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To the Graduate Council:

I am submitting herein a thesis written by Jackson Huskey entitled "The Comparative Effects of Liquid and Dry Milk on Utilization of Calcium and Phosphorus by Calves." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Dairying.

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**THE COMPARATIVE EFFECTS OF LIQUID AND DRY MILK
ON UTILIZATION OF CALCIUM AND
PHOSPHORUS BY CALVES**

**A Thesis
Presented to
the Graduate Council of
The University of Tennessee**

**In Partial Fulfillment
of the Requirements for the Degree
Master of Science**

**by
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CHAPTER I

INTRODUCTION

When the calf could nurse the cow and the farmer took what milk was left, few nutritional problems had to be contended with. When a good market for whole milk developed, dairymen began to use milk-replacer type feeds for calves, and many nutritional problems required attention.

Most of the milk replacers are built around a milk product such as dried skim milk, dried buttermilk, or dried whey. These milk products may also be mixed with grain products and fed dry along with free access to hay and water. For younger calves the milk replacer is usually reconstituted to liquid form and fed from a bucket equipped with a nipple.

Much research work has been done to develop rations that are suitable for calves and to compare these rations to whole milk or other milk products. However, very few reports have appeared in the literature which compare milk fed as a liquid to the same product fed in the dry form. Evidence has been presented to show that most of the nursed liquid milk-by-passes the rumen via the esophageal groove, but milk fed in a dry meal goes first into the rumen.

In the rumen the milk constituents could be changed in such a way that dry milk would differ nutritionally from milk fed as a

liquid. In this investigation a comparison has been made of the utilization of calcium and phosphorus from reconstituted skim milk fed as a liquid with that from dry skim milk fed in a calf starter.



CHAPTER II

REVIEW OF LITERATURE

Chemical and Physical Properties of Dry Skim Milk

Dried skim milk is a concentrated high quality feed for dairy calves. Some of the compounds and relationships in milk are unique and very beneficial in the nutrition of the calf (4, 5, 14, 20, 21, 57). Dried skim milk contains about 50 per cent lactose, 35 per cent protein, 8 per cent ash, < 5 per cent water, and a small amount of fat (6, 21, 25). According to Thomas et al. (55) dried skim milk may also contain varying amounts of free fatty acids.

Dry skim milk may be produced by either a spray or roller process, both of which employ heat (11). According to Jenness (21) the heat treatment ranges from 160 to 350°F in the spray process and 194 to 270°F in the roller process. Either process affects the milk by concentration of the milk constituents and chemical changes caused by heat.

Jenness (21) stated that concentrating the milk solids greatly changes the colloidal and ionic systems in milk. Some of the changes are reversible and others are irreversible. The effects of the changes vary with the temperature used in the processing (2, 7, 18).

In reports comparing raw and pasteurized milk (10, 11, 27) the heat treatment has very little effect on the nutritive value of milk. Comparisons of pasteurized and evaporated milk indicate that calcium is as available (26) or slightly more available (51) from evaporated milk than from pasteurized milk.

Reports by Bell (2) and Hill (18) agree that pasteurization temperatures have very little detrimental effect on milk, but they found that higher temperatures do have measurable effects. Hill (18) found that boiling cow's milk precipitated the calcium and phosphorus as calcium phosphates.

Bell (2) studied the effect of various temperatures on the solubility of calcium and phosphorus in milk. Using the Pasteur-Chamberland Filter and centrifuge speeds of 38,000 to 40,000 RPM, he found that heating fresh skim milk to 170°F or above caused a measurable loss of precipitated calcium salts. The amount of precipitate depended on the temperature of the heat treatment.

From studies comparing reconstituted dried skim milk with fresh skim milk, there are definite indications that calcium and phosphorus are more available from the fresh milk product. Kramer (26) reported that both children and adults retained more calcium when it was supplied from fresh skim milk than from reconstituted non-fat milk. In this work phosphorus followed the same general trend as calcium.

Trout (46) studied samples of non-fat dry milk and commercially available fresh skim milk over a period of eight months. In

this study no sediment was noted in the fresh skim milk but only 92 per cent of the milk solids were in solution when tested immediately after reconstituting the non-fat dry milk.

According to Jenness (21) the calcium salts go back into the reconstituted system slowly and are more soluble in cold than in warm solutions. Reports by Danniels and Loughlin (7) and Hill (18) indicated that the precipitation of calcium salts from reconstituted milk may lower the calcium content enough to cause deficiency symptoms to develop in calves fed the milk.

Savage and Crawford (41) observed calves with weak backs and other rachitic conditions fed calf starter containing as much as 22 per cent dried skim milk. They could prevent the rachitic symptoms by adding cod liver oil, steamed bone meal, or ground limestone to the starter. These reports indicate that even if the insoluble salts were injected, in the dry form, they were not utilized efficiently.

In Hill's (18) report, it was stated that the loss of calcium salts caused a softer curd to form in the calf stomach and some of the other nutrients in the milk were more easily digested.

Physiology and Function of the Esophageal Groove

In the very young ruminant fed an all liquid diet, essentially all of the milk by-passes the rumen. As the calf grows and begins to eat solid feeds, the esophageal groove begins its function of

letting some feed enter the rumen and directing other feed to the true stomach. In describing the esophageal groove Dukes (8) stated:

The esophageal groove functions as a conduit closure for milk or water on the way to the reticulo-omasal orifice. The reflex by which the groove is closed has been thought to diminish in sharpness as the animal matures . . . The shift from the sucking desire to the thirst desire is significant in the mechanics of the esophageal groove.

When a calf's feed includes milk, calf starter, and hay, the volume of the rumen liquor increases progressively with age (42). Normally very little, if any, milk taken from a nipple enters the rumen (42, 52, 53, 54) and the amount does not increase with age (42).

Wise (52) observed that solid feeds such as grain and hay do not stimulate the closure of the esophageal groove. Other workers agreed on the course of the solid foods, but there has been some disagreement about the course of liquids drunk from an open pail (42, 53, 54). Wise (53) found that about 50 per cent of the milk taken from an open pail entered the rumen.

In the two methods of feeding milk, via nipple or open pail, the position of the head is different but this has no effect on the function of the esophageal groove.(3, 52, 54).

Functional Development of the Rumen

Preston (38) criticized the prolonged use of liquids in the calf's ration because liquid feeds delay development of the rumen

by stimulating the operation of the esophageal groove and allowing more feed to by-pass the rumen. He agreed with other workers (23, 44) that mature type rumen fermentation results in the synthesis of large quantities of B-complex vitamins, as well as the formation of amino acids and good-quality protein from ordinary sources. Development of adult type rumen function is governed not so much by age as by the rate at which the calf learns to eat solid foods.

Kesler (23) studied calves fed milk, grain, and hay and found normal adult type rumen contents at six weeks of age.

Harris (15) gave these criteria for evaluating rumen function in calves: the ability to digest cellulose, type of bacteria, rumen acid production, bacterial population, or number of protozoa. The fermentative action in the rumen could account for any differences in the utilization of milk fed in the dry or liquid form.

According to Wood (57) much of the lactose entering the rumen is converted to volatile fatty acids (VFA) which are high in propionic acid. Hershberger (17) found that acetic and propionic acids were produced from lactose in approximately the same proportions. In his work, starch, maltose, or glucose increased in vitro cellulose digestion. However, additions of alanine, α -ketoglutarate and lactose, decreased cellulose digestion. All of the additives except alanine increased the formation of VFA. Lactose may lower the pH enough to inhibit cellulose digestion (1, 57).

There are reports indicating that either changes in the diet (9, 12, 30, 34) or ruminal destruction of carbohydrates (36) may be responsible for the increased level of blood fatty acids and reduced level of blood glucose in the young calf.

McCandless (34) studied a number of young ruminants with respect to blood glucose changes. The first week the small animals were fed from their dam's milk, then they were switched to calf starter and hay. At 10 days of age the average blood glucose level was 97 milligrams per 100 milliliters of blood. During the next four ten-day periods the levels dropped to 85, 80, 77 and 61 milligrams per 100 milliliters, respectively. They stated that the glycemic levels were inversely related to the size and functional development of the rumen.

Lupien et al. (30) found that neither the rumen development nor the dietary changes caused the blood glucose and fatty acid levels to change. They worked with calves that had the rumen, reticulum, omasum and proximal third of the abomasum removed. The calves, including the controls, were also splenectomized and the vagus nerve was severed. The gastrectomy of the three to four-week-old calves had no effect on the declining glucose level and there was a steady rise in blood fatty acids. Other factors which they suggest might cause the blood changes are a deficiency of the adrenal-pituitary mechanism in the ruminant or disappearance of glucose from the red blood cells.

Changes in the Feed Material in the Abomasum

Before the "ruminated" milk enters the abomasum it has been mixed thoroughly with other feed ingredients, changed by rumen microorganisms, and some of it has been absorbed. The nature and consistency of this material is probably quite different from the curd that forms when liquid milk first enters the abomasum.

According to Kesler et al. (23) the pH of the abomasum contents is 3.4 to 4.0. The rennin and acid coagulate the casein and probably dissolve most of the calcium salts into the ionic form, as reported by Charley et al. (5).

Digestion and Absorption in the Small Intestine

The ruminated ingesta entering the small intestine has lost a larger part of its lactose and is higher in VFA than ingesta from rations in which liquid milk was fed (57). The water part of the liquid milk may have an effect on the consistency of the ingesta.

Marcuss (32) has shown with rats that liquid type feeds move through the gastrointestinal tract at different rates than do solid type feeds. They found that liquid left the stomach faster and was absorbed quicker than dry feed materials. However, both materials reached the caecum at the same time.

According to Charley and Saltman (5) the high acid materials entering the small intestine gradually become less acid as they move through the intestine. They assumed that as the pH rises, the free

Ca^{++} may be attached to lactose or amino acids and be absorbed or form insoluble complexes with CO_3 , PO_4 , acetate or other fatty acids. At this stage much of the protein is broken down and the amino acids can aid in calcium and phosphorus utilization. Lysine acts similar to lactose to enhance calcium absorption, according to Lengemann (28).

Koroda (25) found that proteins high in glycine, histidine, and arginine, such as serum albumin, gelatin, milk and fish protein, increased the absorption of calcium from the small intestine. However, proteins high in threonine, glutamic and aspartic acids, such as oval-albumin, legumin and wheat protein, slightly inhibited calcium absorption.

Effect of Lactose and other Carbohydrates on Calcium and Phosphorus Utilization

Evidence has been presented earlier that a large part of the lactose that enters the rumen is converted to VFA (3, 17, 20, 57). Fournier (12) noted that lactose fed to young rats caused hypertrophy of the caecum, which led him to believe that the increased acid production might cause the increased calcium absorption. However, when he removed the caecum from part of the rats, the group fed lactose still absorbed and retained more calcium. Removal of the caecum did not modify the effect of lactose.

Other workers (1, 3, 14, 21) attribute the effect of fatty acids to a lower pH which makes the calcium and phosphorus more

soluble and thus more available to be absorbed. Lactose is more difficult to hydrolyze and the bacteria that digest it favor a lower pH than the bacteria that digest other carbohydrates (57).

Most of the workers who have compared lactose with other carbohydrates have agreed that lactose is the most effective in enhancing calcium absorption (3, 14, 20, 57). Vaughn (48) stated that lactose owes its effect on calcium absorption to the fact that it is slowly absorbed and is available throughout the small intestine whereas other carbohydrates are absorbed more rapidly.

Charley and Saltman (5) maintained that the method by which lactose affects calcium and phosphorus absorption cannot be explained by the intestinal microflora, influence on pH, or higher osmotic pressure. They assumed that the Ca^{++} is bound directly to the lactose and transported by sites on or in the mucosal membrane. Whether the complex is transported through the biological membrane or serves as a metal ion buffer to maintain Ca^{++} in a form readily available for transfer is not known. They did find that the molar ratio of lactose to Ca^{++} must be 40:1 to prevent the appearance of calcium precipitates for extended periods of time in vitro.

Lengemann (28) and Jenness (21) cited work by Fournier indicating that lactose has more effect on calcium utilization than that associated with absorption. Fournier believed that the structure of the lactose molecule is important and that it has a specific action on the bone cell in the metabolism of calcium.

Lengemann (28) conducted experiments designed to test many of the theories on the effect of lactose on calcium absorption. He found when lactose is placed in the gastrointestinal tract with calcium, it has a remarkable ability to stimulate calcium absorption. However, lactose placed in an adjacent, ligated section of the small intestine, to the calcium dose, or lactose injected intraperitoneally had no effect on calcium absorption.

To further support the idea that lactose acts only in absorption Lengemann cultured embryo chick bones in 0, 10^{-4} , 10^{-3} M solutions of lactose for 24 hours and seven-day periods. The lactose caused no difference in Ca^{45} uptake by the bones. He concluded that the lactose must be present with the calcium at the area of intestinal absorption to stimulate uptake.

Many workers have referred to an effect of lactose on phosphorus absorption but do not give it as much attention as calcium absorption. Bergein (3) studied the effect of different sugars on calcium and phosphorus absorption. He found the effect on phosphorus to be less than on calcium absorption and in some cases phosphorus absorption was not stimulated by the carbohydrate. Other reports (26, 39, 56) agree that the effect on phosphorus absorption is not as great as the effect on calcium.

Some work has been reported (3, 41) comparing lactose fed with and without vitamin D. Lactose cannot replace vitamin D but it may be very beneficial if the vitamin D is low in the ration.

The Supply of Calcium and Phosphorus in Calf Rations

Milk and milk products are high in calcium and phosphorus which, with the aid of the other properties of milk, are in the most available form for the calf (4, 16, 35). Most of the many calf rations recommended in the literature (22, 24, 37, 41) include milk products, which is very desirable from this standpoint. These rations also contain a large number of other ingredients in an attempt to formulate a highly digestible feed that will meet the calf's requirements.

According to Harper (14) the amount of calcium absorbed into the body is affected by the body's needs, the amount supplied, the kind of food that supplies it, and the speed with which the food passes through the gastrointestinal tract.

Hansard et al. (13) found that the efficiency with which the calf used calcium decreased markedly with age. In his report a ten-day-old calf retained 93 per cent of its dietary calcium; whereas a six-month-old calf retained only 33 per cent. In the young calf almost all of the absorbed calcium was retained but in the older animal a large part of it was re-excreted into the gut. They calculated that the maintenance requirement of the ten-day-old calf was one-half gram of calcium per hundred pounds body weight per day. For six-months-old and older cattle the maintenance requirement was two grams per hundred pounds body weight per day.

Wentworth et al. (49) working with three- to six-month-old calves, found that five grams of calcium per day gave normal growth rates. However, for maximum mineralization, nine grams or more were required per day. Hughes and Cave (19) agreed with these values, as their eight-week old calves retained an average of eight grams of calcium and 5.3 grams of phosphorus per day.

Maynard and Loosli (33) recommended 4, 7, 12 and 13 grams of calcium per day and 3, 6, 8 and 11 grams of phosphorus for 50, 100, 150 and 200 pound calves, respectively. Calves fed a liberal amount of milk or milk product, good quality legume hay, and some concentrates should have an ample supply of calcium and phosphorus. They stated that only in the case of a limited supply of one or both of the minerals should the level of lactose or the form of the milk be practically important in supplying the calf with adequate calcium and phosphorus.

CHAPTER III

MATERIALS AND METHODS

This investigation was conducted with Holstein calves from the University of Tennessee dairy herd at Knoxville. Part of the calves used for calcium and phosphorus utilization studies were simultaneously used in a study of protein utilization. The growth and balance experiments with those calves were conducted as the first phase of this investigation. The second phase was a comparison of liquid and dry milk on low calcium rations.

Feeding and Management

In the first phase, 47 calves were fed starters which varied in protein content, but which were adequate in calcium and phosphorus. The calcium and phosphorus balances conducted in this phase included 21 male calves. Eight male calves were used in the second phase of the investigation. In this phase groups L and M were fed low calcium rations specifically to study the utilization of calcium and phosphorus from liquid and dry milk.

The calves originally were assigned to groups on the basis of their 7-day weights. The first 28 days were used as a preliminary period. They were kept with their dams for two days then moved to individual stalls. The milk feeding schedule was: colostrum and whole milk for the first seven days, ten pounds of

reconstituted (1:10) skim milk per calf per day for the second week, 12 pounds for the third week and 14 pounds per calf per day for the fourth week. The calves had free access to water and hay, and were fed up to four pounds of starter per day during the preliminary period. After the experimental rations were started, water was available at all times and ground hay was fed as part of the starter mix. Liquid milk was fed to groups 9 and 11 to equal about 20 per cent of the total dry matter intake. The hay used was mostly grass because of its lower protein content. The formulas of the starters used in the first study are given in Table I. Group 7 was a control group which was not fed any milk during the experimental period.

Groups L and M were made up from calves that had finished a different experiment at 91 days of age. They were fed the low calcium starters described in Table II from 92 to 120 days of age. The first three weeks were used as a preliminary period and the last week as the collection period. Group L was fed ten pounds per day of reconstituted (1:10) skim milk to supply 16 per cent of the dry feed allowance. Most of the calcium supplied by these two starters came from milk.

The calves fed starters 7, 8, 9, 10 and 11 were weighed and measured for heart girth and height at withers each week to record the growth responses from seven days to 105 days of age.

Four male calves were selected from each group to use in the balance study. The ages of the calves during the collection

TABLE I
 FORMULAS OF THE STARTERS FED TO GROUPS
 7, 8, 9, 10 AND 11 FROM 28 TO 91 DAYS OF AGE

Ingredient	GROUPS				
	7	8	9	10	11
	— (pounds per 1000 pounds) —				
Ground hay	200	200	200	200	250
Corn starch	170	370	425	370	445
Corn meal	600	205	350	205	280
Dry skim milk	---	200	--- ^a	200	--- ^a
Salt	10	10	10	10	10
Dicalcium phosphate	10	15	5	5	5
Vitamins A and D	10	10	10	10	10

^aStarters 9 and 11 were supplemented with reconstituted skim milk to supply 20 per cent of the dry matter intake.

TABLE II
FORMULAS OF THE LOW CALCIUM STARTERS
FED TO GROUPS L AND M

Ingredients	STARTERS	
	L	M
	(pounds in mix)	
Corn meal	565	565
Ground oat straw	130	130
Corn gluten meal	42	42
Salt	8	8
Vitamins A and D	5	5
Dry skim milk	--- ^a	143
Total pounds	750	893

^a Starter L was supplemented with reconstituted skim milk to supply 16 per cent of the dry feed allowance.

period varied from 80 to 90 days for groups 7, 8, 9, 10 and 11, and 113 to 120 days for groups L and M.

For the balance study the calves were placed in metabolism crates for a three-day adjustment period, and this was followed by a six-day collection period. Feces and urine were collected and weighed once daily. Each collection day a representative sample of the feces was sealed in a glass jar and frozen. A 5 per cent aliquot of the daily urine collection was taken and added to the composite urine sample which was kept in a refrigerator. At the end of the collection period, a 5 per cent aliquot of each daily collection of feces was composited from each calf. This was weighed, oven dried, and then left to equilibrate in air to obtain the air-dry feces weight. The urine composite of each calf was diluted to one liter with distilled water.

Chemical Analysis

The feed, feces, and urine samples were analyzed for calcium and phosphorus by a method described by Lyke (31). All of the analyses were made in duplicate for each sample. The urine samples were prepared for analysis by evaporating 20-milliliter portions in crucibles containing a piece of filter paper. The dry skim milk, starter and air-dried feces samples were weighed into crucibles as two-gram samples. All of the samples were ashed at 600 degrees Centigrade for 12 hours. A piece of filter paper was

ashed as a control with the urine. The ash from each sample was dissolved in six normal hydrochloric acid and diluted to 25 milliliters with distilled water.

For phosphorus analysis one milliliter of the original 25 milliliters was diluted 1:200 and a 5-milliliter portion of this was placed in a colorimeter tube. To this was added 3.6 milliliters of distilled water, one milliliter of molybdic acid reagent, and 0.4 milliliter of 1-amino-2-naphthol-4-sulfonic acid reagent. After 20 minutes reaction time, the corrected transmission at 660 was determined. The percentage phosphorus in the sample was calculated from a standard curve of phosphorus values.

The calcium analysis was made on the original 25 milliliters using 5-milliliter portions from the feed and feces samples and 20-milliliter aliquote from the urine samples. The calcium was precipitated as calcium oxalate, dissolved in 10 per cent sulfuric acid and titrated with standardized (0.02N) potassium permanganate (KMnO_4). The titration with KMnO_4 was checked against a standard calcium solution.

Proximal analyses (29) were made of all of the feed and feces samples. The coefficients of apparent digestibility were calculated for each calf.

The average daily gains of all calves used in the balance study were calculated for the three-week period including the collection period. Correlation coefficients were calculated between average

daily gains and calcium retention as milligrams of calcium retained.

Analysis of variance as outlined by Snedecor (43), was used to compare the calcium and phosphorus retention from liquid vs. dry skim milk and high vs. low calcium intake. The analysis was made comparing all calves on liquid or dry milk for the former and only the calves on low calcium intake for the latter.



CHAPTER IV

RESULTS

Chemical Analysis of the Starters

The results of the proximate analysis of the starters are given in Table III. The percentage of calcium and phosphorus and the ratio of calcium to phosphorus in the starters are also given. Starters 7, 9, 11 and L were low in calcium and phosphorus. Starter 7 was used as a low protein basal ration and starters 9, 11 and L were supplemented with liquid milk.

Feed Consumption and Growth

Feed consumption and weight gains for the first phase of this study are shown in Table IV as averages for the groups. Even though the hay, grain and milk in starters 8 and 10 were mixed together, the actual consumptions of each are given separately in the table to help compare the different groups. The calves fed liquid milk (groups 9 and 11) could consume all of their milk and leave part of the grain and hay mixture. The groups fed dry milk (8 and 10) had to eat all of the starter to get the milk it contained. The liquid milk fed was limited as closely as possible to supply an amount equal to the dry milk consumption in groups 8 and 10.

Calves fed the dry milk, groups 8 and 10, consumed less total feed, 270.2 and 238.2 pounds, respectively, during the

TABLE III

PROXIMATE CHEMICAL ANALYSIS OF EACH STARTER AS FED^a

Starter No.	Dry Matter	Ether Extract	Crude Fiber	Crude Protein	Nitrogen Free Extract	Ash	Calcium	Phosphorus	Ca:P
				(%)					
7	89.32	2.72	5.87	8.27	68.06	4.41	0.58	0.35	1.66:1
8	92.68	1.23	4.14	12.00	70.37	4.91	0.71	0.38	1.88:1
9	93.35	1.49	4.81	5.56	77.94	3.61	0.44	0.22	2.05:1 ^b
10	92.71	1.05	3.35	11.68	72.54	4.18	0.63	0.38	1.66:1
11	91.46	1.43	5.21	5.67	75.70	3.44	0.44	0.24	1.84:1 ^b
L	90.89	3.67	6.59	11.33	67.39	2.91	0.05	0.23	0.22:1 ^b
M	91.71	3.13	5.86	15.60	63.15	3.97	0.26	0.36	0.72:1

^aPercentages given for starters 7, 8, 9, 10 and 11 are averages of three to five mixes.

^bThis Ca:P ratio does not include the calcium and phosphorus supplied by liquid milk.

TABLE IV
SUMMARY OF FEED CONSUMPTION, GAINS AND FEED
EFFICIENCY FOR THE EXPERIMENTAL PERIOD
28 TO 91 DAYS

	Starter Number				
	7	8	9	10	11
Number of calves	8	8	9	11	12
Grain fed (lb)	204.8	162.2	172.3	142.9	151.8
Hay fed (lb)	51.2	54.0	43.1	47.7	50.6
Milk fed, dry basis (lb)	--	54.0	58.8	47.7	58.8
Feed consumption (lb)	256.0	270.2	274.2	238.3	261.2
Gains (lb)	59.9	79.3	95.7	63.9	83.9
Average daily gain (lb)	0.95	1.26	1.52	1.01	1.33
Pounds of feed per pound of gain (lb)	4.27	3.41	2.86	3.73	3.11

experimental period than those fed liquid milk. The respective consumption of dry feed by groups 9 and 11 was 274.2 and 261.2 pounds. Of the total dry feed consumed, milk accounted for 54.0, 58.8, 47.7 and 58.8 pounds for groups 8, 9, 10 and 11, respectively. Note that in each case the groups fed liquid milk consumed more milk than the groups fed dry milk. Also, when the two trials were averaged, the calves fed liquid milk ate slightly more non-milk ingredients than the calves fed dry milk. The higher total feed consumption was probably an important factor in the increased weight gains of the calves fed liquid milk over those fed dry milk.

The total weight gains for the 28- to 91-day period, Table IV, page 24, were 79.3, 95.7, 63.9 and 33.9 pounds for groups 8, 9, 10 and 11, respectively. When the total gains were compared by analysis of variance, the gains from liquid milk were higher ($P < 0.01$) than the gains obtained from dry milk. The summary of the statistical analysis is given in Table V.

The feed consumption and weight gains by groups L and M were similar to those obtained for the other four groups (8, 9, 10 and 11). Group L consumed slightly more feed, but both groups ate most of their six pounds (dry basis) daily feed allowance. The weight gains for groups L and M averaged 1.40 and 1.06 pounds per day, respectively. These average daily gains compare favorably with the respective 1.43 and 1.13 average daily gains for the liquid and dry milk groups in the first phase of this study. However, due

TABLE V

ANALYSIS OF VARIANCE SUMMARY: TOTAL GAINS
OF CALVES WHILE ON EXPERIMENT,
1961 AND 1962

Source of Variation	Degrees of Freedom	Sums of Squares	Variance	F Value	F Table	
					P=0.01	P=0.05
Total	38	10,401	----	----	---	---
Year	1	1,879	1879	12.8**	7.56	4.17
Milk Type	1	3,240	3240	22.0**	7.56	4.17
Error Term	36	5,282	147			

to the small number of calves and the variation between calves, the difference between groups L and M were not statistically significant as shown in Table VI.

The calves in Groups 8, 9, 10 and 11 were measured each week for heart girth and height at withers. The weekly averages for the liquid and dry milk groups are given in Table VII. The averages include 19 calves in the dry milk groups and 20 calves in the liquid milk groups. The calves in the two treatments were about equal at the 28-day measurement. During the 63-day experimental period the calves fed liquid milk grew an average of 6.7 inches in heart girth while the calves fed dry milk grew only 5.8 inches. The height at withers increased in about the same proportion, 4.0 inches for the liquid milk group and 3.7 inches for the dry milk group.

The extra growth on the liquid milk would be expected to have a relationship to increased calcium utilization. However, when the average daily gains for the three-week period including the balance trial were correlated with the percentage of calcium retained, the coefficient of correlation (0.23) was not statistically significant. The correlation coefficient between average daily gains for the same period and total milligrams of calcium retained was only 0.13 which was not significant at the 10 per cent probability level.

Calcium and phosphorus utilization and balances

A total of 29 male calves were used in the balance studies, 21 in the first phase and eight in the second phase. The calves in the

TABLE VI
ANALYSIS OF VARIANCE SUMMARY: WEIGHT GAINS
OF CALVES IN EXPERIMENTAL GROUPS L AND M

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Value	F Table	
					P=0.01	P=0.05
Total	7	666				
Milk Type	1	180	180	2.01	35.12	10.13
Between Calves	3	217	72.3	0.81	29.46	9.28
Error Term	3	269				

TABLE VII

AVERAGE HEART GIRTH AND HEIGHT AT WITHERS OF CALVES
FED LIQUID AND DRY MILK FROM 28 TO 91 DAYS

Age	Heart Girth		Height at Withers	
	Groups 9 and 11 (liquid)	Groups 8 and 10 (dry)	Groups 9 and 11 (liquid)	Groups 8 and 10 (dry)
(Days)	(in)			
7	30.8	30.5	29.5	28.9
14	31.3	31.0	29.6	29.2
21	31.7	31.4	29.9	29.4
28	32.5	32.0	30.3	29.8
35	33.2	32.2	30.7	30.2
42	33.7	33.0	31.1	30.5
49	34.4	33.6	31.4	30.7
56	35.3	34.2	32.0	31.2
63	36.1	35.0	32.4	31.8
70	36.8	35.6	32.9	32.0
77	37.5	36.1	33.4	32.6
84	38.1	37.0	33.8	32.8
91	39.2	37.8	34.3	33.5
98	39.9	38.9	34.8	33.7
105	40.8	39.7	35.4	34.0
28 to 91 day increases	6.7	5.8	4.0	3.7

first phase were fed rations which were high in calcium and phosphorus. In the second phase the ration was adequate in phosphorus but was purposely made low in calcium. The percentages of calcium and phosphorus in each starter are given in Table III, page 23. The ratios of calcium to phosphorus (Ca:P) were 1.68:1, 1.88:1, 2.05:1, 1.66:1, 1.84:1, 0.22:1 and 0.72:1 for starters 7, 8, 9, 10, 11, L and M. When starter 9, 11 and L were corrected for the intake of liquid milk, the as-fed Ca:P ratios were calculated to be 1.92:1, 1.74:1 and 0.73:1, respectively.

The results of the balance trials are summarized in Table VIII. The total retention and apparent digestibility were quite variable between calves. When the group averages were compared, the liquid milk was slightly superior to the dry milk for both calcium and phosphorus availability. However, when these differences were compared by analysis of variance, Table IX, X and XI, the differences between liquid and dry milk were not statistically significant.

The total retention of phosphorus was reduced ($P < 0.01$) when low calcium rations were fed. The retention of phosphorus for the high and low levels of calcium intake averaged 4204 and 3326 milligrams of phosphorus per day, respectively. The percent of calcium retention was slightly higher on the low calcium rations but the milligrams of calcium retained were greatly reduced ($P < 0.01$) Table XII. The low calcium groups retained an average of 3903 milligrams per day while the groups on high calcium intake retained 6928 milligrams per calf per day.

TABLE VIII

APPARENT DIGESTIBILITY AND TOTAL RETENTION OF CALCIUM AND PHOSPHORUS

Group	Average Apparent Digestibility		Average Retention of Total Intake		Average Retention Milligrams Per Day	
	Calcium	Phosphorus	Calcium	Phosphorus	Calcium	Phosphorus
	— (%) —		— (mg) —			
7	18.66	61.50	14.61	49.78	1758	3987
8	50.67	69.78	59.80	45.13	7528	333946
9	55.92	77.34	54.18	49.13	7469	4014
10	51.40	73.40	50.30	54.20	5216	3769
11	53.80	80.40	52.90	57.00	7507	5080
L	66.13	81.35	62.73	42.13	4199	3891
M	58.20	70.90	52.29	28.70	3607	2761
Liquid Milk Rations	58.62	79.70	56.60	49.15	6389	4328
Dry Milk Rations	53.42	71.36	54.13	43.01	5450	3492

TABLE IX
ANALYSIS OF VARIANCE SUMMARY: CALCIUM BALANCE
FOR ALL CALVES CALCULATED ON PER CENT
OF CALCIUM INTAKE RETAINED

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Value	F Table	
					P=0.01	P=0.05
Total	24	3608.5				
Milk type	1	169.0	169.0	1.15	8.10	4.35
Calcium level	1	203.8	203.8	1.38	8.10	4.35
Error term	22	3235.7	147.1			

TABLE X

ANALYSIS OF VARIANCE SUMMARY: PHOSPHORUS BALANCE
FOR ALL CALVES CALCULATED ON PER CENT
OF PHOSPHORUS INTAKE RETAINED

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F Value	F Table	
					P=0.01	P=0.05
Total	24	4463.6				
Milk type	1	322.2	322.2	2.53	8.10	4.35
Calcium level	1	1340.5	1340.5	10.53**	8.10	4.35
Error term	22	2800.9	127.3			

TABLE XI
ANALYSIS OF VARIANCE SUMMARY: CALCIUM BALANCE
FOR GROUPS L AND M

Source of Variation	Degrees of Freedom	Sum of Square	Variance	F Values	F Table	
					P=0.01	P=0.05
Total	7	1748.81				
Milk type	1	198.80	198.80	0.89	34.12	10.13
Between calves	3	879.82	293.27	1.31	29.46	9.28
Error term	3	670.19	223.40			

TABLE XII

ANALYSIS OF VARIANCE SUMMARY: CALCIUM BALANCE
FOR ALL CALVES CALCULATED AS MILLIGRAMS
OF CALCIUM RETAINED PER DAY

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Value	F Table	
					P=0.01	P=0.05
Total	24	121,480,474	-			
Milk Type	1	6,793,419	6,793,419	2.36	8.10	4.35
Calcium Level	1	51,330,907	51,330,907	17.82**	8.10	4.32
Error Term	22	63,356,148	2,879,825			

Digestibility of Other Nutrients

Coefficients of digestibility were calculated for the calves in groups L and M. The results were averaged and are presented in Table XIII. These data show that the groups were essentially equal in their ability to digest the different rations. Calves in group M were slightly superior in their ability to digest crude fiber but those in group L were equal or slightly superior in their ability to digest the other nutrients.

TABLE XIII
AVERAGE APPARENT DIGESTIBILITY COEFFICIENTS
FOR GROUPS L AND M

Ration	Dry Matter	Ether Extract	Crude Fiber*	Nitrogen Free Extract	Crude Protein	Ash
L (liquid milk)	77.68	83.40	32.92	78.24	75.69	83.82
M (dry milk)	77.12	84.14	40.01	82.71	76.40	71.45

* Crude fiber and nitrogen free extract averages include only three calves.

CHAPTER V

DISCUSSION

The results of this investigation indicate that reconstituted skim milk produced slightly higher calcium and phosphorus balances than the same product fed to calves in the dry form. The reason for this difference is not clear either from this experiment or reports in the literature. The fact that the dry milk enters the rumen and is changed by microbiological action while the liquid milk goes directly into the abomasum, probably accounts for most of the differences.

Another factor that should be considered in favor of liquid milk is the addition to the diet of warm water in the reconstituted milk. The amount of total liquids consumed may be very important for the proper function of the calf, especially in cold weather when the water supply is cold or frozen.

The more natural eating method of the calf taking the milk via nipple may be another factor in favor of liquid milk over dry milk even in adverse conditions, whereas the consumption of dry feeds may be reduced with a subsequent reduction in growth. Evidence supporting this reason is the fact that while in the metabolism crate the 13 calves fed liquid

milk gained an average of 5.4 pounds while the 12 calves on dry milk gained only 3.7 pounds per calf.

Digestibility of the Feed Nutrients

The coefficients of apparent digestibility as shown in Tables VIII and XIII, pages 31 and 37 respectively, are about equal for the two forms of milk. The differences that did occur were usually in favor of the calves fed liquid milk. Digestibility of dry matter, ether extract, and crude protein was about the same for calves in groups L and M. Calves in group M digested crude fiber and nitrogen-free-extract slightly more efficiently than did calves in group L. The extra protein entering the rumen in the dry milk could have stimulated microbial digestion of cellulose. The effect of protein probably counteracted the effect noted by Hershberger et al. (17) that lactose lowers cellulose digestion.

The higher nitrogen-free-extract digestibility on the dry milk ration may be caused by the inability of the calf to digest lactose efficiently (1, 3, 12, 14, 21, 39, 57) on the liquid milk ration, whereas the rumen bacteria may have metabolized most of the lactose fed in the dry form (35, 57).

Group L digested ash and particular calcium and phosphorus more efficiently than Group M. This accounts for the higher digestibility and total retention of calcium and phosphorus on the liquid milk ration than on the dry milk ration. Since a large part of the

calcium and phosphorus was supplied in the milk, especially in groups L and M, most of these two minerals by-passed the rumen in the liquid milk while in the dry milk all of the nutrients were subjected to fermentation in the rumen. Any changes in the calcium and phosphorus in the rumen probably lowered its availability to the calf since reports in the literature indicate that the calcium and phosphorus in milk are in the most available forms (19, 33, 35, 56).

When the minerals pass through the digestive tract via the rumen their absorption is delayed in comparison to the minerals in the liquid milk that by-passed the rumen. According to Harper (14) the speed with which the food passes through the digestive tract is very important in the utilization of calcium. In the rumen there was more time for insoluble salts and soaps with fatty acids to form, according to Charley and Saltman (5). The production of short chain fatty acids from lactose also reduces the amount of lactose entering the small intestines. Evidence has been presented indicating that the presence of large amounts of lactose in the small intestines aids in calcium absorption. The presence of lactose probably has more effect than the lower pH associated with organic acid production in the rumen.

Calcium and Phosphorus Balances

The 6,389 and 5,450 milligrams of calcium and 4,328 and 3,492 milligrams of phosphorus retained per calf each day on liquid and dry milk, respectively (Table VIII) are in agreement with

the digestibility data on the two minerals. The total retention for these three-month old calves were less than the 8.0 grams of calcium and 5.3 grams of phosphorus retained by eight month old calves as reported by Hughes and Care (19). However, the two minerals were retained in about the same proportion in the different age calves.

The total intake was slightly higher for both calcium and phosphorus on the liquid milk ration (11,832 and 8,805 milligrams, respectively) than on the dry milk ration (10,846 and 8,309 milligrams, respectively). The higher retention with increased intake agrees with reports in the literature (13, 14, 48). However, the greater efficiency of calcium and phosphorus utilization at the higher intakes does not agree with the literature reports (4, 14, 19, 33). The indications are that the calcium and phosphorus from liquid milk were comparatively more available than from dry milk.

On the low calcium rations the percentage of the calcium intake that was digested and retained was higher than that on the adequate calcium levels. The total milligrams of calcium retained, however, were greatly reduced on the low calcium intake. More efficient utilization of calcium on the lower intake would be expected to be greater than the 5.71 per cent noted. The high phosphorus content in the low calcium rations probably decreased the utilization of calcium (33). Also, the low calcium retention left the calves with an excess of phosphorus, thus the utilization of phosphorus was reduced.

Growth

Increased growth on the liquid milk ration was in agreement with the feed consumption and feed efficiency data on the different rations. Growth rates on these liquid and dry milk rations were equal to or slightly less than those reported in the literature (35, 37, 40).

Growth and feed utilization on ration 7 was low as would be expected. This was a basal low-protein ration that contained no milk. The results obtained from group 7 are included in this report only for comparison with the other rations which were more nearly adequate.

The growth of the calves in heart girth and height at withers were greater for the calves fed liquid milk. This greater skeletal growth would be expected to cause an increased utilization of calcium for bone formation. The low correlation between calcium utilization and average daily gains during the balance period may have been caused by the calves' response to the metabolism crates. Some of the calves grew normally in the crate while others actually lost weight. This variable response would upset the correlation between growth and calcium utilization.

CHAPTER VI

SUMMARY

Dry skim milk was fed to Holstein calves in dry and liquid forms from 28- to 91-days of age in one experiment and from 92- to 120-days in a second experiment. In the first experiment, 24 calves fed reconstituted skim milk were compared to 23 calves fed dry skim milk mixed in the starter. These calves were weighed and measured for heart girth and height at withers each week. Nine of the male calves fed liquid milk and eight male calves fed the dry milk mixture were used in a digestion and balance study. In the second experiment four male calves fed liquid milk and four male calves fed dry milk were compared for a three-week preliminary period and a one-week balance study on low calcium rations.

The total feed consumption for the 28- to 91-day period was calculated and broken down into grain, hay, and (dry) milk consumed. In each group the calves on liquid milk consumed more than those on dry milk but the differences were not statistically significant at the 5 per cent level of probability. For dry milk, groups 8 and 10, the respective feed required per pound of gain were 3.41 and 3.73 pounds, while groups 9 and 11 on liquid milk required only 2.86 and 3.11 pounds of feed per pound of gain. The 1.43 pounds average daily gain on the liquid milk was higher ($P < 0.01$) than the 1.13 pounds average daily gain on dry milk.

During the 28- to 91-day experimental period the heart girth increased 6.7 and 5.8 inches and the height at withers increased 4.0 and 3.7 inches for calves on liquid and dry milk, respectively.

The groups fed dry and liquid milk were compared for digestion, percentage retention, and total milligrams of calcium and phosphorus retained. For each factor the groups fed liquid milk were slightly but not statistically significantly ($P > 0.05$) greater than those fed dry milk. Groups L and M in the second phase were fed low calcium rations that lowered the percentage of phosphorus retention ($P < 0.01$). The percentage of calcium retained was slightly higher on the low calcium rations but the total milligrams of calcium retained were greatly reduced ($P < 0.01$).

The digestibility of dry matter, ether extract, and crude protein was about equal for the two forms of milk. Calves fed dry milk digested slightly more crude fiber and nitrogen-free-extract than did those on liquid milk. Calves fed the liquid milk rations were higher in their apparent digestibility of ash, particularly calcium and phosphorus.

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