# INCREASING VALINE, ISOLEUCINE, AND TOTAL BRANCHED CHAIN AMINO ACIDS FOR THE LACTATING SOW[1]

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## Summary

One hundred eighty-five sows were used to evaluate effects of the interrelationship between isoleucine and valine on sow and litter performance. Litter weight and weight gain at weaning increased as dietary valine, isoleucine, and total branched chain amino acids increased. Increasing dietary valine increased concentrations of milk DM and fat. Milk DM, CP, and fat increased as dietary isoleucine increased. Both valine and isoleucine increased litter weights. The independent increases in litter weaning weights from adding valine and isoleucine suggest separate modes of action in the lactating sow.

(Key Words: Valine, Isoleucine, Lactation, Sows.)

## Introduction

The increasing productivity of the lactating sow is creating a need to review nutrient requirements for maximizing litter and sow performance. Until recently, branched chain amino acids received little attention in swine nutrition research. Research using mammary vein cannulation in sows and dairy cows has indicated that isoleucine and valine are taken up by the mammary gland in amounts 30 to 80% greater than their output in milk protein. These high extraction rates would result in requirements for these amino acids greater than the sum of milk amino acid output and the sow's maintenance requirement, which has been one of the methods used to estimate amino acid requirements of lactating sows. No research has evaluated the ability of the individual branched chain amino acids to spare each other in meeting the needs of the mammary gland for milk synthesis. Because the dietary requirement for total branched chain amino acids (TBCAA) has implications in practical diet formulation, the objectives of this experiment were to evaluate the effects of increasing valine at deficient isoleucine (.50%), increasing isoleucine at deficient (.72%) and adequate valine (1.07%), and increasing TBCAA in the diet as supplied by supplemental isoleucine and(or) valine on sow lactation performance, milk composition, and litter growth performance.

## Procedures

Animals. One hundred eighty-five parity 1 (130) and parity 2 (55) sows from the Kansas State University Swine Teaching and Research farm were used in this experiment. All sows were maternal line (PIC Line C-15) bred to terminal line (PIC Line 326) boars. During gestation, sows were housed in outside dirt lots and fed in individual stalls. Gestating sows were fed 4 to 5 lb/d depending on body condition. The gestation diet was sorghum-soybean meal based formulated to .65% lysine, .90% Ca, and .80% P. On d 110 of gestation, all sows were fed 5 lb/d of the control diet (.50% isoleucine, .72% valine) until farrowing, at which time sows were allotted to one of the seven dietary treatments. Treatments were allotted randomly within groups of seven as sows farrowed to minimize variation in lactation

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length between treatments. Sows farrowed from November, 1994 through June, 1995. Three or four observations were made per treatment per lactation group, and seven lactation groups (blocks) were used. Litter size was equalized by 24 h after farrowing, and all sows began the study with at least 10 pigs.

Diet Formulation. The lactation diets (Table 1) were formulated to be in excess (at least 110% relative to lysine) of all amino acid requirement estimates based on ratios relative to lysine derived from NRC (1988) and ARC (1981), except for isoleucine and valine. All other nutrients were in excess of NRC (1988) requirement estimates. Diets were formulated to .90% lysine, .90% Ca, and .80% P. The control diet contained .50% isoleucine and .72% valine. Crystalline L-isoleucine and L-valine replaced cornstarch in the control diet at .35% increments to create the remaining six diets. The treatments included three levels of valine (.72, 1.07%, or 1.42%) and three levels of isoleucine (.50, .85, and 1.20%). The low and intermediate levels of valine were combined with all three levels of isoleucine, but the highest level of valine was combined only with the low level of isoleucine. This combination of treatments provided TBCAA levels of 2.6, 2.9, 3.3, and 3.6%.

Milk Criteria. Twelve sows per treatment (84 total) were milked manually on either d 17 or 18 of lactation. Sows were separated from their litters for a minimum of 45 min before milking. All sows were milked approximately 2 h after the initial morning feeding. Sows were restrained, and milk was collected from the first and last productive glands on both sides of the body. Each gland was milked until approximately 75 mL of milk was collected. Milk letdown was enhanced by infusing 10 IU of oxytocin into an ear vein of the sow. Samples from each gland were pooled for chemical analysis and stored at 2 to 4°C. All analyses were conducted within 48 h after collection.

Statistical Analysis. The GLM procedure of SAS was used to determine treatment effects. Litter size after cross-fostering was used as a covariate and lactation group as a blocking factor for all response criteria. Days of lactation was used as a covariate for litter weaning weights, litter weight gain, and sow backfat and BW changes from d 0 to weaning and for days to estrus. Initial sow weight and backfat thickness also were used as covariates for changes in these characteristics. Chi-square analysis was used to determine differences in distribution of days to estrus and percentage of sows returning to estrus. Preplanned nonorthogonal contrasts were used to test the effects of valine, isoleucine, and TBCAA. Contrasts were: main effects of valine, isoleucine and their interaction; linear and quadratic effects of increasing valine at deficient isoleucine; linear and quadratic effects of TBCAA; and valine vs isoleucine within a TBCAA level. Additional comparisons of linear and quadratic effects of increasing isoleucine at deficient and adequate valine were conducted to aid in evaluation of the isoleucine response.

**Table 1. Diet Composition**[a]

| Ingredient | Percent |
|---|---|
| Corn | 55.085 |
| Hard red winter wheat | 26.635 |
| Soybean meal, (47% CP) | 7.475 |
| Spray-dried blood meal | 1.428 |
| Soybean oil | 3.000 |
| Monocalcium phosphate | 2.354 |
| Limestone | 1.052 |
| Salt | .500 |
| Corn starch[b] | 1.050 |
| Sow add pack | .250 |
| Vitamin premix | .250 |
| Trace mineral premix | .150 |
| L-lysine-HCl | .383 |
| L-threonine | .220 |
| DL-methionine | .113 |
| L-tryptophan | .055 |
| Total | 100.0 |

[a]Basal diet was formulated to 13.6% CP, .90% lysine, .72% valine, .50% isoleucine, 1.35% leucine, .90% Ca, and .80% P.
[b]Corn starch was replaced in .35% increments with L-valine or L-isoleucine or both to provide the remaining six experimental diets.

## Results

Valine. Dietary valine had no effect on number of pigs weaned ($\bar{x}$ = 10.9; Table 2) or survival rate after cross-fostering ($\bar{x}$ = 98.1%, data not shown). Increasing dietary valine from 44.7 to 64.7 g/d (.72 to 1.07%; Table 3), regardless of isoleucine level, increased litter weights and weight gains at d 14 and weaning ($P<.08$ and $P<.07$, respectively). Sow ADFI ($P<.08$) and lysine ($P<.08$) and isoleucine ($P<.05$) intakes were reduced when sows were fed 1.07% dietary valine compared to .72% valine (Table 3). Sow BW loss ($P<.02$) and backfat loss ($P<.0001$) increased with increasing valine from .72 to 1.07% across all three isoleucine levels. Increasing valine to 1.07% in the diet increased days to estrus by .5 d (Table 3; $P<.07$).

Increasing valine from .72 to 1.42% at .50% isoleucine (Table 2) tended to increase litter weights at d 14 and weaning (linear; $P<.10$ and .15, respectively) and increased litter weight gains at d 7 and 14 and weaning (linear; $P<.06$, .04, and .08, respectively). Sow ADFI and lysine and isoleucine intakes tended to decrease and then increase (quadratic; $P<.15$) as dietary valine was increased (Table 3) in diets containing .50% isoleucine. Valine intake increased (44.9, 64.2, and 87.9 g/d; linear, $P<.0001$) as dietary valine increased. As dietary valine increased from .72 to 1.42%, sow backfat loss increased (linear, $P<.04$; quadratic, $P<.13$); however, dietary valine had no effect on sow BW change or days to estrus ($P>.21$).

Isoleucine. Dietary isoleucine had no effect on number of pigs weaned or survival rate. Increasing isoleucine across valine levels resulted in increased litter weights (linear, $P<.07$) and weight gains (linear, $P<.06$) at d 7 and 14 and weaning (Table 2). Litter weaning weight increased (linear, $P<.06$) as isoleucine increased to 1.20% in the diet; however, the greatest increase (84% of the incremental gain) was observed at .85% dietary isoleucine. Increasing dietary isoleucine increased sow BW loss (Table 4; linear, $P<.01$) and tended (linear, $P<.14$) to increase sow backfat loss. Dietary isoleucine had no effect on sow feed intake ($P>.77$), but isoleucine intake (g/d) increased (linear, $P<.0001$) as isoleucine increased in the diet.

Total Branched Chain Amino Acids. Total branched chain amino acids increased litter weights and weight gains (Table 2) at d 7 and 14 and weaning (linear; $P<.07$, .03, and .02, respectively). The level of TBCAA in the diet did not affect ADFI ($P>.20$). However, TBCAA intakes increased (linear, $P<.0001$) and isoleucine and valine intakes increased (quadratic, $P<.0001$) as dietary TBCAA increased in the diet (Table 3). Increasing TBCAA in the diet resulted in increased sow BW and backfat losses (linear, $P<.001$).

Milk Composition. Milk composition was affected by dietary isoleucine, valine, and TBCAA levels (Table 4). The only milk criterion to be increased by increasing valine across isoleucine levels (Table 4) was the other N fraction ($P<.07$), which includes all other N besides whey and casein proteins (i.e., urea N, sloughed cellular N, and free amino acids). Increasing isoleucine across valine levels of .72 and 1.07% increased milk DM, CP, fat, and casein (linear, $P<.01$) and decreased whey (linear, $P<.06$) and other N fractions (linear, $P<.01$).

Increasing dietary valine from .72 to 1.42% at .50% isoleucine resulted in increased milk DM (linear, $P<.004$; quadratic, $P<.01$); lipid (linear, $P<.01$); and other N (quadratic, $P<.06$) and decreased lactose (linear, $P<.10$). Increasing isoleucine at either .72 or 1.07% valine increased milk DM (linear, $P<.05$), CP (linear, $P<.09$), and lipid (linear, $P<.04$). In addition, increasing dietary TBCAA increased milk DM (linear, $P<.002$), lipid (linear, $P<.005$), and casein protein fractions (linear, $P<.08$) and decreased the whey fraction (linear, $P<.10$).

## Discussion

Increasing dietary valine from .72 to 1.07% across isoleucine levels resulted in a

4 lb increase in litter weight gain with no interaction between valine and isoleucine levels. This suggests that the responses to valine and isoleucine for litter weaning weight are independent. In addition, litter weaning weight increased linearly up to 1.42% dietary valine (84 g/d).

Summarizing the results of this and previous experiments using high-producing sows on a g/d basis indicates a valine requirement between 70 and 80 g/d, which is double the requirement estimate (37 g/d) for lower-producing sows.

Previous research has suggested a total isoleucine requirement for the lactating sow of .39% (71% of lysine), with sows that were nursing nine pigs and had pig weight gains from d 7 to 21 of 5.25 lb. In comparison, in our experiment, an average of 10.9 pigs were weaned, and pig weight gain was 7.2 lb from d 7 to 20 of lactation for sows fed the .85% isoleucine and 1.07% valine diet. This corresponds to an isoleucine requirement of 94% of lysine, approximately .2% greater than the requirement estimated for the lactating sow by NRC (1988) and ARC (1981).

The data also suggest that a TBCAA requirement exists for the lactating sow. However, only isoleucine and valine were evaluated in this experiment, and leucine will need to be evaluated in future research. Litter weaning weight increased (linear, $P<.02$) through 3.6% TBCAA. However, the litter weaning weight at that level was matched at 3.3% dietary TBCAA, when the 3.3% level was provided by balanced levels of isoleucine (.85%), valine (1.07%), and leucine (1.35%) as compared to high levels of isoleucine or valine alone. This balanced combination of TBCAA provided numerically greater ($P<.16$) litter and pig growth performance than the other diets containing 3.3% TBCAA. Therefore, the TBCAA requirement is at least 3.3% (203 g/d) in the lactating sow diet when a balance of the branched chain amino acids are fed and is higher when an imbalanced branched chain amino acid profile is fed. Future research will need to delineate the possibilities of higher TBCAA inclusion levels and the role leucine has in milk production for sows with the genetic capacity for high milk production.

The lower percentage (74.3 vs 96.3%) of sows returning to estrus when fed higher levels of isoleucine (.85 and 1.20%) at the deficient valine level compared to the higher isoleucine levels at the intermediate valine level is difficult to explain. This response suggests that an altered hormonal or metabolite balance might occur when diets deficient in valine and high in isoleucine are fed. This may be indicative of an amino acid imbalance between the branched chain amino acids. An alternative explanation may be a chance occurrence because of the relatively low number of sows (24 to 28 per treatment) used for reproductive data.

Valine increased milk fat and DM concentrations, with minimal effect on total milk protein concentration and without altering the relative distribution of protein fractions. However, isoleucine increased milk DM, CP, and fat. Isoleucine also consistently increased the casein fraction of the milk protein and decreased the whey fractions. However, when the total whey excreted in the milk was calculated by multiplying the whey fraction percentage and the CP percentage together, very little difference existed between treatments in total whey output. This indicates that the whey proteins truly aren't affected by the isoleucine and(or) valine levels in the diet.

Increasing dietary valine or isoleucine also increased percentage fat in milk samples. However, increasing milk fat concentration alone does not always result in increased pig growth. Higher milk fat provides greater energy for the pig's growth, but this may be at the expense of other important nutrients or volume of milk produced.

The relative increase in the casein fraction and corresponding reduction in the whey fraction of the milk protein have not been reported before as a result of changing dietary amino acids. Because casein has a greater concentration of lysine as a percentage of protein than whey (8.1 vs 7.1%), milk with more casein may provide greater amounts of the first limiting amino acid for growth (lysine), improving the milk's biological value for the pig. The increase in milk fat along with the alterations in ratios of casein and whey proteins by the high isoleucine treatments gave the milk much greater nutritional value and was likely one of the reasons for the increased pig growth observed for the increasing isoleucine levels. Valine did not alter the milk protein fractions, and so the possibility remains that increased dietary valine (and isoleucine) may have increased total milk volume output by the sow; however, this was not measured in our experiment.

In conclusion, the isoleucine requirement of the high-producing lactating sow may be higher than current NRC and ARC estimates but does not appear to be greater than 94% of lysine. The independent increases in litter weaning weights and changes in milk composition from added valine and isoleucine suggest separate modes of action for these animo acids in milk synthesis. The importance of valine and isoleucine for milk production must be considered when formulating diets for lactating sows.

**Table 2. The Effects of Valine and Isoleucine on Litter Growth Performance[a]**

| Valine, %: | .72 | | | 1.07 | | | 1.42 | |
|---|---|---|---|---|---|---|---|---|
| Isoleucine, %: | .50 | .85 | 1.20 | .50 | .85 | 1.20 | .50 | |
| Item TBCAA, %[b]: | 2.57 | 2.92 | 3.27 | 2.92 | 3.27 | 3.62 | 3.27 | CV |
| No. of sows | 26 | 27 | 24 | 28 | 26 | 27 | 27 | — |
| Mean parity | 1.3 | 1.3 | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 25.2 |
| No. of pigs after fostering | 11.1 | 11.0 | 11.1 | 11.1 | 11.0 | 11.2 | 11.0 | 5.6 |
| No. pigs weaned[c] | 10.9 | 10.8 | 11.0 | 10.8 | 10.8 | 10.8 | 10.9 | 3.9 |
| Lactation length, d | 20.0 | 20.8 | 20.5 | 20.2 | 20.4 | 19.7 | 20.3 | 9.5 |
| Litter wt, lb | | | | | | | | |
| Day 0 | 37.0 | 35.9 | 37.2 | 36.6 | 38.8 | 37.2 | 36.6 | 11.2 |
| Day 7 | 65.0 | 64.6 | 67.5 | 64.8 | 69.2 | 67.9 | 67.5 | 11.3 |
| Day 14 | 101.2 | 101.0 | 105.2 | 101.9 | 108.9 | 106.7 | 105.8 | 10.9 |
| weaning[c] | 139.7 | 136.0 | 139.3 | 136.7 | 144.4 | 143.1 | 140.4 | 11.3 |
| Litter wt gain, lb | | | | | | | | |
| Day 0 to 7 | 28.0 | 28.6 | 30.2 | 28.4 | 30.6 | 30.6 | 13.9 | 19.1 |
| Day 0 to 14 | 64.2 | 65.0 | 67.9 | 65.5 | 70.3 | 69.4 | 31.4 | 14.4 |
| Day 0 to weaning[c] | 97.7 | 100.1 | 102.3 | 100.1 | 105.8 | 105.8 | 47.1 | 13.5 |

Statistical Analysis ($P<$)

| | Main Effects | | | | Valine at .50% Isoleucine[d] | | TBCAA[e] | |
|---|---|---|---|---|---|---|---|---|
| | | Isoleucine | | | | | | |
| | Valine | Lin. | Quad. | Val × Ile | Lin. | Quad. | Lin. | *Quad.* |
| Mean parity | .83 | .76 | .93 | .86 | .91 | .86 | .99 | .93 |
| No. of pigs after fostering | .61 | .95 | .08 | .69 | .56 | .71 | .62 | .16 |
| No. of pigs weaned | .28 | .89 | .42 | .44 | .50 | .39 | .33 | .33 |
| Lactation length | .27 | .91 | .15 | .35 | .50 | .91 | .59 | .05 |
| Litter weights | | | | | | | | |
| Day 0 | .30 | .56 | .69 | .11 | .72 | .66 | .60 | .67 |
| Day 7 | .17 | .07 | .64 | .21 | .22 | .48 | .07 | .98 |
| Day 14 | .06 | .05 | .51 | .20 | .10 | .56 | .03 | .95 |
| weaning | .06 | .07 | .51 | .57 | .15 | .83 | .02 | .99 |
| Litter weight gain, lb | | | | | | | | |
| Day 0 to 7 | .29 | .05 | .79 | .74 | .06 | .54 | .04 | .82 |
| Day 0 to 14 | .08 | .04 | .58 | .49 | .04 | .62 | .02 | .82 |
| Day 0 to weaning | .07 | .06 | .53 | .86 | .08 | .93 | .01 | .89 |

[a]Litter size after fostering used as a covariate.
[b]Total branched chain amino acids (isoleucine + valine + leucine).
[c]Lactation length used as a covariate.
[d]Contrasting dietary valine levels of .72, 1.07, and 1.42% at .50% dietary isoleucine.
[e]Contrasting means of total branched chain amino acid levels 2.57, 2.92, 3.27, and 3.62%.

**Table 3. The Effects of Valine and Isoleucine on Sow Feed Intake, BW and Backfat Changes, and Return to Estrus[a]**

| Item | Valine, %: | .72 | | | 1.07 | | | 1.42 | |
|---|---|---|---|---|---|---|---|---|---|
| | Isoleucine, %: | .50 | .85 | 1.20 | .50 | .85 | 1.20 | .50 | |
| | TBCAA, %[b]: | 2.57 | 2.92 | 3.27 | 2.92 | 3.27 | 3.62 | 3.27 | CV |
| Feed intake/d | | | | | | | | | |
| ADFI, lb | | 13.7 | 13.5 | 13.9 | 13.2 | 13.6 | 13.1 | 6.17 | 10.2 |
| Lysine, g | | 56.0 | 55.0 | 56.7 | 54.0 | 55.6 | 53.5 | 55.7 | 10.2 |
| Valine, g | | 44.9 | 44.0 | 45.1 | 64.2 | 66.3 | 63.6 | 87.9 | 10.9 |
| Isoleucine, g | | 31.4 | 52.2 | 76.5 | 30.1 | 52.9 | 71.7 | 31.1 | 12.1 |
| TBCAA, g | | 160.3 | 178.8 | 206.7 | 175.2 | 202.7 | 215.4 | 202.5 | 10.4 |
| Sow BW, lb | | | | | | | | | |
| Day 0 | | 390.2 | 388.7 | 396.2 | 379.2 | 384.5 | 388.9 | 386.0 | 6.9 |
| Change[c] | | 5.2 | 5.3 | .5 | 2.7 | -1.1 | 7.9 | 2.5 | 919.7 |
| Sow backfat, in | | | | | | | | | |
| Day 0 | | .71 | .67 | .64 | .60 | .59 | .70 | .63 | 19.8 |
| Change[d] | | .15 | -.06 | -.19 | -.43 | -.53 | -.53 | -.37 | 273.7 |
| Days to estrus | | 4.5 | 5.0 | 4.5 | 5.1 | 5.0 | 5.1 | 4.7 | 23.9 |
| Percentage in estrus[e] | | 88.5 | 77.8 | 70.8 | 78.6 | 100.0 | 92.6 | 85.2 | — |

Statistical Analysis ($P<$)

| | Main Effects | | | | Valine at .50% Isoleucine[f] | | TBCAA[g] | |
|---|---|---|---|---|---|---|---|---|
| | | Isoleucine | | | | | | |
| | Valine | Lin. | Quad. | Val × Ile | Lin. | Quad. | Lin. | Quad. |
| Feed intake | | | | | | | | |
| ADFI | .08 | .92 | .77 | .22 | .83 | .15 | .20 | .58 |
| Lysine | .08 | .92 | .77 | .22 | .83 | .15 | .20 | .58 |
| Valine | .0001 | .88 | .54 | .31 | .0001 | .18 | .0001 | .0001 |
| Isoleucine | .05 | .0001 | .89 | .07 | .83 | .15 | .0001 | .0001 |
| TBCAA | .0001 | .0001 | .72 | .17 | .0001 | .16 | .0001 | .44 |
| Sow BW | | | | | | | | |
| Day 0 | .08 | .13 | .64 | .81 | .62 | .21 | .95 | .48 |
| Change | .02 | .01 | .44 | .64 | .53 | .54 | .001 | .15 |
| Sow backfat | | | | | | | | |
| Day 0 | .04 | .62 | .08 | .003 | .03 | .02 | .64 | .0002 |
| Change | .0001 | .14 | .74 | .63 | .04 | .13 | .001 | .37 |
| Days to estrus | .07 | .97 | .43 | .38 | .54 | .21 | .16 | .68 |

[a]Litter size after cross-fostering and lactation length used as covariates.
[b]Total branched chain amino acids (isoleucine + valine + leucine).
[c]Initial sow BW used as a covariate.
[d]Initial sow backfat used as a covariate.
[e]Percentage of sows in estrus by d 10 postweaning. Values differ ($P<.06$) based on Chi-square distribution.
[f]Contrasting dietary valine levels of .72, 1.07, and 1.42% at .50% dietary isoleucine.
[g]Contrasting means of total branched chain amino acid levels 2.57, 2.92, 3.27, and 3.62%.

Table 4. The Effects of Valine and Isoleucine on Milk Composition, %[a]

| Item | Valine, %: | .72 | | | 1.07 | | | 1.42 | |
|---|---|---|---|---|---|---|---|---|---|
| | Isoleucine, %: | .50 | .85 | 1.20 | .50 | .85 | 1.20 | .50 | |
| | TBCAA, %[b]: | 2.57 | 2.92 | 3.27 | 2.92 | 3.27 | 3.62 | 3.27 | CV |
| DM | | 16.17 | 16.8 | 17.1 | 15.86 | 17.02 | 17.33 | 17.6 | 5.1 |
| CP | | 5.16 | 5.31 | 5.61 | 4.94 | 5.39 | 5.33 | 5.30 | 9.5 |
| Fat | | 5.76 | 6.00 | 6.67 | 5.87 | 6.38 | 6.66 | 6.89 | 14.7 |
| Lactose | | 4.47 | 4.48 | 4.24 | 4.50 | 4.29 | 4.45 | 4.23 | 7.6 |
| Ash | | .78 | .77 | .77 | .79 | .80 | .75 | .76 | 6.5 |
| N fractions | | | | | | | | | |
| Casein | | 53.9 | 55.2 | 57.1 | 51.6 | 55.3 | 57.9 | 53.9 | 11.5 |
| Whey | | 35.5 | 35.0 | 33.2 | 36.2 | 34.7 | 31.9 | 34.9 | 17.1 |
| Other[c] | | 10.6 | 9.8 | 9.7 | 12.3 | 10.0 | 10.3 | 11.2 | 18.5 |

Statistical Analysis ($P<$)

| | Main Effects | | | | Valine at .50% Isoleucine[d] | | TBCAA[e] | |
|---|---|---|---|---|---|---|---|---|
| | | Isoleucine | | | | | | |
| | Valine | Lin. | Quad. | Val × Ile | Lin. | Quad. | Lin. | Quad. |
| DM | .93 | .0002 | .25 | .62 | .004 | .01 | .002 | .84 |
| CP | .25 | .005 | .47 | .42 | .50 | .11 | .20 | .77 |
| Fat | .47 | .002 | .83 | .72 | .01 | .23 | .005 | .71 |
| Lactose | .85 | .24 | .77 | .25 | .10 | .22 | .57 | .38 |
| Ash | .81 | .19 | .58 | .33 | .36 | .53 | .20 | .55 |
| N fractions | | | | | | | | |
| Casein | .73 | .01 | .94 | .67 | .97 | .33 | .08 | .33 |
| Whey | .82 | .06 | .65 | .85 | .83 | .67 | .10 | .39 |
| Other | .07 | .01 | .10 | .41 | .43 | .06 | .52 | .61 |

[a]Litter size after cross-fostering used as a covariate.
[b]Total branched chain amino acids (isoleucine + valine + leucine).
[c]Other = all other N (free amino acids, urea N, sloughed cellular N).
[d]Contrasting dietary valine levels of .72, 1.07, and 1.42% at .50% dietary isoleucine.
[e]Contrasting means of total branched chain amino acid levels 2.57, 2.92, 3.27, and 3.62%.