]	35.1[c]	35.4[bc]	0.7	0.04
Milk fat, %	3.37	3.43	3.27	3.16	3.25	0.08	0.2
Milk protein, %	3.04	3.04	3.02	3.04	3.08	0.02	0.6
Fat yield, kg/d	1.22	1.31	1.27	1.17	1.20	0.04	0.09
Protein yield, kg/d	1.10[b]	1.15[a]	1.17[a]	1.13[ab]	1.14[a]	0.01	0.02
Lactose, %	4.72	4.69	4.71	4.71	4.66	0.02	0.4
SNF, %	8.47	8.44	8.44	8.46	8.45	0.03	0.9
Feed DM digestibility, %	63.6	64.0	64.6	64.3	64.0	0.8	0.9
Apparent CP digestibility, %	57.1[b]	60.8[ab]	61.7[a]	61.8[a]	63.2[a]	1.2	0.03
SB Excretion,[3]							
g/kg of Fecal DM	61.3[a]	31.0[b]	33.4[b]	22.7[c]	10.6[c]	6.0	0.001
% of Daily SB intake	12.0[a]	6.9[b]	7.8[b]	4.2[bc]	2.4[c]	1.3	0.006
Blood plasma urea, m*M*	5.11	5.67	5.41	5.33	5.44	0.16	0.2
Blood plasma glucose, mg/dl	54.4	54.7	55.5	52.6	55.3	1.3	0.5

[a,b,c]Means in the same row with different superscripts differ as indicated.

[1]RWSB = Raw whole SB, RSBWH = roasted SB in whole and half sizes, RSBHQ = roasted SB in half and quarter sizes, RSBQQ = roasted SB in quarter and smaller sizes, and RSBCG = coarsely ground roasted SB. The SB were heated at 146°C in a commercial roaster (Jet-Pro roaster®; Jet-Pro Co., Springfield, OH) and steeped 30 min before cooling.

[2]3.5% FCM = 0.432 (kilograms of milk) + 16.2 (kilograms of fat).

[3]Visible SB particles in feces.

agreement with other comparisons of raw and heated SB (6, 9, 14, 15, 23). In contrast, Scott et al. (21) reported no change in milk fat percentage; however, milk protein percentage was lower in cows fed roasted SB than in cows fed raw SB. A reduction in the particle size of roasted SB did not change milk fat or protein percentage in this study or in other studies (21, 23). Increased milk production and no change in milk protein percentage resulted in increased milk protein yield ($P = 0.02$) for cows fed the RSBWH and RSBHQ treatments compared with cows fed the RWSB treatment. Milk fat yield, milk lactose, and SNF contents were not different among treatments.

Feed DM digestibility did not change according to particle sizes of the raw and roasted SB (Table 4). The mean feed DM digestibility was 64.1%. Using cows fitted with ruminal and duodenal cannulas, Tice et al. (23) observed no change in OM digestibility when cows were fed RWSB or roasted SB as whole, cracked, or finely ground. Higher DM digestibility (21) and a trend toward higher DM digestibility (5) were reported for cows fed RWSB than for cows fed roasted whole SB. Heat treatment of SB did not affect the amount of DM digested but did improve digestibility of DM in primiparous cows (13). Digestibility of OM in the total gastrointestinal tract for cows fed RWSB or SB extruded at 132°C and 149°C was not different (22).

Cows fed RWSB excreted the largest amount of visible SB particles in feces, and cows fed RSBCG had the least amount of visible particles in feces (61.3 vs. 10.6 g of SB/kg of fecal DM). Excretion of visible SB particles in feces was not different for cows fed the RSBWH and RSBHQ treatments. Excretion of visible SB particles in feces (grams per kilogram of fecal DM and as a percentage of daily SB intake) decreased with smaller particle sizes of SB (RSBQQ and RSBCG) (Table 4). One would expect to identify fewer of the small SB particles in feces, so this trend was anticipated. However, the difference between the RWSB and RSBWH treatments was interesting. Both SB treatments had particle sizes that were similar before consumption by the cow, but more of the unheated SB appeared in feces. Tice et al. (23) observed a linear increase in ruminal NH_3 as particle size of roasted SB decreased, suggesting that degradation of protein increased in the rumen as particle size decreased. Glucose and urea concentrations in blood plasma did not differ among treatments in the present study.

The RWSB treatment had the lowest apparent digestibility of CP, although it did not differ significantly from that of the RSBWH treatment. Aldrich et al. (1, 2) have observed trypsin inhibitor in unheated SB following in vitro or in situ incubation of unheated SB in rumen fluid. The digestibility of total amino acids from the postfermentation SB residue was reduced, as measured in a chicken bioassay, similar to when unheated SB were fed directly; this result suggests that the trypsin inhibitor in unheated SB was not totally inactivated upon passage through the rumen.

Results from the present experiment and that of Tice et al. (23) suggest that a reduction in the particle size of SB beyond RSBQQ increased the degradation of protein in the rumen and decreased fecal excretion of CP. The intestinal availability of protein was probably reduced with finer particles and was reflected in reduced milk production with RSBQQ and RSBCG treatments.

CONCLUSIONS

Results of this study suggest that properly roasted SB should contain mostly half and quarter pieces. Grinding of roasted SB to yield smaller particles is not recommended.

ACKNOWLEDGMENTS

The authors acknowledge the assistance given by the farm and field crew at the US Dairy Forage Research Center farm at Prairie du Sac, Wisconsin. The authors thank Brian Yandell, Department of Horticulture and Statistics, University of Wisconsin, for assistance with statistical analysis of the data. Wisconsin Soybean Marketing Board, Inc., Madison, is gratefully acknowledged for partial funding of this research.

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