Response of lactating dairy cows to high protein distillers grains or 3 other protein supplements

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ABSTRACT

This study compared high protein dried distillers grains (HPDDG) with soybean meal (SBM), canola meal (CM), and dried distillers grains with solubles (DDGS) as protein supplements in dairy diets. A lactation trial used 12 multiparous cows averaging 78 d in milk at the start of the experiment in a 4 × 4 Latin square design with 28-d periods. Weeks 1 and 2 of each period were used for adjustment and wk 3 and 4 for data collection. Each treatment diet consisted of 55% forage and one of the 4 protein supplements in a concentrate mix. Total mixed diets averaged 15.3% crude protein, with 38% of the protein from one of the 4 protein supplements. Dry matter intake (24.4 kg/d) and crude protein intake (3.57 kg/d) were similar for all 4 diets. Milk production (31.8 kg/d), protein yield (1.05 kg/d), fat yield (1.29 kg/d), and protein percentage (3.31) were similar for all 4 treatment diets. Milk fat percentage was lower when fed DDGS (3.78) than when fed SBM or HPDDG (4.21), but similar with CM (4.07). Feed efficiency (1.44 kg of energy-corrected milk/kg of dry matter intake) and nitrogen efficiency (0.29) were not affected by diet. Total milk nitrogen and true milk protein were highest when fed the HPDDG diet. Molar proportions of acetate, propionate, and the acetate to propionate ratio in ruminal contents and ruminal ammonia concentrations were similar for all diets. Arterial and venous concentrations of total essential AA tended to be lower when fed CM, reflecting lower concentrations of His, Ile, Leu, and Val when fed the CM diet. Extraction efficiency of AA from blood by the mammary gland indicated that Met was the first limiting AA when fed the SBM diet, whereas Lys was first limiting for the other diets. Phenylalanine was third limiting with all diets. Feeding HPDDG was equally as effective as feeding SBM, CM, and regular distillers grains as a protein supplement for lactating cows.

Key words: distillers grain, high protein distillers grain, canola meal, lactating cow

INTRODUCTION

Dried distillers grains with solubles (DDGS) is the primary coproduct of ethanol production from corn and other grains. Several studies (e.g., Nichols et al., 1998; Anderson et al., 2006; Kleinschmit et al., 2006) demonstrated that DDGS can effectively replace soybean meal (SBM) as a protein source, but there is less evidence comparing DDGS with other protein supplements. Mulrooney et al. (2009) reported similar milk production when fed DDGS or canola meal (CM) as the protein supplement, although milk yield and protein yield responses and extraction efficiency of AA by the mammary gland (i.e., arteriovenous difference of an AA across the mammary gland relative to arterial concentration of the AA) indicated some benefits of feeding a combination of CM and DDGS rather than only one of them as the protein supplement.

Ethanol plants are attempting to improve the fermentation of corn to ethanol and this is resulting in new products (Robinson et al., 2008). One way this is accomplished is through fractionation of the corn in which the germ and the bran are removed before fermentation. This new product, called high protein dried distiller grains (HPDDG), is higher in CP and lower in fat (44% CP, 3.4% fat) than DDGS (30% CP, 10% fat) produced through traditional ethanol fermentation processes (Robinson et al., 2008). The HPDDG is a product that is closer in nutrient composition to CM and SBM. Hubbard et al. (2009) recently reported that feeding HPDDG increased milk production relative to the feeding of an SBM-based diet, but HPDDG has not been compared with CM. The objective of this study was to determine the response in milk production to diets that contained each of SBM, HPDDG, CM, or DDGS as the supplemental protein.

MATERIALS AND METHODS

All procedures for this study were conducted under approval of the South Dakota State University Animal

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Table 1. Ingredient composition of diets¹

Item, % of DM	SBM	HPDDG	CM	DDGS
Corn silage	27.5	27.5	27.5	27.5
Alfalfa hay	27.5	27.5	27.5	27.5
Corn ground dry	29.3	28.4	28.8	21.3
DDGS	0.0	0.0	0.0	21.2
SBM, 44% CP	11.1	0.0	0.0	0.0
HPDDG	0.0	12.0	0.0	0.0
Canola meal	0.0	0.0	12.7	0.0
Fat ²	2.0	1.8	1.2	0.0
Dicalcium phosphate	0.40	0.60	0.17	0.0
Magnesium oxide	0.07	0.08	0.05	0.07
Limestone	0.73	0.72	0.71	1.05
Salt	0.55	0.55	0.55	0.55
Mineral-vitamin mix ³	0.6	0.6	0.6	0.6
Vitamin A, D, E mix ⁴	0.2	0.2	0.2	0.2
Vitamin E ⁵	0.05	0.05	0.05	0.05

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

²Energy Booster 100 (Milk Specialties Company, Dundee, IL).

³Guaranteed analysis: Mg, 10.0%; Mn, 1.7%; Zn, 2.6%; Cu, 4,712 mg/kg; Co, 119 mg/kg; I, 396 mg/kg; Se, 140 mg/kg; Fe, 4,640 mg/kg; vitamin A, 2,640,000 IU/kg; vitamin D, 528,000 IU/kg; vitamin E, 10,560 IU/kg.

⁴Guaranteed analysis: vitamin A, 5,500,000 IU/kg; vitamin D, 880,000 IU/kg; vitamin E, 2,200 IU/kg.

⁵44,000 IU/kg.

Care and Use Committee. Twelve multiparous Holstein cows (78 ± 24 DIM) were used in a replicated 4×4 Latin square design with 28-d periods. Weeks 1 and 2 of each period were for adjustment to diets and wk 3 and 4 for data collection. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources. All diets contained 27.5% alfalfa hay and 27.5% corn silage on a DM basis (Table 1). The diets were formulated to be isonitrogenous at 16.0% CP and isolipogenic at 4.7% fat (Table 2). Energy Booster (Milk Specialties Company, Dundee, IL) was added to all except the DDGS diet to maintain approximately equal ether extract concentration in all diets. All other nutrients were formulated to meet or exceed the requirements according to NRC (2001). Cows were housed in a free-stall barn and individually fed diets as a TMR for ad libitum intake once daily (0800 h) using Calan Broadbent feeder doors (American Calan Inc., Northwood, NH). Feed intakes were recorded daily.

Samples of forages, concentrates, SBM, HPDDG, CM, and DDGS were collected for 2 consecutive days at the end of each period and stored at -20°C until analysis. Samples were composited by period and dried at 55°C in a Despatch oven (Despatch Oven Co., Minneapolis, MN) for 48 h. Composites were ground through a 4-mm screen in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) and then through a 1-mm screen in

an ultracentrifuge mill (Brinkman Instruments Co., Westbury NY). Samples were corrected to 100% DM by drying an aliquot of the composite at 105°C for 24 h (method 930.15; AOAC, 2002). Samples were analyzed for CP (method 990.03; AOAC, 2002), ether extract with petroleum ether (method 930.39; AOAC, 2002), and ash (method 942.05; AOAC, 2002). Neutral detergent fiber was determined with sodium sulfite and α -amylase (Van Soest et al., 1991), and ADF (Robertson and Van Soest, 1981) sequentially with an Ankom Fiber Analyzer (Ankom Technology Corp., Fairport, NY). Composition of the TMR was calculated based on analyses and concentrations in the diets of the concentrate mix and the individual forages.

Cows were milked 3 times daily at 0600, 1400, and 2100 h and yields were recorded. Milk samples were collected for each milking on 2 consecutive days during the last 2 wk of each period. Samples were mixed by gentle inversion and composited by weight corresponding to the respective milking for each cow on sampling day. These samples were sent to Heart of America DHI laboratory (Manhattan, KS) for composition analysis where fat, true protein, and lactose were determined using mid-infrared spectroscopy (Bentley 2000 Infrared Milk Analyzer, Bentley Instruments, Chaska, MN; method 972.16; AOAC, 2002). Concentrations of MUN were determined using chemical methodology based on a modified Berthelot reaction (ChemSpec 150 Analyzer, Bentley Instruments; Chaney and Marbach, 1962), and SCC was determined using a flow cytometer laser

Table 2. Nutrient composition of diets¹

Item	SBM	HPDDG	CM	DDGS
Formulated, % of DM unless noted				
CP	16.0	16.0	16.0	16.0
RDP ²	11.1	10.2	11.0	10.1
RUP ²	4.9	5.8	5.0	5.8
Ether extract	4.7	4.7	4.7	4.7
ADF	19.0	19.2	20.5	19.6
NDF	27.3	28.0	29.4	30.3
Forage NDF	22.9	22.9	22.9	22.9
NFC	46.4	47.0	45.1	45.1
NE _L , ² Mcal/kg	1.59	1.59	1.59	1.59
Ca	0.9	0.9	0.9	0.9
P	0.4	0.4	0.4	0.4
Measured, % of DM unless noted				
DM, %	68.8	68.8	69.6	69.2
CP	15.4	15.0	15.6	15.3
Ether extract	4.7	4.6	4.5	4.1
ADF	16.2	16.6	17.7	17.0
NDF	27.4	31.1	28.9	31.2
Forage NDF	22.7	22.7	22.7	22.7
Ash	6.22	6.27	6.71	6.22
NFC ³	42.4	40.5	41.5	40.8
NE _L , ² Mcal/kg	1.54	1.56	1.56	1.58
Ca	1.01	0.89	1.05	1.00
P	0.33	0.32	0.35	0.35
Mg	0.35	0.33	0.35	0.34
K	1.00	0.89	0.93	0.97
S	0.19	0.21	0.22	0.26
PSPS DM basis, mm ⁴				
>19.0	15.3	14.9	16.2	17.3
19.0–8.0	21.7	21.5	21.8	21.4
8.0–1.18	38.3	36.4	34.9	28.4
<1.18	24.7	27.2	27.1	32.0

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

²Estimated values from NRC (2001).

³NFC = 100 – ether extract – CP – NDF – ash.

⁴PSPS = Penn State Particle Separator.

(Somacount 500, Bentley Instruments; method 975.16; AOAC, 2002). An extra sample was taken one day during the last week of each period for milk nitrogen fractions. Samples were mixed by gentle inversion and analyzed for total milk protein (method 991.20; AOAC, 2002), nonprotein nitrogen (method 991.21; AOAC, 2002), and noncasein nitrogen (method 998.05; AOAC, 2002), with true protein (method 991.23; AOAC, 2002) and casein nitrogen (method 998.07; AOAC, 2002) calculated by difference.

Body condition scores on a scale of 1 to 5 (Wildman et al., 1982) and BW were recorded approximately 3 h after feeding for 3 consecutive days at the start of the experiment and at the end of each period. Blood was collected at the end of each period from the coccygeal artery and subcutaneous abdominal vein into vacuum tubes containing heparin (Becton Dickinson and Co., Franklin Lakes, NJ). Plasma was obtained by centrifuging at $500 \times g$ and stored at -20°C until analyzed for

AA via HPLC (model 1100, Agilent Technologies Inc., Palo Alto, CA) with a PCX 5200 postcolumn derivatizer (Pickering Laboratories Inc., Mountain View, CA) as described by Mondina et al. (1972), Pickering (1989), and Grunau and Swiader (1992). Extraction efficiencies of AA by the mammary gland were calculated based on the following equation: arteriovenous difference of AA (g/L) $\times$ 100/concentration (g/L) in plasma of coccygeal artery.

Samples of rumen fluid were obtained via an esophageal tube fitted with a suction strainer on 2 consecutive days at the end of each period approximately 3 h after feeding. The first 150 mL was discarded to minimize saliva contamination and then approximately 250 mL of rumen fluid was collected. A 10-mL aliquot was mixed with 2 mL of 25% (wt/vol) metaphosphoric acid and frozen at -20°C until centrifuged at $20,000 \times g$ and analyzed for concentrations of ammonia-N (Weatherburn, 1976) and VFA. Concentrations of VFA were

Table 3. Composition of forages and concentrate mixes for treatment diets¹

Item, % of DM unless noted	Ingredient							Concentrate mix			
	Alfalfa	Corn silage	SBM	HPDDG	CM	DDGS	Corn	SBM	HPDDG	CM	DDGS
DM, %	88.6	47.4	88.0	90.4	92.4	89.9	86.2	87.7	88.2	88.5	88.6
CP	19.5	7.00	50.6	44.5	43.7	29.8	8.44	18.1	17.2	18.4	17.9
EE ²	1.41	2.50	1.49	3.42	3.77	9.57	2.30	4.72	4.20	4.17	3.40
ADF	32.1	21.2	5.55	10.1	16.4	5.18	2.37	3.44	4.21	6.64	5.18
NDF	42.6	40.1	9.08	28.7	22.0	26.1	9.66	10.4	18.6	13.8	18.8
NFC ³	27.1	46.3	31.5	21.9	21.4	29.5	78.6	59.0	52.5	55.5	51.6
Ash	9.41	4.05	7.35	1.93	9.13	5.06	1.00	7.81	7.52	8.11	8.31
Ca	1.59	0.20	0.56	0.01	1.44	0.04					
Mg	0.38	0.25	0.30	0.11	0.59	0.37					
P	0.27	0.22	0.71	0.43	1.16	0.89					
K	1.80	0.60	2.46	0.39	1.38	1.18					
S	0.23	0.11	0.42	0.86	0.84	1.02					

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

²EE = ether extract.

³NFC = 100 – EE – CP – NDF – ash.

measured using a 6890 gas chromatograph (Hewlett-Packard, Anondale, PA) equipped with a column (0.25 mm i.d. × 15 m; Nukol, 17926 to 01C, Supelco Inc., Bellenfonte, PA). The split ratio in the injector port (250°C) was 100:1 with a flow of 1.3 mL/min of He. Column and detector temperatures were maintained at 130 and 225°C, respectively.

Means of DMI, milk yield, and milk composition were used in statistical analysis. Analysis of variance was conducted using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC): $Y = \text{treatment} + \text{square} + \text{period} + \text{cow (square)}$, where cow (square) was the random variable. The treatment × square and treatment × period interactions were tested and removed because they were not significant. Least squares means of the treatments were calculated and separation was determined using PDIF. Significance was declared at $P < 0.05$ and tendencies noted at $P < 0.10$.

RESULTS AND DISCUSSION

Nutrient Composition

All diets (Table 2) were slightly lower in CP (15.3%) than the anticipated 16% CP, which was acceptable because with a protein evaluation study such as this it was important that diets not contain excess protein. Analyses of ingredients (Table 3) indicated where these minor discrepancies occurred. The alfalfa hay contained less protein than preliminary analyses indicated. Also, the CP in the HPDDG (44.6%) was lower than values used in formulation (46%). The ether extract content of the DDGS used was on the low end of the fat content of typical DDGS, which is why the DDGS diet contained

slightly less ether extract (4.1%) than the other diets (4.6%).

Particle Size

Particle size of diets was determined on all treatment diets using the Penn State Particle Separator during wk 3 and 4 of each period (Table 2; Kononoff et al., 2003). Each sieve was dried to determine the percent on a DM basis, as recommended by Kononoff et al. (2003). The amount of DM retained on the top sieve of the particle separator was between 14.9 and 17.3%. The middle sieve was low in all diets, ranging from 21.4 to 21.8%. The screen and pan had from 28.4 to 38.3% on the screen and 24.7 to 32.0% in the pan. All diets were similar in particle size distribution and within normal expected ranges.

DMI, Milk Production, and BW

Dry matter intake (24.8 kg/d), milk production (31.8 kg/d), ECM (34.7 kg/d), and feed efficiency (1.44) were similar for all diets (Table 4). This was similar to results by Liu et al. (2000), where there was no change in milk production when feeding DDGS versus a blend of SBM, DDGS, and fishmeal. However, Nichols et al. (1998) and Anderson et al. (2006) observed an increase in milk production when feeding DDGS versus SBM-based control diets. But, those studies did not balance the fat content of all diets; thus, part of their response might have been attributable to the increased fat content of the DDGS diets. Hubbard et al. (2009) observed increased milk production when HPDDG was fed in place of SBM. Piepenbrink et al. (1998), Brito and

Table 4. Dry matter intake, milk yield, milk composition, and BW (LSM) from lactating dairy cattle fed treatment diets¹

Item	Diet ²				SEM	P-value
	SBM	HPDDG	CM	DDGS		
DMI, kg/d	24.1	24.6	25.2	23.6	0.85	0.45
Milk yield, kg/d	31.7	31.2	31.7	32.7	1.59	0.63
ECM, ³ kg/d	35.1	34.8	34.6	34.3	1.74	0.95
ECM/DMI	1.48	1.45	1.38	1.46	0.09	0.64
N efficiency ⁴	0.299	0.300	0.272	0.296	0.02	0.29
Fat, %	4.21 ^a	4.21 ^a	4.07 ^{ab}	3.78 ^b	0.16	0.02
Fat, kg/d	1.33	1.31	1.28	1.24	0.08	0.53
Protein, %	3.33 ^a	3.36 ^a	3.33 ^a	3.23 ^b	0.09	0.08
Protein, kg/d	1.04	1.05	1.05	1.05	0.05	0.99
Lactose, %	4.71	4.73	4.72	4.75	0.06	0.58
Lactose, kg/d	1.50	1.48	1.50	1.55	0.09	0.65
MUN, mg/dL	9.85	9.21	9.83	9.81	0.45	0.50
SCC, 10 ³ cells/mL	535	359	359	324	211	0.21
BW, kg	683	681	686	684	17.9	0.56
BW, kg of change/d	−0.65	−0.93	−1.04	−0.88	0.14	0.11
BCS ⁵	3.45	3.47	3.47	3.47	0.08	0.87
BCS, change/d	0.0004	0.07	0.03	0.06	0.03	0.35

^{a,b}Values within rows with different superscripts differ ($P < 0.05$).

¹Least squares means.

²SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

³ECM = $0.327 \times \text{milk (kg)} + 12.95 \times \text{fat (kg)} + 7.20 \times \text{protein (kg)}$.

⁴N in milk/N intake.

⁵BCS on scale of 1 to 5, where 1 = emaciated and 5 = overly fat (Wildman et al., 1982).

Broderick (2007), and Sanchez and Claypool (1983) all observed similar milk production when feeding CM in place of SBM; however, Brito and Broderick (2007) and Sanchez and Claypool (1983) reported an increase in DMI when CM was fed in place of SBM. Mulrooney et al. (2009) observed similar production when DDGS or CM was fed and slightly higher production with blends of the 2 protein supplements. Body weights (684 kg; Table 4), BW changes, BCS (3.47), and BCS changes were similar across treatments. No treatment effects on these parameters were expected.

Milk Composition

Milk fat percentage (Table 4) was higher with the SBM and HPDDG diets than with the DDGS diet, whereas with the CM diet it was similar to all other diets. The lower fat content observed when DDGS was fed with adequate forage fiber as in this experiment was somewhat unexpected because Kalscheur (2005) observed that milk fat content was lower only in diets supplemented with wet or dried distillers grains with solubles diets that contained less than 50% forage and 22% forage NDF. The similar milk fat percentage with the SBM and CM diets agreed with others (Sanchez and Claypool, 1983; Piepenbrink et al., 1998; Brito and

Broderick, 2007; Mulrooney et al., 2009). When Hubbard et al. (2009) fed HPDDG in place of SBM, milk fat yields were higher because of higher milk production coupled with numerically higher fat test.

Milk protein content was higher in the SBM, HPDDG, and CM diets than in the DDGS diet, but protein yield was similar across all diets because of the numerically higher milk yield when DDGS was fed. Milk protein content is seldom affected by feeding distillers grains with solubles unless protein is limiting in the diet (Schingoethe et al., 2009), which may have occurred in this study because the diets contained marginal amounts of protein, especially RDP (NRC, 2001). Then the Lys limitation in DDGS may cause a slight decrease in milk protein content (Nichols et al., 1998; Kleinschmit et al., 2006). Considering the limitations of calculating estimated balances of RDP (NRC, 2001), all 4 diets were low but positive for estimated RDP balance (359, 104, 247, and 133g/d for the SBM, HPDDG, CM, and DDGS diets, respectively), with the 2 distillers product diets having the lowest RDP (Table 2) and RDP balance. Estimated balances for RUP (−8, 208, 9, and 87 g/d, respectively) are even less reliable because accurate data are not available on HPDDG or on some of the other dietary ingredients. Thus, the above-estimated RDP and RUP balances illustrate that

Table 5. Protein fractionations of milk protein (LSM) from lactating dairy cattle fed treatment diets

Item	Diet ¹				SEM	P-value
	SBM	HPDDG	CM	DDGS		
Total CP, ² %	3.36 ^b	3.43 ^a	3.33 ^b	3.29 ^b	0.09	0.01
NPN, ² %	0.20	0.19	0.19	0.19	0.01	0.25
True protein, ² %	3.17 ^b	3.28 ^a	3.15 ^b	3.09 ^b	0.09	0.01
Casein N, ² %	2.65 ^b	2.77 ^a	2.67 ^{ab}	2.57 ^b	0.08	0.01
% of total protein						
True	93.9	94.4	93.3	94.1	0.29	0.17
Casein	78.9	79.2	79.7	78.3	0.81	0.41

^{a,b}Values within rows with different superscripts differ ($P < 0.05$).

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

²N $\times$ 6.38.

using such simulated calculations based on currently available NRC (2001) formulations can be inaccurate and possibly of minimal value. Sanchez and Claypool (1983) and Brito and Broderick (2007) observed no change in milk protein percentages when feeding CM, whereas Piepenbrink et al. (1998) observed an increase in protein percentage when CM was fed and Mulrooney et al. (2009) observed similar milk protein percentages when fed DDGS, CM, or their blends. Milk urea nitrogen concentrations were similar across all treatments but were low, likely because of the intended low CP in the diets.

Milk Protein Fractions

Milk protein fractions (Table 5) were analyzed to determine whether the AA profile of the protein source fed affected milk protein. Total and true protein contents were highest ($P < 0.05$) with the HPDDG diets at 3.43 and 3.28%, respectively. When fed the SBM, CM, and DDGS diets, total and true protein contents were similar ($P > 0.05$). The percentage of casein in the milk was highest with HPDDG and lowest with the SBM and DDGS diets ($P < 0.05$). With CM, casein content was in the middle, which was similar ($P > 0.05$) to the content with all other diets. This showed that the increase in true protein could be partly attributable to an increase in casein.

Rumen Parameters

The total VFA concentrations and proportions of various VFA (Table 6) were not affected by the dietary treatment ($P > 0.07$). This is in contrast with Nichols et al. (1998), where the addition of DDGS to the diet resulted in a decrease in total VFA. Piepenbrink et al. (1998) observed decreased total VFA concentra-

tions when CM was included in the diet. The proportions of acetate (68.3%), propionate (18.2%), butyrate (9.99%), and isovalerate (1.37%) were not affected by treatments, which indicated a similar fermentation pattern among diets and was consistent with other studies (Nichols et al., 1998; Anderson et al., 2006; Brito and Broderick, 2007). There was a trend ($P > 0.07$) for slightly lower concentrations of isobutyrate and valerate with HPDDG and CM, but these changes did not necessarily reflect the branched-chain AA composition of the protein supplements (NRC, 2001), were not likely biologically significant, and did not relate to RDP balance or AA composition of the protein supplements. Ammonia concentrations in the rumen (3.9 mg/dL) were unaffected by treatments but were relatively low, as expected, because diets were low in protein (Roffler and Satter, 1975).

Blood AA

Total essential AA concentrations in arterial plasma (Table 7) tended to be lower when fed CM and concentrations in venous plasma were lower ($P < 0.05$) with CM (Table 8), as also reported by Piepenbrink and Schingoethe (1998). Leucine and Phe concentrations were higher ($P < 0.05$) with HPDDG than with SBM and CM and tended ($P > 0.05$) to be higher with DDGS. There was a tendency for an increase in venous concentrations of Met when HPDDG was fed as compared with SBM, which was somewhat related to the higher Met concentration in corn protein. There was no effect of treatment on the venous or arterial concentrations of Lys in this experiment. As expected based on the AA composition of the protein supplements (NRC, 2001), Met concentration in plasma tended to be lowest with the SBM diet whereas Lys tended to be lowest with the 2 distillers product diets, which again reflected

Table 6. Ruminal VFA and ammonia (LSM) from lactating dairy cattle fed treatment diets¹

Measurement	Diet				SEM	P-value
	SBM	HPDDG	CM	DDGS		
VFA, %						
Acetate (A)	67.8	68.9	69.0	67.4	0.77	0.33
Propionate (P)	18.3	17.8	18.0	18.6	0.57	0.69
Isobutyrate	1.07 ^a	0.90 ^b	0.92 ^b	0.95 ^{ab}	0.06	0.07
Butyrate	10.2	9.68	9.58	10.5	0.36	0.17
Isovalerate	1.44	1.43	1.34	1.28	0.09	0.42
Valerate	1.20 ^{ab}	1.16 ^b	1.18 ^b	1.33 ^a	0.05	0.08
A:P	3.74	3.95	3.87	3.66	0.16	0.52
Total, mM/L	49.7	52.6	54.8	43.2	6.35	0.48
Ammonia, mg/dL	4.50	3.93	4.49	2.52	0.83	0.18

^{a,b}Values within rows with different superscripts differ ($P < 0.05$).

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

AA composition of the protein supplements. Arterio-venous differences (Table 9) were essentially similar for all diets.

Transfer efficiency and uptake to output ratios consider only AA relative to secretion as milk protein (Kleinschmit et al., 2007). Extraction efficiency, however, may be the ideal method for evaluating AA requirements because it takes into account the entire

essential AA needs of the mammary gland and includes AA extracted for all needs such as protein synthesis and catabolism (Schingoethe, 1996; Nichols et al., 1998; Kleinschmit et al., 2007). Also, the possibility of inaccuracies when estimating mammary blood flow is not a concern because mammary blood flow is not a part of the calculations for extraction efficiency, whereas it is included in the other 2 calculation methods. In this

Table 7. Amino acid concentrations in plasma from the coccygeal artery (LSM) in lactating dairy cows fed treatment diets¹

Item	Diet				SEM	P-value
	SBM	HPDDG	CM	DDGS		
Essential AA, $\mu\text{mol/dL}$						
Arg	8.73	7.56	8.17	8.95	0.66	0.41
His	4.87 ^a	5.31 ^a	4.05 ^b	5.09 ^a	0.40	0.03
Ile	11.90	10.69	9.48	10.65	0.86	0.13
Leu	15.37 ^{bc}	18.54 ^a	12.73 ^c	16.49 ^{ab}	1.25	0.01
Lys	8.01	7.50	7.73	7.49	0.55	0.82
Met	1.83	2.18	2.02	2.01	0.15	0.34
Phe	3.65 ^b	4.40 ^a	3.54 ^b	4.03 ^{ab}	0.19	0.01
Thr	8.28	9.41	8.63	7.79	0.66	0.23
Trp	3.01	3.16	2.70	2.05	0.26	0.58
Val	25.68 ^a	24.20 ^a	20.19 ^b	23.52 ^{ab}	1.68	0.03
Total essential AA	91.27 ^a	92.98 ^a	79.24 ^b	88.89 ^{ab}	4.83	0.08
Nonessential AA, $\mu\text{mol/dL}$						
Ala	20.87	23.01	22.06	21.34	1.26	0.54
Asp	3.18	2.87	3.19	3.26	0.29	0.22
Asn	0.73	0.86	0.70	0.80	0.07	0.22
Glu	24.24	27.59	25.75	26.63	1.25	0.11
Gln	4.29 ^b	4.63 ^b	5.27 ^a	4.72 ^{ab}	0.22	0.01
Gly	27.04	27.07	26.75	25.70	1.85	0.92
Pro	6.26 ^b	8.67 ^a	5.66 ^b	6.11 ^b	0.53	0.01
Ser	8.64	9.21	7.95	8.43	0.53	0.35
Tyr	4.26 ^b	5.90 ^a	4.31 ^b	4.98 ^{ab}	0.35	0.01
Total nonessential AA	105.53	117.72	107.59	108.05	4.49	0.19

^{a-c}Values within rows with different superscripts differ ($P < 0.05$).

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

Table 8. Amino acid concentrations ($\mu\text{mol/dL}$) in plasma from the subcutaneous abdominal vein (LSM) in lactating dairy cows fed treatment diets¹

	Diet					
Item	SBM	HPDDG	CM	DDGS	SEM	<i>P</i> -value
Essential AA, μmol/dL						
Arg	5.62	4.65	5.67	4.85	0.65	0.52
His	3.57 ^a	4.06 ^a	2.74 ^b	3.77 ^a	0.38	0.01
Ile	7.89 ^a	6.56 ^{ab}	4.93 ^b	6.39 ^{ab}	0.84	0.08
Leu	9.33 ^a	11.80 ^a	6.30 ^b	9.87 ^a	1.13	0.01
Lys	3.27	3.22	2.96	2.78	0.39	0.69
Met	0.67 ^b	1.03 ^a	0.87 ^{ab}	0.76 ^{ab}	0.11	0.07
Phe	1.70 ^b	2.44 ^a	1.66 ^b	1.85 ^b	0.16	0.01
Thr	5.77	6.30	5.66	5.66	0.62	0.79
Trp	2.69	2.61	2.25	2.93	0.24	0.34
Val	20.48 ^a	19.87 ^a	14.64 ^b	17.86 ^{ab}	1.60	0.01
Total essential AA	61.02 ^a	61.54 ^a	47.71 ^b	56.48 ^{ab}	4.07	0.02
Nonessential AA, μmol/dL						
Ala	17.29	19.17	17.44	17.49	1.28	0.55
Asp	1.95 ^b	2.63 ^a	1.96 ^b	1.93 ^b	0.22	0.04
Asn	0.41 ^b	0.59 ^a	0.43 ^b	0.50 ^{ab}	0.06	0.05
Glu	17.54 ^b	21.85 ^a	19.39 ^{ab}	18.40 ^{ab}	1.28	0.04
Gln	1.89 ^b	2.11 ^{ab}	2.35 ^a	2.06 ^{ab}	0.13	0.06
Gly	24.32	26.87	25.57	25.07	1.82	0.69
Pro	4.39 ^b	6.56 ^a	3.87 ^b	4.50 ^b	0.44	0.01
Ser	5.91	6.40	4.89	5.41	0.53	0.12
Tyr	2.38 ^b	4.09 ^a	2.26 ^b	2.78 ^b	0.32	0.01
Total nonessential AA	81.97 ^b	96.30 ^a	83.13 ^b	85.51 ^{ab}	4.13	0.06

^{a,b}Values within rows with different superscripts differ ($P < 0.05$).

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

Table 9. Arteriovenous differences in AA plasma (LSM) from lactating dairy cows fed treatment diets¹

Item	Diet				SEM	<i>P</i> -value
	SBM	HPDDG	CM	DDGS		
Essential AA, μmol/dL						
Arg	3.14	2.89	2.70	3.90	0.56	0.42
His	1.29	1.25	1.31	1.32	0.09	0.92
Ile	3.81	4.16	4.80	4.27	0.52	0.59
Leu	6.02	6.86	6.38	6.62	0.32	0.27
Lys	4.71	4.29	4.77	4.73	0.24	0.24
Met	1.18	1.14	1.17	1.25	0.10	0.87
Phe	1.95	1.96	1.84	2.19	0.14	0.29
Thr	2.50 ^{ab}	3.04 ^a	3.05 ^a	2.32 ^b	0.26	0.09
Trp	0.39	0.76	0.50	0.32	0.16	0.22
Val	5.18	5.48	5.50	5.65	0.32	0.74
Total essential AA	29.99	31.63	31.93	32.43	1.67	0.72
Nonessential AA, μmol/dL						
Ala	3.89	3.90	3.58	3.78	0.58	0.53
Asp	1.24	1.24	1.22	1.34	0.13	0.89
Asn	0.32	0.25	0.29	0.31	0.05	0.83
Glu	6.71	5.74	6.25	7.33	0.60	0.13
Gln	2.44	2.46	2.93	2.68	0.16	0.11
Gly	2.61 ^a	1.13 ^b	1.47 ^b	1.08 ^b	0.42	0.06
Pro	1.87	2.12	1.79	1.62	0.25	0.51
Ser	2.65	2.83	2.09	3.09	0.36	0.72
Tyr	1.88	1.81	2.06	2.20	0.15	0.23
Total nonessential AA	23.85	21.07	23.83	23.00	1.52	0.40

^{a,b}Values within rows with different superscripts differ ($P < 0.05$).

¹SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

Table 10. Extraction efficiencies¹ (%) of essential AA (EAA) from blood to mammary gland (LSM) for lactating dairy cows fed treatment diets^{2,3}

EAA	Diet				SEM	P-value
	SBM	HPDDG	CM	DDGS		
Arg	36.3 (6)	39.2 (4)	32.6 (9)	43.2 (5)	5.25	0.52
His	27.2 ^b (9)	26.2 ^b (9)	37.4 ^a (7)	26.5 ^b (9)	3.76	0.05
Ile	35.6 (7)	39.1 (5)	45.8 (6)	26.5 (9)	3.54	0.17
Leu	41.6 ^b (5)	37.7 ^b (6)	51.1 ^a (4)	41.8 ^b (6)	3.08	0.01
Lys	60.1 (2)	58.8 (1)	63.3 (1)	63.6 (1)	2.81	0.49
Met	64.1 (1)	54.0 (2)	58.5 (2)	63.2 (2)	3.99	0.16
Phe	54.0 ^a (3)	44.2 ^b (3)	52.2 ^a (3)	54.1 ^a (3)	3.04	0.03
Thr	31.1 (8)	32.3 (7)	36.6 (8)	30.6 (8)	3.17	0.51
Trp	45.7 ^a (4)	31.5 ^b (8)	49.4 ^a (5)	45.4 ^a (4)	3.26	0.01
Val	21.4 ^b (10)	22.6 ^b (10)	27.6 ^a (10)	25.3 ^{ab} (10)	2.00	0.03
Tyr	44.5 ^a [5]	30.7 ^b [9]	47.8 ^a [5]	44.2 ^a [5]	3.10	0.04
Total EAA	33.6 ^b	34.5 ^b	39.9 ^a	37.0 ^{ab}	1.81	0.04

^{a,b}Values within rows with different superscripts differ ($P < 0.05$).

¹Extraction efficiencies = arteriovenous difference of AA (g/L) $\times$ 100/concentration (g/L) of AA in plasma of coccygeal artery.

²SBM = soybean meal; HPDDG = high protein dried distillers grains with solubles; CM = canola meal; DDGS = dried distillers grains with solubles. Dietary treatments consisted of 4 different protein sources (SBM, HPDDG, CM, and DDGS) intended to supply equal amounts of protein (approximately 38% of the total dietary protein) from the respective supplemental protein sources.

³Numbers in parentheses indicate the apparent order of limiting AA. Numbers in brackets are for Tyr if it were considered an essential AA.

study, extraction efficiency (Table 10) indicated that Met was the first limiting AA by the mammary gland with SBM, whereas Lys was first limiting with the other diets. Phenylalanine was third limiting with all diets but was less limiting ($P < 0.05$) with the HPDDG diet than with the other diets. Likewise, Leu, Trp, and Val were less limiting with the HPDDG diet. If Tyr were considered to be an essential AA, as it is in most animal tissues (Schingoethe, 1996), it was less limiting with the HPDDG diet than with the other diets. Thus, whereas the first limiting AA were essentially of the same degree of limitation with all protein supplements evaluated, there were some indications of improved AA balance when fed HPDDG.

CONCLUSIONS

The recently available HPDDG is a high protein, lower fat product of ethanol processing available to the feed industry. When fed to lactating cows as the source of supplemental protein, HPDDG was equal to SBM, CM, and DDGS. Cows fed the HPDDG diet produced the most casein in the milk protein and thus may have provided the most desirable AA profile for casein production. Extraction efficiency of AA from blood by the mammary gland indicated that Lys was the first limiting AA for HPDDG, CM, and DDGS diets, whereas Met was first limiting for the SBM diet.

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