INTERACTIVE INFLUENCE OF DIETARY PROTEIN AND LIPID IN LACTATION

C. S. Park, Y. J. Choi[a,b], G. R. Fisher and G. M. Erickson

North Dakota State University, Fargo, North Dakota 58105, USA

Summary

Twenty cows, by order of calving, were used in a completely randomized 2x2 factorial experiment. Variables were two protein levels (14 and 18% crude protein) and concentration of fat (2 and 6% ether extract) in diets. Fat addition, via unprocessed whole sunflower seed, insured forage utilization in diets to meet energy requirement of cows. A total of 36 wks of lactation was subdivided into three 12-wk stages of lactation. Net energy lactation was set at 1.72, 1.57 and 1.42 Mcal/kg for each stage. Higher protein diets improved the efficiency of energy (FCM/net energy intake) which was particularly noted for diets containing high fat (85.7%). However, diets with low protein-high fat resulted in the lowest efficiency (67.7%). No difference in milk yield and butterfat was due to different levels and combinations of protein and lipid in diets. High protein diets depressed blood cholesterol and glucose compared to low-protein counterparts. Relative decline in milk production was slower for lower fat diets than for higher fat groups, especially mid to later stage of lactation. Results of this experiment tend to support our thesis on the synergistic effect of dietary protein and energy (lipid) upon efficiency of lactation.

(Key Words: Protein, Lipid, Diet Interaction, Lactation Efficiency)

Introduction

Success in future dairy operations depends on the efficiency of milk production. Recent recognition of the beneficial effects of adding fats to dairy rations for improved energetic efficiency is an important development for dairy and related industries.

Recent studies have demonstrated the effectiveness of added fat to maintain milk production and fat content (Palmquist and Jenkins, 1980; Clapperton and Steele, 1983; Steele, 1984). Some workers have suggested that effects of lipid supplement on milk and milk fat yield are not beneficial (Lucas and Loosli, 1944; Moore et al., 1945). Research information is currently available on feeding various types of fats and oils and their effects on dairy cows. Most of the information, however, has been derived from experiments involving 1) a few animals with relatively short term trials and 2) addition of various types of fats to rations containing fixed, and generally low levels of either protein or energy or both. These two prevailing limitations could have been attributable to rather inconsistent responses of lactating cows to fat feeding.

Recent works (Palmquist and Jenkins, 1980; Clapperton and Steele, 1983) suggested that the efficacy of fat supplementation was higher in rations of higher protein concentration than in rations of lower protein content. Further, fat-added, high energy dairy rations may also be expected to respond to greater concentrations of ration protein (Van Horn et al., 1985), although this prospect has not been well studied to date.

The objectives of this study were as follows: 1) To examine the interactive influence of dietary protein and lipid in lactation. 2) To determine the effect of fat addition at rations of two protein levels on the persistency and productive lactational response of cows in mid to later lactation.

Materials and Methods

Twenty Holstein cows from the North Dakota State University dairy research herd, by order of calving, were used in a completely randomized 2x2 factorial experiment. Four treatments involved in the factorial experiment are presented in table 1.

These diet treatments were in complete rations

[a] Present Address: Animal Science Department, College of Agriculture, Seoul National University, Suweon 440-744, Korea

[b] Address reprint requests to Dr. Y.J. Choi, Animal Science Department, College of Agriculture, Seoul National University, Suweon 440-744, Korea

Received January 13, 1988
Accepted March 24, 1988

TABLE 1. VARIABLES AND TREATMENT COMBINATION

Treatment	Factor		Stage of lactation[a]		
	Protein	Fat	I	II	III
	(%, DM)		(Mcal/kg, NE_l)		
A	18	6	1.72	1.57	1.42
B	18	2	1.72	1.57	1.42
C	14	6	1.72	1.57	1.42
D	14	2	1.72	1.57	1.42

[a]Stage I, early; 0-12 wks of lactation;
Stage II, middle; 12-24 wks of lactation;
Stage III, late; 24-36 wks of lactation.

TABLE 2. INGREDIENT AND CHEMICAL COMPOSITION FOR EXPERIMENTAL DIETS[a]

Variable	Treatment			
	A	B	C	D
	(% dry matter)			
Formulated level				
Crude protein	18	18	14	14
Lipid	6	2	6	2
Ingredient				
Hay	6.7	1.4	1.7	0.0
Corn silage	35.7	25.2	57.9	45.8
Concentrate	57.6	73.4	40.4	54.2
	(% concentrate)			
Corn	18.6	30.9	15.8	30.5
Barley	18.6	30.9	15.8	30.5
Soybean meal, 46	37.2	30.9	31.6	30.5
Sunflower seed	16.2	0.0	25.3	0.0
Dicalcium phosphate	2.2	.4	4.0	.6
Limestone	1.6	1.3	1.9	2.3
Constant ingredient[b]	5.6	5.6	5.6	5.6
Chemical analysis	(% dry matter)			
Crude protein	18.9	18.6	14.8	14.6
Ether extract	6.4	2.6	6.5	2.6
Acid detergent fiber	22.7	16.9	27.3	23.2
Calcium	.92	.83	.96	.85
Phosphorus	.59	.59	.64	.58

[a]Represent diets for early lactation. Ratio of ingredients differ for middle or late lactating diet.
[b]The 5.6% constant ingredients consisted of 2.3% trace mineralized salt (NaCl, 95.0%) and 3.3% molasses, with vitamin A and D added to provide 3,300 and 600 IU/kg of diet, respectively.

(all-in-one) consisting of corn silage, hay and grain mixtures (table 2). Fat supplementation via whole sunflower seed, ensured forage utilization in treatment rations to meet energy requirement of cows. Rations were sampled biweekly and composited monthly. These samples were analyzed for crude protein, ether extract, calcium and phosphorus by AOAC (1980) procedures. Acid detergent fiber determination was by method of Goering and Van Soest (1970). Since it is essential that energy not be a limiting factor for milk production, the energy concentration of the ration had been varied, as shown in table 1, according to the lactation stage of the cow. Mixtures were presented to cows as total mixed rations, fed twice daily. Access to water was provided continuously, and dicalcium phosphate and trace mineralized salt were available free choice at all times.

Trial duration was 36 wks of lactation. The basic observation period was comprised of 2-wk intervals to provide a detailed structuring of response. Thus, the 36 wks of lactation were divided into three stages of lactation, which were further subdivided into six 2-wk periods.

Response criteria consisted of production parameters including milk production, lactational persistency and milk composition. Cows were milked twice daily. Milk production and feed intake were summarized by each period (14 d). Milk sampled over d 13 and 14 of each period was analyzed for butterfat. Jugular blood samples were taken 2 h following morning feeding once every 2-wk period. Blood samples were centrifuged at 4000 x g for 30 min and serum was frozen for later assay of glucose (Raabo and Terkildsen, 1960), triglyceride (Bucolo and David, 1973), and total cholesterol (Allain et al., 1974). Lecithin cholesterol acyltransferase (LCAT) activity was assayed by the procedure of Verdery and Gatt (1981). Insulin activity was assayed by the method of Yalow and Berson (1960).

Statistical procedures used were the analysis of variance for main effects and Student Newman Keul's test for mean comparison and squared correlation. The lactation curve was fitted into an appropriate nonlinear model (Snedecor and Cochran, 1967).

Results and Discussion

The effects of dietary protein and lipid on production responses are shown in table 3. Milk yield, butterfat and feed dry matter intake were not different ($P > .05$) between dietary protein and lipid. This result was in agreement with that of Macleod et al. (1984) who reported that there were no significant interactions between energy and protein densities for feed intake, milk yield, percent and yield of fat and lactose, yield of protein or plasma urea nitrogen. These results were not consistent with the results of Cowan et al. (1981). They observed that during wk 0 to 8, increasing protein in the low roughage diet from 11.1% to 14.7% of DM increased milk yield by 7 kg/day whereas cows fed on a high roughage diet increased only 3 kg/day.

The efficiency of energy, defined as FCM (fat corrected milk, kg) x 100/net energy (Mcal), was significantly influenced by protein and lipid levels (table 3). The high protein (18%) diets improved ($P < .05$) energy efficiency especially for diets containing higher amounts of fat. This increased energetic efficiency with fat supplementation on high level of protein diets agrees with previous finding (Lindberg, 1984). However diets with low protein-high fat results in the lowest efficiency of energy (67.7%). Smith et al. (1981) reported that high fat diet did not affect milk yield, but increased yield of fat, FCM and energy efficiency. From this point of view, while not conclusive, higher protein diet should contain a high energy to improve the energy efficiency. This is especially true of high crude protein diets for cows in early lactation (Van Horn et al., 1985).

Paquay et al. (1973) reported that an optimal dietary N: energy ratio exists, which changes during lactation. The optimal dietary digestible N: metabolizable energy ratio was about 2.2 g/MJ during the first 3 mo of lactation and then fell steadily to 1.3 g/MJ at the end of the lactation. Expressed in g N intake/MJ energy intake, the optimal ratio ranged from 1.55 to 1.1 during lactation.

The fitted lactation curve (figure 1) reveals that cows fed the low protein-high fat diet exhibited the fastest decline of milk production after 15 wk of lactation relative to those on other diets. The lactation curve also indicates that relative decline in milk production, i.e. persistency, was slower for lower fat diets than for higher fat groups, especially mid to later stages of lactation (figure 1). Maximum milk yield occurred in wk 5 to 7 on all diets.

Selected blood metabolites response resulting from dietary treatments are presented in table 4. There was a significant interaction between dietary protein and fat on blood sugar levels and total cholesterol levels. High-protein diets depressed blood cholesterol and glucose compared to low-protein counterparts. The mechanisms of such a hypocholesterolemic effect of high protein remain elusive since rates of entry, turnover and conversion of cholesterol are not specifically known in the bovine. A number of studies have shown a hyperlipidemic (hyper-cholesterolemic) effect of fat supplementation (Goering et al., 1976; Yang et al., 1978; Rafalowski and Park, 1982; Park et al., 1983; Park, 1985). Bickerstaffe et al. (1972) demonstrated that the net lipid synthesis in the rumen was greater with high-fat diets. The high-fat

TABLE 3. TREATMENT EFFECTS ON PRODUCTION RESPONSES OF LACTATING COWS

	Diet				By protein		By lipid	
	A	B	C	D				
Crude protein, % DM	18	18	14	14	18	14		
Lipid, % DM	6	2	6	2			6	2
Milk, kg	27.5	28.5	25.5	26.9	28.1	25.8	26.3	27.7
Butterfat, %	3.62	3.58	3.60	3.61	3.60	3.60	3.61	3.60
Dry matter intake, kg/d	19.0	20.2	21.9	21.6	19.8	21.7	19.6	21.4
Energy efficiency[1]	85.7^{b}	81.8^{ab}	67.7^{a}	73.8^{ab}	84.3^{b}	71.3^{a}	76.5	78.0

[1] Efficiency calculated as FCM (kg) x 100/net energy (Mcal).

[a,b] Means in the same row bearing different superscript letters are different ($P < .05$).

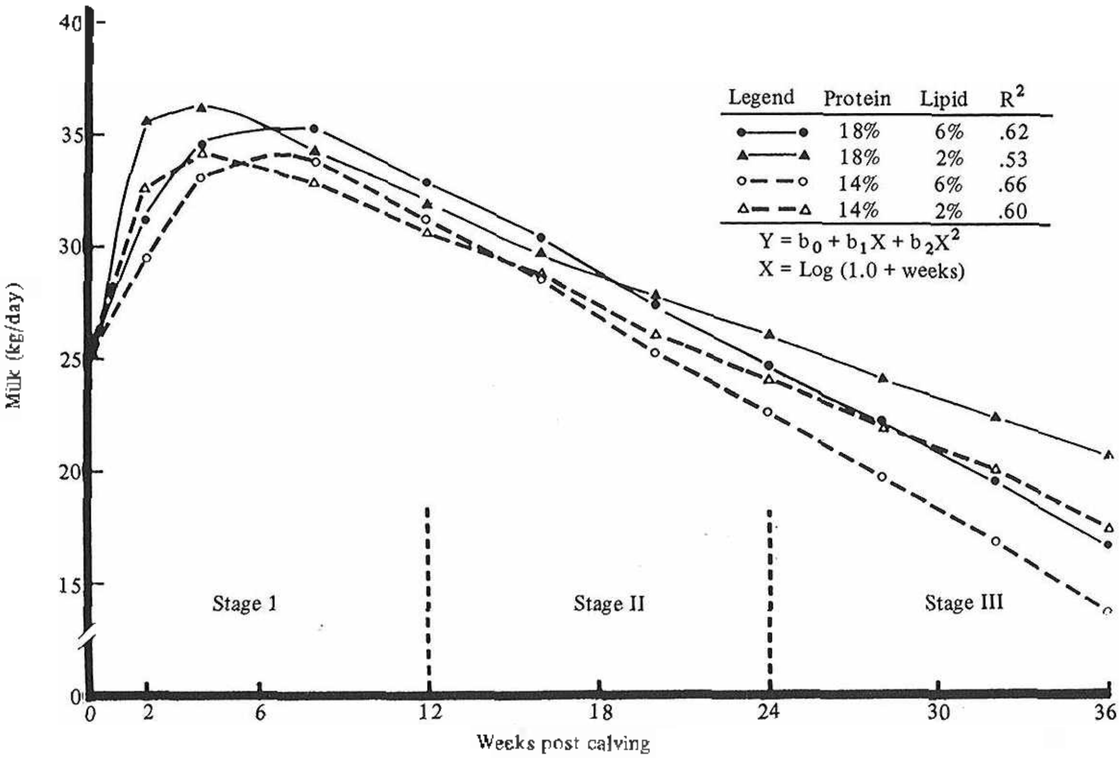

Figure 1. Milk production response curve

TABLE 4. TREATMENT EFFECTS ON SELECTED BLOOD METABOLITES OF LACTATING COW

	Diet				By protein		By lipid	
	A	B	C	D				
Crude protein, % DM	18	18	14	14	18	14		
Lipid, % DM	6	2	6	2			6	2
Glucose, mg %	47.0[a]	46.1[a]	50.1[ab]	53.2[b]	46.5[a]	51.2[b]	48.5	49.5
Triglyceride, mg %	26.1	19.1	25.3	18.1	22.2	21.7	25.5[b]	18.6[a]
Total cholesterol, mg %	305.4[ab]	203.1[a]	323.2[b]	259.5[ab]	248.5[a]	291.3[b]	314.2[b]	231.2[a]
Lecithin cholesterol acyltransferase, nmoles/ml/hr	209.2	160.0	187.6	134.5	184.7	160.3	199.3[b]	147.7[a]
Insulin, μU/ml	21.8	32.3	17.3	24.6	27.0	21.2	19.4	27.0

[a,b]Means in the same row bearing different superscript letter are different ($P < .05$).

diets cause inhibition of methane production resulting in an excess of reduced cofactors, thereby increasing lipid synthesis from acetate (Czerkawski et al., 1975). Palmquist and Jenkins (1980) reviewed that added dietary fat increased concentration in plasma of very low density lipoprotein triglyceride which increased its uptake by the mammary gland. The increased uptake inhibits short chain fatty acid synthesis and consequently changes the composition of milk fatty acids. In some cases, secretion of milk fat was increased. They also demonstrated that 3 to 5% fat might be added to diets for lactation to increase energy intake of high-producing cows and/or to reduce starch feeding, thereby increasing the ratio of forage to concentrate to prevent depression of milk fat.

LCAT, which mediate the synthesis of esterified cholesterol in plasma, for high-fat groups, was higher ($P < .05$) than that for the low-fat groups (199.3 vs 147.7 nmoles/ml/hr). The reason for such difference in this enzymatic activity influenced by dietary fat concentration may require further investigation. Although not significant, high protein and/or low lipid diet stimulate the insulin release (table 4). Increased blood insulin level could imply greater amino acid uptake by mammary acini, with increase in protein synthesis as was demonstrated by in vitro studies (Park et al., 1982). Although increased circulating insulin may be involved either directly or indirectly, in the low milk fat syndrome (Jenny et al., 1974), our results show that higher level of circulating insulin by high protein and/or low lipid diets did not depress milk fat secretion as shown in table 4.

Literature Cited

Allain, C.A., L.S. Poon, C.S.G. Chan, W. Richmond and P.C. Fu. 1974. Enzymatic determination of total serum cholesterol. Clin. Chem. 20:470.

AOAC. 1980. Official methods of analysis. 13 ed. Washington, D.C.

Bickerstaffe, R., D.E. Noakes and E.F. Annison. 1972. Quantitative aspects of fatty acid biohydrogenation, absorption, and transfer into milk in lactating goat, with special reference to the cis- and trans- isomers of octadecenoate and linoleate. Biochem. J. 130: 607.

Bucolo, G. and H. David. 1973. Quantitative determinations of serum triglycerides by the use of enzymes. Clin. Chem. 19:476.

Clapperton, J.L. and W. Steele. 1983. Effects of concentrates with beef tallow on food intake and milk production of cows fed grass silage. J. Dairy Sci. 66:1032.

Cowan, R.T., G.W. Reid, J.F. D. Greenhalgh and C.A.G. Tait. 1981. Effects of feeding level in late pregnancy and dietary protein concentration during early lactation on feed intake, milk yield, liveweight change and nitrogen balance of cows. J. Dairy Res. 48:201.

Czerkawski, J.W., W.W. Christie, G. Breckenridge and M.L. Hunter. 1975. Changes in the rumen metabolism of sheep given increasing amounts of linseed oil in their diet. Br. J. Nutr. 34:25.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analysis. USDA Agric. Handbook 379.

Goering, H.K., C.H. Gordon, T.R. Wrenn, J. Bitman, R.L. King and F.W. Douglas, Jr. 1976. Effect of feeding protected safflower oil on yield, composition, flavor, and oxidative stability of milk. J. Dairy Sci. 59: 416.

Jenny, B.F., C.E. Polan and F.W. Thye. 1974. Effects of high grain feeding and stage of lactation and serum insulin, glucose and milk fat percentage in lactating cows. J. Nutr. 104:379.

Lindberg, G.L. 1984. Protein and energy interaction in early lactation dairy cows. M.S. Thesis, North Dakota State Univ., Fargo.

Lucas, L.H. and J.K. Loosli. 1944. The effect of fat upon the digestion of nutrients by dairy cows. J. Anim. Sci. 3:3.

Macleod, G.K., D.G. Grieve, I. McMillan and G.C. Smith. 1984. Effect of varying protein and energy densities in complete rations fed to cows in first lactation. J. Dairy Sci. 67:1421.

Moore, L.A., G.T. Hoffman and M.H. Berry. 1945. The effect of two different methods of feeding cod-liver oil on fat test in milk. J. Dairy Sci. 28:161.

Paquay, R., J.M. Godeau, R. DeBaere and A. Lousse. 1973. Utilization of nutrients by the dairy cow and optimal N: Energy ratio in the diet. J. Dairy Research 40:329.

Park, C.S. 1985. Influence of dietary protein on blood cholesterol and relative metabolites of growing calves. J. Anim. Sci. 61:924.

Park, C.S., J.J. Smith, W.W. Eigel and T.W. Keenan. 1982. Selected hormonal effects on protein secretion and amino acid uptake by acini from bovine mammary gland. Int. J. Biochem. 10:889.

Park, C.S., W. Rafalowski and G.D. Marx. 1983. Effect of dietary fat supplement on lipid metabolism of Holstein heifers. J. Dairy Sci. 66:528.

Palmquist, D.L. and T.C. Jenkins. 1980. Fat in lactation rations: Review. J. Dairy Sci. 63:1.

Raabe, E. and T.C. Terkildsen. 1960. On the enzymatic determination of blood glucose. Scand. J. Clin. Lab. Invest. 12:402.

Rafalowski, W. and C.S. Park. 1982. Whole sunflower seed as a fat supplement for lactating cows. J. Dairy Sci. 65:1484.

Smith, N.E., L.S. Collar, D.L. Bath, W.L. Dunkley and A.A. Franke. 1981. Digestibility and effects of whole cottonseed fed to lactating cows. J. Dairy Sci. 64:2209.

Snedecor, G.W. and Cochran, G.W. 1967. Statistical methods. 6th ed. Iowa State Univ. Press, Ames, Iowa.

Steele, W. 1984. Lipid supplementation of dairy cow diets. J. Dairy Sci. 67:1716.

Van Horn, H.H., O. Blanco, B. Harris, Jr. and D.K. Beede. 1985. Interaction of protein percent with caloric density and protein source for lactating cows. J. Dairy Sci. 68:1682.

Verdery, R.B. and S. Gatt. 1981. Assay for lecithin cholesterol acyltransferase. Methods of Enzymology. 72:375. Academic Press, Inc.
Yalow, R.S. and S.A. Berson. 1960. Immunoassay of endogenous plasma insulin in man. J. Clin. Invest. 39:1157.
Yang, Y.T., R.L. Baldwin and J. Russell. 1978. Effects of long supplementation with lipids on lactating dairy cows. J. Dairy Sci. 61:1400.