Influence of Carnichrome on the energy balance of gestating sows[1,2]

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ABSTRACT: Twelve multiparous sows with an average initial weight of 182 kg were used in a randomized complete block design to determine the effects of feeding Carnichrome (50 mg of carnitine and 200 μg of chromium picolinate per kilogram of feed, as fed) on energy and nitrogen utilization in early, mid-, and late gestation. All sows were fed a diet with or without Carnichrome for the preceding 28-d lactation, the weaning-to-estrus period, and for the duration of gestation. Daily feeding allowances over pregnancy were based on calculated energy and nutrient requirements to achieve a target sow maternal weight gain of 20 kg and remained constant throughout gestation. Heat production (HP) and its partitioning (activity, thermic effect of feeding short term [TEF_{st}], basal) were determined in early (wk 5 or 6), mid- (wk 9 or 10), and late (wk 14 or 15) pregnancy using indirect calorimetry. Net maternal weight gain and total number of fetuses averaged 21.6 kg and 16.4, respectively. Organic matter and energy digestibility for the Carnichrome diet was greater ($P < 0.05$), which resulted in greater DE and ME contents (0.6%, $P < 0.05$) compared with the control diet. The digestibility coefficient of energy in the current experiment for a typical corn and soybean meal diet (92%) was greater than that predicted from DE values of corn and soybean meal in feeding tables (88%). Carnichrome had no effect on total HP, energy retained as protein or lipid, and maternal energy retention in early, mid-, or late gestation. Heat production in late gestation increased linearly (4.0 kJ/[kg $BW^{0.75}$·d]) for each additional day from d 90 to 110, despite the reduction of ME intake per unit of $BW^{0.75}$. Metabolizable energy requirement for maintenance was 405 kJ/(kg $BW^{0.75}$·d). On average, activity HP was 116 kJ/(kg $BW^{0.75}$·d), which was equivalent to 20% of ME intake; however, this value ranged from 11 to 37% between sows, which corresponds to duration of standing ranging from 210 to 490 min/d. Energy cost of standing activity averaged 0.30 kJ/(kg $BW^{0.75}$·min). In conclusion, Carnichrome had no effect on the components of heat production and maternal weight gain during gestation, although it improved energy and organic matter digestibility of the diet.

Key Words: Carnitine, Chromium, Gestation, Heat Production, Sows

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Introduction

Carnitine is a vitamin-like compound that is essential in the transport of long- and medium-chain fatty acids across the mitochondrial membrane for β-oxidation (Fritz, 1955). Chromium is a trace mineral that is essential for activating specific enzymes and stabilizing proteins and nucleic acids (Anderson, 1987). Both carnitine and chromium have been shown to improve reproductive performance of sows (Lindemann et al. 1995b; Musser et al., 1999b). Likewise, Real et al. (2002) found that the total number of pigs produced over two parities was greater when sows were fed diets with carnitine or chromium compared with control diets, with the greatest improvement observed from feeding a diet containing both carnitine and chromium (Carnichrome). In previous research, feeding dietary carnitine during gestation increased sow weight gain and backfat (Musser et al., 1999b), whereas dietary chromium tended to increase weight gain (Lindemann et al., 1995b). These observations suggest that sows fed diets with carnitine or chromium retain more energy than sows fed control diets. However, other experiments have not observed

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any benefits to adding carnitine or chromium to the diet (Lindemann et al., 1995a; Musser et al., 1999a).

There has been no research conducted to evaluate the effects of the combination of both carnitine and chromium (Carnichrome) on the energy balance of sows. A greater response to carnitine and chromium together would be expected as opposed to individually based on the synergistic response obtained in other experiments (Real et al., 2002; Woodworth et al., 2002). The objective of the current study was to quantify the effect of the addition of Carnichrome (supplied by Lonza Inc., Fair Lawn, NJ) on heat production (**HP**) and its components (activity, $\mathbf{TEF_{st}}$, basal) and energy gain during early, mid- and late gestation of multiparous sows.

Materials and Methods

Animals and Housing

Fifty-four Large White × Landrace sows were assigned to one of two dietary treatments, control or Carnichrome (50 mg of L-carnitine and 200 μg of chromium picolinate per kilogram of feed), based on parity and weight at entry to the farrowing house in a randomized complete block design experiment. All sows were fed dietary treatments for the preceding 28-d lactation, when a separate lactation diet was fed, the weaning-to-estrus period, and for the duration of the subsequent gestation. Once confirmed pregnant on d 28 of gestation, 12 sows (six blocks with two sows per block) were selected for indirect calorimetry measurements based on parity, weight entering the farrowing house, weight loss in lactation, number of pigs suckled in lactation, and weaning-to-estrus interval. The experiment was conducted in two series, with measurements taken on eight sows in the first series and four sows in the second series. Four of the six blocks of sows used for the indirect calorimetry measurements were littermate sisters. Energy balance was measured during three stages of gestation, early (wk 5 or 6), mid (wk 9 or 10), and late (wk 14 or 15) for each block. Sows were moved to the metabolism unit 4 to 5 d before commencement of digestibility and respiration measurements. Sows were placed for 7 d in a metabolism cage that was in a respiration chamber, where digestibility and energy balance measurements were taken, simultaneously. Day 1 was used to allow the sow to adapt to the respiration chamber. Collection of urine and excreta, and gas exchange measurements commenced on d 1. In the morning of d 8, energy balance and digestibility measurements were terminated and the sows were weighed. Average parity number of the sows used in the experiment was 1.8, and their mean live weight was 181 kg on d 35 of gestation. All sows on which indirect calorimetry measurements were taken were slaughtered at the end of pregnancy (d 111 on average) and total uterus, individual fetal, placenta, and empty uterus weights were recorded. Predicted fetal and uterine energy retention were determined using the equations of Noblet et al. (1985) and Noblet et al. (1990) and were adjusted for the difference between predicted and actual fetal weights at slaughter on d 111 of gestation. Digestibility and energy balance measurements were conducted at the INRA facilities in Saint Gilles, France.

Two respiration chambers with a volume of 12 m^3 were available for measurement of gas exchanges in individual sows. The dimensions of each respiration chamber were as follows: length, 2.50 m; width, 1.80 m; and height, 1.75 m. Metabolism cages (2.40 m long, 0.75 m wide, and 1.10 m high) were equipped with two infrared beams located at the front and rear of the cages to detect standing or sitting activity of the sow. Interruption of an infrared beam for at least 20 s was considered to represent a standing activity (i.e., sitting or standing). In addition, the metabolic cage was mounted on force sensors (Type 9104A; Kistler, Winterthur, Switzerland), which produced an electric signal assumed to be proportional to the physical activity of the animal. In order to measure the duration of eating, feeders were placed on load cells. The temperature in the respiration chamber was maintained at 22°C, to keep animals within their thermoneutral zone; relative humidity was set at 70%. Care and use of animals were performed according to the Certificate of Authorization to Experiment on Living Animals (No. 04739, delivered by the French Ministry of Agriculture to J. Noblet).

Diets and Feeding

All sows were fed a lactation diet with (as fed) 1.0% lysine, 0.80% calcium, and 0.75% P, with or without Carnichrome for the 28-d lactation (Table 1). Feed intake in lactation averaged 6.1 kg/d and ranged from 5.9 to 6.2 kg/d (as fed). The two experimental gestation diets were corn/soybean meal-based and formulated to meet or exceed NRC (1998) nutrient requirement estimates. The only difference between the two diets was that the control diet had 5 g/kg of a corn/soy blend added, whereas the Carnichrome diet had 5 g/kg of Carnichrome 10% added to provide 50 mg of L-carnitine and 200 μg of chromium from chromium picolinate per kilogram of feed (as fed). Diet composition and chemical characteristics are reported in Table 1. Before the initiation of the experiment, the required amounts of corn and soybean meal (47% CP) needed to mix both experimental diets were reserved. In mixing each batch of feed, all ingredients were blended before splitting the batch. At this time, 0.5 kg of the corn/soybean meal blend was added to half the batch, and 0.5 kg of the Carnichrome 10% was added to the other half of the batch.

During the gestation period, sows received their diet in one meal per day (0900) in pellet form (diameter 4.5 mm, pelleted at 60°C). Feeding levels were determined using energy requirements for maintenance (Noblet and Etienne, 1987; energy requirement for maintenance, $\mathbf{ME_m}$ [MJ] = 0.45 × $BW^{0.75}$ [kg]); fetal growth (Noblet et al., 1985; energy uterus gain [MJ] = {4.8 ×

Table 1. Composition of the experimental diets (as fed)

Item	Gestation diet	Lactation diet
Components, g/kg diet		
Corn	800.7	120.0
Wheat	—	227.0
Barley	—	254.4
Wheat bran	—	100.0
Soybean meal, 47% CP	145.0	211.3
Dicalcium phosphate	25.8	12.6
Limestone	8.0	10.8
Soy oil	10.0	20.0
Molasses	—	30.0
Salt	5.0	4.5
Lysine·HCl	—	0.9
Corn-soy blend[a]	0.5	0.5
Vitamin and trace mineral[b]	5.0	5.0
Acidifier[c]	—	1.0
Phytase[d]	—	2.0
DM, g/kg	885	—
Chemical analysis, per kg DM		
CP, (N × 6.25) g	157	—
Ash, g	61	—
Crude fiber, g	26	—
NDF, g	91	—
ADF, g	30	—
ADL, g	4	—
Starch, g	597	—
Fat, g	50	—
GE, MJ	18.37	—

[a]Corn/soybean meal blend (50:50) for the Carnichrome treatment was replaced with carnichrome 10% blend, which provided 50 ppm L-carnitine and 200 ppb chromium from chromium picolinate.
[b]Vitamins and minerals provided the following (per kilogram of diet): vitamin A 10,000 IU; vitamin D_3 1,500 IU; vitamin E 30.0 IU; vitamin K_3 2.0 mg; thiamin 2.0 mg; riboflavin 4.0 mg; pyridoxine 3.0 mg; cyanocobalamin 0.02 mg; niacin 20.0 mg; D-panthotenate 10.0 mg; biotin 0.2 mg; folic acid 3 mg; choline chloride 500 mg; Zn 100.0 mg; Cu 10.0 mg; Mn 40.0 mg; Fe 80.0 mg; I 0.60 mg; Co 0.1 mg; and Se 0.20 mg.
[c]Natuphos BASF, France. Provided 500 FTU/kg of feed.
[d]Formic and lactic blend, CEVA, Nutrition Animale, France.

fetus BW gain [kg]} ÷ 0.5); and maternal weight gain (Dourmad et al., 1996, 1997, 1998; energy for maternal gain [MJ] = {9.7 × BW gain [kg] + 54 × P2 gain [mm]} ÷ 0.75); where BW is average body weight of the sow, which is calculated as weight at service plus half the targeted weight gain plus half the products of conception and uterine weight gain in gestation. The gestational energy requirements were determined by calculating the daily energy requirement for maintenance (ME_m) multiplied by 115 d, plus energy for target maternal weight gain, and energy for products of conception and uterine gain, and summing these to give the total gestational energy requirement. Feeding level was kept constant throughout pregnancy. Water was available ad libitum throughout the experimental period.

Measurements

Sows were weighed at the beginning (d 1), at the end of each balance period (d 8), and every 2 wk between collections. Urine was collected daily in a HCl solution, and an aliquot was taken each day and pooled per sow. The N_2 losses (as ammonia) in the air were recovered either in condensed water from the air-conditioning system or as trapped ammonia after bubbling an aliquot of the outgoing air (Noblet et al., 1993a). A sample of feed was collected and analyzed for its DM content at the time of distribution to the sows (for each balance period). Feed samples were pooled at the end of the trial for each treatment. Feces were collected daily and pooled and, at the end of the period, weighed, mixed, subsampled, analyzed for DM content; a sample was freeze-dried for subsequent analysis. Feed and feces were analyzed for DM, ash, CP (N × 6.25), Weende crude fiber, and diethyl ether extract according to the AOAC (1990), and their gross energy contents were measured with an adiabatic bomb calorimeter (IKA, Staufen, Germany). Cell wall fractions NDF, ADF, and ADL were determined according to Van Soest et al. (1991), with preceding amylolytic treatment. Starch content was determined using the Ewer's polarimetric method (European Economic Community, 1972). Nitrogen in the urine was analyzed on fresh material, whereas the energy content was obtained after freeze-drying approximately 50 mL of urine in polyethylene bags. Analyses on feed samples were performed in triplicate, whereas analyses on excreta were performed in duplicate.

Concentrations of O_2, CO_2, and CH_4 in the respiration chamber were measured continuously. The O_2 was measured with a paramagnetic analyzer (Oxymat 6; Siemens, Hamburg, Germany), whereas CO_2 and CH_4 were measured with two absorption infrared analyzers (Unor 6N; Maihak AG, Hamburg, Germany). However, only one CH_4 analyzer was available for both chambers, so the CH_4 concentration was measured for each sow during 3 or 4 d (out of 7 d) during each experimental period. The signal of the force sensors and the weights of the trough and water tank were measured 50 to 60 times per second. When the weight of the trough was detected as unstable, the corresponding beginning and ending times and the change in weights of the trough or water tank were recorded. Measurements of gas concentrations, signals of the force sensors, and weights of trough and water tank were averaged over 10 s and stored on a microcomputer for further analysis. The aim of these simultaneous measurements was to relate the instantaneous variation in O_2 and CO_2 to physical activity of the sow and eating events in the chamber.

Calculations and Statistical Analysis

Apparent digestibility coefficients of energy and the different chemical fractions were calculated according to standard procedures (Noblet and Shi, 1993). Daily HP was calculated from gas exchanges, including CH_4 production, according to the formula of Brouwer (1965). The retained energy corresponded to the difference in ME intake and HP. Energy retained as protein was calculated from the N balance, whereas retained energy as lipid corresponded to the difference between retained energy and energy retained as protein.

The kinetics of O_2 consumption and CO_2 production by the animal were estimated as described by van Milgen et al. (1997). In this approach, the O_2 and CO_2 concentrations in the respiration chamber are modeled by accounting for the physical aspects of gas exchanges and for the O_2 consumption and CO_2 production by the animal. The objective is to adjust model variables relating to O_2 consumption and CO_2 production by the animal so that the difference between the observed and the predicted O_2 and CO_2 concentrations is minimal. The model is described as a series of differential equations, which are integrated numerically using ACSL Optimize (Aegis Simulation, 1999). Dependent variables in the model were O_2 and CO_2 concentrations in the respiration chamber, whereas independent variables included time, level of physical activity (signal of force sensor), and quantity of feed intake. In practice, the model provides estimates of gas exchanges that are due to resting (L/min), physical activity (liters per unit of force), and feed intake (L/g). Subsequently, corresponding unitary HP-values were calculated from the respective O_2 consumption and CO_2 production as described by Brouwer (1965), excluding the correction for N and CH_4 production. The respiratory quotient was calculated as the ratio between CO_2 production and O_2 consumption.

Animals in the fed state were assumed to have a constant basal HP (kJ/d). Ingestion of a meal and associated short-term physiological events, such as digestion and absorption, cause a temporary increase in HP (TEF_{st}). This phenomenon was modeled as compartmental system, which was parameterized to include the unitary TEF_{st} (kJ/g of feed) and the time after ingestion of a meal to attain 50% of the corresponding HP (total TEF [**TTEF**], hours). The daily TEF_{st} (kJ/d) corresponds to the product of unitary TEF_{st} and the mean daily feed intake. Finally, activity (i.e., the signal of the force sensor) also results in increased HP, to which a component of HP can be attributed. The daily HP that was due to physical activity was calculated as the product of unitary HP (kilojoules per unit of force) and total force detected over a day.

The results were analyzed as a randomized complete block design with repeated measures over time using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). The best-fitting covariance structure according to AIC was used in the model. Sow was the experimental unit of analysis with block included as a random effect. For the analysis, treatment (n = 2) and stage of pregnancy (n = 3) were the main effects, and treatment × stage of pregnancy interactive effects were tested. Heat production from d 93 to 111 of gestation was modeled as a function of day of gestation and adjusted for the sow effect to determine the increased daily heat production in the last 3 wk of gestation. The standard error reported is based on the mean difference used to calculate the F-tests. Sow within dietary treatment variance was used as the error term to test the main effect of dietary treatment. We considered an alpha of $P < 0.05$ significant and $P > 0.05$ to $P < 0.10$ to be a trend.

Results

Both the control and Carnichrome diets were analyzed for L-carnitine by microdetermination of carnitine and carnitine acetyl transferase (Parvin and Pande, 1977). The control and Carnichrome diets were analyzed to have 1.4 and 57.1 ppm free L-carnitine, respectively.

Sow Weights and Litter Data

Average parity and sow weight at weaning and at d 35, 70, 103, and 111 (slaughter) of gestation were not different between the control and Carnichrome treatments (Table 2). Maternal weight gain in gestation also was not different (20.0 vs. 23.2 kg) between the two treatments. Backfat (P2) level increased 0.8 and 1.1 mm from d 30 of gestation to slaughter, on d 111, for the control and Carnichrome treatments, respectively, with sows on the Carnichrome treatment having significantly (12.1 mm; $P < 0.05$) higher backfat throughout gestation than sows on the control treatment (10.8 mm). Total uterus, fetal, placenta, and empty uterus weight were not different between the two treatments. The prolificacy of the sows used in the present experiment were very high, with sows producing on average 16.4 total pigs, with no difference between the two treatments. Average fetal weight at slaughter of the sows on d 111 of gestation were not different between the control and Carnichrome treatments at 1.21 vs. 1.32 kg, respectively.

Digestibility of Dietary Nutrients

Digestibility coefficients of organic matter and energy were greater ($P < 0.05$) and tended ($P < 0.10$) to be greater for crude protein and dry matter for the Carnichrome compared with the control treatment (Table 3). The digestibility coefficients of DM decreased ($P < 0.05$), whereas for organic matter and energy, they tended ($P < 0.08$) to decrease with stage of gestation. Treatment had no effect on methane energy loss, but, with increasing stage of gestation, methane production decreased ($P < 0.05$). However, there was a tendency ($P < 0.09$) for a treatment × stage of gestation interaction, with methane energy loss tending to be greater for the control compared with the Carnichrome treatment in early gestation (1.11 vs. 0.91%), but not different in mid- or late gestation. The energy content of the urine averaged 3.7% of DE but was not affected by treatment and was greater ($P < 0.05$) in mid- compared with early or late gestation. The ME:DE ratio was significantly ($P < 0.01$) greater in late compared with early or mid-gestation. The DE and ME value for the Carnichrome diet were greater ($P < 0.03$) than for the control

Table 2. Effect of treatment on sow body weight and uterine growth[a]

Item	Treatment: Control	Carnichrome[b]	SE	$P <$
No. of sows	6	6		
Average parity	1.8	1.8		
Sow BW, kg				
Weaning	181.5	181.7	5.6	0.98
Day of gestation				
35	180.6	182.0	6.0	0.84
70	207.6	206.3	7.1	0.86
103	222.2	224.8	6.3	0.71
111 (slaughter)	226.5	229.5	6.9	0.69
Maternal weight gain, kg[c]	20.0	23.2	5.3	0.58
Average backfat, mm	10.8	12.1	0.4	0.03
Weight, kg[d]				
Total uterus	34.8	34.1	2.4	0.78
Fetuses	20.7	20.3	1.6	0.82
Placenta	4.3	4.3	0.5	0.99
Empty uterus	7.4	7.1	0.5	0.49
Total number of fetuses	17.3	15.5	1.7	0.34
Average fetal weight, kg[c]	1.2	1.3	0.1	0.37

[a]Average backfat during gestation was 11.6 mm.
[b]Provided 50 ppm L-carnitine and 200 ppb chromium from chromium picolinate.
[c]Slaughter weight – total fetal weight – placenta weight – weaning weight.
[d]At slaughter (d 111 on average of gestation).

diet, whereas the DE value tended to be ($P < 0.06$) and the ME value was greater ($P < 0.03$) in early and late compared with mid-gestation.

Nitrogen and Energy Balance

Nitrogen intake was similar for both treatments and at the three stages of gestation (Table 4). Nitrogen losses in the feces were greater ($P < 0.02$) for the control compared with the Carnichrome treatment. Losses of N in the urine were lower ($P < 0.01$) in early and late gestation (20.6 and 19.9 g/d, respectively) compared with mid-gestation (23.6 g/d). Consequently, N retention was greater ($P < 0.01$) in early and late gestation (17.0 and 18.3 g/d) compared with mid-gestation (13.9 g/d).

Daily ME intake was similar for both treatments, but it was greater ($P < 0.05$) in late compared with mid-gestation and not different from early gestation (Table 4). There was a tendency ($P < 0.09$) for a treatment ×

Table 3. Effect of treatment and stage of gestation on digestibility and energy values of the dietary treatments

Item	Treatment: Control	Carnichrome[a]	SE	Stage of gestation: Early	Mid	Late	SE	$P <$: Treatment (T)	Stage (S)	T × S
No. of experimental units	6	6		12	12	12				
Mean BW, kg	203.7	204.5	5.8	181.6[b]	206.9[c]	223.8[d]	1.4	0.90	0.01	0.20
DMI, g/d[e]	1,771	1,768	30.7	1,760	1,772	1,776	9.3	0.93	0.30	0.86
Apparent digestibility, %										
DM	89.9	90.6	0.4	91.0[b]	89.5[c]	90.1[bc]	0.6	0.10	0.04	0.22
OM	93.0	93.7	0.3	93.9	92.9	93.3	0.4	0.05	0.08	0.24
CP	87.9	89.2	0.5	88.7	87.8	89.1	0.7	0.06	0.19	0.14
Energy	91.8	92.7	0.3	92.9	91.7	92.2	0.5	0.03	0.06	0.27
Energy of CH_4, % DE	0.95	0.92	0.06	1.01[b]	0.97[b]	0.83[c]	0.06	0.67	0.04	0.09
Energy of urine, % DE	3.72	3.69	0.10	3.61[b]	3.94[c]	3.57[b]	0.14	0.77	0.04	0.80
ME:DE, %	95.5	95.4	0.2	95.3[b]	95.3[b]	95.9[c]	0.2	0.76	0.01	0.50
Energy values, MJ/kg DM										
DE	16.86	17.02	0.06	17.06	16.84	16.93	0.08	0.03	0.06	0.27
ME	16.07	16.24	0.06	16.27[b]	16.02[c]	16.19[b]	0.09	0.03	0.03	0.21

[a]Provided 50 ppm L-carnitine and 200 ppb chromium from chromium picolinate.
[b,c,d]Means with different superscripts differ ($P < 0.05$).
[e]Dry matter content of the diet increased ($P < 0.05$) with stage of gestation, 88.1, 88.5, and 88.9%.

Table 4. Effect of treatment and stage of gestation on nitrogen and energy balance of sows

	Treatment			Stage of gestation				P <		
Item	Control	Carnichrome[a]	SE	Early	Mid	Late	SE	Treatment (T)	Stage (S)	T × S
No. of experimental units	6	6		12	12	12				
Nitrogen balance, g/d										
Intake	44.5	44.5	0.8	44.2	44.6	44.8	0.2	0.99	0.16	0.94
Losses										
Feces	5.4	4.8	0.2	5.0	5.4	4.9	0.3	0.02	0.21	0.14
Urine	21.2	21.5	0.8	20.6[b]	23.6[c]	19.9[b]	0.8	0.73	0.01	0.51
Evaporation	1.4	1.4	0.2	1.3	1.4	1.4	0.3	0.86	0.96	0.87
Retention	16.3	16.4	0.9	17.0[b]	13.9[c]	18.3[b]	0.9	0.90	0.01	0.29
Energy balance, MJ/d										
ME intake[e]	28.4	28.8	0.5	28.6[bc]	28.4[b]	28.8[c]	0.2	0.62	0.03	0.09
Heat production	24.1	24.1	0.9	22.6[b]	23.1[b]	26.4[c]	0.5	0.94	0.01	0.67
Energy gain	4.4	4.7	0.7	6.0[b]	5.2[b]	2.4[c]	0.5	0.65	0.01	0.94
Energy gain as										
Protein	2.4	2.5	0.1	2.5[b]	2.1[c]	2.7[b]	0.1	0.90	0.01	0.29
Lipid	1.9	2.3	0.6	3.5[b]	3.2[b]	–0.3[d]	0.5	0.62	0.01	0.92
Energy gain in										
Fetal tissues[fh]	1.1	1.1	0.1	0.1[b]	0.8[c]	2.4[d]	0.1	0.71	0.01	0.90
Uterine tissues[gh]	1.5	1.4	0.1	0.4[b]	1.3[c]	2.6[d]	0.1	0.68	0.01	0.91
Maternal tissues	3.1	3.6	0.8	5.7[b]	4.2[c]	0.1[d]	0.6	0.53	0.01	0.87
Respiratory quotient	1.00	1.00	0.01	1.02[b]	1.01[b]	0.97[c]	0.01	0.64	0.01	0.29

[a]Provided 50 ppm L-carnitine and 200 ppb chromium from chromium picolinate.
[b,c,d]Means with different superscripts differ ($P < 0.05$).
[e]Dry matter content of the diet increased ($P < 0.01$) with stage of gestation, 88.1, 88.5, and 88.9%.
[f]$\ln(\text{energy}) = 11.64 - 13.94e^{-0.0182t} + 0.0822n$, where t = day of gestation, n = number fetuses (Noblet et al., 1985; Noblet, 1990).
[g]$\ln(\text{energy}) = 13.84 - 8.041e^{-0.0070t} + 0.0831n$, where t = day of gestation, n = number fetuses (Noblet et al., 1985; Noblet, 1990).
[h]Adjusted for the difference between actual weight of fetuses at slaughter of sows and predicted weight of fetuses.

stage of gestation interaction, with energy intake tending to be greater for the Carnichrome compared with the control treatment in early gestation (28.9 vs. 28.3) but not different in mid- and late gestation. There was no difference in HP between the control and Carnichrome treatments, but HP was greater ($P < 0.01$) in late compared with early and mid-gestation, and thus energy retention in maternal gain was lower ($P < 0.01$) in late gestation. The combination of the higher HP and the higher protein retention in late gestation compared with mid-gestation resulted in a decrease ($P < 0.01$) in lipid deposition, with sows in late gestation mobilizing lipid reserves. The lower ($P < 0.01$) respiratory quotient in late compared with mid-gestation confirms this result. Calculated fetal and uterine energy retention increased ($P < 0.01$) with stage of gestation, especially between mid- and late gestation. Increased HP and energy retained in the uterine tissues in late gestation resulted in decreased maternal energy retention in late gestation.

Components of Heat Production

The average time required to consume daily feed allowance was 21 min/d, with an average rate of feed consumption of 100 g/min (Table 5). The rate of feed consumption per unit of body weight was lower ($P < 0.05$) for mid- and late compared with early gestation. Duration of total standing activity averaged 266 min/d and values ranged from 80 to 511 min/d (Figure 1). Irrespective of sow behavior, the energy cost of standing averaged 0.30 kJ/(kg BW$^{0.75}$·min) and was not affected by treatment or stage of gestation.

As sows were fed a constant feed allowance throughout gestation, ME intake per unit of metabolic body weight decreased ($P < 0.01$) with stage of gestation as a consequence of weight gain in gestation (Table 6; Figure 2). This resulted in a logical decrease of HP expressed as kJ/(kg BW$^{0.75}$·d) between early and mid-gestation. But in late gestation, HP was greater in spite of the reduced ME intake. This is partly explained by the slightly greater activity heat production (**AHP**). In addition, heat production in late gestation increased by 4.0 kJ/(kg BW$^{0.75}$·d) for each additional day from d 93 to 111 (Figure 2). This is equivalent to an increased ME requirement of 0.34 MJ/d for each additional day from d 93 to 111 for a 250-kg sow ([$250^{0.75} \times 4.0$]/0.75/1000) or an additional 25 g/d of a standard corn/soybean meal diet (13.7 MJ/kg of ME).

As the duration of standing time (minutes per day) increased, AHP total standing activity (expressed as kJ/[kg BW$^{0.75}$·d]) also increased (Figure 1), with AHP over total standing being three times greater for sows standing for 500 compared with 100 min/d. Activity HP averaged 116 kJ/(kg BW$^{0.75}$·d), but there was considerable variation between sows with a range of 60 to 201 kJ/(kg BW$^{0.75}$·d). Maintenance energy requirement (expressed as kJ/[kg BW$^{0.75}$·d]) was greater ($P < 0.01$) in late compared with mid-gestation, and tended ($P < 0.09$) to be greater than in early gestation (Table 6). Energy

Table 5. Effect of treatment and stage of gestation on standing and physical activity of sows

Item	Treatment			Stage of gestation				P <		
	Control	Carnichrome[a]	SE	Early	Mid	Late	SE	Treatment (T)	Stage (S)	T × S
No. of experimental units	6	6		12	12	12				
Behavior, min/d										
Eating	23	19	2	21	21	20	1	0.13	0.47	0.62
Standing not eating	225	265	78	267	242	226	23	0.63	0.36	0.28
Total standing	247	284	79	288	263	247	20	0.66	0.15	0.28
Percentage of day spent standing	17.2	19.7	5.5	20.0	18.2	17.1	1.7	0.66	0.37	0.30
Activity HP, MJ/d										
Total	6.0	6.6	1.2	5.7	6.2	6.9	0.6	0.62	0.19	0.95
Standing and/or eating	0.5	0.4	0.1	0.4	0.4	0.5	0.04	0.55	0.71	0.79
Standing and/or not eating	3.2	4.0	0.9	3.7	3.5	3.5	0.4	0.38	0.89	0.41
While lying	2.3	2.2	0.7	1.6[b]	2.3[b]	3.0[c]	0.4	0.89	0.03	0.74
AHP, kJ/(kg $BW^{0.75}$ ·min)										
While lying	0.04	0.04	0.01	0.03	0.04	0.05	0.01	0.93	0.13	0.97
While standing	0.29	0.31	0.03	0.31	0.30	0.29	0.02	0.58	0.61	0.33
Rate of feed consumption, g/min	93	111	11	99	99	103	4	0.14	0.54	0.46
Rate of feed consumption, g/(min·kg $BW^{0.75}$)	1.8	2.1	0.2	2.1[b]	1.8[c]	1.8[c]	0.1	0.14	0.01	0.71

[a]Provided 50 ppm of L-carnitine and 200 ppb of chromium from chromium picolinate.
[b,c]Means with different superscript letters differ ($P < 0.05$).

in gain and maternal energy retention decreased, while uterine energy retention increased ($P < 0.01$) per unit of metabolic body metabolic weight with stage of gestation. Basal or resting HP was the main component of total HP, which represented on average 54.2% of total ME intake. Basal or resting HP was greater ($P < 0.01$) in late compared with early and mid-gestation. The daily TEF_{st} represented 7.5% of ME intake and was not affected by treatment or stage of gestation. Carnichrome had no affect on any of the components of HP in early, mid-, or late gestation.

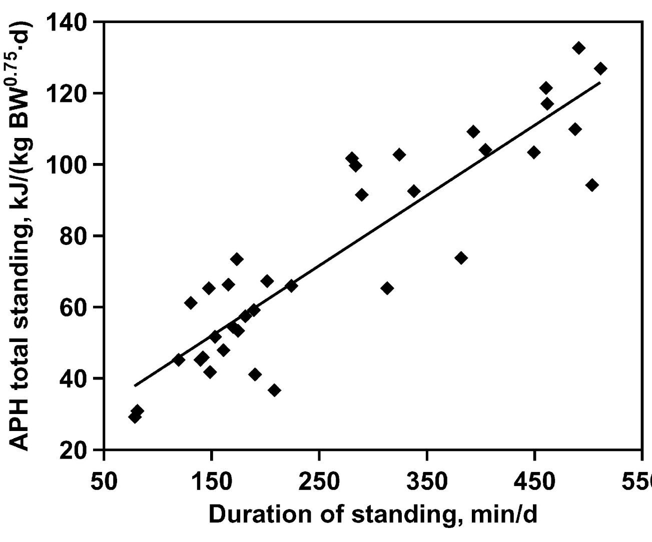

Figure 1. The relationship between duration of standing (min/d) and activity heat production (APH) during standing time. Activity heat production, kJ/(kg $BW^{0.75}$ ·d) = 0.20 (duration of standing, min/d) + 22; r^2 = 0.81.

Discussion

Effect of Carnichrome on Digestibility

The digestibility coefficient of energy in the current experiment for a typical corn/soybean meal diet (92%) was greater than that predicted from DE values of corn and soybean meal proposed by the NRC (1998) or by Sauvant et al. (2002) for growing pigs (88% for energy). This value is also higher than the digestibility coefficient of the gestation diet used in the present experiment when measured in 60-kg growing pigs (88%; our unpublished data). However, the digestibility of energy reported in the present experiment is similar to the value as calculated from energy values proposed for adult pigs by Sauvant et al. (2002). This is in agreement with the data reported by Le Goff and Noblet (2001) that digestibility of feed energy is greater in adult sows than in growing pigs and different values should be used for both stages. The higher DE and ME values and decreased fecal N excretion for the Carnichrome diet is supported by results of Rincker et al. (2001); they found that L-carnitine supplementation improved N balance and the utilization of GE provided in the diet of weanling pigs. Cho et al. (1999) also found that supplementation of L-carnitine improved crude fat and GE digestibility, which resulted in improved ADG. In present experiment, the higher energy and organic matter digestibility for the Carnichrome treatment and a tendency for lower methane energy loss resulted in a higher ME intake in early gestation for the Carnichrome compared with the control treatment. This resulted in maternal weight gain to be numerically higher for the Carnichrome compared with the control-fed sows.

Table 6. Effect of treatment and stage of gestation on partitioning of heat production in gestating sows

Item	Treatment		SE	Stage of gestation			SE	P <		
	Control	Carnichrome[a]		Early	Mid	Late		Treatment (T)	Stage (S)	T × S
No. of experimental units	6	6		12	12	12				
Energy balance, kJ/(kg $BW^{0.75}$·d)										
ME intake	531	535	5	580[b]	521[c]	499[d]	4	0.50	0.01	0.67
Heat production										
Total	448	446	14	458[b]	424[c]	458[b]	8	0.93	0.01	0.79
Activity	110	124	22	115	115	120	11	0.55	0.89	0.91
Energy gain	84	89	12	122[b]	96[c]	41[d]	9	0.70	0.01	0.95
Uterine energy gain	26	25	3	8[b]	23[c]	46[d]	2	0.62	0.01	0.84
Maternal energy gain	60	69	14	115[b]	77[c]	1[d]	10	0.56	0.01	0.86
Adjusted HP[e]	450	444	10	459[b]	426[c]	457[b]	7	0.62	0.01	0.72
Adjusted energy gain[e]	82	90	11	121[b]	96[c]	42[d]	8	0.48	0.01	0.96
Components of HP, % ME intake										
Basal HP[f]	54.6	53.9	3.4	51.0[b]	51.3[b]	60.4[c]	2.5	0.85	0.01	0.90
TEF_{st}	8.3	6.7	0.9	7.4	7.3	7.8	0.7	0.12	0.84	0.14
ME requirement for maintenance, kJ/(kg $BW^{0.75}$ ·d)[g]	407	404	16	406[bc]	385[b]	425[c]	9	0.87	0.01	0.79

[a]Provided 50 ppm L-carnitine and 200 ppb chromium from chromium picolinate.
[b,c,d]Means with different superscript letters differ significantly ($P < 0.05$).
[e]Adjusted for similar AHP, kJ/(kg $BW^{0.75}$·d).
[f]FHP + TEF_{lt}.
[g]Estimated using efficiency of ME utilization for protein of 60% and for fat of 80% (Noblet et al., 1991, 1999; Noblet and Etienne, 1987).

Changes in Heat Production and N Retention Over Pregnancy

In late gestation from d 90 to 110, HP increased rapidly with the advancement of pregnancy. The additional heat loss with the advancement of pregnancy is related to the changes in composition (protein vs. fat) and partitioning (uterine vs. maternal tissues) of the energy gain and not due to extra heat production arising from pregnancy itself (Noblet and Etienne, 1987). The large increase in HP in late gestation in the present experiment can also be attributed to the high prolificacy of the sows used, with an average of 16.4 total pigs born. Increased HP in late gestation was calculated to be 4.0 kJ/(kg $BW^{0.75}$·d) for each additional day from d 90 to 110 of gestation. Energy available for maternal gain decreased as gestation progressed as a result of increased uterine energy requirement, increased energy required for maintenance as sows became heavier, and increased HP (Table 7). Total ME intake would have to increase by 37% (approximately 9.4 MJ/d) from d 90 to 110 of gestation in order to achieve zero maternal energy retention.

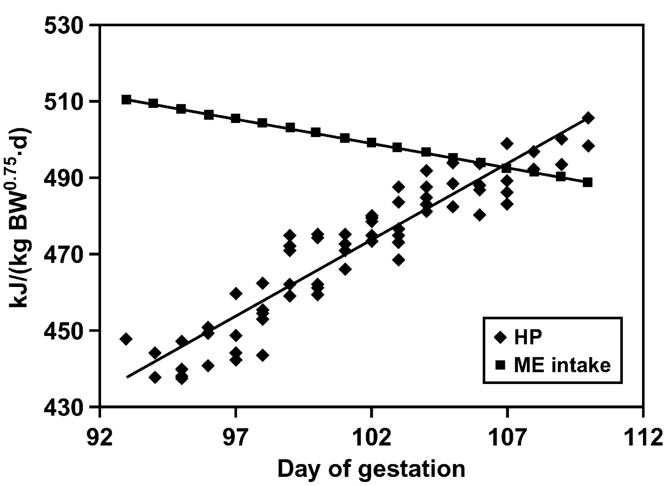

Figure 2. The relationship between day of gestation, heat production (HP), and ME intake. HP, kJ/(kg $BW^{0.75}$ ·d) = 4.0 (day of gestation) + 66; adjusted for the sow effect; $r^2 = 0.89$; n = 70. ME intake, kJ/(kg $BW^{0.75}$ ·d) = –1.3 (day of gestation) + 629; $r^2 = 0.99$; n = 70.

The ME_m was estimated as the difference between ME intake and ME requirements for fat and protein deposition. Assuming energetic efficiencies in pregnant sows of 0.80 and 0.60 for ME deposited as fat and protein, respectively (Noblet and Etienne, 1987; Noblet et al., 1991, 1999), it was estimated that ME_m averaged 405 kJ/(kg $BW^{0.75}$·d) in the present experiment. This value is lower than the maintenance requirements estimates reported by Close et al. (1985) and Noblet and Etienne (1987) of 420 kJ/(kg $BW^{0.75}$·d) and NRC (1998) of 444 kJ/(kg $BW^{0.75}$·d). Contrary to results from previous experiments (Noblet and Etienne, 1987; Noblet et al., 1997; Ramonet et al., 2000), ME_m for the present experiment was higher in late compared with mid-gestation. This may be attributed to the very metabolically active uterine tissues in late gestation whose weight was quite high when compared with most literature data.

In the present experiment, N retention was higher in early and late gestation compared with mid-gestation. In early gestation, N retention is mainly maternal because retention in the products of conception

Table 7. Effect of day of gestation on estimated HP, uterine and maternal energy retention in late pregnant sows

	Actual		Required for zero energy retention[a]	
Day of gestation	90	110	90	110
BW, kg	215	230	215	230
kJ/(kg $BW^{0.75}$·d)				
ME intake	514	489	448	586
HP	426	505	409	530
Uterine energy retention	39	56	39	56
Maternal energy retention	49	–72	0	0
ME intake, MJ/d	28.9	28.9	25.2	34.6

[a]Calculated ME intake required to result in zero maternal energy retention, using an efficiency of energy retention for gain of 74% (Noblet et al. 1994).

amounts to 1 to 2 g/d (Dourmad et al., 1996). Alternatively, in late gestation, most of N is retained in the udder and products of conception (14 g/d at 105 d after mating, according to Noblet et al., 1985). The increased N retention around d 36 of gestation can be related to an increase in N retention in maternal tissues, whereas that found in late gestation is mainly related to the development of the conceptus. Increasing N retention from mid- to late gestation is consistent with the findings of King and Brown (1993), Everts and Dekker (1994), and Dourmad et al. (1996).

Physical Activity

Activity HP averaged 23.7% of total HP or 21.9% of ME intake and was greater than that reported by Noblet et al. (1993b) at 15.2% of total HP in castrated adult sows, but ranged from 14.2 to 41.5% with large variation between individual sows. The mean cost of standing activity was 0.30 kJ/(kg $BW^{0.75}$·min) standing, which was similar to that reported by Noblet et al. (1993b). On average, 22% of ME intake was used for physical activity, but this was higher in late compared with early gestation. The average duration of standing time of 266 min/d was slightly greater than the 241 min/d reported by Noblet et al. (1993b), but there was a large range in standing time (<150 to >500 min/d). Sows that stood for 100 min/d or less had AHP similar to that of sows lying down at 40 kJ/(kg $BW^{0.75}$·d). Sows standing 500 min/d had three times greater AHP at 120 kJ/(kg $BW^{0.75}$·d). The difference between the highest and the lowest levels of AHP (60 vs. 200 kJ/kg $BW^{0.75}$ daily) represented the equivalent of about 800 g of a corn/soybean meal diet (13.7 MJ/kg of ME daily) for a 230-kg sow.

Effect of Carnichrome on Energy Utilization and Performance

The decreases in plasma nonesterified fatty acids and urea nitrogen observed from feeding L-carnitine and the reduction in plasma insulin and glucose observed from chromium picolinate reported by Woodworth et al. (2002) suggest that energy status of sows was improved from feeding L-carnitine and chromium picolinate (Carnichrome). In previous research, feeding dietary carnitine during gestation increased sow weight gain and backfat (Musser et al., 1999b), and dietary chromium tended to increase weight gain (Lindemann et al., 1995b). Contrary to expectation, Carnichrome had no effect on total HP, energy retained as protein or lipid and maternal energy retention in early, mid-, or late gestation. Because AHP was numerically higher for the Carnichrome compared with the control treatment, HP and retained energy was adjusted to the average AHP of all sows (Table 6). With the adjustment, Carnichrome still did not influence HP or retained energy. Carnichrome had no effect on fetal number, fetal weights, or uterine weights; however, effects were not expected due to the limited number of observations for these measurements in the present experiment.

Implications

When sows were fed Carnichrome in gestation, no effects were observed on heat production or retained energy as protein or lipid in early, mid-, or late gestation. The results of the present experiment indicate that improvements in reproductive performance found in previous experiments with Carnichrome did not seem to be due to changes in heat production or energy retention. Increased heat production in late gestation was determined as an additional 4.0 kJ/(kg $BW^{0.75}$·d) for each additional day from d 90 to 110 of gestation. In the energy balance study, a 20% increase in metabolizable energy intake would be required by sows in late gestation to prevent mobilization of maternal tissues. On average, 20% of metabolizable energy intake was utilized for physical activity, but there was large variation between individual sows in physical activity.

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