# Effect of Dietary Lactose on Gain, Feed Conversion, Blood, Bone and Intestinal Parameters in Postweaning Rats and Swine

R. L. Moser
*University of Nebraska-Lincoln*

E. R. Peo, Jr.
*University of Nebraska-Lincoln*

T. D. Crenshaw
*University of Nebraska-Lincoln*

P. J. Cunningham
*University of Nebraska-Lincoln*

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# EFFECT OF DIETARY LACTOSE ON GAIN, FEED CONVERSION, BLOOD, BONE AND INTESTINAL PARAMETERS IN POSTWEANING RATS AND SWINE[1,2]

R. L. Moser, E. R. Peo, Jr., T.D. Crenshaw
and P. J. Cunningham[3]

*University of Nebraska, Lincoln 68583*


## Summary

Two trials were conducted to determine the effect of lactose on performance, bone integrity and certain blood constituents in postweaning rats and swine. The effect of lactose on calcium and phosphorus and percentage ash content of the small intestine was also determined. In both trials, average daily gains were not influenced by the feeding of diets containing 30% lactose. Feed conversion was depressed in both rats and pigs when 30% lactose was fed. Transitory diarrhea was observed in rats fed 30% lactose, but not in swine. In the rat trial, no significant differences due to treatment were observed for serum Ca or P, but a linear increase (P<.01) in alkaline phosphatase was observed as lactose increased in the diet. Analysis of blood constituents from multiple bleedings during the pig trial showed that in the first 2 weeks, alkaline phosphatase was increased (P<.01) in pigs fed lactose and slightly decreased in those not fed lactose. Lactose affected the change in serum Ca from 0 to 10 weeks (P<.05) as indicated by a marked reduction in serum Ca of pigs not fed lactose and a slight increase for those fed lactose. Serum calcium decreased in the absence of lactose but increased in the presence of lactose (P<.05) in pigs fed .4% Ca diets. In both trials, breaking strength parameters (peak force and stress) were not affected by dietary lactose. Bones from pigs fed no lactose had a higher stress to strain ratio (P<.05) than those from pigs fed lactose. In the rat trial, stress to strain ratio was variable across all treatments. Percentage of bone ash increased (P<.01) as lactose increased in the diet. Dietary treatments did not affect the mineral content of specific gut segments.

**(Key Words:** Lactose, Ca:P Ratio, Serum Calcium, Alkaline Phosphatase, Bone Strength, Swine, Rat.)

## Introduction

The importance of lactose as the primary carbohydrate in the diet of suckling animals has been recognized for many years. Lactose functions primarily as an energy source but is considered to perform other functions, such as improving protein, calcium and magnesium digestibility (Sewell and West, 1965; Entringer *et al.*, 1975).

The nutritional and physiological roles of lactose seem to diminish with time because (1) the specific activity of lactase in the digestive tract decreases with age (Simoons, 1969; Ekstrom *et al.*, 1975a), and (2) the animal no longer receives lactose from milk because milk is replaced with diets made up largely of plant feedstuffs. Also, moderate to high levels of dietary lactose fed to postweaning animals have caused digestive upsets, specifically diarrhea (Becker *et al.*, 1957).

Lactose has been found to enhance the absorption of calcium (Ca) from the digestive tract in a variety of species, including rats (Lengemann *et al.*, 1959), chicks (Kline *et al.*, 1932), dairy calves (Robinson *et al.*, 1929) and humans (Kobayashi *et al.*, 1975). Limited research in this area has been conducted with swine.

Armbrecht and Wasserman (1976) recently showed that lactose enhances the uptake of Ca from the ileum of the small intestine of rats. Since Ca and phosphorus (P) play vital roles in mineral nutrition and since lactose seems to

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[3]Current address: Bonneville, IA.

be involved in the absorption of Ca, the objectives of the research reported herein were (1) to determine the effect of lactose on performance, bone integrity and certain blood constituents in postweaning rats and swine and (2) to determine the effect of lactose on mineral content of certain gut segments of the small intestine of swine.

## Experimental Procedure

*Animals*

*Rat Trial.* Sixty Holtzman rats (54 g) were allotted to six treatment groups (10 rats per treatment) in a randomized complete block design (blocked by initial weight). Sex distribution was the same for each treatment. The rats were weaned at 3 weeks of age and fed a standard laboratory diet until allotted to the treatments at 4 weeks of age. Rats were individually caged, with feed and water offered *ad libitum.* All rats were weighed and feed intakes were recorded weekly. The experiment was terminated after 28 days.

*Pig Trial.* Ninety-six crossbred (Large White × Landrace × Hampshire × Duroc × Yorkshire) pigs (31 kg) were allotted to eight treatment groups in a randomized complete block design (blocked by weight). Eight pigs (two barrows and six gilts) were placed in each pen. Treatments 2, 4, 6 and 8 were replicated to provide feed intake and feed efficiency data. Feed and water were offered *ad libitum.* Pigs were weighed biweekly and feed intakes were recorded over a 70-day feeding period.

*Diets*

*Rat Trial.* Experimental diets consisted of a corn-soybean meal base with various levels of cornstarch and lactose (see table 1 for composition). Diets 1, 2 and 3 contained 0, 15 and 30% cornstarch, respectively; diets 4, 5 and 6 were prepared with 10, 20 and 30% lactose substituted for cornstarch. The total amount of purified carbohydrate in diets 3, 4, 5 and 6 was 30%. All diets were formulated to contain 16% crude protein, .6% Ca and .6% P, and analyses revealed the actual percentages to be 17.0, .59 and .62, respectively.

*Pig Trial.* Experimental diets (table 2) consisted of a corn-soybean meal base with 0 or 30% lactose, with .4 or .6% Ca and .4 or .6% P. Diets containing no lactose included 30% cornstarch so that the total addition of purified carbohydrate sources remained the same in all diets. Diets were calculated to contain 14% crude protein.

*Blood.* At the end of the rat trial, each rat was anesthetized with ether, and a blood

TABLE 1. COMPOSITION OF DIETS. RAT TRIAL[a]

| Ingredient, % | Internat'l Ref. No. | Diet | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Ground yellow corn | 4-02-992 | 76.00 | 57.15 | 38.21 | 38.21 | 38.21 | 38.21 |
| Soybean meal (44%) | 5-04-604 | 17.10 | 20.90 | 24.80 | 24.80 | 24.80 | 24.80 |
| Cornstarch[b] | 4-02-889 | ... | 15.00 | 30.00 | 20.00 | 10.00 | ... |
| Lactose[c] | 4-07-881 | ... | ... | ... | 10.00 | 20.00 | 30.00 |
| Dicalcium phosphate | 6-01-080 | 1.30 | 1.46 | 1.62 | 1.62 | 1.62 | 1.62 |
| Limestone | 6-02-632 | .50 | .39 | .27 | .27 | .27 | .27 |
| Dried brewer's yeast | 7-05-528 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Dried fish solubles | 5-01-971 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| Salt | 6-04-151 | .50 | .50 | .50 | .50 | .50 | .50 |
| Trace minerals[d] | | .10 | .10 | .10 | .10 | .10 | .10 |
| Vitamin premix[e] | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

[a]Calculated analysis: 16% crude protein .6% Ca .6% P.

[b]Commerical cornstarch.

[c]$\alpha$-lactose monohydrate.

[d]Contributed the following in milligrams per kilogram of diet: Zn 200; Fe, 100; Mn, 55; Cu, 10; Co, 1; I, 1.5.

[e]Contributed the following per kilogram of diet: vitamin A, 3,300 USP units; vitamin $D_3$, 440 ICU; vitamin E, 22 IU; riboflavin, 2.2 mg; pantothenic acid, 13.2 mg; niacin, 17.6 mg; choline chloride, 110 mg; vitamin $B_{12}$, 2.2 mcg; ethoxyquin, 4.4 mcg; menadione sodium bisulfate, 2.2 mg; in a ground corn carrier.

TABLE 2. COMPOSITION OF DIETS. PIG TRIAL

| Ingredient, % | Internat'l Ref. No. | Diet 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Ground yellow corn | 4-02-992 | 44.54 | 43.55 | 43.91 | 42.82 | 44.54 | 43.55 | 43.91 | 42.82 |
| Soybean meal (44%) | 5-04-604 | 22.70 | 22.90 | 22.80 | 23.10 | 22.70 | 22.90 | 22.80 | 23.10 |
| Cornstarch[a] | 4-02-889 | 30.00 | 30.00 | 30.00 | 30.00 | ... | ... | ... | ... |
| Lactose[b] | 4-07-881 | ... | ... | ... | ... | 30.00 | 30.00 | 30.00 | 30.00 |
| Monosodium phosphate | 6-04-287 | .53 | 1.32 | .53 | 1.32 | .53 | 1.32 | .53 | 1.32 |
| Limestone | 6-02-632 | .88 | .88 | 1.41 | 1.41 | .88 | .88 | 1.41 | 1.41 |
| Salt | 6-04-151 | .25 | .25 | .25 | .25 | .25 | .25 | .25 | .25 |
| Trace minerals[c] | | .10 | .10 | .10 | .10 | .10 | .10 | .10 | .10 |
| Vitamin premix[d] + ASP 250[e] | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Analyzed, %[f] | | | | | | | | | |
| Crude protein | | 13.8 | 14.4 | 15.5 | 14.0 | 14.8 | 14.9 | 15.1 | 14.9 |
| Ca | | .48 | .49 | .65 | .58 | .45 | .45 | .64 | .59 |
| P | | .40 | .60 | .42 | .60 | .41 | .60 | .39 | .59 |

[a]Commercial cornstarch

[b]α-lactose monohydrate.

[c]Contributed the following in milligrams per kilogram of diet: Zn, 200; Fe, 100; Mn, 55; Cu, 10; Co, 1; I, 1.5.

[d]Contributed the following per kilogram of diet: vitamin A, 3,300 USP units; vitamin $D_3$, 440 ICU; vitamin E, 22 IU, riboflavin, 2.2 mg; pantothenic acid, 13.2 mg; niacin, 17.6 mg; choline chloride, 110 mg; vitamin $B_{12}$, 2.2 mcg; ethoxyquin, 4.4 mcg; menadione sodium bisulfate, 2.2 mg; in a ground corn carrier.

[e]Contributed the following per kilogram of diet: chlortetracycline, 110 mg; sulfamethazine, 110 mg; penicillin, 55 milligrams. Withdrawn from diets 7 days before slaughter.

[f]Percentage on as-fed basis.

sample was taken via heart puncture. In the pig trial, blood samples were taken via brachial puncture at 0, 2 and 10 weeks. Serum Ca concentration was determined by atomic absorption spectrophotometry[4]. Serum concentration was determined on the protein-free filtrate prepared by trichloroacetic acid precipitation. P analysis was carried out colorimetrically by the method of Goldenberg and Fernandez (1966). Serum alkaline phosphatase activity was determined according to a colorimetric method of the Sigma Chemical Co. (1974), with paranitrophenyl phosphate used as the substrate. Sigma units per milliliter were converted to IU/liter by multiplying by a factor of 16.7.

*Bones.* The femur and third and fourth metatarsals from the right side of each pig and both femurs of each rat were removed at the end of the respective trials. Bones were autoclaved at 110 C for 10 min and cleaned of all adhering tissue. Rat fermurs were ether extracted for 24 hr with a side-arm extraction apparatus. Outside diameter of the bones was calculated as the average of two measurements 90° to each other at the center of each bone. Cross-sectional area of the bone was estimated with the formula shown in table 3. Bone breaking strength was determined with an Instron testing instrument[5]. Bones were placed on two supports and force was applied at the center of the bone. The distance between the two supports for pig femurs and metatarsals was 7.8 and 4.2 cm, respectively; rat femurs were placed on two supports 11 mm apart. The parameters utilized for estimation of bone strength are listed in table 3. Broken rat femurs were dried overnight at 100 C, weighed and ashed in a muffle furnace at 600 C for 4 hr for determination of percentage ash.

*Tissues.* At slaughter, the digestive tracts of the five heaviest pigs (one barrow and four gilts) from each treatment were selected for mineral analysis. One segment was removed from each of three gut sections: duodenum, jejunum and ileum. To obtain the segments, two cross-sectional cuts were made 3 cm apart. Segments were then severed longitudinally and rinsed with distilled water. Segments from the duodenum were removed 10 cm distal to the attachment of the common bile duct to the duodenum. Jejunal and ileal segments were removed 3 m and 10 cm proximal to the cecum, respectively. Gut segments were then frozen and stored for subsequent mineral analyses. Gut segments were washed of all adhering digesta, blotted dry, weighed and ashed in a muffle furnace at 600 C for 4 hours. Ca and P concentrations of the segments were analyzed by methods cited previously.

Data on performance and blood constituents in the rat trial were analyzed by least-squares analysis as outlined by Harvey (1960). All other data were analyzed by analysis of variance methods described by Barr and Goodnight (1972) and Steel and Torrie (1960).

TABLE 3. FORMULAS FOR ESTIMATING CERTAIN PHYSICAL CHARACTERISTICS AND BREAKING STRENGTH OF BONES. RAT AND PIG TRIALS

| Item | |
|---|---|
| Cross-sectional area, cm² | $= (\frac{\text{diameter}}{2})^2 \cdot \pi$ |
| Peak force, kg | |
| Stress, kg/cm² | $= \frac{\text{Peak force}}{\text{cross-sectional area}}$ |
| Stress:strain, kg/cm²/mm[a] | $= \frac{\text{stress}}{\text{deformation, mm}}$ |

[a]Bone deformation due to applied force.

## Results and Discussion

### *Rat Trial*

Gain, feed consumption and feed efficiency of the rats are shown in table 4. No significant differences in average daily gain or average daily feed intake were observed among treatments. There was a trend for poorer growth rate as lactose increased in the diet (treatments 4, 5 and 6). Rats fed diet 2 (containing 15% cornstarch) had the lowest average gain and feed intake, largely because of an extremely poor performance by one rat. Feed to gain ratio increased ($P<.01$) as dietary lactose increased in the diets. Feed efficiency was similar for rats fed up to 20% dietary lactose and rats fed the corn-soybean meal control; rats fed 30% lactose had the poorest feed efficiency.

During the first week, growth rate was 29% slower in rats fed 30% lactose (treatment 6)

[4]Perkin-Elmer Model 303 Atomic Absorption Spectrophotometry, Perkin-Elmer Co., Norwalk, CT.
[5]Model TM 1123, Instron Corp., Canton, MA.

TABLE 4. EFFECT OF DIETARY LEVELS OF CORNSTARCH AND LACTOSE ON PERFORMANCE[a], BLOOD[b] AND BONE PARAMETERS[c] OF GROWING RATS

| Item | Treatment: Control 1 | 15% Starch 2 | 30% Starch 0% Lactose 3 | 20% Starch 10% Lactose 4 | 10% Starch 20% Lactose 5 | 0% Starch 30% Lactose 6 |
|---|---|---|---|---|---|---|
| No. of animals | 10 | 10 | 10 | 10 | 10 | 10 |
| Performance | | | | | | |
| ADG, g | 5.09 | 4.74 | 5.09 | 5.14 | 4.96 | 4.80 |
| ADFI, g | 16.42 | 15.33 | 15.74 | 16.02 | 16.07 | 16.27 |
| F:G[d] | 3.30 | 3.28 | 3.17 | 3.22 | 3.31 | 3.50 |
| Blood | | | | | | |
| Ca, mg/100 ml | 16.82 | 15.64 | 17.01 | 17.70 | 16.08 | 16.64 |
| P, mg/100 ml | 9.76 | 9.71 | 9.93 | 9.28 | 9.75 | 9.32 |
| Alkaline phosphatase, IU/ml[d] | .082 | .079 | .077 | .077 | .091 | .120 |
| Bone | | | | | | |
| Peak force, kg[e] | 3.94 | 4.28 | 4.52 | 4.47 | 4.62 | 4.23 |
| Stress, $kg/cm^2$ [e] | 50.9 | 59.1 | 59.1 | 58.4 | 61.7 | 56.9 |
| Stress:strain, $kg/cm^2/mm$[f] | 406 | 439 | 500 | 329 | 434 | 373 |
| Bone ash, %[degh] | 64.73 | 65.24 | 64.50 | 65.89 | 65.53 | 65.85 |

[a]Initial weight, 54 g; 28-day test period; started 1 week after weaning.

[b]Blood sampled at termination of test period.

[c]Average for both femurs/rat; moisture-free bones; ash expressed as a percentage of dry weight.

[d]Linear effect of lactose (P<.01).

[e]Linear effect of starch (P<.10).

[f]Cubic effect of lactose (P<.05).

[g]Quadratic effect of lactose (P<.05).

[h]Cubic effect of lactose (P<.10).

than in rats fed the control diet. Rats assigned to treatments 2, 3, 4 and 5 showed a response similar to that of those fed the control diet. All rats fed 30% lactose exhibited marked diarrhea, enlarged abdomens and rough hair coats, while rats fed other diets containing lactose showed none of these symptoms. After 1 week, rats fed 30% lactose performed as well as rats fed other diets; as a result, there were no significant differences in overall gain between treatments. Also, no signs of diarrhea or other symptoms of lactose feeding were observed throughout the remainder of the trial.

The effects of dietary levels of cornstarch and lactose on serum Ca, P and alkaline phosphatase are summarized in table 4. No significant differences were observed among treatment means for serum Ca and P, but serum alkaline phosphatase increased linearly (P<.01) as lactose increased in the diets, with the greatest increase (32%) observed between treatments 5 and 6.

The effects of levels of lactose and cornstarch on bone strength parameters and percentage of ash are summarized in table 4. Peak force and stress increased linearly (P<.10) with increasing levels of cornstarch. No significant differences in either peak force or stress were observed among lactose treatments. Stress to strain ratios of femurs varied from treatment to treatment, with higher (P<.05) ratios obtained for bones from rats fed treatments 3 and 5 than for bones from rats fed treatments 4 and 6. Percentage of bone ash decreased (P<.10) as dietary cornstarch increased. In contrast, percentage ash increased as lactose increased (linear effect P<.01; quadratic P<.05). Overall, the percentage ash of femurs from rats fed lactose and of those from rats not fed lactose were 65.8 and 64.8%, respectively.

*Pig Trial*

The effects of lactose level on gain, feed intake and feed conversion are presented in table 5. Ca and P level had no effect on performance; therefore only comparisons of pigs fed lactose *versus* no lactose are shown. Average daily gain was not affected by level of lactose. Pigs fed lactose consumed more (P<.01) feed and had poorer (P<.01) feed conversion than pigs fed no lactose.

The effect of lactose and Ca and P levels on changes in serum Ca concentrations at three bleeding periods are summarized in table 6. No significant differences in change of serum Ca were observed among treatments during the first 2-week period. Dietary P level affected (P<.05) changes in serum Ca during the 2- to 10-week period, with serum levels decreasing in pigs fed .4% P but increasing in pigs fed .6% P. The change in serum Ca concentration for the total test period (0 to 10 weeks) was affected (P<.05) by dietary lactose level. Serum Ca of pigs fed no lactose was drastically reduced while that of pigs fed lactose increased slightly. Also there was a significant (P<.05) lactose level × Ca level interaction on serum Ca change for the total test period, with serum Ca decreasing in the absence of lactose but increasing in the presence of lactose in pigs fed .4% dietary Ca. Pigs fed .6% Ca responded in the same manner (with respect to serum Ca) when fed either level of lactose.

The effects of dietary treatment on changes in serum P concentration are shown in table 7. Serum P decreased with time across all treatments. During the 2- to 10-week bleeding period, the decrease (−1.31) was more dramatic (P<.05) in pigs fed lactose than in pigs fed no lactose (−.62).

The effects of lactose and Ca and P levels on change in serum alkaline phosphatase activity at three bleeding periods are shown in table 8. Lactose affected the change in alkaline phosphatase activity from 0 to 2 weeks (P<.01) as revealed by a sharp increase (+.022) in activity in pigs fed lactose compared to a slight decline (−.007) in pigs fed no lactose. During the second bleeding period (2 to 10 weeks), alkaline phosphatase activity decreased in all pigs. However, the decrease (−.049) was greater (P<.01) in pigs fed lactose than in pigs fed no

TABLE 5. EFFECT OF LEVEL OF LACTOSE ON GAIN, FEED INTAKE AND FEED CONVERSION OF GROWING-FINISHING SWINE[a]

| Item | Lactose, % | |
|---|---|---|
| | 0[b] | 30 |
| Avg daily gain, kg | .78 | .79 |
| Avg daily feed intake, kg[c] | 2.11 | 2.32 |
| Feed to gain ratio[c] | 2.66 | 2.94 |

[a]Initial weight, 31 kg; 70-day test.

[b]Control diets contained 30% cornstarch.

[c]Treatment effect (P<.01).

TABLE 6. EFFECT OF LEVEL OF LACTOSE AND CA AND P LEVELS AND RATIOS ON CHANGES IN SERUM CA OF GROWING-FINISHING SWINE[a]

| Dietary level of lactose, % | Dietary level of Ca and P, % | Serum Ca change (mg/dl) by period (weeks) | | |
|---|---|---|---|---|
| | | 0 to 2 | 2 to 10[b] | 0 to 10[cd] |
| 0 | .4, .4 | −1.03 | −.10 | −1.13 |
| | .4, .6 | −1.11 | +.16 | − .95 |
| | .6, .4 | + .46 | −.51 | − .05 |
| | .6, .6 | −1.14 | +.72 | − .42 |
| 30 | .4, .4 | +1.04 | −.37 | + .67 |
| | .4, .6 | − .87 | +.99 | + .13 |
| | .6, .4 | + .30 | −.52 | − .21 |
| | .6, .6 | − .48 | +.29 | − .19 |

[a](−) denotes decrease (+) denotes increase.

[b]Treatment effect of P level (P<.05).

[c]Treatment effect of lactose level (P<.05).

[d]Lactose level × Ca level interaction (P<.05).

lactose (−.026). Change of alkaline phosphatase activity for the total test period (0 to 10 weeks) was not affected by lactose level.

Dietary Ca levels affected alkaline phosphatase activity during the 0- to 2-week period; activity in pigs fed either of the Ca levels was increased, but pigs fed .4% Ca showed a greater (P<.05) increase in activity than those fed .6% Ca. Dietary P level also affected (P<.01) alkaline phosphatase activity during the 0- to 2-week period; activity rose (+.15) in pigs fed .6% P but did not change in pigs fed .4% P. Dietary Ca and P levels had no effect on the overall change in alkaline phosphatase activity from 0 to 10 weeks.

The effects of lactose and Ca and P levels on peak force, stress and stress to strain ratios of bones are summarized in table 9. No significant treatment × bone interactions were observed for any of the parameters determined. Therefore, femurs, and third and fourth metatarsals were pooled across all treatments for comparisons. No significant differences were observed across all treatments for peak force or stress, but bones from pigs fed .6% Ca had a greater peak force and stress than those from pigs fed .4% Ca. Pigs fed no lactose had higher (P<.05) stress to strain ratios than pigs fed

TABLE 7. EFFECT OF LEVEL OF LACTOSE AND CA AND P LEVELS AND RATIOS ON CHANGES IN SERUM P OF GROWING-FINISHING SWINE[a]

| Dietary level of lactose, % | Dietary level of Ca and P, % | Serum P change (mg/dl) by period (weeks) | | |
|---|---|---|---|---|
| | | 0 to 2 | 2 to 10[b] | 0 to 10 |
| 0 | .4, .4 | −1.98 | − .36 | −2.34 |
| | .4, .6 | −1.07 | − .77 | −1.85 |
| | .6, .4 | − .73 | − .49 | −1.21 |
| | .6, .6 | − .94 | − .66 | −1.60 |
| 30 | .4, .4 | − .58 | − .52 | −1.10 |
| | .4, .6 | − .06 | −1.78 | −1.84 |
| | .6, .4 | − .94 | − .61 | −1.55 |
| | .6, .6 | − .30 | −1.51 | −1.80 |

[a](−) denotes decrease (+) denotes increase.

[b]Treatment effect of lactose level (P<.05).

TABLE 8. EFFECT OF LEVEL OF LACTOSE AND CA AND P LEVELS AND RATIOS ON CHANGES IN SERUM ALKALINE PHOSPHATASE OF GROWING-FINISHING SWINE[a]

| Dietary level of lactose, % | Dietary level of Ca and P, % | Serum alkaline phosphatase Change (IU/ml) by period (weeks) | | |
|---|---|---|---|---|
| | | 0 to 2[bcdef] | 2 to 10[bcgh] | 0 to 10[i] |
| 0 | .4, .4 | −.021 | −.021 | −.042 |
| | .4, .6 | +.002 | −.032 | −.031 |
| | .6, .4 | −.004 | −.026 | −.030 |
| | .6, .6 | −.011 | −.023 | −.034 |
| 30 | .4, .4 | +.005 | −.048 | −.043 |
| | .4, .6 | +.028 | −.049 | −.021 |
| | .6, .4 | +.018 | −.055 | −.037 |
| | .6, .6 | +.025 | −.048 | −.023 |

[a](−) denotes decrease (+) denotes increase.

[b]Treatment effect of lactose level (P<.01).

[c]Treatment effect of Ca level (P<.05).

[d]Treatment effect of P level (P<.01).

[e]Ca level × P level interaction (P<.01).

[f]Lactose × Ca × P interaction (P<.05).

[g]Treatment effect of P level (P<.05).

[h]Lactose × Ca × P interaction (P<.10).

[i]Ca × P interaction (P<.05).

lactose. Levels of dietary Ca and P had no effect on stress to strain ratio.

No significant differences were observed for percentage of Ca, P and ash in an average of three gut segments (from the duodenum, jejunum and ileum) across all treatments (table 10). When the mineral content of specific gut segments from all treatments was compared (tabel 11), percentage of Ca was found to be lower (P<.10) and phosphorus and ash percentages greater (P<.01) in the ileum as compared to the average of duodenum and jejunum. When

TABLE 9. EFFECT OF LEVEL OF LACTOSE AND CA AND P LEVELS AND RATIOS ON BONE STRENGTH PARAMETERS OF GROWING-FINISHING SWINE[a]

| Dietary level of lactose, % | Dietary level of Ca and P, % | Bone strength parameters | | |
|---|---|---|---|---|
| | | Peak force, kg | Stress, $kg/cm^2$ | Stress:strain $kg/cm^2/mm$[b] |
| 0 | .4, .4 | 208 | 74.2 | 24.3 |
| | .4, .6 | 204 | 74.2 | 25.7 |
| | .6, .4 | 214 | 74.9 | 26.1 |
| | .6, .6 | 218 | 77.3 | 26.4 |
| 30 | .4, .4 | 213 | 68.1 | 21.8 |
| | .4, .6 | 194 | 71.6 | 24.4 |
| | .6, .4 | 210 | 71.6 | 23.8 |
| | .6, .6 | 216 | 76.2 | 26.7 |

[a]Average of fresh femur and third and fourth metatarsal from one side.

[b]Treatment effect of lactose (P<.05).

TABLE 10. EFFECT OF LEVEL OF LACTOSE AND CA AND P LEVELS AND RATIOS ON MINERAL CONTENT OF GUT SEGMENTS[a] AND ILEAL SEGMENTS[b] ONLY OF GROWING-FINISHING SWINE

| | | Mineral content | | | | | |
|---|---|---|---|---|---|---|---|
| | | Gut segments, %[ac] | | | Ileal segment, %[bc] | | |
| Dietary level of lactose, % | Dietary level of Ca and P, % | Ca | P | Ash | Ca | P | Ash |
| 0 | .4, .4 | .066 | .968 | 7.51 | .057 | 1.070 | 7.33 |
| | .4, .6 | .068 | .967 | 7.82 | .054 | 1.055 | 7.93 |
| | .6, .4 | .055 | .938 | 6.89 | .051 | .970 | 8.09 |
| | .6, .6 | .057 | .930 | 7.24 | .054 | .975 | 7.67 |
| 30 | .4, .4 | .070 | 9.56 | 7.77 | .060 | .973 | 8.17 |
| | .4, .6 | .056 | 1.007 | 7.17 | .052 | 1.104 | 7.96 |
| | .6, .4 | .071 | .962 | 7.71 | .066 | 1.048 | 7.89 |
| | .6, .6 | .074 | .995 | 6.92 | .046 | 1.111 | 8.05 |

[a]Average of three 3-cm segments; one each from duodenum, jejunum and ileum.

[b]Segment taken 10 cm distal to cecum.

[c]Percentage of dry weight.

compared alone, the duodenum was found to have a lower (P<.01) percentage of phosphorus than the ileum.

*Discussion*

Postweaning rats and swine were able to tolerate lactose at levels up to 30% of the diet without suffering detrimental effects on growth rate, a finding similar to those of Riggs and Beaty (1947) for rats and Ekstrom *et al.* (1975b) for swine. The 29% reduction in gain noted during the first week among rats fed 30% lactose was sufficiently compensated for in subsequent weeks so that no differences among treatments were observed in total gain. However, feed utilization in both rats and swine fed lactose was reduced compared to that in pigs and rats fed no lactose. Among swine, the poor feed conversion was attributed to a greater feed intake by pigs fed lactose. The transitory diarrhea and enlarged abdomens observed during the first week of the feeding period among rats fed 30% lactose were also observed by Riggs and Beaty (1947). In relation to these findings, Fischer (1957a) reported that an increase in size of the cecum, colon and rectum of rats fed 25% lactose was due to the large fraction of lactose that escaped hydrolysis and underwent fermentation in the intestine. After 1 week, incidence of diarrhea and other symptoms induced by the feeding of lactose decreased (Fischer, 1957b), suggesting that the rats had adapted to the 30% lactose diets. Adaptation may have resulted from dietary lactose causing an increase in lactase activity, as reported by Bolin *et al.* (1969). However, Leichter (1973) reported that intestinal lactase cannot be regulated by administration of dietary lactose. No symptoms of diarrhea were observed in pigs fed lactose, supporting the postulation of Atkinson *et al.* (1957) that pigs can tolerate lactose better than rats.

TABLE 11. EFFECT OF LEVEL OF LACTOSE AND CA AND P LEVELS AND RATIOS ON MINERAL CONTENT OF SAMPLES FROM SPECIFIC GUT SEGMENTS OF GROWING-FINISHING SWINE

| | Gut segment[a] | | |
|---|---|---|---|
| Item | Duodenum | Jejunum | Ileum |
| Ca, %[b] | .067 | .072 | .055 |
| P, %[cd] | .931 | .935 | 1.038 |
| Ash, %[c] | 7.81 | 6.34 | 7.84 |

[a]Percentage of dry weight.

[b]Gut response duodenum, jejunum *versus* ileum (P<.01).

[c]Gut response duodenum, jejunum *versus* ileum (P<.10).

[d]Gut response duodenum *versus* ileum (P<.01).

The lactose × Ca interaction observed in the pig trial suggests that pigs fed low Ca diets (.4%) may benefit from the addition of lactose

to the diet, as indicated by the increased serum Ca concentration.

The effect of lactose on alkaline phosphatase activity was similar in rats and swine. Alkaline phosphatase activity increased as lactose increased in the diets fed to rats, and it increased dramatically during the first 2 weeks in pigs fed lactose. This was in contrast to a gradual decrease in activity in pigs fed no lactose. This observation is similar to the findings of Liptrap *et al.* (1970). Because an increase in serum alkaline phosphatase activity is an indication of improper bone formation and because increased alkaline phosphatase activity would be expected only when dietary Ca levels were low (Hurwitz and Griminger, 1961; Miller *et al.*, 1962), our results suggest that improper calcification was taking place. The rise in serum alkaline phosphatase was not compatible with the theory that lactose enhances Ca absorption in the gut. However, the increase in serum Ca that was observed when .4% Ca was fed to pigs in the presence of lactose supports the theory. The enhancing effect of lactose on serum alkaline phosphatase was not observed after 2 weeks, suggesting that the abnormal effects of lactose on Ca metabolism were corrected during the 2- to 10-week period. The effect of dietary Ca and P on alkaline phosphatase activity was inconsistent.

The effect of lactose on bone-breaking strength was variable across all treatments. Since the change in alkaline phosphatase activity from 0 to 10 weeks in pigs fed lactose was no different from the change in activity in pigs fed no lactose (table 8), proper bone calcification may have been taking place for all pigs at the time of slaughter.

In the rat trial, percentage ash increased with increasing dietary lactose, a finding similar to that reported by Outhouse *et al.* (1937) and one which suggests a favorable effect of lactose on bone ash in rats. Alkaline phosphatase activities did not correspond with the bone ash results.

Mineral content of specific gut segments was analyzed to provide an indication of the effect of lactose on Ca and P absorption. Dietary treatment did not affect mineral content of the gut. Ca levels were low in all gut segments. The duodenum and ileum contained a higher percentage of ash than jejunum, suggesting that mineral absorption may be higher in these gut sections.

## Literature Cited


Armbrecht, H. J. and R. H. Wasserman. 1976. Enhancement of $Ca^{++}$ uptake by lactose in the rat small intestine. J. Nutr. 106:1265.

Atkinson, R. L., F. H. Kratzer and G. F. Stewart. 1957. Lactose in animal and human feeding: A review. J. Dairy Sci. 40:1114.

Barr, A. J. and J. H. Goodnight. 1972. A user's guide to the statistical analysis system (SAS). North Carolina State Univ., Raleigh.

Becker, D. E., S. W. Terrill, A. H. Jensen and L. J. Hanson. 1957. High levels of dried whey powder in the diet of swine. J. Anim. Sci. 16:404.

Bolin, T. D., R. C. Pirola and A. E. Davis. 1969. Adaptation of intestinal lactose in the rat. Gastroenterology 57:406.

Ekstrom, K. E., N. J. Benevenga and R. H. Grummer. 1975a. Changes in the intestinal lactase activity in the small intestine of two breeds of swine from birth to 6 weeks of age. J. Nutr. 105:1032.

Ekstrom, K. E., N. J. Benevenga and R. H. Grummer. 1975b. Effects of various dietary levels of dried whey on the performance of growing pigs. J. Nutr. 105:846.

Entringer, R. P., M. P. Plumlee, J. H. Conrad, T. R. Cline and S. Wolfe. 1975. Influence of diet on passage rate and apparent digestibility by growing swine. J. Anim. Sci. 40:486.

Fischer, J. E. 1957a. Effects of feeding a diet containing lactose upon D-galactosidase activity and organ development in the rat digestive tract. Amer. J. Physiol. 188:49.

Fischer, J. E. 1957b. Effects of feeding diets containing lactose, agar, cellulose, raw potatoe starch, or arabinose on the dry weights of cleaned gastrointestional tract organs in the rat. Amer. J. Physiol. 188:550.

Goldenberg, H. and A. Fernandez. 1966. Simplified method for the estimation of inorganic phosphorus in body fluids. Clin. Chem. 12:871.

Harvey, W. R. 1960. Least-squares analysis of data with unequal subclass numbers. USDA, ARS 20–8.

Hurwitz, S. and P. Griminger. 1961. The response of plasma alkaline phosphatase, parathyroids and blood and bone minerals to calcium intake in the fowl. J. Nutr. 73:177.

Kline, O. L., J. A. Keenan, C. A. Elvehjem and E. B. Hart. 1932. Lactose in nutrition. J. Biol. Chem. 98:121.

Kobayashi, A., S. Kawai, Y. Ohbe and Y. Nagashima. 1975. Effects of dietary lactose and a lactase preparation on the intestinal absorption of calcium and magnesium in normal infants. Amer. J. Clin. Nutr. 28:681.

Leichter, J. 1973. Effect of dietary lactose on intestinal lactase activity in young rats. J. Nutr. 103:392.

Lengemann, F. W., R. H. Wasserman and C. L. Comar. 1959. Studies on the enhancement of radiocalcium and radiostrontium absorption by lactose in the rat. J. Nutr. 68:443.

Liptrap, D. O., E. R. Miller, D. E. Ullrey, K. K. Keahey and J. A. Hoefer. 1970. Calcium levels for developing boars and gilts. J. Anim. Sci. 31:540.

Miller, E. R., D. E. Ullrey, C. L. Zutant, B. V. Baltzer, D. A. Schmidt, J. A. Hoefer and R. W. Luecke,

1962. Calcium requirement of the baby pig. J. Nutr. 77:7.

Outhouse, J., J. Smith, L. Merritt and F. R. White. 1937. A comparative study of the growth promoting and bone calcifying effects of several carbohydrates. J. Nutr. 14:579.

Riggs, L. K. and A. Beaty. 1947. Some unique properties of lactose as a dietary carbohydrate. J. Dairy Sci. 30:939.

Robinson, C. S., C. F. Huffman and M. F. Mason. 1929. The results of the ingestion of certain calcium salts and of lactose. J. Biol. Chem. 84:257.

Sewell, R. F. and J. P. West. 1965. Some effects of lactose on protein utilization in the baby pig. J. Anim. Sci. 24:239.

Sigma Chemical Co. 1974. The colorimetric determination of phosphatase. Tech. Bull. No. 104 (Revised Ed.), St. Louis, MO.

Simoons, F. J. 1969. Primary adult lactose intolerance and the milking habit: A problem in biological and cultural interrelations. I. Review of medical research. Amer. J. Dig. Dis. 14:819.

Steel, R.D.G. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York.