Title: Sow performance in response to dietary betaine fed in lactation and weaning-to-35 d post-insemination during moderate heat stress – **NPB #13-052**

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Industry Summary:

Heat stress has serious negative consequences for the swine industry by reducing feed intake and reproductive performance of sows. Based on commercial observations, heat stress during the summer reduces fertility up to 15% and increases non-productive sow days by 5 to 19 days per year. In the present study, we determined the impact of dietary betaine as a heat abatement strategy in sows. Betaine is an osmolyte and has an important role in maintaining water homeostasis and cell integrity and has been demonstrated to reduce heat stress in other species. We used a total of 649 sows that were balanced by parity (169, 153, and 327 sows representing parity 1, 2, and 3 to 6) and assigned them within parity to a 2 x 2 factorial arrangement of treatments. Factors included betaine concentration: 1) in lactation (0 or 0.2%) and 2) from weaning through early gestation (0 or 0.2%). Lactation diets were corn-soybean meal based with 10% rice bran and 6.0% wheat middlings, and formulated to contain 651 ppm of choline, 3.31 g standardized ileal digestible (SID) Lys/Mcal ME and a SID Met+Cys:Lys ratio of 0.56. Gestation diets were corn-soybean meal based with 30% wheat middlings, 15% rice bran, and formulated to contain 651 ppm choline, 1.82 g SID Lys/Mcal ME and a SID Met+Cys:Lys ratio of 0.69. Sows were started on lactation diets (with or without betaine) the day they farrowed. Sows that did not return to estrus within 14 d after weaning were removed from further study. Average room temperature was 25.2±2°C during lactation and 24.1±3°C during the weaning-to-35 d post-insemination period. Sows that received betaine during lactation had greater body losses (1.02 vs 1.18 kg/d, SEM ± 0.06, $P = 0.002$) due to a lower feed intake (4.29 vs. 4.14 kg/d, SEM ± 0.07, $P = 0.08$). No difference in litter gain (52.3 vs. 51.35 kg, SEM ± 0.6, $P = 0.16$) and number of pigs weaned were observed (10.95 vs. 10.90, SEM ± 0.5, $P = 0.5$). Feed efficiency was greater (0.327 vs. 0.284, SEM ± 0.01, $P = 0.001$) for sows fed diets without betaine. Feeding betaine post-weaning tended to increase ($P=0.08$) the number of sows returning to estrus within 14 d (0.92 vs. 0.88, SEM ±0.03) and tended to reduce wean-to-estrus interval (5.78 vs. 6.68, SEM ±0.4, $P=0.06$). Supplementation of betaine to mature sows post-weaning reduced farrowing rate (0.897 vs. 0.790, SEM±0.025, Interaction, $P = 0.07$). Feeding betaine post-weaning to parity 1 sows resulted in the greatest total number of pigs born ($P < 0.08$) and pigs born alive ($P < 0.05$). Feeding betaine during lactation to parity 4+ sows resulted in the greatest total number of pigs born ($P < 0.08$). Subsequent litter size was not affected in Parity 2 and 3 sows.

Key Findings:

- Supplementation of 0.2% betaine during lactation did not improve sow and litter performance.
- Supplementation of 0.2% betaine during lactation increased litter size in sows that were parity 4 or greater.
- Supplementation of 0.2% of betaine post-weaning increased the number of sows bred and reduced the wean-to-estrus interval.
- Feeding 0.2% betaine post-weaning increased litter size in parity 1 sows.

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Scientific Abstract:

The study was conducted to evaluate the effect of feeding dietary betaine during lactation and weaning-to-35 d post-insemination on sow reproductive performance during the summer months. A total of 649 sows were balanced by parity (169, 153, and 327 sows representing parity 1, 2, and 3 to 6) and assigned within parity to a 2 x 2 factorial arrangement of treatments. Factors included betaine concentration: 1) in lactation (0 or 0.2%) and 2) from weaning through early gestation (0 or 0.2%). Lactation diets were corn-soybean meal based with 10% rice bran and 6.0% wheat middlings, and formulated to contain 651 ppm of choline, 3.31 g SID Lys/Mcal ME and a SID Met+Cys:Lys ratio of 0.56. Gestation diets were corn-soybean meal based with 30% wheat middlings, 15% rice bran, and formulated to contain 651 ppm choline, 1.82 g SID Lys/Mcal ME and a SID Met+Cys:Lys ratio of 0.69. Sows were started on lactation diets the day they farrowed. Sows that did not return to estrus within 14 d after weaning were removed from further study. Data were analyzed using the MIXED procedure of SAS and GLIMMIX was used for dichotomous variables using the logit link function. Average room temperature was 25.2±2°C during lactation and 24.1±3°C during the weaning-to-35 d post-insemination period. Sows that received the betaine supplemented diet during lactation had greater body weight losses (1.02 vs 1.18 kg/d, SEM ± 0.06, $P = 0.002$) due to lower feed intake (4.29 vs. 4.14 kg/d, SEM ± 0.07, $P = 0.08$). No difference in litter gain (52.3 vs. 51.35 kg, SEM ± 0.6, $P = 0.16$) and number of pigs weaned were observed (10.95 vs. 10.90, SEM ± 0.5, $P = 0.50$). Feed efficiency was greater (0.327 vs. 0.284, SEM ± 0.01, $P = 0.001$) for sows fed the diet without betaine. Feeding betaine post-weaning tended to increase (P=0.08) the number of sows returning to estrus within 14 d (0.92 vs. 0.88, SEM ±0.03) and to reduce wean-to-estrus interval (5.78 vs. 6.68, SEM ± 0.4, $P = 0.06$). Supplementation of betaine to mature sows post-weaning reduced farrowing rate (0.897 vs. 0.790, SEM±0.025, Interaction, $P = 0.07$). Feeding betaine post-weaning to parity 1 sows resulted in the greatest number of total pigs born ($P < 0.08$) and pigs born alive ($P < 0.05$). Feeding betaine during lactation to parity 4+ sows provided the greatest total number of pigs born ($P < 0.08$). Parity 2 and 3 did not respond to betaine supplementation for subsequent litter size. Feeding betaine post-weaning to parity 1 and 2 sows reduced respiration rate (22.0 vs. 15.8 breaths per minute, SEM ± 2, $P = 0.03$). Results suggest that the use of 0.2% betaine during lactation did not improve sow and litter performance. However, the use of 0.2% betaine during lactation increased litter size in sows of parity 4 or greater. In addition, the use of 0.2% of betaine post-weaning increased the number of sows bred in a shorter interval after weaning. Moreover, feeding betaine post-weaning increased litter size in parity 1 sows.

Introduction

High environmental temperatures are a common challenge facing swine producers causing significant economic losses. Environmental heat stress that the animal experiences is a combination of various factors, most prominently temperature and humidity. Heat is also generated within the animal as it metabolizes nutrients. With high environmental temperatures, heat dissipation to the surrounding environment will become more difficult. In response to control body temperature, pigs will have increased blood flow to the skin surface, increased respiration rate, and display behavioral changes such as wetting of the skin, if possible, to increase evaporative heat losses. Reduced feed intake is a common response to heat stress because it reduces the heat associated with metabolism. Both short term (Heitman et al., 1958; Bond et al., 1959; Nienaber and Brown-Brandl, 2008) and long-term (Nichols et al., 1982; Nienaber et al., 1987a) heat stress reduce feed intake and growth of swine. Feed intake is estimated to be reduced by approximately 0.05 to 0.08 lbs per °F above 75°F and growth rate is expected to decrease in hot environments by approximately 0.03 to 0.04 lbs/d for every °F above 75 °F (Verstegen et al., 1995; Noblet et al., 2001). The impact of temperature is dependent on the weight of the pig. Heavier pigs are more sensitive to high temperatures than younger, lighter pigs. Lactating sows may be particularly sensitive to heat stress because of their high level of metabolism. In sows, it is estimated that heat stress reduces fertility by up to 15% and increases non-productive sow days by 5 to 19 days (St. Pierre et al., 2003). Nutritional strategies to mitigate the negative impact of heat stress have been evaluated, many of which have focused on the use of fat as a "cool" energy source and the reduction of nutrients with a high heat increment, such as fiber and protein. In poultry, betaine has been evaluated as a heat abatement strategy in heat stressed poultry and shown to positively impact growth performance (Zulkifli et al., 2004). In sows, Ramis et al. (2011) reported greater litter weight at weaning, a shorter weaning-to-estrus interval, and improved subsequent reproductive performance (pigs born alive and weaned per litter) in sows supplemented with 0.19% betaine. Temperatures in the farrowing rooms in that study were between 22 and 25 C.

Betaine, or tri-methyl glycine, is a methyl donor and osmo-regulator that occurs naturally (Kidd et al. 1997). The function of betaine as a methyl donor is well known and it can serve as a substrate for methionine synthesis, therefore providing a methionine sparing effect. The role of betaine as an osmolyte has important implications because it can maintain cell volume and integrity under challenging conditions. Indeed, betaine has been shown to improve performance in poultry when exposed to stress conditions such as coccidiosis infection (Klasing et al., 2002) and heat stress in broilers (Zulkifli et al., 2004; Farooq et al., 2005) and rabbits (Hassan et al., 2011). Maintaining osmotic balance is extremely important and it has been estimated that 30 to 60% of the maintenance requirement of visceral tissue is associated with the sodium/potassium pump. Betaine functions as an osmolyte inside the cell, maintaining water balance in the cell. Osmolytes have been demonstrated to increase the ability of cells to withstand osmotic stress by 42%, which resulted in a sparing effect on sodium/potassium pump activity of 64% (Moeckel et al., 2002). Under normal conditions (no imposed stress), betaine has been shown to reduce energy requirements by 5.5% (Schrama et al., 2003). These results suggest that betaine can reduce the maintenance energy requirements through improved osmotic regulation, which will increase energy availability for growth. This is especially evident during stressful conditions, such as heat stress. It has also been clearly established that severe heat stress can compromise gut integrity and barrier function (Hall et al., 2001; Cronje, 2005), allowing toxic components, such as endotoxins to enter the bloodstream. Betaine may play a role in minimizing damage to gut barrier function as evidenced by improved structure of the lining of the intestinal tract in poultry (Kettunen et al., 2001c), improved nutrient absorption in poultry and swine (Eklund et al., 2005), and reduced gut lesions due to coccidia challenge in poultry when betaine was supplemented.

Together these data provide a compelling argument that betaine supplementation may be an effective strategy to minimize the impact of heat stress in sows. This may be especially the case in environments that further challenge the stress response of sows, as may be the case in commercial industry settings, where exposure to subclinical disease can occur. We propose that betaine can be effectively used as a heat abatement strategy in sows.

Objectives

The objective of the current research was to evaluate the impact of dietary betaine as a heat abatement strategy in sows exposed to heat stress. We hypothesized that supplemental betaine can reduce the negative impact of heat stress and that this impact is greater in first parity sows. This will result in increased production efficiency and economic return.

Materials & Methods

Animals and diets

Animals were humanely treated following the practices outlined in the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2010). Protocols were under the regulation of licensed veterinarians.

The study was conducted in a commercial research facility (2,600 sows) in Oklahoma. Six hundred forty nine sows (Camborough, PIC, Hendersonville, TN) were placed on test during the summer of 2014. A total of 30 groups of sows (22 to 24 sows per group) were used during the period of June through August. Prior to entering the farrowing room, sows were fed a common gestation corn-soybean meal based diet with 30% wheat middlings, 15% rice bran, and formulated to contain 1.82 g SID Lys/Mcal ME. Within each group, sows were randomly assigned to 1 of 4 dietary treatments and balanced by parity, with a final total of 169, 153, and 327 sows representing parity 1, 2, and 3 to 6, respectively. The design of this study was a RCBD in 2 x 2 factorial arrangement. Factors included dietary betaine (Vistbet®, AB Vista, Malborough, UK) supplemented at 0 or 0.2% and the period of supplementation (lactation or post-weaning until 35 d post-insemination).

Diets were formulated according to the NRC (2012) nutrient recommendations and manufactured by a commercial feed mill (Hanor Company, Enid, Oklahoma). Lactation diets (Table 1) were corn-soybean meal with 10% rice bran and 6.0% wheat middlings formulated to contain 3.31 g SID Lys/Mcal ME. Post-weaning diets (Table 1) were corn-soybean meal based with 30% wheat middlings, 15% rice bran and formulated to contained 1.82 g SID Lys/Mcal ME. For both diets, inclusion of betaine was made at the expense of corn. Diets were color coded to visually confirm that proper diets were fed to the correct treatment groups. Feed samples were collected at the feed mill for every batch and every week at the farm to chemically verify the diets.

Lactation period

Sows were weighed individually when they entered the farrowing room (264 ± 29 kg) at d 109 ± 1 of gestation. Sows started on lactation treatment diets the day they farrowed. Feed was offered at 0800 and 1400 h to appetite. Daily feed disappearance was measured from farrowing to weaning. Number and weight of pigs at birth (alive, still born, and mummies) were recorded and placenta and weight of fluids was calculated from the equations reported by Walker and Young (1993). Litter birth weight, estimated placenta weight and estimated weight of fluids were subtracted from the weight of the sow at placement to estimate sow weight at farrowing. Sows were weighed for a second time at d 21 of lactation. The difference between sow weight at d 21 and farrowing weight represent the body weight loss (or gain) during lactation.

Cross-fostering was done 18 to 24 h after farrowing to allow for colostrum intake from their own mothers. Litter size was standardized to 12 pigs according to the standard operating procedures of the commercial farm. Litter weight gain was calculated as the difference between the weight of the litter at d 21 and the weight of the litter after cross-fostering. Date and weight of dead piglets were recorded. Pigs did not have access to creep feed or supplemental milk during the experiment. Handling, processing, and vaccination of piglets were performed according to the recommendations of licensed veterinarians and were identical for all the litters. Piglets were weaned at the first opportunity after d 21 (22 ± 1 d).

Post-weaning to 35 d post-insemination

The breeding barn at the farm facilities has a full capacity to house 480 sows. It is equipped with drop feeders (capacity of 3.62 kg) and is designed to deliver two types of diets, each for one half of the barn. After weaning, sows were distributed in the barn corresponding to their treatment designation. Therefore, one side of the room received the gestation diet supplemented with betaine and the other side received the control diet without betaine. Sows had ad libitum access to feed before signs of estrus were detected. At that point, sows were artificially inseminated and feed drops were adjusted to offer 1.8 to 2.7 kg of feed depending on sow body condition. Feed was delivered in two meals at 2 h and 8 h.

Estrus detection and artificial insemination were performed following the the standard operating procedures of the farm. Sows that did not return to estrus within 14 d discontinued the dietary treatments and were not used in the final analysis. After d 35 post-insemination, sows were moved to the gestation barn and were fed the standard gestation diet (control without betaine). Data collection during this period included: the number of sows bred within 14 d after weaning, weaning to breeding interval, and farrowing rate. Sows that were culled for non-reproductive problems or died were not considered in the calculation of farrowing rate. Once sows reached approximately d 110 of gestation, they were moved to the farrowing room and litter size at birth was recorded (born alive, still born, and mummies).

Rectal Temperature and Respiration Rate

Two subset of 40 sows were selected to determine rectal temperature using a digital thermometer (M750 Series, GLA Agriculture Electronics, San Luis Obispo, CA) and respiration rate by counting the number of flank movements for 60 seconds. Data were collected in one subset of sows at d 18 ± 1 of lactation and in the second subset of sows at d 13 ± 4 post-insemination. Rectal temperatures and respiration rate were measured from 16 h to 18 h in both subsets.

Ambient temperature and humidity of the farrowing room and breeding barn were recorded using data recorders (logtag, MicroDAQ Ltd., Contoocook, NH). Data recorders measured and logged temperature and humidity every 10 minutes.

Statistical Analysis

Sow and litter performance data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model included the effect of betaine, parity group, and their interaction as fixed effects. The groups of sows (22 to 24 sows) that entered the farrowing room together were considered as random effect. Subsequent reproductive performance data were analyzed using the MIXED procedure of SAS for days to estrus, total number of pigs born, and pigs born alive. The GLIMMIX procedure of SAS was used for binary responses. The model included the effect of betaine during lactation, the effect of betaine post-weaning, parity group, and their interaction as fixed effects. Groups of sows were considered a random effect. Least squared means of total pigs born and pigs born alive were compared using Tukey’s method. Respiration rate and rectal temperature were analyzed using the MIXED procedure of SAS. The model included the effect of betaine, parity group and their interaction as fixed effects and the sow as random effect.

Results

Average temperature of the farrowing room during the lactation period was 25.2 ± 2ºC (Figure 1) and humidity was 72.5± 2% (data not shown). Average temperature of the breeding barn (during the post-weaning until 35 d post-insemination period) was 24.1± 3ºC (Figure 2) and humidity was 73.3± 8% (data not shown).

During the lactation period, body weight loss was greater (*P = 0.002*) when sows received the betaine-added diet compared to the control diet and this was related to a lower daily feed intake in sows supplemented with betaine (Table 2; $P = 0.08$). No differences in litter gain ($P = 0.17$) and number of pigs weaned were observed ($P = 0.55$). Feed efficiency, calculated as total gain during lactation (sow body weight gain or loss plus total litter gain) divided by total feed intake during lactation, was greater ($P = 0.001$) for sows fed the control diet without betaine.

Supplementation of betaine post-weaning tended to reduce ($P = 0.06$) the number of days to estrus and tended to increase ($P = 0.08$) the number of sows that returned to estrus within 14 days (Table 3). Supplementation of betaine post-weaning to mature sows reduced farrowing rate (Interaction, $P = 0.07$). A three factor interaction was observed for total number of pigs born ($P = 0.06$) and pigs born alive ($P = 0.04$) and we conducted an exploratory analysis to further separate the parity groups and determine the impact of betaine within these parity groups.

For parity 1 sows, we observed an interactive effect of betaine supplementation during lactation and supplementation post-weaning on total number of pigs born ($P = 0.03$) and pigs born alive ($P = 0.008$) (Figure 3). When betaine was supplemented during lactation, but was not fed subsequently post-weaning, the total number of pigs born and the number of pigs born alive were not significantly affected; however, when betaine was continued post-weaning, the total number of pigs born ($P < 0.08$) and pigs born alive ($P < 0.05$) decreased. In contrast, when betaine was not supplemented during lactation, feeding betaine during the post-weaning to d 35 post-insemination period increased the total number of pigs born and pigs born alive and not feeding betaine during the post-weaning to d 35 post-insemination period reduced these measurements. By multiple comparison, feeding betaine post-weaning to d 35 post-insemination only to parity 1 sows provided the greatest number of total pigs born ($P < 0.08$) and pigs born alive ($P < 0.05$).

Supplementation of betaine during lactation to parity 4+ sows increased the total number of pigs born in the subsequent litter ($P = 0.026$) (Figure 4). Supplementation of betaine post-weaning to parity 4+ sows reduced total number of pigs born ($P = 0.014$) and number of pigs born alive ($P = 0.08$). By multiple comparison, feeding betaine during lactation to parity 4+ sows provided the greatest total number of pigs born ($P < 0.08$). We did not observe any effects of betaine supplementation ($P > 0.4$) for parity 2 and 3 sows on total number of pigs born and pigs born alive (Figure 5).

Rectal temperature measured on d 18 ± 1 of lactation and d 13 ± 4 post-insemination was not impacted by dietary supplementation of betaine (Table 4). Supplementation of betaine tended to reduce respiration rate of sows when measured on d 13 post-insemination and this appeared to be most evident in young sows ($P = 0.03$).

Discussion

Supplementation of betaine during lactation increased body weight losses, which was a consequence of lower feed intake in sows supplemented with betaine. Previous studies have reported variable responses in feed intake due to betaine (Haydon et al., 1995; Lawrence et al., 2002) in finishing pigs. Matthews et al. (1998) proposed that effect of betaine in swine diets depended on crude protein inclusion and energy density in the diet. In our recent field studies with finishing pigs, we also observed a reduction in feed intake when betaine was supplemented at 0.2%, but we did not observe this effect in a subsequent study when lower concentrations of betaine were fed. The mechanism by which betaine may impact feed intake is not clearly understood. Ramis et al. (2011) observed a reduction in feed intake in sows fed betaine, similar to our results, but they did not observe an effect on sow body losses when betaine was included at 0.2% in lactation diets. Moreover, Ramis et al. (2011) reported an improvement in litter gain and no differences in the number of pigs weaned when betaine was supplemented, which is in contrast to the present study.

A reduction in the weaning-to-estrus interval due to betaine was observed when betaine was supplemented during lactation by Ramis et al. (2011) and Greiner et al. (2014). In the present experiment, betaine supplementation during lactation did not impact weaning-to-estrus interval, however, betaine supplementation after weaning reduced the weaning-to-estrus interval and increased the number of sows that showed signs of estrus within 14 d post-weaning.

The greatest benefit of using betaine in diets for sows has been reported for subsequent litter size. Van Wettere et al. (2012) reported an increase in subsequent litter size when betaine was fed to mature sows during gestation. Interestingly, in our study we observed an increase in subsequent litter size in mature sows when betaine was fed during lactation. In young sows, an increase in subsequent litter size was observed when betaine was supplemented post-weaning. The mechanism by which betaine increases litter size is under study.

Results from this study suggest that the use of 0.2% betaine during lactation did not improve sow and litter performance. However, the use of 0.2% betaine during lactation increased litter size in sows of parity 4 or greater. In addition, the use of 0.2% of betaine post-weaning increased the number of sows bred in a shorter interval after weaning. Moreover, feeding betaine post-weaning increased litter size in parity 1 sows.

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Table 1. Composition of the experimental diets, as fed basis[1]

	Diet[2]	
Item	Lactation	Post-weaning
Ingredient, %		
Corn, medium grind	45.92	47.03
Soybean meal, 46.5% CP	32.10	4.00
Rice bran	10.00	15.00
Wheat middlings	6.00	30.00
Poultry fat	2.35	0.00
Limestone	1.12	1.45
Monocalcium phosphate, 21% P	0.99	0.87
Potassium, magnesium sulfate[3]	0.50	0.50
Salt	0.40	0.40
Sow vitamin-mineral premix[4]	0.20	0.20
Choline chloride, 60%	0.13	0.13
Anti-caking aid[5]	0.10	0.10
Organic mineral source [Zn-Mn-Cu][6]	0.08	0.08
L-Lysine	0.05	0.15
L-Threonine	0.04	0.08
DL-Methionine	0.02	0.00
Dye	0.03	0.03
Calculated nutrient composition		
NRC ME Mcal/Kg	3.30	3.04
SID Lys, %	1.05	0.56
g SID Lys/Mcal ME	3.31	1.82
SID Met + Cys:Lys	0.56	0.69
Choline, ppm	651	651

[1]Diets were formulated to exceed NRC (2012) requirements.

[2]To create betaine added diets, betaine (Vistbet®, AB Vista, Malborough, UK) was added at 0.2% at the expense of corn

[3]Dynamate (Mosaic, Plymouth, MN), added as a laxative.

[4]Supplied per kg of complete diet: vitamin A, 11,023 IU; vitamin D_3, 1,763.7 IU; vitamin E, 51 IU; vitamin K, 4.4 mg; vitamin B12, 0.044 mg; riboflavin, 8.8 mg; d-pantothenate, 26.5 mg; niacin 55.1 mg; thiamine, 3.3 mg; pyridoxine, 3.3 mg; folic acid, 1.21 mg; biotin, 0.28 mg. Zn, 125 mg; Fe, 100 mg; Mn, 50 mg; Cu, 25.0 mg; I, 0.7 mg; Se, 0.3 mg; phytase, 661 FTU (Phyzyme, Danisco A/S, Copenhagen, Denmark), and chromium, 0.4 mg/kg

[5]Dry anti-caking aid and non-nutritive carrier (KALLSIL, Kemin Industries, Inc., Des Moines, IA)

[6]Supplied per kg of complete diet: zinc, 50 mg from zinc amino acid complex, manganese, 20 mg from manganese amino acid complex, and copper, 10 mg from copper amino acid complex (Availa, Zimpro Corporation, Eden Prairie, MN)

Table 2. Impact of betaine supplementation during lactation on sow and litter performance.

	Betaine inclusion, %[1]							
	0.2		0.0			P –values		
Item	Mature[2]	Young[2]	Mature	Young	SEM	Betaine	Parity Group	Interaction
Number of sows	165	159	162	163				
BW at farrowing, kg	268.46	237.14	267.72	236.5	2.081	0.708	<0.001	0.980
BW at d 21 of lactation, kg	249.2	206.7	252.1	209.1	1.889	0.159	<0.001	0.896
Sow body losses, kg	19.5	30.5	15.7	27.2	1.467	0.002	<0.001	0.834
Sow average daily losses, kg	0.930	1.450	0.750	1.290	0.070	0.002	<0.001	0.834
Litter weight after cross-fostering, kg[3]	18.76	18.17	18.44	17.89	0.222	0.130	0.005	0.909
Litter weight at d 21, kg	71.88	67.42	71.65	68.99	0.827	0.380	<0.001	0.244
Litter gain, kg	53.22	49.34	53.41	51.10	0.767	0.167	<0.001	0.271
Litter ADG, kg	2.530	2.351	2.533	2.434	0.036	0.199	<0.001	0.236
Number of pigs weaned	10.89	10.92	10.87	11.04	0.093	0.548	0.289	0.439
Feed intake until d 21	100.3	72.1	101.7	76.4	1.927	0.093	<0.001	0.396
ADFI until d 21	4.821	3.476	4.896	3.685	0.092	0.080	<0.001	0.409
Feed conversion	0.327	0.241	0.356	0.298	0.015	0.001	<0.001	0.282
Lactation days	22.22	22.05	22.15	22.10	0.099	0.889	0.175	0.416

[1]Betaine was supplemented from farrowing until weaning.
[2]Young sows were defined as parity 1 and 2 sows and mature sows consisted of sows of parity 3, 4, 5, and 6.
[3]Litters were standardized to 12 pigs per litter.

Table 3. Effect of supplementation of betaine during lactation and/or post-weaning to mature and young sows on subsequent reproductive performance (least squares means).

		0.2% betaine in lactation[1]		0% betaine in lactation			P values[2]						
Betaine Post-weaning, %[3]:		**0.2**	**0**	**0.2**	**0**	**SEM**	**P**	**B-L**	**P x B-L**	**B-PW**	**P x B-PW**	**B-L x B-PW**	**P x B-L x P-PW**
Variable	**Parity[4]**												
Number of sows	Young	80	83	83	76								
	Mature	82	80	80	85								
Days to estrus	Young	5.86	7.94	6.17	6.73								
	Mature	5.43	6.24	5.64	5.81	0.676	0.062	0.559	0.724	0.06	0.384	0.261	0.647
Bred:weaned[2]	Young	0.919	0.838	0.925	0.878								
	Mature	0.95	0.9	0.908	0.916	0.033	0.27	0.967	0.434	0.083	0.555	0.336	0.604
Farrowed:weaned[2]	Young	0.811	0.788	0.8	0.838								
	Mature	0.763	0.875	0.816	0.916	0.042	0.174	0.243	0.571	0.042	0.074	0.554	0.746
Total pigs born[2]	Young	12.38[b]	13.39[ab]	13.33[ab]	12.54[b]								
	Mature	14.00[a]	14.45[a]	13.3[ab]	14.31[a]	0.458	0.001	0.57	0.475	0.193	0.341	0.335	0.068
Pigs born alive[2]	Young	11.58[b]	12.84[a]	12.75[ab]	11.93[b]								
	Mature	13.00[a]	13.18[a]	12.59[ab]	13.18[a]	0.436	0.02	0.906	0.587	0.325	0.79	0.172	0.043

[1]Betaine was supplemented in lactation diets from farrowing until weaning.

[2]Probability values for the effects of parity group (**P**; young and mature), betaine supplementation in lactation (**B-L**), parity group by betaine supplementation in lactation interaction (**P x B-L**), betaine supplementation from weaning until 35 d post-insemination (**B-PW**), parity group by betaine supplementation from weaning until 35 d post-insemination (**P x B-PW**), betaine supplementation in lactation by betaine supplementation from weaning until 35 d post-insemination interaction (**B-L x B-PW**), and the three way interaction of parity group by betaine supplementation in lactation by betaine supplementation from weaning until 35 d post-insemination (**P x B-L x P-PW**).

[3]Lactating sows continued in the study and were fed either diets without or with supplemental betaine from weaning until d 35 post insemination.

[4]Young sows were defined as parity 1 and 2 sows and mature sows consisted of sows of parity 3, 4, 5, and 6.

[5]Data represent sows that were bred within 14 d after weaning.

[ab]Means within rows representing a variable that do not have a common superscript differ ($P < 0.05$).

Table 4. Effect of betaine supplementation during lactation and/or post-weaning on rectal temperature and respiration rate in mature and young sows.

	Betaine inclusion, %							
	0.2		0.0					
	Parity Group[1]					P –values		
Item	Mature	Young	Mature	Young	SEM	Betaine	Parity Group	Interaction
At d 18 ± 1 of lactation[2]								
Rectal temperature, °C	39.57	39.36	39.53	39.70	0.120	0.211	0.874	0.122
Respiration rate	74.89	62.58	81.90	65.77	8.684	0.562	0.110	0.827
At d 13 ± 4 post insemination[3]								
Rectal temperature, °C	38.53	38.49	38.46	38.53	0.077	0.825	0.851	0.470
Respiration rate	12.33[a]	15.82[a]	13.20[a]	22.00[b]	2.032	0.091	0.005	0.200

[1]Young sows were defined as parity 1 and 2 sows and mature sows consisted of sows of parity 3, 4, 5, and 6.
[2]Farrowing room temperature during data collection was 27.8°C ± 0.67.
[3]Breeding barn temperature during data collection was 28.0°C ± 0.34.
[ab]Means within a row that do not have a common superscript differ ($P < 0.03$).

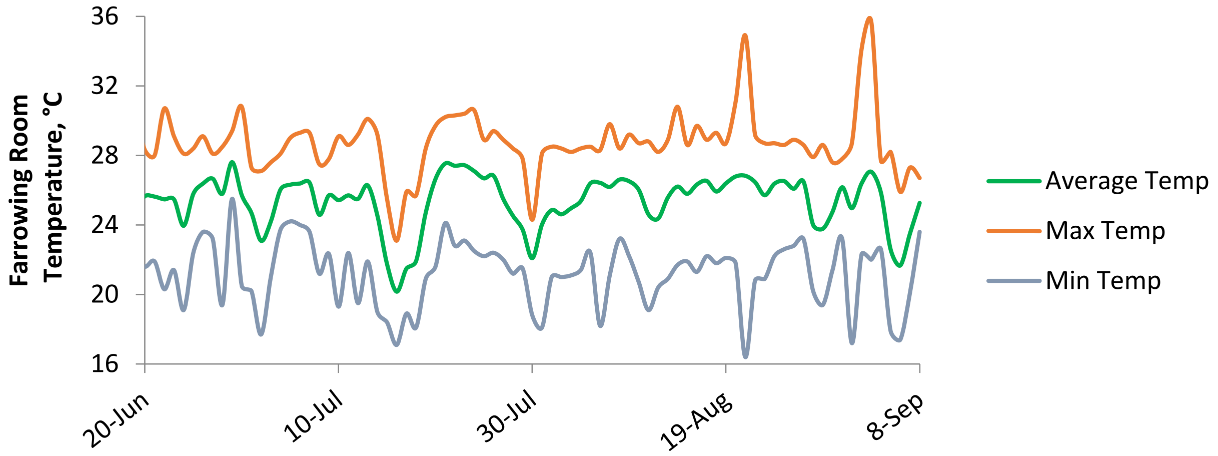

Figure 1. Temperature fluctuation of the farrowing room during the experimental period.

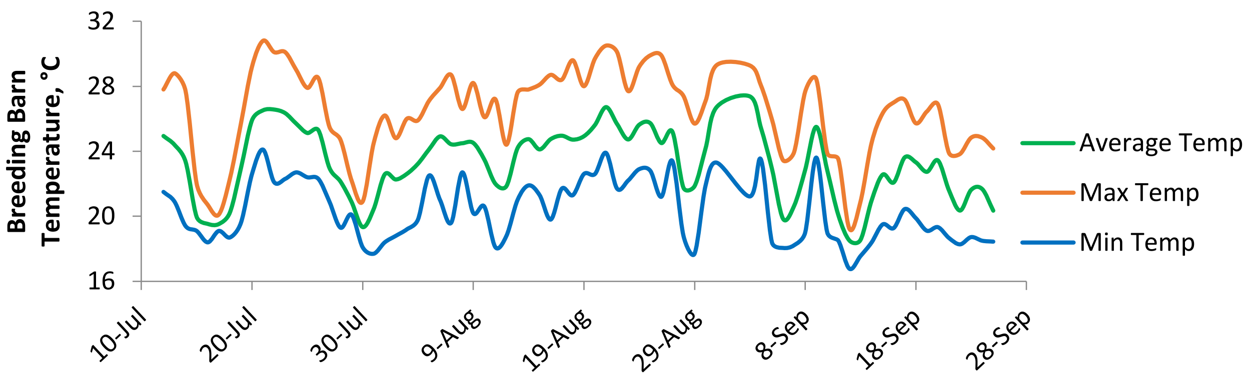

Figure 2. Temperature fluctuation of the breeding barn during the experimental period.

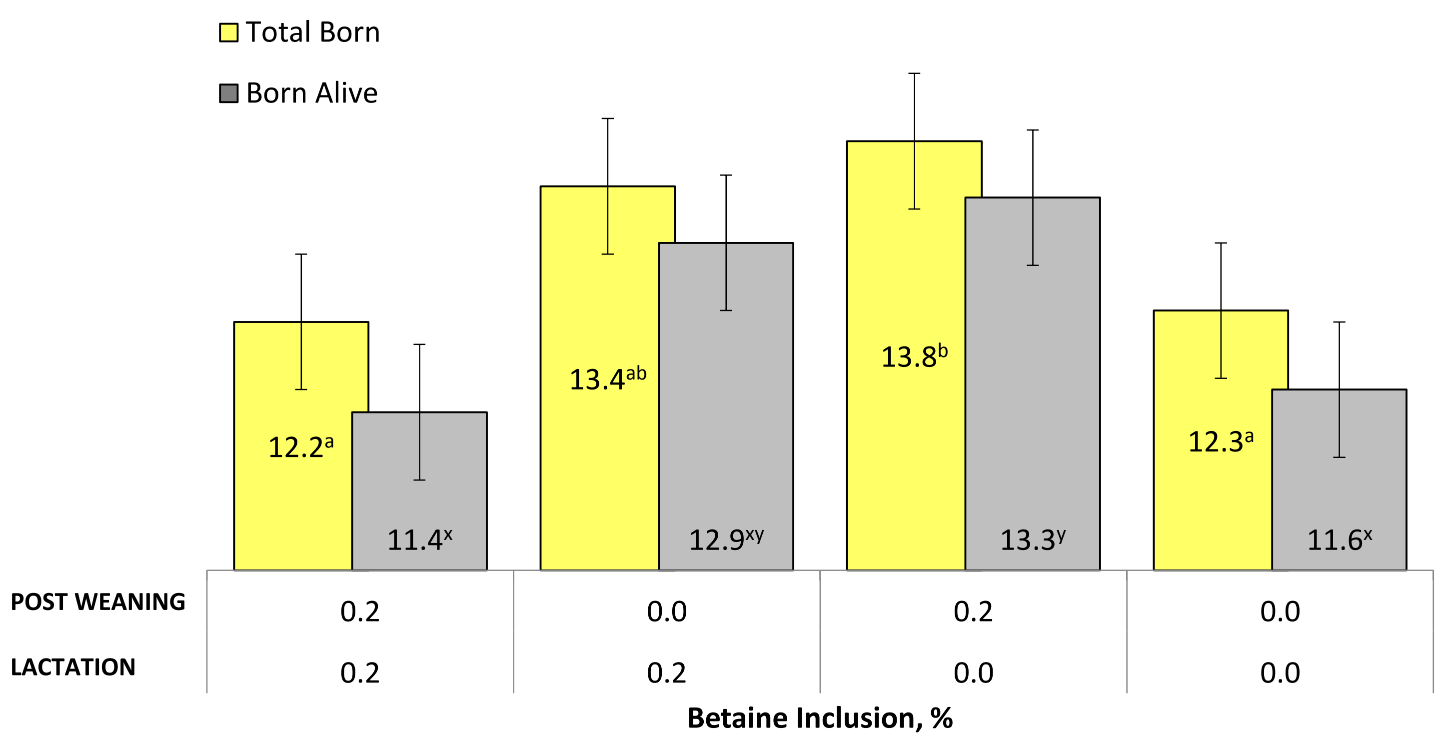

Figure 3. Effect of supplementation of betaine during lactation and/or post-weaning to parity 1 sows on total number of pigs born and pigs born alive (least squares means, n =32, SEM = 0.6). Interactive effect of betaine supplemented during lactation and post-weaning on total pigs born ($P = 0.028$) and pigs born alive ($P = 0.008$). Means without a common superscript differ (ab, $P < 0.08$; xy $P < 0.05$).

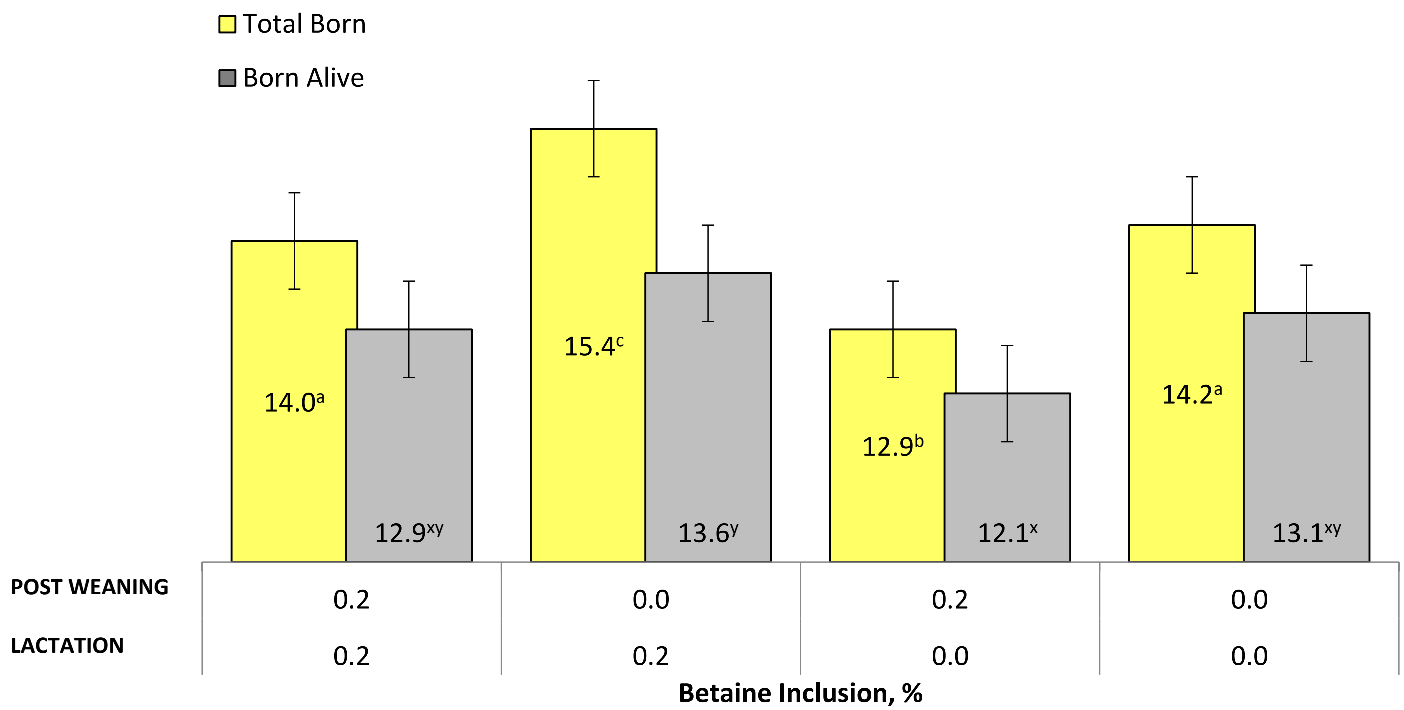

Figure 4. Effect of supplementation of betaine during lactation and/or post-weaning to parity 4+ sows on total number of pigs born and pigs born alive (least squares means, n = 40, SEM = 0.6). Interactive effect of betaine supplemented during lactation and post-weaning on total pigs born (P = *0.028*) and pigs born alive (P = *0.008*). Means without a common superscript differ (ab, $P < 0.08$; xy $P < 0.03$).

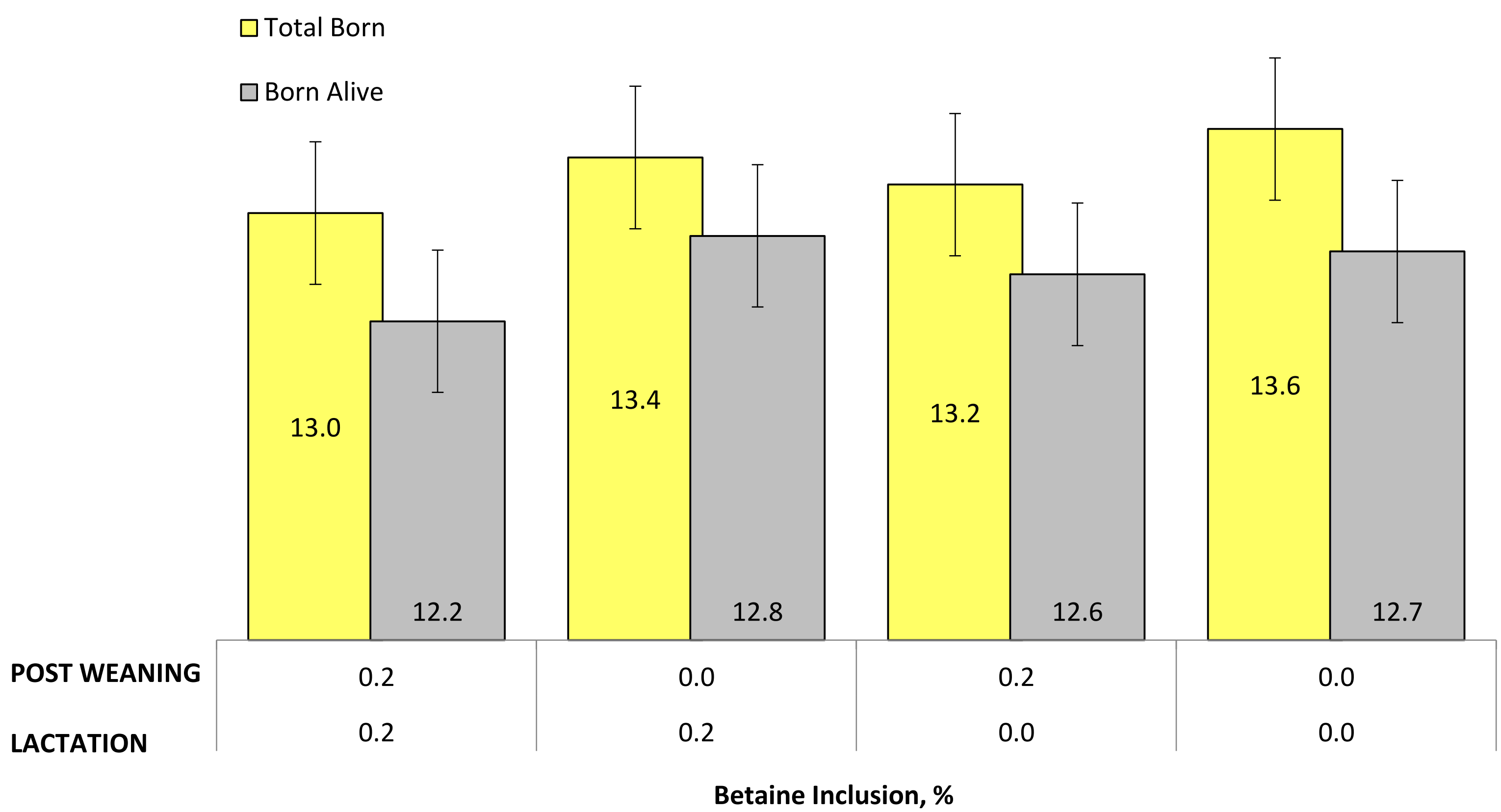

Figure 5. Effect of supplementation of betaine during lactation and/or post-weaning to parity 2 and 3 sows on total number of pigs born and pigs born alive (least squares means, n = 58, SEM = 0.5). No significant effects of dietary treatments were observed (*P > 0.40*).