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Effects of a High-Protein Corn Product on Nutrient Digestibility and Production Responses in Mid-Lactation Dairy Cows

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Abstract

An experiment was conducted to assess the effects of a high-protein corn product (56% crude protein; CP) relative to other sources of protein on the lactation performance of dairy cows. Twenty-four Holstein cows (1,367 ± 105 lb of body weight, 111 ± 34 days in milk, 2.28 ± 0.46 lactations; mean ± standard deviation) were randomly assigned to treatment sequence in a replicated 4 × 4 Latin square design balanced for carryover effects. Cows were individually fed one of four diets with a different protein concentrate source during each 28-day period, including: soybean meal (SBM), high-protein corn product (HPCP), soybean meal with rumen-bypass soy protein (SBMBP), and canola meal with rumen-bypass soy protein (CANBP). Diets were formulated for equal concentrations of CP and balanced to meet lysine and methionine requirements. The SBM diet was formulated to provide 5.7% rumen-undegradable protein (RUP), while SBMBP and CANBP diets were formulated for 6.8% RUP to match HPCP. The CANBP diet increased dry matter intake compared with SBM and HPCP. Treatment affected milk yield, as SBMBP and CANBP increased yield compared with SBM, but HPCP decreased milk yield compared to all treatments. HPCP reduced CP intake as a percent of total intake and increased the CP content of feed refusals, indicative of selection against HPCP. HPCP decreased apparent total tract CP digestibility, leading to less urine nitrogen excretion and greater fecal nitrogen output. SBMBP and CANBP performed equally in nearly every variable measured, except SBMBP increased milk urea nitrogen concentration. In conclusion, the HPCP diet reduced milk yield, milk component yields, urine nitrogen excretion, and increased fecal nitrogen excretion due to lesser total tract CP digestibility.

Keywords

milk yield, dietary protein, formulation

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Summary

An experiment was conducted to assess the effects of a high-protein corn product (56% crude protein; CP) relative to other sources of protein on the lactation performance of dairy cows. Twenty-four Holstein cows (1,367 ± 105 lb of body weight, 111 ± 34 days in milk, 2.28 ± 0.46 lactations; mean ± standard deviation) were randomly assigned to treatment sequence in a replicated 4 × 4 Latin square design balanced for carryover effects. Cows were individually fed one of four diets with a different protein concentrate source during each 28-day period, including: soybean meal (SBM), high-protein corn product (HPCP), soybean meal with rumen-bypass soy protein (SBMBP), and canola meal with rumen-bypass soy protein (CANBP). Diets were formulated for equal concentrations of CP and balanced to meet lysine and methionine requirements. The SBM diet was formulated to provide 5.7% rumen-undegradable protein (RUP), while SBMBP and CANBP diets were formulated for 6.8% RUP to match HPCP. The CANBP diet increased dry matter intake compared with SBM and HPCP. Treatment affected milk yield, as SBMBP and CANBP increased yield compared with SBM, but HPCP decreased milk yield compared to all treatments. HPCP reduced CP intake as a percent of total intake and increased the CP content of feed refusals, indicative of selection against HPCP. HPCP decreased apparent total tract CP digestibility, leading to less urine nitrogen excretion and greater fecal nitrogen output. SBMBP and CANBP performed equally in nearly every variable measured, except SBMBP increased milk urea nitrogen concentration. In conclusion, the HPCP diet reduced milk yield, milk component yields, urine nitrogen excretion, and increased fecal nitrogen excretion due to lesser total tract CP digestibility.

Introduction

Corn grain is a useful feed ingredient in lactating dairy cow diets, serving as a readily available energy substrate; however, it is low in crude protein (approximately 7%). Through several methods of corn processing to produce value-added products such as ethanol or corn sweeteners, the composition of the resulting co-products possess elevated concentrations of protein, which have beneficial use to livestock as a protein source.

Dry-milling is the most common process used for ethanol production and has resulted in large quantities of distillers grains with solubles (DGS) available for livestock feed in the United States. Since most of the starch has been removed from the grain kernel after fermentation, DGS has an elevated composition of crude protein compared with the whole kernel at approximately 27 to 31%. Removal of bran and germ components before fermentation with wet- or dry-milling enhances the efficiency of ethanol production while further increasing the protein concentration of the resulting distillers grains from approximately 25% to more than 40%. Removal of the fat portion of the DGS increases protein concentration marginally to approximately 34%. Distillers grains with solubles have been fed to beef and dairy cattle successfully as a protein source, and the inclusion has become more common as ethanol production grows.

More nascent technologies are being evaluated to further add value to DGS. One concept includes using sieving and sedimentation to separate particles based upon size and density, which can increase protein concentration up to 40%. Distillers grains with solubles are a potentially attractive feedstock for second-generation, fiber-based ethanol production because of the fiber content and ability to streamline production processes. Considering the protein concentration of DGS and that second-generation ethanol production only utilizes fiber and residual starch, a co-product high in crude protein is produced (34 to 50%). The ability to cost-effectively integrate various technologies into existing production processes will ultimately determine their viability in the future, and the feeding value of these co-products is yet to be determined.

Not all protein sources are created equally because of differences in amino acid (AA) profiles. The two most limiting AA in the lactating dairy cow are generally lysine and methionine. Lysine concentration as a percentage of CP is greatest in soybean meal and least in corn products, while methionine concentration is greatest in canola meal and least in soybean meal. When diets are formulated for similar CP concentration, the lack of methionine or lysine in certain protein concentrates may inhibit performance if there are insufficient essential AA provided in other forms. Therefore, the objective of this experiment was to assess the productivity responses of high-producing Holstein cows by replacement of common protein sources with a proprietary high-protein corn product, while maintaining consistent concentrations of methionine and lysine across diets, and to assess nitrogen digestibility and retention.

Experimental Procedures

Twenty-four multiparous Holstein cows near peak lactation (111 ± 34 DIM, 2.3 ± 0.46 lactations, mean ± SD) from the Kansas State University Dairy Teaching and Research Center (Manhattan, KS) were randomly assigned to treatment in a replicated 4 × 4 Latin square design balanced for carryover effects. Cows were housed in a tie-stall barn. Treatment periods were 28 d, with 25 d for diet adaptation and 3 d for sample collection. Cows were fed twice daily and milked thrice daily.

Cows were individually fed 1 of 4 diets *ad libitum* with a different protein concentrate source during each 28-d period, including: soybean meal (SBM), high-protein corn product (HPCP), soybean meal with bypass protein (SBMBP) and canola meal with bypass protein (CANBP). A base total mixed ration was delivered to each cow with treatment top-dressed and mixed by hand at each feeding. Diets were formulated for equal concentrations of CP and balanced to meet lysine and methionine requirements. The SBM diet was formulated to provide 5.7% rumen-undegradable protein (RUP), while SBMBP and CANBP diets were formulated for 6.8% RUP to match HPCP. The diets also were formulated to provide equal concentrations of forage NDF and starch. Nutrient composition and ingredients are shown in Table 1.

Feed offered and refused for each cow was recorded daily during the final 3 days of each treatment period. Water intake was recorded daily. Milk samples were collected at every milking during the final three days of each treatment period and analyzed for composition by MQT Labs (Kansas City, MO). Fecal grab samples were collected for determination of total tract digestibility, and urine samples were collected. Total daily urinary N excretion was calculated using the estimated volume of urine excretion from creatinine analysis.

Results were analyzed using mixed models to account for the fixed effects of treatment, period, treatment × period interaction, and the random effect of cow. Differences were declared significant when $P < 0.05$ according to Tukey's honestly significant difference.

Results and Discussion

Dry matter intake and water intake responses to treatment are shown in Table 2. The CANBP increased the dry matter intake compared with SBM and HPCP ($P < 0.01$). Cows appeared to selectively refuse the HPCP, resulting in a higher concentration of CP in the refusals and decreased total nitrogen intake for this treatment ($P < 0.001$). The HPCP decreased milk yield compared with all other treatments, but SBMBP and CANBP increased milk yield compared with other treatments ($P < 0.001$; Table 3), which likely drove the increased intake response for CANBP. The HPCP decreased milk protein concentration, milk urea nitrogen concentration ($P < 0.01$), and yields of fat, protein, and energy-corrected milk ($P < 0.001$).

As shown in Table 4, HPCP decreased urine nitrogen excretion compared with SMB and CANBP ($P < 0.02$), and it increased fecal nitrogen excretion compared with all other treatments ($P < 0.001$). The pattern of nitrogen flow in this scenario aligns with decreased protein digestibility typical of over-heated protein products. Heating feed products is a process used to reduce moisture concentration for long-term stability or to reduce ruminal digestibility to increase nitrogen available for intestinal absorption (RUP), compared with bacterial degradation for use by ruminal microbes. However, too much heating renders the protein indigestible by either microbial or mammalian enzymes, leading to passage of the nitrogen through the feces. With less protein digested in the intestinal tract, there was less nitrogen absorbed to be excreted in the urine and milk.

The reduction in milk production by HPCP could be the result of two issues: 1) less consumption of total CP from cows sorting against the HPCP, and 2) a reduction in total tract nitrogen digestibility. Lactating dairy cows often sort against (preferentially avoid) longer particles to achieve a more energy dense diet. However, the increased CP concentration of feed refusals for cows fed HPCP suggests that the cows did not prefer the HPCP, despite it being a nutrient-dense product. Analysis of the concentrate top-dresses including the protein supplements revealed up to an 80-fold increase in acid-detergent insoluble crude protein (ADICP; Table 5). The ADICP is a measurement of heat treatment of feedstuffs and Maillard product formation. Maillard product formation decreases feed digestibility and can be seen visually as a darker color imparted to the product with increased heating. The HPCP was very dark in color, supporting the speculation that the product was overheated during the drying process.

The diets in this study were formulated to achieve equal concentration of CP and were balanced to meet lysine and methionine requirements of the cows, partially negating differences in AA profiles between corn, soybean, and canola products. The increase in milk production in SBMBP and CANBP compared with SBM, despite meeting lysine and methionine requirements, demonstrates that increasing RUP supply to the animal (beyond meeting limiting essential AA requirements) may still have positive effects on milk production. This is counter to the thinking that meeting the requirements for the most limiting essential amino acids, methionine and lysine, is all that is needed to enhance milk production.

In other studies, canola meal has been a successful substitute for soybean meal in lactating dairy cow diets, either maintaining or increasing milk production. In the present study, canola meal performed similarly to soybean meal when bypass protein was provided and lysine and methionine were supplemented to meet the cows' requirements. Canola meal can serve as a useful substitute for soybean meal in dairy rations, assuming market conditions are favorable for its use.

Conclusions

In summary, cows fed the HPCP diet produced less milk and milk components. Cows on HPCP consumed less CP and had lower apparent total tract CP digestibility, suggesting that the HPCP production process may have resulted in Maillard production formation, consistent with the increased ADICP measured in this treatment mix. The SBMBP and CANBP diets performed similarly when balanced for methionine and lysine, supporting previous data demonstrating canola meal as a successful substitute for soybean meal. Further efforts to maximize protein quality from high-protein corn product production processes are warranted.

Table 1. Ingredients and nutrient composition of experimental diets

	Diet[1]			
Item, % dry matter	SBM	HPCP	SBMBP	CANBP
Dietary ingredients				
Corn silage	34.5	34.5	34.5	34.5
Alfalfa hay	19.5	19.5	19.5	19.5
Soybean meal, 47.5% solvent extracted	10.7	...	3.9	...
High protein corn product[2]	...	9.4	...	...
Canola meal, 37% solvent extracted	...	...	...	8.9
Expeller soybean meal[3]	...	...	8.0	4.7
Ground corn grain	22.6	22.6	22.6	22.6
Soybean hulls	7.8	8.8	6.8	5.0
Ca salts of long chain fatty acids[4]	0.75	0.75	0.75	0.75
Lysine hydrochloride[5]	0.32	0.68	0.11	0.26
HMBi[6]	0.24	0.17	0.17	0.15
Micronutrient premix[7]	3.6	3.7	3.6	3.6
Diet nutrient composition				
Dry matter	52.8	52.6	52.9	52.9
Crude protein	16.8	16.8	16.8	16.8
aNDFom[8]	30.2	30.3	30.0	30.3
Starch	22.5	22.7	22.6	22.7
Ether extract	4.3	4.9	4.5	4.7
Ash	8.2	8.1	8.2	8.3

[1]SBM = soybean meal. HPCP = high-protein corn product. SBMBP = soybean meal + bypass protein. CANBP = canola meal + bypass protein.
[2]Proprietary high-protein corn product.
[3]SoyPlus (Landus Cooperative, Ames, IA).
[4]Megalac-R (Arm & Hammer Animal Nutrition, Princeton, NJ).
[5]Lysine hydrochloride, lecithin, and hydrogenated vegetable oil, AjiPro-L (Ajinimoto Animal Nutrition North America, Chicago, IL).
[6]Isopropyl ester of 2-hydroxy-4-methylthio butanoic acid, MetaSmart (Adisseo Inc., Antony, France).
[7]The premix consists of 30.5% limestone, 20.8% sodium bicarbonate, 30.5% Kruse lactation premix, 4.40% trace mineral salt, 4.42% white salt, 7.08% magnesium oxide, 4.42% vitamin E premix, 0.69% Zinpro 4-plex, 0.35% Zinpro 120, and 0.19% Rumensin 90.
[8]Amylase-treated neutral detergent fiber, ash-free.

Table 2. Dry matter and water intake

	Diet[1]					
Item	SBM	HPCP	SBMBP	CANBP	SEM	*P*-value
DMI, lb/d	60.8[b]	60.2[b]	61.9[ab]	63.7[a]	1.00	<0.01
Feed refusal CP, %	15.5[b]	18.8[a]	14.6[b]	15.0[b]	0.37	<0.001
Nitrogen intake, g/d	753[ab]	722[b]	762[a]	783[a]	12.7	<0.001
CP intake, % of total DMI	17.0[a]	16.5[b]	17.0[a]	16.9[a]	0.04	<0.001
Water intake, gal/d	28.7[ab]	29.2[a]	29.6[a]	27.2[b]	0.79	<0.001

[1]DMI = dry matter intake. CP = crude protein. SBM = soybean meal. HPCP = high-protein corn product. SBMBP = soybean meal + bypass protein. CANBP = canola meal + bypass protein.
[abc]Means with different superscripts within a row are significantly different by Tukey's HSD ($P < 0.05$).

Table 3. Production of milk, milk components, and milk nitrogen excretion

	Diet[1]					
Item	SBM	HPCP	SBMBP	CANBP	SEM	*P*-value
Milk, lb/d	87.9[b]	82.5[c]	92.6[a]	93.5[a]	3.94	<0.001
Fat, %	3.86	3.91	3.88	3.87	0.10	0.86
Protein, %	3.08[a]	3.00[b]	3.03[ab]	3.04[ab]	0.04	<0.01
Lactose, %	4.81	4.84	4.84	4.84	0.03	0.59
Solids non-fat, %	8.57	8.53	8.54	8.55	0.06	0.59
Milk urea nitrogen, mg/dL	11.7[a]	10.0[c]	11.6[a]	10.8[b]	0.34	<0.01
Somatic cells, 1,000 cells/mL	102	61	72	105	37.0	0.41
Fat, lb/d	3.31[bc]	3.17[c]	3.48[ab]	3.55[a]	0.11	<0.001
Protein, lb/d	2.67[a]	2.47[b]	2.80[a]	2.82[a]	0.11	<0.001
Lactose, lb/d	4.23[b]	3.97[c]	4.50[a]	4.54[a]	0.18	<0.001
Solids non-fat, lb/d	7.52[b]	6.99[c]	7.89[ab]	7.98[a]	0.33	<0.001
Fat-corrected milk, lb/d	91.5[b]	86.9[b]	96.6[a]	97.9[a]	3.31	<0.001
Energy-corrected milk, lb/d	91.9[b]	86.6[c]	96.8[ab]	97.9[a]	3.40	<0.001
Feed efficiency, lb FCM/lb DMI	1.52[ab]	1.49[b]	1.56[a]	1.52[ab]	0.03	0.06
Milk nitrogen secretion, g/d	198[a]	180[b]	204[a]	207[a]	8.2	<0.001

[1]SBM = soybean meal. HPCP = high-protein corn product. SBMBP = soybean meal + bypass protein. CANBP = canola meal + bypass protein.
[abc]Means with different superscripts within a row are significantly different by Tukey's HSD ($P < 0.05$).

Table 4. Urine and feces nitrogen excretion and apparent total tract crude protein digestibility

	Diet[1]					
Item	SBM	HPCP	SBMBP	CANBP	SEM	P-value
Urine nitrogen excretion, g/d	348[a]	255[b]	308[ab]	338[a]	23.9	0.02
Fecal nitrogen excretion, g/d	264[c]	313[a]	270[bc]	287[b]	6.8	<0.001
Apparent total-tract nitrogen digestibility, %	65.1[a]	56.5[c]	64.6[ab]	63.4[b]	0.47	<0.001

[1]SBM = soybean meal. HPCP = high-protein corn product. SBMBP = soybean meal + bypass protein. CANBP = canola meal + bypass protein.
[abc]Means with different superscripts within a row are significantly different by Tukey's HSD (P < 0.05).

Table 5. Post-hoc nutrient analysis of treatment top-dresses

	Diet[1]			
Item, % dry matter	SBM	HPCP	SBMBP	CANBP
Top-dress nutrient composition				
Dry matter	91.7	87.5	92.4	92.1
Crude protein	36.1	35.8	35.6	35.7
aNDFom[2]	16.5	17.1	15.7	17.1
ADICP[3]	0.1	7.9	0.1	1.0
Starch	12.8	13.6	13.5	13.9
Ether extract	7.7	10.9	8.9	9.7
Ash	6.8	6.1	6.5	7.4

[1]SBM = soybean meal. HPCP = high-protein corn product. SBMBP = soybean meal + bypass protein. CANBP = canola meal + bypass protein.
[2]Amylase-treated neutral detergent fiber, ash-free.
[3]Acid detergent insoluble crude protein, a measure of Maillard products.