Effect of condensed corn distillers solubles concentration on lactation performance of Holstein cows

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ABSTRACT

Forty-eight Holstein cows (32 multiparous and 16 primiparous) in mid to late lactation averaging 219 ± 71 days in milk and 30.5 ± 6.6 kg/d of 3.5% fat-corrected milk were used in a 56-d completely randomized design experiment to evaluate condensed corn distillers solubles (CCDS) inclusion in high-fiber total mixed rations (TMR). Inclusion rates evaluated were 0, 6.6, 13.2, and 19.8% CCDS as a percentage of dry matter (DM). Distiller solubles substituted for soybean meal, corn grain, and whole cottonseed such that diets were similar in protein (16.6%) and fat (4.50%). Water was added to 0, 6.6, and 13.2% CCDS treatments so that final TMR DM concentrations (47.8%) were similar across diets. The forage portion of the diet was kept constant at 19.6% annual ryegrass hay and 26.0% sorghum baleage. Diet *in vitro* true digestibility tended to increase as CCDS addition increased, but neutral detergent fiber digestibility trended lower in CCDS diets. Percent P (0.39, 0.55, 0.69, and 0.73%) and S (0.32, 0.35, 0.39, and 0.42%) in TMR increased as CCDS concentration increased. Milk yield (23.5, 24.7, 25.5, and 24.8 kg/d of 3.5% fat-corrected milk) was similar for control and CCDS diets. Milk fat (3.88, 3.73, 3.78, and 3.68%), protein (3.28, 3.27, 3.31, and 3.31%), and lactose (4.61, 4.66, 4.69, and 4.77) percentages were similar across diets. Milk urea nitrogen (16.60, 15.58, 15.43, and 14.75 mg/dL) declined with increasing CCDS addition. Animal activity, body weight, body condition scores, and locomotion scores were not influenced by CCDS. Day 28 poststudy locomotion scores were similar across diets. Ruminal acetate concentrations did not differ among diets, but propionate and butyrate concentrations were elevated in rumen fluid of cows receiving 19.6% CCDS. Although rumen fluid pH values were similar (6.5, 6.4, 6.3, and 6.2), the two highest CCDS diets exhibited depressed acetate:propionate ratios relative to controls.

The results from this study indicate that CCDS may be included in high-fiber TMR for lactating dairy cows at up to nearly 20% of diet DM; however, caution is recommended because high CCDS P concentrations may create Ca:P imbalances and excess P may be introduced into the environment.

Key words: condensed corn distillers solubles, lactating dairy cattle, total mixed ration

INTRODUCTION

Recent estimates are that more than 40% of the corn grown for grain in the United States was used by the ethanol biofuel industry in 2013 (USDA, 2014). A consequence of this expansion is increased availability of ethanol by-products. Each pound of corn used in ethanol production generates about one-third pound of dried distillers grains, the most popular ethanol by-product fed to livestock. Other by-product feeds such as wet corn distillers solubles, corn germ and several new by-products are becoming increasingly available to the cattle industry (Schingoethe et al., 2009).

The by-product condensed corn distillers solubles (CCDS), also known as corn syrup, is a condensed form of corn stillage remaining after ethanol production. This product is normally dried and added back to dried distillers grains (dried distillers grains plus solubles), but some ethanol plants offer CCDS for sale to livestock producers within a reasonable trucking distance.

As with many agricultural by-products, nutrient composition of CCDS can be quite variable. Several reports indicate that CCDS may contain as little as 17% and as much as 27% CP, with fat levels ranging from less than 5% (Gilbery et al., 2006) to more than 20% (Da Cruz et al., 2005). Although data are limited, the rumen undegradable protein content of CCDS has been estimated to range from as little as 15% (Gilbery et al., 2006) to as high as 30% of total protein (Schingoethe et al., 2009). The by-product is also known to be quite high in P, K, and S, and concentrations of these minerals often vary considerably between ethanol

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plants due to different management practices employed in ethanol manufacture. More recent data indicate that ethanol plants are condensing the thin stillage to DM ranging from 27 to 35% (Gilbery et al., 2006; Warner et al., 2011). However, remaining moisture in these CCDS products continues to limit the distance this product can economically be transported.

In some of the earlier research, Hatch et al. (1972) demonstrated that including 2.5% distillers solubles as a replacement for urea in liquid protein supplements improved weight gain and feed conversion for finishing beef steers. Subsequent finishing cattle studies with CCDS also noted improved feed conversion (Rust et al., 1990; Ham et al., 1994), whereas others observed improved weight gains in finishing cattle receiving up to 20% CCDS (Sharp and Berkelo, 1996). In supporting research, Nebraska workers (Larson et al., 1993) reported that, as a whole, wet distillers products contained an average of 169% of the energy present in rolled corn for yearling cattle and 128% when fed to calves.

Relatively high fat content in CCDS has created concern with respect to its potential negative impact on rumen fermentation and digestion. Corn oil has been shown to reduce DM and fiber digestion in both sheep and cattle (Palmquist and Jenkins, 1980; Jenkins and Fotouhi, 1990). Most dietary supplementation research with CCDS that contained more than 8% fat elicited a depression in rumen acetate, a decrease in acetate:propionate ratio, and an increase in butyrate suggestive of reduced ruminal fiber digestion. However, in high-fiber diets containing as much as 15% CCDS, no adverse effects on rumen or total tract digestibility were recorded (Gilbery et al., 2006). Moreover, in a recent review on feeding distillers by-products to dairy cattle (Schingoethe et al., 2009), it was noted that cattle receiving TMR diets containing CCDS seldom experienced significantly impaired fiber digestion or milk fat depression when fed 50% or more forage in TMR.

Distillers solubles have been evaluated as a substitute for corn and soybean meal in lactating dairy cattle diets (DaCruz et al., 2005; Sasikala-Appukuttan et al., 2008). In the study by DaCruz et al. (2005), milk yield increased with CCDS addition to corn silage-alfalfa hay-based diets, but no differences were noted between diets containing 5 or 10% CCDS. In a follow up lactation study, CCDS was tested at 0, 10, and 20% of diet DM. Milk yield tended to be higher with increasing CCDS level, but no differences were noted for DMI or feed efficiency (**FE**). The authors suggested that higher performance was likely due to higher energy content in diets containing CCDS and noted that CCDS was effective in replacing up to 20% corn and soybean meal in corn silage-alfalfa hay-based TMR.

Since the above-mentioned research was conducted, producers have seen large increases in corn, soybean, and other feed ingredient prices. Thus, interest in feeding high levels of CCDS has grown, particularly for those in close proximity to ethanol plants that offer this product at a reasonable price. Little research exists studying dietary CCDS supplementation in lactating dairy cows offered high-fiber diets. Nor have previous studies attempted to evaluate CCDS fat relative to other common seed-grain fat sources such as whole cottonseed. Therefore, this project was initiated to study the effect of feeding 0, 6.6, 13.2, and 19.8% CCDS to mid lactation Holstein cows receiving sorghum baleage and ryegrass hay-based TMR. Distillers soluble nutrients were substituted for corn, soybean meal, and whole cottonseed such that diets were similar in protein and fat content.

MATERIALS AND METHODS

Forty-eight Holstein cows (32 multiparous and 16 primiparous) in mid to late lactation averaging 219 ± 71 DIM and 30.5 ± 6.6 kg/d of FCM were used in a 56-d completely randomized design experiment to evaluate CCDS inclusion in high-fiber diets. This study was conducted at the Louisiana State University Agricultural Center's Southeast Research Station located near Franklinton ($30^{\circ}47'04''$ N and $90^{\circ}12'19''$ W). All animal procedures were approved by the Louisiana State University Agricultural Center's Animal Care Committee (protocol A2011-19). Cows were stratified according to DIM, parity, and milk production and randomly assigned to 4 CCDS treatments representing 0, 6.6, 13.2, or 19.8% of diet DM or 0, 15, 30, or 45% of concentrate DM. Cows were fed experimental TMR in a 64-cow free stall barn equipped with Calan gates (American Calan Inc., Northwood, NH) for measuring individual TMR consumption. Cows were allowed a minimum of 14 d for adaptation to Calan gates. Following adaptation to the feeding barn, cows were offered a common corn silage-based TMR for 10 d during which animal performance data were collected and used for covariance analysis.

Experimental diets were designed to be similar in DM, protein, and fat content (NRC 2001). Ingredients utilized were BMR 108 forage sorghum (Croplan Genetics, Land O'Lakes, Inc., Minneapolis, MN) baleage, Prine annual ryegrass (Reagan and Massey Seeds Inc., Ponchatoula, LA), hay, ground corn, soybean meal, whole cottonseed, custom dairy minerals, and CCDS (Table 1). Water was added to TMR as needed to maintain TMR DM at approximately 50%. Whole cottonseed concentration was lowered with increasing CCDS in order to maintain dietary fat concentration at

Table 1. Ingredient composition of diets containing increasing concentrations of condensed corn distillers solubles (CCDS)

Ingredient, % of diet DM	CCDS concentration, % of DM			
	0	6.6	13.2	19.8
Ryegrass hay	19.0	19.0	19.0	19.0
Sorghum baleage	26.6	26.6	26.6	26.6
Corn, ground	27.2	24.4	21.9	19.2
Soybean meal, 48%	14.7	13.2	11.8	10.4
Cottonseed, whole	10.1	8.0	5.5	3.2
CCDS	0.0	6.6	13.2	19.8
Dairy mineral ¹	1.9	1.7	1.5	1.3
Calcium carbonate	0.5	0.5	0.5	0.5

¹Custom dairy mineral containing 23% Ca, 4% P, 6% Mg, 3% S, 6% K, 2,700 mg/kg of Zn (inorganic), 1,000 mg/kg of Zn methionine, 1,200 mg/kg of Mn, 650 mg/kg of Cu, 50 mg/kg of I, 15 mg/kg of Co, 18 mg/kg of Se, 660 kIU of vitamin A/kg, 66 kIU of vitamin D/kg, 33 kIU of vitamin E/kg, and 0.20% Rumensin-80 (Elanco Animal Health, Greenfield, IN).

about 4.5% of DM. Otherwise, CCDS substituted for corn and soybean meal in experimental diets. Forage accounted for approximately 45% of diet DM, and concentrate, including CCDS, accounted for 55% of diet DM. Fresh bales of sorghum baleage and ryegrass hay were ground daily with a flail-type hay grinder (model 2554 HayBuster, McConnell Machinery Co., Lawrence, KS), and a basal forage mix was then prepared in a vertical mixer wagon (Jaylor model 3650, Orton, Ontario, Canada). Concentrate components were added to a Calan Data Ranger (American Calan Inc.) to complete experimental TMR (Table 1). The CCDS was mechanically agitated for 0.25 h prior to being added to experimental diets. All CCDS was purchased weekly in 1,000-kg plastic carboys from a local vendor. The CCDS was generated at the Bunge-Ergon ethanol plant in Vicksburg, Mississippi.

Diets were fed twice daily (0800 and 1500 h) in amounts to allow for ad libitum consumption. Orts were weighed immediately prior to morning feeding and recorded daily for each animal. Ort and TMR samples were collected on Monday, Wednesday, and Friday of each week and composited to form weekly samples, which were dried at 55°C for 48 h, ground to 1 mm, and stored in plastic airtight vials for subsequent lab analyses. Baleage, hay, and concentrate samples, including CCDS, were obtained weekly and processed as described above. Ground samples were analyzed for DM and CP (micro Kjeldahl) according to AOAC (1990) procedures. Sample ADF and NDF concentrations were determined using detergent fiber methods of Van Soest et al. (1971). Sodium sulfite and amylase were added to NDF solutions before fiber analyses were conducted. In vitro digestibility of silage samples was determined by the 2-stage rumen fermentation-pepsin technique as described by Goering and Van Soest (1970). Experimental TMR were tested for NDF digestibility by

measuring NDF concentrations before and after a 48-h in vitro fermentation (NRC, 2001). Baleage VFA were determined by gas chromatography (Bateman et al., 2002), and lactic acid concentrations were determined via the enzymatic conversion of L-lactate to pyruvate using the YSI 2700 Select Biochemistry Analyzer (YSI Inc., Yellow Springs, OH). Weekly CCDS and TMR samples were analyzed for ether extract using the Goldfish method (AOAC, 1990). Aflatoxin B₁ concentrations in CCDS were determined using HPLC according to AOAC (1990; method 994.08). Mineral analyses on feed, forage, and TMR samples were determined using inductively coupled plasma optical emission spectroscopy (EPA method 200.7). Crude fat concentrations were determined from an ether extraction using the Soxtec System (Foss Inc., Eden Prairie, MN; AOAC, 1990; method 945.16).

Cows were milked twice daily at 0400 and 1500 h. At each milking, milk yield and conductivity for each cow were measured in AfiFlo milk meters (AfiMilk, Kibbutz Afikim, Israel). Animal activity (steps/h) was also downloaded at each milking using AfiTag pedometers (AfiMilk). Composites of a.m. and p.m. milk samples were collected weekly, preserved with 2-bromo, 2 nitropropane-1, 3-diol, and analyzed for fat, protein, MUN, and lactose via infrared spectroscopy (Mid-South Dairy Herd Improvement Association, St. Louis, MO). Milk SCC was determined via flow cytometry. Body weights, BCS (1 = extremely thin and 5 = extremely obese; Edmonson et al., 1989), and locomotion scores (1 = normal and 5 = extremely lame; Sprecher et al., 1997) were recorded on 2 consecutive days at study initiation and conclusion and on d 14, 28, and 42. Locomotion scores were also recorded on d 84 (4 wk after study conclusion) to assess potential long-term effects of CCDS level on cattle lameness. Condition and locomotion scores were assigned by 3 independent observers.

On the morning of d 56, 10 mL of rumen fluid was collected approximately 4 h postfeeding from each animal via rumenocentesis (Nordlund et al., 1994). Rumen fluid pH was measured immediately with an Orion model 230A portable pH meter (Orion Research Inc., Boston, MA), and the sample was then placed on ice until transported to the Southeast Research Station Forage Quality Laboratory. Five milliliters of rumen fluid was sterilized with 1.0 mL of 25% meta-phosphoric acid, and samples were centrifuged at $7,000 \times g$ for 10 min in a refrigerated centrifuge (4°C), filtered through a 2.0- μ m filter, and stored at -20°C. Rumen fluid VFA were determined by gas chromatography (Bateman et al., 2002).

Lactation performance data were statistically analyzed using the MIXED procedure of SAS (SAS Institute, 2001). All daily intake and milk production data were reduced to cow-week means before statistical analysis. The model for the lactation performance data included CCDS level, week, and CCDS $\times$ week as fixed effects, cow nested within CCDS level as random effects, and cows by week as residual error effects. Performance data collected during the standardization period were used as covariables for the dependent variables. Rumen fluid pH and VFA were evaluated using GLM procedures with a model that included CCDS level tested against residual error. Least square means were separated using Tukey-Kramer adjustment and results are accompanied by the highest standard error. Statistical differences between means were declared at $P < 0.05$, and tendencies were reported at $P > 0.05$ and < 0.10 .

RESULTS AND DISCUSSION

Nutrient Content of Feed Ingredients and Diets

Experimental diets contained approximately 45% forage as sorghum baleage and ryegrass hay and 55% concentrates derived from corn, soybean meal, cottonseed, CCDS, and minerals (Table 1). Condensed corn distillers solubles substituted for approximately 30% of the corn, soybean meal, and minerals and 68% of the whole cottonseed at the highest concentration evaluated (19.6% of DM).

Chemical composition of CCDS was relatively constant throughout the study as indicated by low standard deviation values for CCDS chemical constituents (Table 2). Average distillers solubles DM, CP, and ether extract concentrations were 33.1, 18.8, and 9.8%, respectively. Dry matter and CP content of CCDS were similar to the average ranges 27 to 31% for DM and 18.1 to 19.5% for CP previously reported (Gilbery et al., 2006; Sasikala-Appukuttan et al., 2008). In con-

trast, CCDS in the present experiment contained about 10% crude fat, which was similar to that reported by Warner et al. (2011), but less than half the average ether extract concentrations reported in other studies (Da Cruz et al., 2005; Sasikala-Appukuttan et al., 2008). Differences in crude fat concentration may be related to variations in CCDS manufacture between ethanol plants. Large variations in nutrient composition of distillers by-products have been previously reported (Spiehs et al., 2002).

Mineral concentrations for CCDS, forages, and experimental diets are presented in Table 2. The CCDS contained unusually low levels of Ca and high concentrations of P. Therefore, experimental diets Ca:P ratio declined with increasing CCDS concentration and fell slightly below 1:1 at the highest CCDS supplementation level. Our custom dairy mineral was low in P (4%), which was necessary to prevent the Ca:P ratio from falling below 1:1, the lower limit for lactating dairy cattle (NRC, 2001). Moreover, P concentrations in diets containing CCDS were from 40 to 100% higher than recommended for these lactating Holsteins, which may have contributed excess P into the environment. Sulfur concentration in CCDS approached 1% of DM, but with the exception of the highest CCDS diet, concentrations in experimental diets were below 0.40%, the recommended maximum S concentration in dairy cattle diets (NRC, 2001). The CCDS contained an average of 17.2 μ g/kg aflatoxins, which is below the maximum 20 μ g/kg allowed by the Food and Drug Administration for use in dairy cattle diets. However, as indicated by the relatively high standard deviations, 1 or 2 CCDS samples did exceed the 20 μ g/kg threshold.

Use of water additions to balance differences between CCDS DM and that of substituted concentrates enabled maintenance of relatively constant DM concentrations in experimental diets (Table 2). Previous research indicated DM reductions of up to 10 percentage units with CCDS supplementation (Da Cruz et al., 2005; Sasikala-Appukuttan et al., 2008) compared to less than 3 percentage unit differences in our diets. Diet CP concentrations were 16.5%, which were slightly lower than the desired 17% CP, this being attributed to lower than anticipated CP in ryegrass hay. Dietary crude fat concentrations were similar across diets, though fat from whole cottonseed decreased as CCDS supplementation level increased. As expected, fiber fractions declined with increasing CCDS and in vitro true digestibility increased slightly. In spite of the trend toward higher in vitro true digestibility with CCDS supplementation, diets containing CCDS were somewhat lower in NDF digestibility than the control diet containing 0% CCDS. One of the major concerns with feeding large amounts of CCDS to cattle has been the potential effect of its

Table 2. Mean nutrient value and standard deviation of ryegrass hay (RH), sorghum baleage (SB), condensed corn distillers solubles (CCDS), concentrate mix (CM), and TMR for 0, 6.6, 13.2, and 19.8% CCDS concentrations

Item, % of DM unless otherwise noted	RH	SB ¹	CCDS	CM ²	TMR, %			
					0	6.6	13.2	19.8
DM, %	88.4 ± 1.2	32.9 ± 1.4	33.1 ± 4.6	88.9 ± 2.1	46.3 ± 1.5	47.7 ± 2.1	48.2 ± 1.6	49.0 ± 2.4
CP	11.7 ± 1.5	10.9 ± 0.6	18.8 ± 2.6	20.8 ± 1.4	16.7 ± 1.2	16.3 ± 0.9	16.6 ± 1.6	16.8 ± 1.3
EE ³			9.8 ± 3.0		4.66 ± 1.02	4.41 ± 0.85	4.58 ± 0.79	4.69 ± 0.81
ADF	36.2 ± 1.8	36.8 ± 1.3		4.7 ± 0.4	26.2 ± 2.0	26.2 ± 2.2	23.5 ± 2.3	21.7 ± 3.5
NDF	58.8 ± 2.7	55.1 ± 2.0			40.5 ± 4.8	39.8 ± 3.2	36.0 ± 4.4	33.7 ± 6.0
Ash					8.15 ± 0.33	8.03 ± 1.86	8.37 ± 1.97	8.81 ± 2.02
IVTD ⁴	77.0 ± 2.1	73.4 ± 1.4			81.1 ± 2.3	81.1 ± 2.5	83.9 ± 2.4	85.0 ± 2.2
NDFD ⁵					57.5 ± 12.6	42.2 ± 11.4	49.1 ± 11.5	48.9 ± 12.8
Aflatoxin B ₁ , µg/kg			17.2 ± 5.6					
Ca			0.06 ± 0.02	1.08 ± 0.30	0.76 ± 0.12	0.65 ± 0.12	0.69 ± 0.12	0.71 ± 0.11
P			1.99 ± 0.23	0.75 ± 0.03	0.39 ± 0.02	0.55 ± 0.05	0.69 ± 0.06	0.73 ± 0.06
K			2.36 ± 0.28	1.07 ± 0.44	1.66 ± 0.06	1.71 ± 0.10	1.73 ± 0.10	1.77 ± 0.05
Mg			0.59 ± 0.04	0.41 ± 0.07	0.39 ± 0.02	0.38 ± 0.02	0.41 ± 0.02	0.43 ± 0.02
S			0.98 ± 0.37		0.32 ± 0.01	0.35 ± 0.04	0.39 ± 0.04	0.42 ± 0.03
Cu, mg/kg			4.9 ± 1.3	37.1 ± 7.2	23.0 ± 2.3	22.0 ± 2.0	19.8 ± 1.9	17.5 ± 1.4
Zn, mg/kg			117.4 ± 8.6	184.5 ± 28.4	118.9 ± 11.2	114.2 ± 11.8	110.9 ± 11.8	113.6 ± 10.5
Fe, mg/kg			571 ± 191		584 ± 102	569 ± 104	612 ± 104	555 ± 218
Mn, mg/kg			49.2 ± 10.9	76.8 ± 22.4	104.3 ± 5.7	98.8 ± 7.5	95.6 ± 7.5	93.2 ± 10.5

¹SB fermentation characteristics: pH = 4.25 ± 0.06; lactic acid = 2.7 ± 0.28%; acetic acid = 1.42 ± 0.09%; propionic acid = 0.09 ± 0.01%; butyric acid = 0.03 ± 0.03; and isobutyric acid = 0.18 ± 0.10%.

²CM = corn-soybean meal-mineral mix used in all TMR.

³EE = ether extract.

⁴IVTD = in vitro true digestibility.

⁵NDFD = neutral detergent fiber digestibility.

soluble fat on dietary fiber digestion (Schingoethe et al., 2009). In a beef steer feeding study, supplementation with CCDS improved switchgrass fiber and DM digestibility (Gilbery et al., 2006). However, CCDS used in that study contained only 4.2% fat and improvements in digestibility were attributed to increased microbial protein synthesis. Though no specific studies have been conducted to assess CCDS fat effects on fiber digestion in dairy diets, Schingoethe et al. (2009) in a review on the use of distillers products in dairy cattle diets, concluded that for diets containing 50% or more forage and adequate effective fiber, CCDS-induced depression in fiber digestibility was not likely to be a problem. In our study, CCDS fat substituted for whole cottonseed fat. The oil in CCDS likely is more soluble and more readily biohydrogenated in rumen liquor than cottonseed fat increasing its potential to inhibit ruminal fiber digestibility.

Diet Consumption and Lactation Performance

Dry matter consumption was similar across diets (Table 3), but lower than previously reported for lactating dairy cows supplemented with CCDS (Da Cruz et al., 2005; Bharathan et al., 2008; Sasikala-Appukuttan et al., 2008). Lower DMI in the present study was likely related to low diet DM, high dietary NDF concentrations, later lactation cows, or a combination

of these factors. Fiber intake was not affected by CCDS concentration though numerically lower concentrations in the highest supplementation level may have been a reflection of the lower NDF concentrations prevalent with increasing CCDS additions (Table 2).

Milk yield and FE were similar across all levels of CCDS supplementation (Table 3). Using an energy value for CCDS of 2.09 Mcal of NE_L/kg (Schingoethe et al., 2009), diets were expected to generate an average of 32.2 kg of 3.5% FCM/d (NRC, 2001), which was considerably higher than the 24.7 kg/d FCM average observed in this study, this primarily being related to high dietary NDF and lower than expected DMI. Others have noted dairy cow lactation performance similar to controls when CCDS composed 10% of diet DM (Bharathan et al., 2008). In contrast, other researchers have noted improvements in milk production with CCDS supplementation (Da Cruz et al., 2005; Sasikala-Appukuttan et al., 2008). However, in these reports diets were not balanced for additional fat from CCDS, which led to higher dietary energy concentrations as CCDS supplementation increased. Our diets were balanced for fat concentration; therefore energy intake was similar across dietary treatments, and given similar DMI, no increases in ECM yield were expected. Based on milk yield and diet nutrient composition, CCDS used in the present study contained 2.07 Mcal of NE_L/kg, which was similar to the 2.09 Mcal/kg of NE_L

Table 3. Lactation performance, BW, BCS, and locomotion scores of Holstein cows fed 0, 6.6, 13.2, or 19.8% condensed corn distillers solubles (CCDS)

Item	CCDS concentration, % of DM				SEM	P-value		
	0.0	6.6	13.2	19.8		CCDS	Week	CCDS × week
DMI, kg/d	19.5	19.6	20.6	20.9	0.66	0.37	<0.01	<0.01
NDF intake, kg/d	7.7	7.9	7.4	7.0	0.27	0.22	<0.01	<0.01
Milk yield, kg/d	23.8	23.3	24.6	24.0	0.84	0.54	<0.01	0.70
3.5% FCM, kg/d	23.8	24.7	25.5	24.8	1.03	0.72	<0.01	0.89
FE, ¹ kg of FCM/kg of DMI	1.22	1.26	1.24	1.19	0.10	0.58	<0.01	<0.01
Fat, %	3.88	3.73	3.78	3.68	0.10	0.55	<0.01	0.46
Fat, kg/d	0.92	0.87	0.93	0.88	0.03	0.45	<0.01	0.44
Protein, %	3.28	3.27	3.31	3.31	0.05	0.89	<0.01	0.50
Protein, kg/d	0.78	0.76	0.81	0.79	0.02	0.45	<0.01	0.42
Lactose, %	4.61	4.66	4.69	4.77	0.06	0.28	<0.01	0.18
Lactose, kg/d	1.10	1.09	1.15	1.14	0.03	0.23	<0.01	0.22
SCC, × 10 ³ /mL	180.1	291.2	320.2	283.7	63.1	0.43	0.85	0.73
Milk conductivity, mS	11.12	11.34	10.96	11.07	0.11	0.10	0.07	0.24
MUN, mg/dL	16.60 ^a	15.58 ^{ab}	15.43 ^{ab}	14.75 ^b	0.41	0.02	<0.01	<0.01
Activity, steps/h	103.7	119.2	108.2	102.3	6.6	0.26	<0.01	0.35
Initial BW, kg	655.1	652.2	680.3	660.4	9.8	0.74		
Final BW, kg	672.0	676.0	704.4	681.5	9.9	0.65		
BW change, kg	17.0	23.8	24.1	21.1	2.2	0.58		
Initial BCS ²	3.00	3.00	2.98	3.08	0.12	0.91		
Final BCS	2.14	2.59	2.27	2.76	0.35	0.46		
BCS change	-0.87	-0.42	-0.72	-0.33	0.36	0.56		
Initial locomotion score ³	1.53	1.54	1.61	1.61	0.16	0.96		
Final locomotion score	1.58	1.58	1.47	1.69	0.26	0.92		
Locomotion score change	0.06	0.04	-0.14	0.08	0.28	0.91		
Locomotion score, ⁴ d 84	1.54	1.56	1.47	1.44	0.22	0.94		

^{a,b}Least square means in rows with different superscripts differ significantly ($P < 0.05$).

¹FE = feed efficiency.

²Body condition score: 1 = extremely thin and 5 = extremely obese.

³Locomotion score: 1 = normal and 5 = extremely lame (incumbent).

⁴Locomotion scores taken 28 d after study conclusion.

reported by Schingoethe et al. (2009) for milk cows but lower than reported by Larson et al. (1993) for finishing beef cattle. Higher energy content in beef cattle diets was attributed to lower dietary starch or improvements in energy availability due to the effects of yeast and other micronutrients found in CCDS. Improvements in FE were not seen in the present evaluation nor were they observed in previous CCDS supplementation work (Sharp and Berkelo, 1996; Da Cruz et al., 2005). Lack of improvements in FE may have been related to slight depressions in fiber digestibility, which may have negated increased energy availability through CCDS fat contributions.

Percentage and yield of milk fat, protein, and lactose did not differ with diet ($P > 0.10$). Milk fat percentage ranged from 3.68 to 3.88% (Table 3), which are typical values for late lactation cows consuming high-fiber diets. In contrast, Bharathan et al. (2008) recorded a decline in milk fat percentage from 3.62 to 3.23% and Da Cruz et al. (2005) saw milk fat percentage drop from 3.54 to 3.33% for milk cows receiving 10% CCDS. In both of these studies, cows were earlier in stage of

lactation, diets contained less NDF, and CCDS fat content was more than double that described in the present report. One or more of these factors may explain why we did not observe milk fat depression with increasing CCDS supplementation.

Milk protein and lactose percentage and yield varied little with experimental diets, a finding consistent with that of Sasikala-Appukuttan et al. (2008) who observed similar protein and lactose concentrations in milk cows fed 0, 10, or 20% CCDS. Milk urea nitrogen concentration decreased ($P < 0.02$) with CCDS addition falling from 16.6 mg/dL for controls to 14.7 mg/dL at the 19.8% CCDS supplementation level. Although RUP data are lacking, the MUN decrease with CCDS addition suggests that RUP of CCDS is considerably higher than that found in soybean meal and corn. Dried distiller grains, brewers grains, and other grain by-products are usually moderate to high in RUP (Schingoethe et al., 2009), and depressed MUN observed in the current study and others (Da Cruz et al., 2005; Sasikala-Appukuttan et al., 2008) suggests the same may be true for CCDS.

Table 4. Ruminal VFA and pH for Holstein cows fed diets containing 0, 6.6, 13.2, or 19.8% condensed corn distillers solubles (CCDS)

Item	CCDS concentration, % of DM				SE	P-value
	0	6.6	13.2	19.8		
VFA, $\mu\text{mol/mL}$						
Acetate (A)	57.4	63.8	44.5	63.1	4.62	0.31
Propionate (P)	15.5	18.3	13.8	23.7	1.72	0.10
Isobutyrate	1.1	1.3	0.9	1.1	0.14	0.73
Butyrate	9.8	11.4	9.1	15.7	1.25	0.10
Isovalerate	1.7	1.6	1.1	1.9	0.21	0.51
Valerate	1.4	1.6	1.3	1.9	0.18	0.50
Total	86.9	98.0	70.7	107.4	7.58	0.24
A:P ratio	3.76 ^a	3.50 ^{ab}	3.23 ^b	2.77 ^c	0.17	<0.01
pH	6.5	6.4	6.3	6.2	0.05	0.44

^{a-c}Means in a row with different superscripts differ significantly ($P < 0.05$).

Animal activity (steps/h), BW, BCS, and locomotion scores were not influenced by CCDS supplementation levels ($P > 0.10$; Table 3). Cow BW and BCS reacted in opposite directions from study initiation to conclusion with weight increasing and BCS decreasing over time. This contradiction may be explained by reductions in fat depots, the primary factor used in BCS determination, while overall body mass increased. Losses in fat reserves may have been related to low DMI observed for all experimental diets. Locomotion scores are highly correlated to laminitis and overall hoof quality (Norlund et al., 2004), and risk factors for laminitis may include suboptimal fiber concentrations and impaired rumen NDF digestion. Low locomotion scores (1 = normal gait to 5 = extremely lame) in the present study imply that rumen function was normal and effective fiber was more than adequate even at the highest (19.8%) CCDS treatment. The fact that no changes in locomotion score were noted 28 d after study conclusion further supports our contention that CCDS may be fed at quite high levels in dairy cattle diets provided adequate effective fiber is available.

Ruminal VFA and pH for Holstein cows fed diets containing 0, 6.6, 13.2, or 19.8% CCDS are presented in Table 4. Rumen acetate, isobutyrate, isovalerate, and valerate concentrations were similar for all diets. However, a trend was noted for higher ($P < 0.10$) propionate and butyrate in rumen fluid of cows fed the highest (19.8%) CCDS level. The trend toward higher propionate at the 19.8% CCDS feeding rate resulted in a lower ($P < 0.01$) ruminal acetate:propionate ratio than observed for other diets. Previous researchers have also observed increased butyrate (Sharp and Berkelo, 1996; Bharathan et al., 2008) decreased acetate (Bharathan et al., 2008; Sasikala-Appukuttan et al., 2008) and lower acetate:propionate ratios (Ham et al., 1994) for CCDS-supplemented cows.

Rumen fluid pH means ranged from 6.2 to 6.4 in cows fed CCDS, but no level of supplementation effect was detected. However, one cow fed the 19.8% CCDS diet did have a rumen pH of 5.57, which is slightly lower than the 5.6 pH threshold associated with SARA (Nordlund et al., 2004).

CONCLUSIONS

Data from this study indicate that CCDS is readily consumed by mid to late lactation Holstein cows and lactation performance is similar to that achieved with a corn-soybean meal-whole cottonseed control diet when formulated for similar protein and fat content. Feeding up to 19.8% of diet DMI (45% of concentrates) as CCDS in high NDF diets did not alter milk yield nor did it adversely affect rumen metabolism or animal health. However, caution should be exercised when feeding excessive amounts of CCDS because high P concentrations may lead to Ca:P imbalances and high S concentrations could induce polioencephalomalacia-like symptoms in cows. Distillers by-products such as CCDS may be an economical alternative to traditional concentrates for dairy producers in close proximity to ethanol plants.

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