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Effect of Variation in Proportion of Cornmeal and Steam-Rolled Corn in Diets for Dairy Cows on Behavior, Digestion, and Yield and Composition of Milk

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ABSTRACT

Sixty-six lactating multiparous Holstein cows (113 ± 46 DIM) housed in a free-stall facility were blocked and assigned randomly to one of three treatments to evaluate the effects on animal performance from feeding cornmeal, cornmeal mixed with steam-rolled corn in a ratio of 1:1 on dry matter basis, or steam-rolled corn. The only difference in the dietary ingredients was the type of corn, which was included in the total mixed ration (TMR) at 17% of dry matter. The densities (g/L) of cornmeal and steam-rolled corn were, respectively, 635 and 553. Diets were fed as TMR and were formulated according to the Cornell Penn Miner Dairy® nutrition model. The TMR consisted of 40% forage and 60% concentrate on dry matter basis. The first 2 wk of the 8-wk study was a preliminary period, and data collected during this period were used as covariate in statistical analysis of production data collected during wk 6 to 8. Treatment diets were fed from wk 3 to 8. Total tract digestibilities of dry matter, organic matter, crude protein, starch, and neutral detergent fiber were not significantly different among treatments. Cows fed TMR containing steam-rolled corn had higher body condition and ruminated longer. However, feeding cornmeal and steam-rolled corn together did not improve dry matter and nutrient digestion, milk yield, 3.5% fat-corrected milk yield, and percentage and yield of fat, crude protein, true protein, and lactose in milk, and milk urea nitrogen. In conclusion, feeding steam-rolled corn improved animal body condition and rumination. Partial or complete substitution of cornmeal by steam-rolled corn in diets for lactating dairy cows did not improve dry matter and nutrient digestion, milk yield, and milk composition.
(**Key words:** steam-rolled corn, behavior, digestion, milk yield)

Abbreviation key: CM = cornmeal, **CMSRC** = cornmeal mixed with steam-rolled corn in a ratio of 1:1 on a DM basis, **DRC** = dry-rolled corn, **SFC** = steam-flaked corn, **SRC** = steam-rolled corn.

INTRODUCTION

Starch is a major source of energy in diets for lactating dairy cows. Therefore, it is important to optimize starch utilization by lactating dairy cows to improve the efficiency of milk production. Attempts to improve starch digestion have included dry rolling of corn, or steam processing followed by rolling or flaking. During steam-rolling, cereal grains are usually steamed for 15 min or less to achieve a grain moisture content of 15% and then crushed with rollers of various sizes to produce a thick flake with a density of 438 to 540 g/L (Theurer et al., 1999a). On the other hand, during steam-flaking the grain is steamed for 30 to 60 min in a vertical, stainless steel chamber to achieve a grain moisture content of 18 to 20% and then flaked between preheated rollers to a desired density, usually 386 g/L (Swingle et al., 1999). Steaming corn facilitates the movement of water into the kernel or starch granule. Heat and pressure during flaking (or to a lesser extent during rolling) cause gelatinization and also tear the moist kernel apart, forming a paste of gelatinized starch that binds the kernel together (Zinn and Barrajas, 1997).

Theurer et al. (1995) reported that altering the NE_L intake by increasing the extent of ruminal starch digestion through steam-flaking corn, alters the concentration of milk protein and yield of milk and milk protein in lactating dairy cows. In recent years, there has been extensive use of steam-flaked corn (**SFC**) in dairy herds in several western and northeastern states in the US (Theurer et al., 1999a). Diets containing SFC have been

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reported to have greater ruminal and total tract starch digestion compared with diets containing steam-rolled corn (**SRC**) (Chen et al., 1994; Santos et al., 1999; Theurer et al., 1999a), or dry-rolled corn (**DRC**) (Chen et al., 1994; Crocker et al., 1998; Joy et al., 1997; Plascencia and Zinn, 1996; Theurer et al., 1999a, 1999b). Plascencia and Zinn (1996) reported greater DMI, digestion of starch and nitrogen, NE_L of corn (by 33%), yield of milk and FCM by lactating cows fed SFC-based diets compared with cows fed DRC-based diets. The greater ruminal and total starch digestion in cows fed SFC results in greater cycling of urea to the gastrointestinal tract and increased estimated uptake of AA and other nutrients by the mammary gland (Theurer et al., 1999a; Theurer et al., 1999b). Chen et al. (1994) also reported increased DMI and FCM yield by cows that were fed SFC compared with cows fed SRC. However, greater fiber digestion by lactating Holstein cows has been reported for SRC-based diets compared with SFC-based diets (Santos et al., 1999; Yu et al., 1998).

While steam-rolling is a method commonly used to process corn, barley, and wheat grains that are fed to lactating dairy cows (Theurer et al., 1999a), few studies have compared the effects of feeding SRC versus cornmeal (**CM**) on the lactational performance of dairy cows. In one such study, Yu et al. (1998) reported lower starch digestion and greater digestion of OM, CP, ADF, and NDF by lactating Holstein cows fed SRC (490 g/L) or coarsely ground corn (618 g/L) compared with cows fed finely ground corn (580 g/L) or SFC (309 or 360 g/L density). Milk yields were highest for cows fed the SFC at a medium density (360 g/L). The smaller particle size of finely ground corn or CM particles compared with the larger sizes of SRC would result in a greater surface area exposed to microbial fermentation in the rumen (Knowlton et al., 1996a; Ying and Allen, 1998), thereby resulting in faster rate and greater extent of ruminal starch digestion. Determining the optimum balance of CM and SRC in diets for lactating dairy cows may optimize starch utilization and subsequently improve the efficiency of milk production.

Therefore, the objective of this study was to determine the impact of dietary variation in the proportion of SRC and CM on DM and nutrient total tract digestion, animal behavior, milk yield, and milk composition of lactating multiparous Holstein cows.

MATERIALS AND METHODS

Processing and Determination of Particle Size of Corn Grain

Corn grain with kernels of 1.27-cm average particle size and 87% DM from a common source was used to prepare CM and SRC at a commercial feed mill. Cornmeal was prepared by grinding corn grain to pass through a 3.8-mm screen in a full-circle hammer mill running at 1800 rpm. The corn grain was fed into the hammer mill at a rate of 30 tonne/h. Steam-rolled corn was prepared by feeding the grain into a steam chamber at the rate of 5 tonne/h. The grain was then sprayed with steam from seven nozzles at atmospheric pressure for 40 min, pressed by rollers into 3.18 mm-thick flakes with a density of 553 g/L and passed through coolers. The pressure of steam leaving the nozzles was 2.7 to 4.1 atm, and the rollers were 6.3 cm in diameter, 14.2 cm in length and had 2.38-mm apertures.

The weight, length, width, and thickness of SRC particles were determined with 100 kernels selected at random. The particle size of CM and SRC was determined with an electric powered Ro-Tap® testing sieve shaker with multiple screens ranging from 4-mm to 0.25-mm apertures (model B; W.S. Tyler Combustion Engineering, Inc., Mentor, OH). Triplicate 100-g samples of CM or SRC were placed on the top screen (4-mm mesh size) and the screens were agitated vigorously in a horizontal position at approximately 60 shakes/min for 5 min. The amount of grain held on each screen was collected, weighed, and used for particle size comparison as described by Yu et al. (1998).

Lactation Trial

Animals and treatments. Sixty-six multiparous lactating Holstein cows (113 ± 46 DIM) were blocked into 20 blocks by parity, DIM, and 305-d mature equivalent, and assigned randomly to one of three treatment groups. After parturition, all multiparous cows received 500 ml of 23% calcium solution, 500 ml of 50% dextrose solution, and 5 cc oxytocin intravenously, and 10 cc of vitamin E-selenium, 10 cc of vitamin B complex, and 2 cc of *Escherichia coli* vaccine intramuscularly as a preventative measure. All cows received 500-mg injections of bST (Posilac®; Monsanto, St. Louis, MO) every 2 wk, beginning when cows were confirmed pregnant or were 100 DIM. Cows were group-fed and housed in a free-stall barn for the duration of the study, which lasted for 8 wk. Animals were fed once a day starting at 0730 h, and the pens were cleaned twice a day, in the afternoon starting at 1200 h and early in the morning starting at 0300 h. The animal stalls were bedded with sawdust, which was changed once weekly. Cows were fed an adaptation diet (Table 1) during the first 2 wk of the study, which served as a preliminary period.

Week 3 served as a transition period during which cows were introduced slowly to the test diets, which they were then fed through wk 8. Three test diets containing CM, CM, and SRC mixed in ratio of approximately 1:1 on DM basis (**CMSRC**), or SRC (Tables 1

Table 1. Composition of the adaptation diet and the study diets containing cornmeal (CM), cornmeal mixed with steam-rolled corn in a ratio of 1:1 on DM basis (CMSRC), and steam-rolled corn (SRC) that were fed to lactating multiparous Holstein cows.

	TMR			
Composition	Adaptation[1]	CM	CMSRC	SRC
	% of DM			
Ingredient				
Alfalfa hay	. . .	7.12	7.12	7.12
Corn silage	30.00	22.39	22.39	22.39
Alfalfa-grass silage	12.00	. . .	. . .	. . .
Timothy hay	. . .	10.49	10.49	10.49
Mixed grass hay	5.00	. . .	. . .	. . .
Beet pulp	. . .	10.53	10.53	10.53
Cornmeal	24.00	16.98	8.49	. . .
Steam-rolled corn	. . .	. . .	8.49	16.98
Whole cottonseed	6.00	6.88	6.88	6.88
Concentrate mix[2]	23.00	25.61	25.61	25.61
Chemical[3]				
DM	49.2	61.6	61.2	60.8
OM	91.9	93.6	92.4	92.3
CP	18.3	18.5	18.6	18.6
NDF	34.1	34.5	34.5	34.6
Starch	30.6	24.3	23.9	23.8

[1]The adaptation diet was fed during the first 2 wk of the study, which served as a preliminary period.

[2]Composition of concentrate mix is shown in Tables 2 and 3.

[3]Calculated from the values of feed ingredients shown in Table 3.

and 2) were formulated by the CPM Dairy nutrition model (version 1.0; Cornell-Penn-Miner, Cornell University, Ithaca, NY). Diets consisted of 40% forage and 60% concentrate (DM basis) and were formulated to reflect rations fed to lactating dairy cows in Japan. Alfalfa hay was grown in Boardman, Oregon, and was harvested as fourth cutting. Timothy hay was grown in Ellensburg, Washington, and was harvested as first cutting. About 60 kg of double-pressed alfalfa or timothy hay bales were chopped with an Agri-Chopper (model 5500; AgriMetal, Inc, Wickham, Que, Canada). During mixing, dietary ingredients were put into a Reel-Auggie mixer wagon (model 3300; Knight, Brodhead, WI) in the following order: concentrate mixes, whole cottonseed, processed corn (CM, SRC, or both), beet pulp, alfalfa hay, timothy hay, and corn silage, and allowed to mix for about 5 min before feeding.

Corn silage, alfalfa hay, and timothy hay were analyzed before the beginning of the study and every month thereafter. Whole cottonseed, concentrates, beet pulp, and other byproduct feeds were analyzed before the study and when new deliveries were made as described in Chemical Analyses section. The amounts of feed offered and refused by each group of animals were recorded daily, and samples were collected for 3 consecutive days to monitor sorting and intake. Cows were milked three times per day in a double-six herringbone milking parlor at 0430, 1230, and 2030 h. Milk yield was measured daily for each cow during the last week of the preliminary period and during the test period. Samples of one milking for 2 consecutive days for each cow during the last week of the preliminary period and wk 6 to 8 of the test period were collected for compositional analysis.

Animal behavior and total tract digestion. A subset of five animals per treatment from five blocks was chosen at random, and their behavior was monitored continuously over a 24-h period in 10-min intervals during wk 5 of the test period. Investigators were assigned to watch each of 15 cows and record the feeding behavior by the animals over the 24-h period. Each investigator watched approximately three cows. Animal behavior observations included eating, ruminating,

Table 2.Composition of concentrate mixes used in the adaptation and study diets.

Ingredient[1]	Adaptation diet[2]	Study diets
	% of DM	
Cornmeal	8.00	. . .
Wheat middlings	. . .	8.14
Canola meal	10.00	23.89
Linseed meal	. . .	15.94
Corn gluten feed	. . .	13.75
Corn gluten meal	3.00	9.15
Rendered animal products	8.00	. . .
Fat	2.00	. . .
Urea	3.00	. . .
Soybean meal[3]	22.00	10.95
Roasted soybeans[4]	7.00	. . .
Soybean hulls	14.00	. . .
Fishmeal (Sea Lac)	4.00	8.21
Blood meal	3.00	. . .
Alimet	0.40	. . .
Salt	2.00	1.87
Sodium bicarbonate	4.00	. . .
Calcium bicarbonate	. . .	4.85
Dicalcium phosphate	. . .	1.14
Magnesium oxide	. . .	0.41
Calcium sulfate	. . .	0.91
Vitamin E	. . .	0.27
Selenium (0.06%)	2.30	0.27
Beacon trace mineral[5]	. . .	0.17
Calcium supplement (29% Ca)	7.00	. . .
Dairy 5X[6]	0.30	0.08

[1]Chemical composition of main ingredients is shown in Table 4.

[2]The adaptation diet was fed during the first 2 wk of the study, which served as a preliminary period.

[3]Solvent extracted.

[4]Roasted in a microwave oven.

[5]Beacon trace mineral compound on DM basis contained 16.1% calcium, 0.21% magnesium, 2.9% sulfur, and (per kg) 78,557 mg of manganese, 235,671 mg of zinc, 45,450 mg of copper, 2693 mg of cobalt, 11,783 mg of iron, 925 mg of selenium, 2244 mg of iodine, and 1.72 IU vitamin E.

[6]Dairy 5X contained on DM basis 2.7% CP, 49.9% NDF, 35.1% ADF, 7% fat, 9.8% calcium, 0.06% phosphorus, 1.05% magnesium, 1.33% potassium, 0.04% sulfur, 0.53% sodium, 0.13% salt, 35,946 IU/g of vitamin A, 12,247 IU/g of vitamin D, and 44,535 IU/kg of vitamin E.

drinking water, standing, and lying down. Time spent by animals walking to and from the milking parlor, and when they were disturbed or walking in the pen, was recorded but not reported.

The 15 cows used for the behavior measurements were also used to determine total tract digestion of DM and nutrients. Diets were formulated to contain 0.1% Cr_2O_3 as an indigestible marker and fed during the last 14 d of the test period (Prigge et al., 1981). During the last 5 d of feeding the marker, fecal grab samples were collected manually via the rectum twice daily at 0800 and 1600 h from the cows and stored frozen at −20°C for later processing and chemical analysis. Samples of TMR were collected daily starting 2 d prior to the start of fecal collection and continued for 5 d. The fresh TMR samples were composited by dietary treatment and stored frozen at −20°C for later processing and chemical analysis. Total tract digestibility of DM, OM, CP, starch, NDF, ADF, and hemicellulose was calculated by the ratio technique with the concentrations of nutrients and Cr_2O_3 in feed and feces (Maynard et al., 1979). The ratio technique method does not require DMI in the calculation of DM and nutrient total tract digestibilities.

Animal BW and condition. In wk 2 and 8, cows were weighed on 2 consecutive days after the morning milking. Cows were scored for body condition (Wildman et al., 1982) and lameness (Sprecher et al., 1997) during wk 2 and every week during the test period, and cow health problems were recorded throughout the study. To minimize variation, all cows were body condition scored by the same investigator throughout the study. Body condition scores were based on a five-point scale with 0.25-unit intervals where 1 = thin to 5 = fat. Lameness scores were also based on a five-point scale where 1 = normal gait, 2 = mild lameness, 3 = moderate lameness, 4 = lame, and 5 = severely lame.

Chemical Analyses

Gelatinization scores of CM and SRC starch were measured according to the procedure of Kartchner and Theurer (1981). Frozen composited TMR samples were thawed, dried to a constant weight at 60°C in a forced-air oven, and ground to pass through a 1-mm screen in a Wiley mill (model 3; Arthur H. Thomas Co., Philadelphia, PA). Fecal samples were thawed, and equal subsamples were taken from each collection time and composited by cow followed by drying to a constant weight at 60°C in a forced-air oven and ground to pass through a 1-mm screen as described previously for feed samples. Ground TMR and fecal samples were then analyzed (Northeast DHI Forage Lab, Ithaca, NY) for DM (100°C), ash (500°C), CP (AOAC, 1995), NDF (with amylase and sodium sulfite), ADF, acid detergent lignin (Van Soest et al., 1991), and minerals. Hemicellulose was determined as the difference between NDF and ADF, and cellulose as the difference between ADF and acid detergent lignin. Calcium, phosphorus, magnesium, potassium, sodium, iron, zinc, copper, manganese, and molybdenum were analyzed with a Thermo Jarrell Ash IRIS Advantage Inductively Coupled Plasma Radial Spectrometer (model ICAP 61; Thermo Jarrell Ash, Ithaca, NY). Sulfur was analyzed with a Leco Model SC-432 (Leco, St. Joseph, MI). Chloride ion was analyzed with a Brinkman Metrohm 716 Titrino titration unit with a silver electrode (model 716; Brinkman Instruments, Inc., Westbury, NY). In addition, TMR and fecal samples were analyzed at the University of Georgia (Athens, GA) for Cr_2O_3 according to the method of Brisson (1956). However, because the relatively high content of hay in the TMR made it difficult to acquire representative samples, the chemical analyses of these samples did not reflect the CPM Dairy dietary formulations. As a result CPM Dairy was used to calculate the nutrient content for the TMR (Table 1) from the chemical analyses of the feed ingredients mixed in each respective TMR. Visual analysis of ort samples did not indicate significant sorting.

Milk samples were analyzed (Northeast DHI Dairy Lab, Ithaca, NY) for fat, true protein, crude protein, lactose, and milk urea nitrogen by infrared procedure (Foss 4000; Foss Technology, Eden Prairie, MN) (AOAC, 1995), and analysis of SCC by infrared procedure (Foss 5000; Foss Technology, Eden Prairie, MN) (AOAC, 1995). Milk samples collected from some commercial dairy farms were used as internal standards in the analysis of milk components. These standards were stored under refrigeration at 0 to 4°C for a maximum of 14 d.

Statistical Analysis

Data were analyzed as a randomized block using the general linear model procedure of SAS (1993), and the results were presented as least square means. Treatment and block were the class variables and cow served as the experimental unit. Data collected during wk 2 for BW, BCS, lameness score, milk yield, and milk composition were used as a covariate in the analysis of data collected during the test period using the following model.

$$Y_{ijk} = \mu + \tau_i + \gamma_j + \beta(x_{ij} - x_{..}) + e_{ijk}$$

where,

μ = overall mean,

τ_i = the effect of the ith treatment,
γ_j = the effect of the jth block,
x_{ij} = the ijth observation on the covariate, and
e_{ijk} = residual error.

A similar model was used to analyze digestibility and animal behavior data without covariate analyses. If treatment differences were significant ($P < 0.05$), SRC effects were determined using orthogonal contrasts, which tested CM against the two diets containing SRC (contrast 1) or CMSRC against SRC (contrast 2). Because animals were group-fed with no replications of pens within treatment, the investigators assumed 1) no pen effect, and 2) that errors within pens were independent (St-Pierre and Jones, 1999), allowing for cow to serve as the experimental unit. Because DMI is not used in the ratio technique method of calculating total digestibility, each individual cow served as an experimental unit in statistical analysis of digestibility measurements.

RESULTS

The TMR had similar nutrient compositions (Table 1). Chemical composition of each TMR was calculated with the wet chemistry analyses of the feed ingredients used to formulate the TMR. The chemical composition of corn silage, alfalfa hay, timothy hay, whole cottonseed, and beet pulp (Table 3), and the main ingredients of the concentrate mix (Table 4) was consistent with values reported by NRC (1988) for the respective feedstuffs. The chemical composition of CM and SRC grains was consistent with reported values (NRC, 1988; Santos et al., 1999).

The density and starch gelatinization score for CM and SRC grain, and the weight, length, width, and thickness of SRC particles determined with 100 kernels are shown in Table 5. Particle size distribution of CM and SRC is shown in Table 6. Approximately 70.6% of CM passed through the screen with a 1 mm-mesh size, while only 0.7% of SRC passed through the same screen. The screen with the 4 mm-mesh size retained most of the SRC (93.0%); only negligible amounts of CM (<0.1%) were retained by the same screen. The geometric means calculated using the log normal distribution technique of Ensor et al. (1970) and Waldo et al. (1971) were 0.54 mm for CM and 3.80 mm for SRC.

There were no differences ($P > 0.05$) among treatments in the amount of time that the cows spent eating, chewing, intervals between meals, drinking water, or standing idle (Table 7). However, cows fed diets containing SRC ruminated longer ($P < 0.05$) and spent less time lying down idle ($P < 0.01$). Cows fed the CMSRC-based TMR ruminated longer ($P < 0.05$) than cows fed the SRC based TMR. Final animal BW and total tract digestion of DM and nutrients were not different ($P > 0.05$) among treatments (Table 8). Feeding SRC by itself in a TMR did not improve digestion above that observed when CM was fed alone in a TMR. It was observed from visual analysis of ort samples that there was no significant sorting against the hay or any other forage by the animals, which therefore means that feed consumed by the animals was the same as what had been formulated. Cows fed TMR containing SRC had higher body condition ($P < 0.001$) when compared with cows fed CM-based TMR (Table 8). Treatment had no effect on lameness score.

There were no differences among treatments in milk yield, 3.5% FCM yield, and percentage and yield of fat, CP, true protein, and lactose in milk, and milk urea nitrogen (Table 9). Milk produced by cows fed the CMSRC-based TMR had a higher SCC ($P < 0.001$) than cows fed the other two diets.

DISCUSSION

The density of the CM (635 g/L) used in the present study was higher than that of finely ground corn (580 g/L), but comparable to that of coarsely ground corn (618 g/L), which were both reported by Yu et al. (1998). The quality of SFC or SRC is measured routinely by flake density and enzymatic hydrolysis of starch or percentage starch gelatinization (Theurer et al., 1999a). The flake density of the SRC used in the present study (553 g/L) was higher than the SRC flake density reported by Yu et al. (1988) (490 g/L) and Theurer et al. (1999a) (438 to 540 g/L). As the extent of processing (flaking or rolling pressure) increases, flake density decreases (i.e., 438 g/L flake is more extensively processed than a 553 g/L flake; Theurer et al., 1999a). This relationship may mean that the SRC used in the present study did not meet the optimal quality criteria for steam-rolling of corn. Particle size distribution of CM and SRC is consistent with reports by other workers (Yu et al., 1998).

The larger particle size of SRC compared with CM explains why cows fed TMR containing SRC ruminated longer than did cows fed the CM-based TMR (Van Soest, 1994). Time spent ruminating by lactating Holstein cows fed diets containing cracked corn (3.265 cm particle size) was numerically greater than that spent by cows fed diets containing ground corn (0.827-cm particle size; Knowlton et al., 1996b).

Failure to observe significant differences among treatments in final animal BW, total tract digestion of DM and nutrients, milk yield, 3.5% FCM, and milk composition may be attributed to the fact that the SRC used in the present study was not processed thoroughly

Table 3. Chemical composition of feedstuffs used in diets fed to lactating multiparous Holstein cows.

Composition	Corn silage[1]	Alfalfa hay[1]	Timothy hay[1]	Whole cottonseed	Beet pulp	Concentrate mix[2]	Steam-rolled corn	Corn-meal
	DM basis							
DM, %	29.40	91.70	94.10	89.00	90.90	90.10	82.30	88.60
OM, %	96.57	89.74	92.81	95.31	94.80	85.19	98.61	98.64
Ash, %	3.43	10.26	7.19	4.69	5.20	14.81	1.39	1.36
CP, %	8.00	20.10	10.40	26.10	9.40	37.80	9.10	9.50
SolP[3], % of CP	65.30	40.30	31.00	28.00	13.00	26.00	10.00	15.00
NDF, %	43.60	37.70	62.10	55.10	42.40	23.30	10.20	11.40
NDFCP, %	1.00	3.30	2.40	1.90	5.50	6.30	1.70	1.50
ADF, %	26.70	31.90	38.90	40.40	27.10	11.00	3.80	3.60
Lignin, %	2.80	7.60	4.40	13.40	2.40	3.50	1.70	1.60
NSC, %	41.50	31.00	18.50		42.80	20.70	77.20	74.00
Sugar, %	1.58	6.79	7.63	2.92	6.07		1.42	1.70
Starch, %	32.34	4.19	4.09	3.02	9.28		73.39	70.93
Fat, %	4.00	2.90	2.60	21.20	1.50	4.30	4.70	4.50
Calcium, %	0.23	1.45	0.34	0.19	0.88	3.08	0.02	0.04
Phosphorus, %	0.20	0.34	0.24	0.62	0.09	1.36	0.33	0.30
Magnesium, %	0.18	0.32	0.14	0.39	0.28	0.74	0.13	0.12
Potassium, %	0.91	2.24	1.94	1.25	0.43	1.27	0.43	0.41
Sodium, %	0.00	0.14	0.03	0.00	0.04	0.85	0.00	0.01
Sulfur, %	0.08	0.26	0.14	0.26	0.11	0.57	0.09	0.06
Chloride, %	0.18	0.42	0.66					
Iron, mg/kg	126	481	104	54	444	364	73	53
Zinc, mg/kg	18	25	30	38	29	277	21	22
Copper, mg/kg	5	11	13	6	8	57	1	2
Manganese, mg/kg	22	35	55	20	38	122	7	9
Molybdenum, mg/kg	1	2	1	3	1	3	1	1

[1]Mean of analysis conducted prior to the beginning of the study and every month thereafter during the study.

[2]Chemical composition of main ingredients is shown in Table 4.

[3]Soluble protein.

Table 4. Chemical composition of main ingredients of the concentrate mix.

Composition	Canola meal	Linseed meal	Corn gluten feed	Soybean meal	Corn gluten meal	Fish meal (Sea Lac)	Wheat middlings
	DM basis						
DM, %	88.70	90.60	89.40	89.40	88.90	90.50	87.50
OM, %	92.50	93.43	92.81	93.55	97.06	80.46	94.18
Ash, %	7.50	6.57	7.19	6.45	2.94	19.54	5.82
CP, %	42.10	38.40	21.00	53.20	67.20	65.50	19.10
SolP[1], % of CP	25.00	38.00	52.00	29.00	16.00	23.00	30.00
NDF, %	26.20	30.00	36.60	7.30	5.60		41.20
NDFCP, %	6.40	4.80	3.00	3.10	4.40	18.20	4.90
ADF, %	21.80	18.10	11.40	6.50	3.00		13.40
Lignin, %	9.30	6.50	1.30	2.40	2.20	8.30	5.60
NSC, %	26.00	22.80	32.10	31.63	23.80		30.70
Sugar, %	8.95	5.16		11.99	1.04	0.98	5.41
Starch, %	8.18	9.98		6.72	18.42	1.78	31.38
Fat, %	2.50	4.60	3.90	1.90	1.50	12.00	3.90
Calcium, %	0.68	0.13	0.07	0.30	0.01	5.00	0.10
Phosphorus, %	1.21	0.25	0.88	0.74	0.49	2.87	1.22
Magnesium, %	0.58	0.16	0.39	0.31	0.06	0.21	0.52
Potassium, %	1.35	0.35	1.35	2.47	0.20	1.11	1.23
Sodium, %	0.01	0.02	0.28	0.00	0.02	0.88	0.00
Sulfur, %	0.71	0.34	0.39	0.37	0.79	0.99	0.19
Chloride, %		0.07	0.23				
Iron, mg/kg	128	47	109	116	85	752	138
Zinc, mg/kg	56	20	65	44	18	88	99
Copper, mg/kg	3	4	4	13		23	6
Manganese, mg/kg	55	12	19	34	5	32	132
Molybdenum, mg/kg	2	1	2	4	1	1	2

[1]Soluble protein.

Table 5. Characteristics of cornmeal and steam-rolled corn.

Characteristic	Cornmeal	Steam-rolled corn
Density, g/L	635	553
Gelatinization score (mg glucose/dL)[1]	6.94	23.44
Average grain kernel dimensions[2]		
Weight, g	. . .	0.305 ± 0.057
Length, cm	. . .	1.350 ± 0.120
Width, cm	. . .	1.056 ± 0.107
Thickness, cm	. . .	0.357 ± 0.026

[1]Glucose released from starch digestion by amyloglucosidase enzyme in 1 h.

[2]Steam-rolled corn grain dimensions were determined with 100 kernels.

Table 6. Particle size distribution of cornmeal and steam-rolled corn used in diets for lactating multiparous Holstein cows ($\bar{x}$ ± SD).

Item	Cornmeal[1]	Steam-rolled corn[1]
Screen size (mm)	(% retained on screen)	
4.00	0.003 ± 0.006	93.03 ± 0.64
2.00	2.08 ± 0.12	5.87 ± 0.51
1.00	26.29 ± 0.26	0.45 ± 0.07
0.50	31.76 ± 0.32	0.07 ± 0.03
0.25	22.19 ± 0.75	0.10 ± 0.03
Pan[2]	17.68 ± 0.75	0.48 ± 0.04
Geometric mean size[3]	0.54 ± 1.77	3.80 ± 1.25

[1]Triplicate 100 g-samples of cornmeal or steam-rolled corn were used.

[2]Particles passing through the 0.25 mm-screen and collected in a pan placed underneath the screen.

[3]Calculated using the log normal distribution technique of Ensor et al. (1970) and Waldo et al. (1971).

Table 7. Eating, ruminating, and drinking activities by lactating multiparous Holstein cows which were fed diets containing cornmeal (CM), cornmeal mixed with steam-rolled corn in ratio of 1:1 (CMSRC) on DM basis, and steam-rolled corn (SRC).

	Treatment means					Contrasts	
Item[1]	CM(1)	CMSRC(2)	SRC(3)	SE	*P*	1 vs (2 and 3)	2 vs 3
Eating							
min/d	320	294	349	25	0.3514		
Number of meals							
No./d	7.0	8.2	7.2	0.5	0.3026		
Ruminating							
Standing, min/d	78	144	98	32	0.3659		
Lying, min/d	268	294	276	35	0.8651		
Total, min/d	346	438	374	19	0.0232	0.0318	0.0433
Total chewing time, min/d	666	732	723	40	0.4842		
Drinking water							
min/d	27	20	35	5	0.1480		
Standing idle							
min/d	158	158	137	28	0.8327		
Lying down idle							
min/d	365	288	296	18	0.0285	0.0097	0.7571

[1]The rest of the time animals were either disturbed or walking to and from the parlor.

Table 8. Body weight and nutrient digestion by lactating multiparous Holstein cows which were fed diets containing cornmeal (CM), cornmeal mixed with steam-rolled corn in ratio of 1:1 (CMSRC) on DM basis, and steam-rolled corn (SRC).

	Treatment means					Contrasts	
Item	CM(1)	CMSRC(2)	SRC(3)	SE	*P*	1 vs (2 and 3)	2 vs 3
BW, kg	628	633	633	4.0	0.5379		
Total tract digestibility, %							
DM	62.4	63.5	60.3	1.8	0.5085		
OM	64.0	64.7	61.1	2.0	0.4592		
CP	67.9	68.4	65.5	1.9	0.5578		
Starch	93.9	96.5	94.6	1.3	0.3755		
NDF	46.9	46.8	43.0	2.5	0.4795		
Animal condition							
Body score	2.87	2.95	2.99	0.03	0.0070	0.0025	0.2584
Lameness score	1.10	1.14	1.09	0.04	0.6540		

as reflected by its high flake density (Theurer et al., 1999a; Yu et al., 1998). The flake density of the SRC used in the present study was about 2% higher than the highest flake density usually reported for commercially produced SRC (Theurer et al., 1999a). In general, steam processing during steam-rolling is not as extensive as in steam-flaking (Theurer et al., 1999a). Consequently steam-flaking of corn compared to steam-rolling or dry-rolling of corn consistently improves ruminal starch digestion, milk production, and milk protein yield, whereas steam-rolling compared with dry-rolling of barley or wheat for instance, has been reported not to alter total tract digestion of starch (Chen et al., 1994; Yu et al., 1998; Theurer et al., 1999a). However, digestion of NDF and ADF by lactating dairy cows is higher for SRC-based diets compared with diets containing SFC (Yu et al., 1998; Santos et al., 1999) or finely ground corn (Yu et al., 1998). Yu et al. (1998) also reported that digestion of NDF and ADF by lactating dairy cows was similar between SRC and coarsely ground corn-based diets.

In agreement with the findings of the present study, Yu et al. (1998) reported no differences in milk yield, 3.5% FCM yield, and yield and composition of fat, protein, lactose, and milk urea nitrogen between SRC and finely (or coarsely) ground corn-based diets by lactating Holstein cows. Santos et al. (1999) also failed to observe significant differences in milk yield when lactating Holstein cows were fed either SRC (density of 490 g/L), or SFC (density of 360 g/L) as part of a TMR. Other workers (Crocker at al., 1998; Joy et al., 1997) also reported no improvements in total milk yield, FCM yield, milk

Table 9. Milk yield and composition by lactating multiparous Holstein cows which were fed diets containing cornmeal (CM), cornmeal mixed with steam-rolled corn in ratio of 1:1 (CMSRC) on DM basis, and steam-rolled corn (SRC).

	Treatment means					Contrasts	
Item[1]	CM(1)	CMSRC(2)	SRC(3)	SE	*P*	1 vs (2 and 3)	2 vs 3
Milk, kg/d	39.5	39.2	39.6	0.4	0.6975		
3.5% FCM, kg/d	41.7	40.9	39.7	0.5	0.1027		
Fat							
kg/d	1.49	1.45	1.39	0.03	0.1039		
%	3.79	3.81	3.71	0.07	0.5498		
CP							
kg/d	1.25	1.24	1.24	0.01	0.9246		
%	3.21	3.23	3.22	0.01	0.5762		
True protein							
kg/d	1.18	1.17	1.17	0.01	0.9257		
%	3.04	3.05	3.04	0.01	0.5890		
Lactose							
kg/d	1.91	1.90	1.91	0.02	0.9465		
%	4.87	4.90	4.88	0.01	0.1751		
Milk urea nitrogen							
mg/dl	14.0	14.0	14.3	0.1	0.2918		
Ln SCC	4.19	4.40	4.02	0.08	0.0013	0.7202	0.0003

[1]Measurements were taken in wk 6 to 8 and all cows had DIM equal to or less than 305 d at the end of the study.

protein, or milk urea nitrogen from feeding lactating Holstein cows SFC compared with DRC.

CONCLUSIONS

There were no differences among treatments in milk yield, 3.5% FCM, and yield and percentage fat, CP, true protein, lactose, and milk urea nitrogen. Cows fed the TMR containing SRC had higher body condition and ruminated longer compared with cows that were fed the CM-based TMR. Feeding SRC mixed with CM improved the animal body condition and rumination compared to CM-based TMR. However, partial or complete substitution of CM by SRC in diets for lactating dairy cows did not improve DM and nutrient digestion, milk yield, and milk composition.

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