Effects of Differences in Starch Content of Diets with Whole Cottonseed or Rice Bran on Milk Casein

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ABSTRACT

Forty lactating Holstein cows in early to midlactation were used in a randomized complete block design to measure the effects of the following diets on milk casein. Treatments were four complete rations fed for ad libitum intake consisting of 1) 60% concentrate, 10% alfalfa hay, and 30% corn silage; 2) 45% concentrate, 10% alfalfa hay, 30% corn silage, and 15% whole cottonseed; 3) 60% concentrate, 5% alfalfa hay, 20% corn silage, and 15% whole cottonseed; and 4) 45% concentrate, 10% alfalfa hay, 30% corn silage, and 15% rice bran. Least squares means for daily DM intake all were significantly different and were 3.51, 3.90, 3.28, and 3.74% BW, respectively. Cows fed diet 3 had higher arterial glucose and insulin and venous insulin. Least squares means were significantly different for milk yield, 30.1, 31.4, 28.4, and 31.6 kg/d; for milk protein, 3.30, 3.13, 3.48, and 3.12%; and for casein N, .376, .358, .373, and .330%, respectively. However, milk protein and casein N yields were similar for all cows. The diet that contained the highest percentage of starch did not result in a significantly higher percentage of casein N in the milk but had the lowest milk production. Both whole cottonseed and rice bran, substituted for concentrate, depressed milk protein percentage.

(Key words: starch differences, whole cottonseed, rice bran, milk casein)

Abbreviation key: EP = experimental period, PCM = protein-corrected milk, SP = standardization period, WCS = whole cottonseed.

INTRODUCTION

Whole cottonseed (WCS) has become a popular ration ingredient among dairy producers. Because of its oil content, it is considered a high energy ingredient, especially valuable when cows are exposed to high environmental temperatures and humidity or when they are in negative energy balance in early lactation. Supplemental fat, including that from WCS, has resulted in increased yields (1, 16) and higher milk fat percentage (8, 9, 16, 18, 22). However, WCS and other fat supplements often depress milk protein percentage (1, 8, 9, 10, 16, 18, 22), specifically the casein fraction (8, 9). The mechanism of this depression is not known. Because milk protein concentration is a factor affecting the unit price of milk, dietary manipulation of milk protein is important. However, changes in milk protein concentration by dietary factors are smaller than changes in other milk components (23). Horner et al. (11) increased milk protein percentage by adding niacin to diets containing WCS fed to cows in early lactation. Certain fats (oils) may have a toxic effect on rumen microorganisms, which reduces the ruminal production of microbial protein. Under certain conditions, niacin supplementation may reverse the adverse effects of WCS on ruminal fermentation. Niacin also increases blood glucose and insulin, which suggests an effect on energy balance (11). However, subsequent studies (14) showed no value of niacin supplementation for milk casein synthesis in cows in late lactation exposed to hot weather.

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Short-acting insulin injections have increased milk protein and fat percentages, but these also depressed milk production (21). Besides being necessary for glucose uptake by most tissues, insulin is involved in the incorporation of amino acids into proteins, but insulin is not required by the mammary gland for glucose uptake (15, 21). However, the mammary gland may require insulin to mediate casein synthesis (18), increasing the incorporation of amino acids into milk proteins by activation of messenger RNA. Palmquist and Moser (18) observed a 25% decrease in plasma insulin concentrations when protected tallow was fed and a reduction in milk protein. They (18) suggested that feeding fat supplements impairs amino acid transport into the mammary gland and milk protein synthesis by inducing insulin resistance.

Increasing energy from grain (starch) in the diet also may increase protein in milk when supplemental fat is fed. Because WCS is a dense form of energy, it is considered a concentrate ingredient and therefore commonly is substituted for cereal grain in most rations. However, it is about 64% concentrate (oil plus meal) and 36% forage (linters plus hulls). Therefore, most diets with WCS contained less starch than those with which they were compared. Besides being a dense source of energy, WCS also has 34% ADF. Consequently, it could replace an equal amount of forage, which would maintain starch concentration, the primary gluconeogenic precursor. Emery (10) noted that the percentage of milk protein increased .015 units/Mcal of increased dietary net energy if the additional intake came from grain. However, milk protein was decreased if the additional energy came from fat. Substituting WCS for grain reduces the starch content of the diet. Increasing the starch degradable in the rumen of diets containing fat may be a practical way to increase gluconeogenesis. Lactose depression when supplemental fats are fed (7) also may be attributed to the lack of starch in the diet because glucose is needed for lactose synthesis (13). The amounts of ether extract and protein in rice bran are similar to those in WCS (6, 17, 24); however, rice bran has more starch (6). Rice bran oil is similar in composition to cottonseed oil, consisting predominantly of oleic acid. Rice bran has been fed to finishing cattle as part of the concentrate and in complete rations, resulting in gains similar to soybean meal-sorghum grain rations (24). It has also been fed in wintering rations for cows and weanling calves on pasture with no palatability or rancidity problems (24). Because rice bran has an oil content similar to that of WCS but a higher starch content, it was compared directly with WCS.

The objective of this study was to compare the effects of differences in the starch content in diets based on WCS and rice bran on milk casein synthesis of Holstein cows in early lactation.

MATERIALS AND METHODS

Forty lactating Holstein cows that averaged 29.5 kg of FCM on the previous test day and 101 DIM were used. Following 1 wk of adjustment to the barn and feeding regime, all observations were taken during wk 2, the standardization period (SP), when all cows were fed a diet similar to the herd diet they had been receiving, which contained 15% WCS (diet 2, Table 1). Data collected during the SP were used for covariance adjustment of the traits measured during the experimental periods (EP). At the end of the SP, all cows were ranked on current FCM within parity, blocked in groups of four, and assigned randomly to one of four diets (Table 1). Following 1 wk adjustment to the diets, there were four 1-wk EP in which all observations were taken.

The ingredient composition of the diets is shown in Table 1. Diet 1 served as the control in which all substitutions were made. In diet 2, 15% WCS was substituted for concentrate. Diet 3 also contained 15% WCS, but the WCS was substituted for forage. Diet 4 with rice bran was a direct comparison with diet 2 containing WCS.

The cows were fed complete rations mixed once daily with two 4-h access periods to the feed beginning at 0800 and 2000 h. The cows were fed individually and ad libitum in a tie-stall barn with bunks designed for measurement of individual orts. Water also was available to each cow during the feeding periods and in the drylot between feedings. Following each 4-h feeding period, the cows were moved to the parlor for milking and then to the drylot until the next feeding.

Feed intakes were measured daily with feed samples taken three times per week. Feed samples were oven-dried at 55°C, allowed to air equilibrate, composited by week, and analyzed for DM at 100°C. Protein, ADF, and minerals were characterized by the Northeast DHI Cooperative Forage Testing Laboratory (4). Starch content of feeds was assayed by a modification of the method of Kartchner and Theurer (12), in which Diazyme™ (Miles, Inc., Elkhart, IN) was used to hydrolyze the starch instead of the glucose oxidase-peroxidase solution. Ether extract of feed samples was analyzed by AOAC procedures (5). All cows were weighed once a week to calculate feed intake on the basis of BW. Blood samples were withdrawn during EP 2 and 4 from the coccygeal artery and the subcutaneous abdominal vein. Blood was collected into Na-EDTA vacutainer tubes. The plasma was obtained by centrifugation and frozen. Arterial and venous blood plasma were analyzed for glucose by glucose oxidase (Sigma, St. Louis, MO) and for insulin by radioimmunoassay kit (Micromedic, Horsham, PA). Milk weights and samples were taken at six consecutive milkings during each EP. Percentages of protein, fat, SCC (3), and total solids (5) were measured three times weekly on daily composite samples. Weekly milk composites for each cow were used for analysis of casein N (2, 19).

The general linear models procedure of the SAS (20) was used in data analysis. The model used to compare treatments was $Y_{ijk} = \mu + T_i + P_j + TP_{ijk} + X_{ijk} + E_{ijk}$, where μ represented a mean; T, treatments; P, experimental periods; X, covariate; and e, residual term. The covariate was defined as the value of the dependent variable during SP, and significance was declared at $P < .05$.

RESULTS AND DISCUSSION

Nutrient composition of the diets is shown in Table 2. Crude protein was formulated to be 17% for each diet, but higher CP in corn silage caused slightly higher dietary CP. Acid detergent fiber percentages for diet 3 were low because this diet contained WCS substituted for forage instead of lower fiber concentrate. Diet 4 had low ADF because rice bran in the concen-

TABLE 1. Ingredient composition of the diets with whole cottonseed (WCS) substituted for concentrate or forage (–F) or with rice bran (RB) substituted for concentrate.

	Diet			
	1 Control	2 WCS	3 WCS-F	4 RB
	(% DM)			
Concentrates	60	45	60	60
Corn meal	57.4	56.3	65.1	40.2
Soybean meal	34.0	32.5	25.7	27.6
Molasses	2.7	3.6	2.7	2.7
Limestone	2.2	3.2	2.8	1.8
Salt	.5	.7	.5	.5
Dicalcium phosphate	1.2	1.0	.9	0
Dairy fortifier[1]	.1	.1	.1	.06
Mineral supplement[2]	.7	1.0	1.0	.9
Na_2HCO_3	1.2	1.6	1.2	1.2
Rice bran	0	0	0	25.0
Whole cottonseed	0	15	15	0
Alfalfa hay	10	10	5	10
Corn silage	30	30	20	30

[1]Dairy fortifier contains 1.59% Ca; 3.15% Mg; 5.69% K; 3.05% Na; 32.05% S; 7.62% NaCl; 38,289 ppm Fe; 521 ppm Co; 15,904 ppm Cu; 55,186 ppm Mn; 52,773 ppm Zn; 795 ppm I; 10 million IU vitamin A; 4.4 million IU vitamin D; and 3.8 million IU vitamin E/kg.

[2]Mineral supplement contains 11.67% Mg, 18.0% K, .76% Na, 22.31% S, and 100 ppm Fe.

TABLE 2. Nutrient composition of the complete rations.

	Diet[1]			
Nutrient	1 Control	2 WCS	3 WCS-F	4 RB
	(% DM)			
CP	18.4	18.8	18.2	18.1
Ether extract	3.8	6.2	6.2	5.9
Starch	39.7	36.9	41.9	38.6
ADF	19.8	19.4	16.6	16.1
Ca	1.20	1.17	1.24	1.40
P	.49	.47	.48	.53
Mg	.26	.30	.29	.33
K	1.57	1.56	1.43	1.64
Na	.41	.43	.43	.44
	(Mcal/kg DM)			
Calculated NE_L	1.71	1.75	1.81	1.66
	(ppm in DM)			
Fe	337	355	345	291
Zn	64	64	73	69
Cu	20	21	22	19
Mn	70	65	71	92
Mo	2.3	2.3	2.2	2.3

[1]See Table 1 for description of diets; WCS = whole cottonseed; F = forage; RB = rice bran.

TABLE 3. Effect of treatments on least squares means of feed intake by lactating Holstein cows.

Expression of intake	Diet[1] 1 Control	2 WCS	3 WCS-F	4 RB	SE
DM, kg/d	20.96	22.50	19.31	22.06	.65
DM, % BW	3.51^{bc}	3.90^{a}	3.27^{c}	3.74^{ab}	.10
NE_L,[2] Mcal/d	36.27	37.89	36.04	36.27	1.34
NE_L,[2] % BW	5.93^{b}	6.76^{a}	6.04^{b}	6.19^{b}	.21
Starch, kg/d	8.22	7.97	8.14	8.23	.30
Starch, % BW	1.34	1.42	1.36	1.40	.05

[a,b,c]Means in the same row with different superscripts differ ($P < .05$).

[1]WCS = Whole cottonseed; F = forage; RB = rice bran.

[2]Consumption of calculated net energy.

trate, which is low in ADF, replaced WCS, which has higher ADF. Calcium was formulated to be 1.0% but was higher because corn silage and rice bran contained more Ca (not presented) than anticipated.

The rice bran contained 39.3% starch and 17.5% ether extract, whereas the WCS contained 9.5% starch and 19.8% ether extract. Table 2 shows the starch and ether extract content means of the complete rations. Diets 2, 3, and 4 had similar ether extract, but diet 3 had the highest starch content because WCS was substituted for forage instead of concentrate.

Effects of treatments on feed intake are shown in Table 3. Cows fed diet 2, with WCS substituted for concentrate, ate significantly more DM than those fed diets 1 and 3 but not did 4, in which rice bran was substituted for concentrate. Therefore, there were no palatability problems with rice bran at 15% of the diet fed as a complete ration. Cows fed diet 3 ate the least amount of DM, but the energy content of this diet was the highest, and NE_L consumption was similar to that of cows fed diets 1 and 4. Cows fed diet 2 consumed the highest amount of NE_L; however, starch intakes were similar across diets because less DM was eaten by cows on diet 3, the diet with the highest starch concentration. There also were significant period effects, in which all cows ate more feed in periods 2 and 4 than in periods 1 and 3. These effects cannot be attributed to environmental stress. The study was conducted in October and November when weather conditions were mild.

Treatment effects on blood glucose and insulin are given in Table 4. Cows fed diet 3, with the highest starch content and with WCS substituted for forage, had higher arterial glucose than those on diets 1 and 2, but values were

TABLE 4. Effect of diets on least squares means of plasma glucose and insulin in lactating Holstein cows.

Component	Diet[1] 1 Control	2 WCS	3 WCS-F	4 RB	SE
	(mg/dl)				
Arterial (A) glucose	71.6^{b}	71.5^{b}	79.7^{a}	75.2^{ab}	2.7
Venous (V) glucose	50.6	53.5	53.7	49.6	2.5
A-V Glucose difference	22.5	17.9	26.7	22.3	4.2
Arterial insulin	16.4^{ab}	11.8^{b}	19.7^{a}	15.1^{ab}	2.1
Venous insulin	18.4^{ab}	12.4^{c}	20.5^{a}	15.2^{abc}	2.0
A-V Insulin difference	−2.0	−.7	−1.1	−1.5	1.3

[a,b,c]Means in the same row with different superscripts differ ($P < .05$).

[1]WCS = Whole cottonseed; F = forage; RB = rice bran.

TABLE 5. Effect of diets on least squares means of milk yield and milk components of Holstein cows.

	Diet[1]				
Variable	1 Control	2 WCS	3 WCS-F	4 RB	SE
Milk yield, kg/d	30.1[ab]	31.4[a]	28.4[b]	31.6[a]	.9
3.5% FCM, kg/d	27.8[a]	28.0[a]	23.4[b]	28.6[a]	.9
3.2% PCM,[2] kg/d	30.6	30.2	30.3	30.5	1.0
Casein N, %	.376[a]	.358[ab]	.373[a]	.330[b]	.01
Casein N, kg/d	.111	.111	.104	.104	.004
Fat, %	3.11[a]	2.93[a]	2.40[b]	2.86[a]	.11
Protein, %	3.30[b]	3.13[bc]	3.48[a]	3.12[c]	.06
Protein, kg/d	.98	.97	.97	.97	.03
Total solids, %	12.09	11.96	11.53	11.78	.18
SCC, (× 1000)	145.2	73.4	89.8	98.8	28.4

[a,b,c]Least squares means in the same row with different superscripts differ ($P < .05$).

[1]WCS = Whole cottonseed; F = forage; RB = rice bran.

[2]3.2% protein-corrected milk [% protein × yield (kg/d)]/3.2.

similar to those for cows fed diet 4 with rice bran. However, there were no significant differences among treatments for venous glucose or arteriovenous glucose differences. Cows fed diet 3 had a nonsignificantly higher arteriovenous difference than those fed diet 2, in which WCS was substituted for starch. This indicates that more glucose may have been transferred from the blood and used by mammary tissues in cows fed diet 3 and that glucose may have been limiting in cows on diet 2. Cows fed diet 3 had higher arterial insulin than those fed diet 2 and higher venous insulin than those fed diets 2 and 4. Arteriovenous differences were similar. Although insulin is not required by the mammary gland for glucose uptake, it may increase the transport of amino acids into the mammary gland (18). Horner et al. (11) also noted higher blood glucose and insulin in cows fed diets in which energy came from concentrate compared with those in which WCS was substituted for part of the concentrate. Palmquist and Moser (18) showed a reduction in blood glucose and insulin when a protected lipid supplement replaced concentrate. They calculated that gluconeogenic precursors from the starch fraction of the diet were reduced by 15% when the protected lipid supplement was fed, even though comparable energy was consumed (18).

The oil in rice bran was heat-stabilized to prevent rancidity; however, it is unlikely that the oil in the rice bran was released slowly into the rumen, because the oil in WCS apparently is released. The lower starch content of diet 2 and the higher starch content of diet 3 coincided with the lower and higher glucose concentrations in the blood of the cows on the respective diets.

Although cows fed diet 3 had the highest percentages of milk protein, they produced significantly less milk than those fed diets 2 and 4 and tended to produce less than those fed diet 1 (Table 5). These cows also were the only ones that had a linear decline in yield from 31.8 kg/d in EP 1 to 26.4 kg/d in EP 4. Milk production for all cows was similar when expressed as 3.2% protein-corrected milk (PCM); PCM = [% protein × yield (kg/d)]/3.2. Cows fed diets 2 and 4, in which WCS and rice bran were substituted for concentrate, tended to produce more milk than those in the other two groups. This may be attributed to their higher DM intake, as a percentage of BW, and the lower intake for those on diet 3. Cows fed diet 3 had a lower fat percentage and therefore produced significantly less FCM than the other groups. The FCM yields reflect low fat tests from all treatment groups, especially for diet 3. Anderson et al. showed an increase in milk, FCM, and SNF productions when WCS was substituted for an equal amount of concentrate. However, Smith et al. (22) observed no significant change in milk yield as diets with increasing amounts of WCS were fed.

Cows fed diet 3 had higher casein N percentage than those fed diet 4 with rice bran and tended to have higher casein N percentage than those fed diet 2 (Table 5). Because diet 3 had WCS substituted for forage instead of concentrate and blood glucose and insulin concentrations of cows fed this diet were higher, the higher percentage of casein in the milk may be attributed to more glucose being provided to the mammary gland or to an independent role of insulin, in which messenger RNA is activated in order to increase incorporation of amino acids into proteins. However, cows on diet 4 had significantly lower casein percentages than those on diets 1 and 3 and tended to have lower percentage ($P < .06$) than those on diet 2. This effect cannot be explained when comparing rice bran and WCS, because glucose and insulin concentrations for cows on diet 2, with WCS substituted for concentrate, were similar to those of cows fed diet 4, in which rice bran was substituted for WCS. The starch content of diet 4 was higher than that of diet 2. Diet 1 had a high starch content, comparable with that in diet 3, yet arterial glucose concentrations were similar to those for diet 2, the lowest starch diet. However, arteriovenous glucose differences were higher (not significant) for diet 1 compared with diet 2, indicating more glucose uptake by the mammary gland if blood flows were similar (Table 4). Diet 1 also led to a higher (not significant) blood insulin concentration than diet 2 and, subsequently, a milk casein concentration comparable with that of cows fed diet 3. We cannot explain the low blood glucose for cows on diet 1. There also were period effects for casein N in which all EP were different. All cows produced the most casein N in comparison-period 4 and the least in EP 3 (Figure 1). Cows fed diet 3 produced milk with significantly higher protein percentage, 3.48%, than all other treatment groups, which corresponds to the previously discussed casein N data. This is in agreement with Emery (10), in whose experiment a regression showed a .015 unit increase in percentage of milk protein for each megacalorie increase in intake from grain or forage. This increased concentration of protein usually was accompanied by increased production of milk with a decreased concentration of fat (10). However, cows fed diet 3 ate less feed and produced less milk than those on lower starch diets. Because cows on

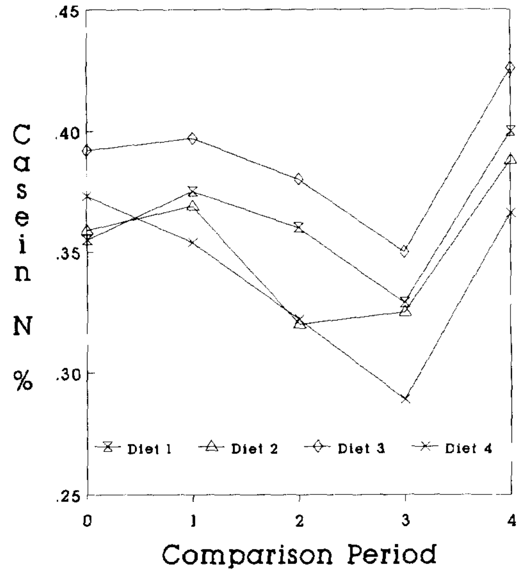

Figure 1. Effect of treatments on percentage casein N of Holstein cows across experimental periods.

diet 3 produced less milk, protein and casein N yields were similar across treatments.

Cows fed diet 3 had the lowest milk fat percentage, 2.40%, which reflects the low fiber and high percentage of concentrate in that diet. However, we cannot explain why cows fed diets 1, 2, and 4 had low fat tests. The same trend in milk fat, protein, and total solids that occurred in period effects also occurred with casein; period 4 had the highest percentage and period 3 the lowest percentage for all cows (Figure 1). We cannot explain this effect.

When rice bran and WCS each were substituted for concentrate, the results were similar for fat, protein, casein N, and milk yields, which suggests that at this level of rice bran the increase in starch content was not sufficient to alleviate the milk protein depression that occurs when feeding fat. However, when WCS was substituted for forage, there was a higher milk protein concentration. This substitution reduced the amount of fiber in the diet and lowered milk fat test. Substituting WCS for part of the concentrate and forage is a practical method of alleviating some of that depression, because WCS is about 36% forage (linters plus hulls) and 64% concentrate (oil plus meal). Whether the depression in milk protein that occurs when fat is fed is due directly to limiting glucose or indirectly to a depression in insulin is not known. More studies are needed to determine the mechanism and whether rice bran can be fed at higher levels to supply supplemental energy without causing deleterious effects on digestion or milk protein.

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