Animal (2010), **4:12**, pp 2004–2011 © The Animal Consortium 2010
doi:10.1017/S1751731110001242

animal

Effect of *N,N*-dimethylglycine supplementation in parturition feed for sows on metabolism, nutrient digestibility and reproductive performance

A. Cools[1,2†], D. Maes[2], J. Buyse[3], I. D. Kalmar[1], J.-A. Vandermeiren[1] and G. P. J. Janssens[1]

[1]*Laboratory of Animal Nutrition, Faculty of Veterinary Medicine, Ghent University, Heidestraat 19, B-9820, Merelbeke, Belgium;* [2]*Department of Reproduction, Obstetrics and Herd Health, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, B-9820, Merelbeke, Belgium;* [3]*Department of Biosystems, Laboratory of Livestock Physiology, Immunology and Genetics, Catholic University of Leuven, Kasteelpark Arenberg 30, B-3001 Leuven, Belgium*

(Received 8 February 2010; Accepted 28 April 2010; First published online 16 June 2010)

The current pilot study assessed the influence of N,N*-dimethylglycine (DMG) on insulin sensitivity, glucose and fat metabolism, nutrient digestibility and reproductive performance of sows in the peripartal period. At day 105 of gestation, 25 sows were randomly assigned to the control (*n *= 13) or the DMG group (*n *= 12). Sows from the DMG group were supplemented with 1 g DMG/kg feed until day 3 of lactation. After an overnight fast 1 day after farrowing, a blood sample of each sow was drawn. The plasma was analyzed for insulin, glucose, fructosamine, leptin, thiobarbituric acid reactive substances (TBARS), ferric reducing ability of plasma (FRAP), non-esterified fatty acids (NEFA) and triglycerides (TG) and an oral glucose tolerance test was performed. A rectal feces sample was collected and the apparent fecal digestibility (AFD) of crude fat (CFAT), crude protein (CP) and nitrogen-free extract (NFE) was calculated after proximate analyses. Finally, a colostrum sample was collected from each sow and analyzed for the presence of DMG. Reproductive performance parameters were recorded. The results showed an improvement in the AFD of CFAT, CP and NFE when DMG was supplemented. This beneficial effect confirms the hypothesis that DMG acts as an emulsifying agent. The improvement in digestibility in the DMG group was accompanied by a numerical increase in plasma TG (*P *= 0.067). Plasma NEFA concentrations were not different between treatment groups. DMG supplementation neither affected glucose clearance nor influenced plasma insulin, glucose, fructosamine or leptin levels. TBARS and FRAP also remained unaffected, despite previously reported anti-oxidative properties of DMG. Furthermore, no significant impact on reproductive performance could be recorded. In conclusion, DMG supplementation significantly improved nutrient digestibility. Possible beneficial effects on energy metabolism and reproductive performance of sows should be tested when DMG is supplemented for a longer period of time or at a higher dose.*

Keywords: sow, *N,N*-dimethylglycine, nutrient digestibility, glucose metabolism, reproduction

Implications

The supplementation of *N,N*-dimethylglycine (DMG) in parturition feed of sows has an emulsifying effect. This resulted in improvements in not only fat digestibility, but also the digestibility of the protein and the nitrogen-free dietary fraction. However, measures of reproductive performance were not affected by DMG supplementation. The addition of this supplement to gestation and lactation feed should be investigated. Supplementation of DMG over a longer period of time can possibly be beneficial in terms of sow body condition and reproductive performance of sows.

† Present address: Faculty of Veterinary Medicine, Laboratory of Animal Nutrition, Heidestraat 19, B-9820 Merelbeke, Belgium. E-mail: an.cools@ugent.be

Introduction

The peripartal period is a critical period in commercial sow herds. During the last third of gestation, the sow's metabolic and hormonal state dramatically changes (Weldon *et al.*, 1994a; Pere *et al.*, 2000). Sows can become catabolic during the last month of gestation (Close *et al.*, 1985), which was evidenced by increased concentrations of non-esterified fatty acids (NEFA) and glycerol in plasma (Revell *et al.*, 1998). This is due to increased fetal demand and can lead to reduced appetite (Weldon *et al.*, 1994a) and, in very rare cases, even to porcine ketosis (Alsop *et al.*, 1994). After day 85 of gestation, insulin sensitivity decreases (Pere *et al.*, 2000). Poor glucose tolerance during late gestation has also been reported (Weldon *et al.*, 1994b) and related to an increased

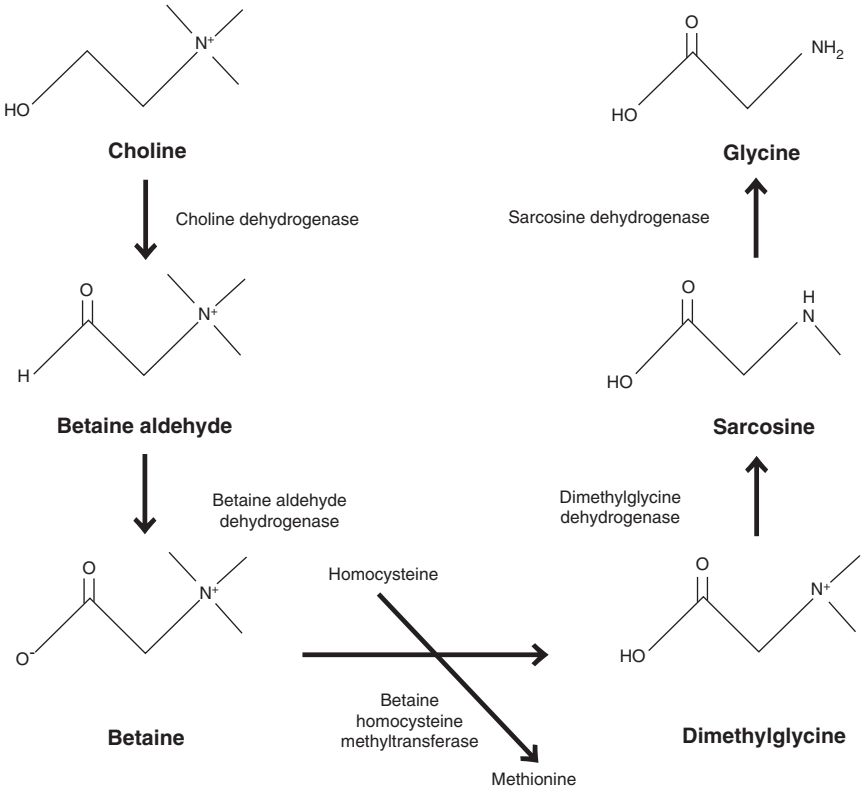

Figure 1 Overview of the choline pathway in which dimethylglycine (DMG) is an intermediate metabolite.

number of stillborn piglets (Kemp *et al.*, 1996), *post-partum* hypophagia (Weldon *et al.*, 1994a), hypogalactia and subsequently to increased pre-weaning piglet mortality (Ayoade, 2003).

Several studies indicate that both feed composition and the amount of feed offered during late gestation are of major importance in preventing reproductive problems in the peripartal period and the first few days of lactation. Overfeeding sows during late gestation and high back fat thickness at parturition predispose to several problems in the first few days *post partum*: low voluntary feed intake (Revell *et al.*, 1998), higher catabolic rate (Hulten *et al.*, 1993), increased NEFA mobilization and decreased insulin secretion (Weldon *et al.*, 1994a). In this regard, it is important to consider not only the amount of energy but also the source from which the energy is derived. For instance, van der Peet-Schwering *et al.* (2004) reported a decreased glucose tolerance and an increased number of stillborn piglets when sows were fed extra energy from fat during late gestation. But none of these problems were recorded when energy was supplied as starch, indicating the importance of feed components (van der Peet-Schwering *et al.*, 2004).

General feed composition not only influences the reproductive performance of sows, but also feed additives can have an influence on production results. Choline is one of those supplements. It has been commonly used for many decades as an additive in sow feed and its beneficial effect on sow and piglet performance has been reported in several studies (Kornegay and Meacham, 1973). More recently, a study on supplementation of betaine, a metabolite of choline, reported significantly improved total tract digestibility of crude fat (CFAT), crude ash (CA) and fiber (CF) in weaned piglets without affecting digestibility of crude protein (CP) and nitrogen-free extract (NFE) (Eklund *et al.*, 2006). A less known substance is *N,N*-dimethylglycine (DMG), which – similar to choline and betaine – is related to glycine metabolism (Figure 1). DMG can act as a methyl donor (Friesen *et al.*, 2007) similar to betaine and, additionally, has anti-oxidative properties (Hariganesh and Prathiba, 2000). As methyl donation capacity (Jin *et al.*, 2007) and anti-oxidative action (Lai, 2008) are both associated with increased insulin sensitivity, DMG can possibly influence insulin sensitivity. Other studies report that DMG, used as a dietary supplement, reduces blood lactate level and improves athletic performance in men (Tonda and Hart, 1992), horses (Greene *et al.*, 1996) and dogs (Gannon and Kendall, 1982). Only one study investigated the effect of DMG as a feed additive in livestock production, namely on broiler performance (Kalmar *et al.*, 2010). In that study, an improved feed conversion rate of DMG-supplemented broilers was reported. Besides the application of DMG as a supplement for both humans and animals, DMG-derived molecules are also used as surfactants in industrial applications (Guan and Tung, 1998), which indicates that DMG can possibly function as an emulsifying agent when added to the feed.

The current pilot study assessed the influence of DMG on insulin sensitivity, glucose and fat metabolism, nutrient digestibility and reproductive performance of sows in the peripartal period.

Material and methods

The experiment was approved by the Ethics Committee of the Faculty of Veterinary Medicine, Ghent University Belgium (EC 2008/070) and by the Federal Public Service Health Food Chain Safety and Environment, Belgium.

Animals, experimental design and dietary treatment

The experiment was performed at the experimental farm of a feeding company (AVEVE N.V., Leuven, Belgium) during the months June, July and August 2008. In the herd, a 3-week batch production system for sows was practiced. One group of the batch system, comprising 25 sows (Rattlerow Seghers hybrid) of different parities, was included in the study. The sows were housed individually in mechanically ventilated stables with a 12-h light period from weaning until day 28 of gestation and were fed a standard gestation diet (Table 1). Thereafter, the sows were moved to a group housing system with *ad libitum* access to a gestation feed, rich in soluble fiber, for creating a feeling of satiety (Table 1). At day 105, the beginning of the experiment (day 1), the sows were removed from the gestation unit, body weight (BW) of each individual sow was recorded and they were transferred to the farrowing unit. They were housed individually in farrowing crates until weaning. Sows were randomly allocated into two treatment groups: a control group ($n = 13$, parity 3.8 ± 3.0) and a DMG group ($n = 12$, parity 3.8 ± 2.4).

All sows were daily fed 3.5 kg of a standard gestation feed starting from day 105 of gestation until day 109 of gestation (day 5). On days 110 and 111 of gestation (days 6 and 7), all sows received 3.0 and 2.5 kg of the same standard gestation feed, respectively (Table 1). From day 112 of gestation (day 8) until 3 days after the calculated farrowing date (day 14), all sows received the same parturition feed containing 1% celite® (source of acid insoluble ash (AIA)) as an external marker to measure apparent fecal digestibility (AFD; Sales and Janssens, 2003; Tables 1 and 2). The amount of parturition feed provided to each sow at days 112, 113 and 114 of gestation was 2.0, 1.5 and 1.0 kg, respectively. One kg was given daily until parturition, and from parturition onward the daily amount was increased again with 0.5 kg a day. On day 15 of the trial, all sows were switched to a standard lactation diet (Table 1) that was provided *ad libitum*. Feed samples of each diet were taken and analyzed according to the Association of Official Analytical Chemists (AOAC) methods (Thiex, 2002; Table 1). For the parturition feed also, the amount of AIA was determined as described by (Sales and Janssens, 2003).

From day 1 (day 105 of gestation) until day 14 of the trial, all sows in the DMG group received 1 g DMG (Taminizer-D, supplied by Taminco N.V., Ghent, Belgium) per kg feed supplemented on top of their daily feed portion. The dose of 1000 ppm was based on the supplementation levels recommended for choline nutrient requirements of swine (NRC, 1998).

During the entire experiment, all sows had free access to fresh drinking water (drinking nipple – flow 1.5 to 2 l/min).

Blood sampling and oral glucose tolerance test (OGTT)

One day after parturition, a blood sample was taken and an OGTT performed after an overnight fasting period of 12 h, as described by Kemp *et al.* (1996) and van der Peet-Schwering *et al.* (2004). For sows that started farrowing after 2100 h, blood sampling and OGTT were performed 2 days after the actual farrowing date, also after an overnight fasting period of 12 h.

At 0700 h, a 30-ml blood sample was taken from the vena jugularis. Blood samples were divided into four subsamples: 9 ml on serum cloth activator (fructosamine and insulin analyses), 9 ml on lithium heparin (leptin, triglycerides (TG), thiobarbituric acid reactive substances (TBARS) and ferric

Table 1 *Feeding scheme and nutrient content of the different diets provided to the sows before, during and after the trial*

Feeding period[1]	Insemination – day 28	Day 29 to day 104	Day 105 to day 111	Day 112 – parturition + 3[6]	Farrowing + 4[7] – weaning[8]
Type of feed Control DMG	Gestation	Gestation	Gestation No DMG +DMG[4]	Parturition No DMG + AIA[5] +DMG[4] + AIA[5]	Lactation
Feeding level	Restricted	*ad libitum*	Restricted	Restricted	*ad libitum*
Dry matter[2]	884.9	907.8	884.9	902.9	911.3
Crude ash[2]	62.3	62.6	62.3	78.6	58.2
Crude protein[2]	135.3	135.5	135.3	148.6	160.6
Crude fat[2]	41.4	33.6	41.4	51.3	51.1
Crude fibre[2]	76.8	62.2	76.8	70.0	59.6
NE[3]	8.7	8.0	8.7	9.5	9.5

DMG = *N,N*-dimethylglycine.
[1]Period of reproduction cycle during which the particular feed was given to the sows.
[2]Diet analyses (g/kg feed).
[3]Net energy (MJ/kg feed), calculated value using feed formulation software (Bestmix® Feed, Adifo N.V., Maldegem, Belgium).
[4]*N,N*-dimethylglycine, supplemented on top of feed at a ratio of 1 g/kg feed.
[5]Acid insoluble ash 1% added to the parturition feed.
[6]Three days *post partum*.
[7]Four days *post partum*.
[8]Weaning at day 26 ± 2 of lactation.

Table 2 *Composition of the parturition diet*

Ingredient	Amount (%)
Soybean meal	17.49
Barley	14.26
Sugar beet pulp	14.26
Wheat	12.55
Wheat bran	9.50
Soy hulls	6.45
Molasses[1]	5.70
Manioc	4.75
Wheat gluten feed	3.29
Maize	2.38
Fish oil	1.98
Pork lard	1.98
Chalk	1.65
Mineral premix[2]	1.04
Celite	0.99
Soy oil	0.48
Sodium chloride	0.47
Linseed	0.42
Choline chloride	0.16
Vitamin premix[3]	0.07
Methionine	0.05
Luctarom S[4]	0.05
Trace elements[5]	0.02
L-threonine	0.01

[1]Sugar beet molasses.
[2]Mineral premix: 4.8% mono iron sulphate, 0.5% copper sulphate, 85.3% magnesium phosphate, 6.8% monocalcium phosphate and 2.6% zinc sulphate.
[3]Vitamin premix: 6.33 g/kg vitamin A, 272.15 g/kg vitamin E, 0.063 g/kg vitamin D_3, 5.02 g/kg vitamin K, 75.30 g/kg vitamin PP, 5.02 g/kg vitamin B_1, 25.10 g/kg vitamin B_2, 37.65 g/kg vitamin B_3, 15.06 g/kg vitamin B_6, 7.53 g/kg vitamin B_9, 0.08 g/kg vitamin B_{12} and 0.75 g/kg vitamin H.
[4]Luctarom S is an industrial flavor, added to the feed to improve feed intake. The product has no nutritional value.
[5]Trace elements premix: 485.07 g manganese/kg premix, 1.02 g cobalt/kg premix, 12.03 g iodine/kg premix, 2.00 g selenium/kg premix.

reducing ability of plasma (FRAP) analyses), 9 ml on K_3EDTA (NEFA analyses) and 3 ml on sodium fluoride/potassium oxalate (glucose analyses). The blood subsamples were stored on iced water (4°C) for about 5 h. Subsequently, tubes were centrifuged at 3000 × **g** for 10 min and plasma and serum samples were stored frozen at −20°C until analysis. After this blood sampling, the tail of each sow was washed with disinfectant soap. At 0750 h, a blood sample from a small incision in the tail was taken and the glucose concentration in this blood sample was measured using a glucose meter (Precision Xceed™, Abbott Diabetes Care, Louvain-la-Neuve, Belgium). This device has a coefficient of variation of 6.7% and the accuracy is according to ISO 15197 standards for glucose meters (Scandinavian evaluation of laboratory equipment for primary health care (SKUP, 2006)). Ten minutes later (0800 h), sows were fed 3 g glucose/kg $BW^{0.75}$ and blood samples were taken at 11 time points (10, 20, 30, 40, 50, 60, 70, 80, 90, 105 and 120 min after glucose feeding) followed by glucose analysis as described above. Area under the curve (AUC) for glucose was calculated according to the trapezoidal method.

Colostrum and feces sampling

After the OGTT was completed, sows were fed their morning feed portion. Subsequently, a colostrum sample was taken from each sow after an intramuscular injection of 1 ml oxytocine. Finally, a fresh rectal feces sample of each sow was taken. Both the colostrum and feces samples were stored frozen at −20°C until analysis.

Analyses of blood samples

Insulin was analyzed using an immunoradiometric assay kit (BioSource INS-IRMA Kit, BioSource Europe S.A., Nivelles, Belgium). Glucose and fructosamine were both determined spectrophotometrically (Roche/Hitachi Modular P Analyzer, Roche Diagnostics, Mannheim, Germany) by adding hexokinase and glucose-6-phosphate dehydrogenase (Gluco-quant, Roche Diagnostics, Mannheim, Germany) for glucose analysis and nitrotetrazolium-blue (Fructosamine, Roche Diagnostics, Mannheim, Germany) for fructosamine analyses. TG were also measured spectrophotometrically (Monarch Chemistry System, Instrumentation Laboratories, Zaventem, Belgium) using a commercial colorimetric diagnostic kit (IL Test kit No. 181610-60, Instrumentation Laboratories, Zaventen, Belgium). Leptin in plasma samples was measured using a multispecies immunoradiometric assay kit (Multi-Species Leptin RIA Kit, Linco Research Inc., St Charles, Missouri, USA). Plasma NEFA concentrations were determined using a WAKO NEFA-HR(2) test (Wako Chemicals GmbH, Neuss, Germany), modified for use on the Monarch Chemistry System. Plasma lipid peroxidation, expressed as TBARS, was measured spectrophotometrically (Monarch Chemistry System, Instrumentation Laboratories) as described in detail by Lin *et al*. (2004). Results are reported as the concentration of malondialdehyde (MDA) measured per milliliter of plasma after reaction. Similarly, the total plasma anti-oxidative capacity of plasma, expressed as FRAP, was measured spectrophotometrically (Monarch Chemistry System, Instrumentation Laboratories) as described by Benzie and Strain (1996). Results are reported as the concentration of Fe^{2+} measured per liter of plasma after reaction.

Colostrum analyses

First, the colostrum samples were extracted with hexane to remove the fat fraction. The aqueous layer that contained the DMG was then separated from the hexane layer. Subsequently, diethylglycine sodium salt was added to the aqueous extract as an internal standard. After evaporation of the aqueous solution under a nitrogen stream, *N,O*-bis(trimethylsilyl)trifluoroacetamide and dimethylformamide were added to derivatize both the DMG and the internal standard. Finally, the sample was injected in a gas chromatograph equipped with a split injector and flame ionization detector. The results were calculated based on the internal standard.

Feces analyses

Feces samples of each sow were analyzed for AIA, dry matter, CP, CA, CFAT and CF according to Thiex (2002). Using these results and the analyses of the parturition feed, the AFD of these nutrients was calculated using the external

marker method with AIA as the external marker, according to the following formula:

$$AFD = [1-(F/D \times D_{AIA}/F_{AIA})] \times 100$$

with F = % nutrient in the feed, D = % nutrient in the feces, F_{AIA} = % AIA in the feed and D_{AIA} = % AIA in the feces (Goddard and McLean, 2001).

Reproductive performance parameters

The following reproductive parameters of the sows were investigated: gestation length, number of total born, live born and stillborn piglets and the number of weaned piglets. The litter weight at birth and at weaning and the mortality rate of piglets before weaning were also recorded.

Statistical analyses

The effect of DMG supplementation on glucose tolerance, blood parameters, AFD and reproduction parameters were analyzed using Student's *t*-test for independent samples after performing a Kolmogorov–Smirnov test to verify normality and Levene's test to determine equality of variance. The DMG content in the colostrum and the number of stillborn piglets were not normally distributed and therefore these data were analyzed using the non-parametric Mann–Whitney test. All statistical analyses were performed using SPSS 17.0 (SPSS, 2008), considering statistical significance when $P < 0.05$. All data are reported as mean ± s.d.

Results

Oral glucose tolerance test

The OGTT was successfully performed in 11 sows of the control group and 10 sows of the DMG group. Four sows (two from the control and two from the DMG group) were excluded from the OGTT because their tail was too short to perform the protocol correctly. Basal glucose levels, measured 10 min before the sows were offered their individual glucose load, were similar for both treatments (4.2 ± 1.1 mmol/l and 4.1 ± 1.7 mmol/l for control and DMG group, respectively, $P > 0.05$). Glucose tolerance, represented as the AUC after the OGTT, was not significantly influenced by supplementation of DMG. The average AUC values were 612 ± 105 mmol × min/l for the control group and 650 ± 151 mmol × min/l for the DMG group. A maximal increase in blood glucose level of 2.4 ± 1.4 mmol/l above basal level was recorded for sows of the control group after 57 ± 35 min, which was not significantly different from the maximal increase observed in sows of the DMG group (2.7 ± 1.5 mmol/l after 54 ± 29 min). After 120 min, blood glucose levels had decreased again to 4.7 ± 0.8 mmol/l in the control group and to 5.2 ± 0.7 mmol/l in the DMG group ($P > 0.05$).

Blood parameters

The results of the blood parameters are given in Table 3. Supplementation of DMG had no significant influence on glucose, insulin or fructosamine ($P > 0.05$). Similarly, leptin concentration in blood samples was not significantly affected by dietary treatment ($P > 0.05$). Although no significant difference could be seen for NEFA ($P > 0.05$), TG tended to be lower ($P = 0.067$) for the control group (0.29 ± 0.16 ng/ml) compared to the DMG group (0.47 ± 0.31 ng/ml). Neither TBARS nor FRAP were significantly affected by supplementation of DMG ($P > 0.05$).

Table 3 *Results (mean ± s.d.) of the blood parameters of sows in the control group (*n = *13) and the DMG group (*n = *12)*

Parameter	Control group	DMG group	*P*-value
Glucose (mmol/l)	4.3 ± 0.4	4.2 ± 0.5	0.394
Insulin (mU/l)	18.3 ± 12.8	21.2 ± 17.2	0.597
Fructosamine (μmol/l)	247 ± 19	241 ± 14	0.397
Leptin (ng/ml)	1.9 ± 0.6	1.8 ± 0.6	0.874
TBARS (nmol/ml)[1]	1.3 ± 0.5	1.5 ± 0.6	0.318
FRAP (μmol/l)[2]	116 ± 20	129 ± 30	0.198
Triglycerides (mmol/l)	0.29 ± 0.16	0.47 ± 0.31	0.067
NEFA (mmol/l)	0.63 ± 0.31	0.77 ± 0.32	0.291

DMG = *N,N*-dimethylglycine; TBARS = thiobarbituric acid reactive substances; MDA = malondialdehyde; FRAP = ferric reducing ability of plasma; NEFA = non-esterified fatty acids.
Blood samples were taken at day one *post partum*. Sows of the DMG group were supplemented with 1 g DMG/kg feed during 14 days.
[1]TBARS expressed as the amount of MDA measured in plasma.
[2]FRAP expressed as the concentration of Fe^{2+} measured in plasma.

Table 4 *Results (mean % ± s.d.) of the AFD of nutrients of sows of the control group (*n = *11) and the DMG group (*n = *9)*

Parameter	Control group	DMG group	*P*-value
AFD crude fat	84 ± 9	91 ± 2	0.032
AFD CP	67 ± 17	81 ± 4	0.024
AFD NFE[1]	75 ± 15	87 ± 4	0.029

AFD = apparent fecal digestibility; DMG = *N,N*-dimethylglycine; NFE = Nitrogen-free extract.
Feces samples were taken at day 1 *post partum*. The DMG group was supplemented with 1 g DMG/kg feed during 14 days.
[1]NFE calculated based on the complete proximate analyses of feed and feces samples (NFE = dry matter – crude fiber – crude fat – CP – crude ash).

AFD of nutrients

Feces samples of 11 sows of the control group and nine sows of the DMG group were analyzed. No rectal feces samples could be taken from two sows of the control group and three sows of the DMG group because these five sows were constipated. The AFD results are given in Table 4. AFD of CFAT, CP and of NFE were significantly improved in the DMG group compared to the control group ($P < 0.05$).

Colostrum analyses

Colostrum samples of 13 sows of the control group and 11 sows of the DMG group were analyzed. From one sow of the DMG group, the amount of colostrum sampled was insufficient for analysis. The concentration of DMG in the colostrum of both groups was low and not significantly

Table 5 *Results (mean ± s.d.) of reproductive performance parameters of sows of the control group (n = 13) and the DMG group (n = 12)*

Parameter	Control group	DMG group	*P*-value
Gestation length (days)	116.4 ± 3.3	115.4 ± 1.2	0.334
Number of total born piglets	13.9 ± 2.5	13.6 ± 3.0	0.759
Number of live born piglets	13.0 ± 2.6	13.3 ± 2.7	0.743
Number of stillborn piglets[1]	0.9 ± 1.4	0.3 ± 0.6	0.180
Litter weight at birth (kg)	19.2 ± 2.4	20.5 ± 3.0	0.259
Mean individual piglet weight at birth (g)	1522 ± 215	1590 ± 248	0.469
Number of weaned piglets	10.9 ± 1.5	10.8 ± 2.3	0.908
Mortality during lactation (%)	13.8 ± 16.6	18.5 ± 15.2	0.466
Litter weight at weaning (kg)	68.8 ± 7.4	69.0 ± 13.2	0.966
Mean individual piglet weight at weaning (g)	6378 ± 916	6487 ± 1117	0.792

DMG = *N,N*-dimethylglycine.
The DMG group was supplemented with 1 g DMG/kg feed during 14 days.
[1]In contrast to all the other parameters, the number of stillborn piglets was tested using a non-parametric test instead of a parametric test because data were not normally distributed.

different from each other (7 ± 7 μg/g and 11 ± 16 μg/g for the control and DMG groups, respectively, $P > 0.05$).

Reproductive performance parameters

The reproductive performance parameters, shown in Table 5, were not significantly influenced by DMG supplementation ($P > 0.05$). However, the number of stillborn piglets was numerically lower in the DMG group (0.3 ± 0.6) than in the control group (0.9 ± 1.4, $P > 0.05$). In general, after a lactation period of 26 ± 2 days, an average number of 10.9 ± 1.9 piglets/litter were weaned with a total litter weight of 69 ± 10 kg.

Discussion

The results of this study observed at day 1 *post partum* indicated that the preprandial blood glucose levels were almost two-fold those recorded in studies testing glucose tolerance in a similar way at days 104 and 108 of gestation (Kemp *et al.*, 1996; van der Peet-Schwering *et al.*, 2004). Similarly, maximal increase in blood glucose level during the OGTT in this study performed *post partum* was higher and occurred later in time than in OGTT performed in late gestation (Kemp *et al.*, 1996; van der Peet-Schwering *et al.*, 2004). In line with this study and the previously mentioned studies of Kemp *et al.* (1996) and van der Peet-Schwering *et al.* (2004), the results of intravenous glucose tolerance tests performed on sows at day 109 of gestation and at day 4 of lactation confirm that glucose half-life is shorter in late gestation than in early lactation (Quesnel *et al.*, 2009). Different explanations can be given for the basal hyperglycemia and decreased glucose clearance rate observed in early lactation. Oliviero *et al.* (2008) reported elevated plasma cortisol levels for more than 1 day after parturition for sows housed in farrowing crates. These increased cortisol levels could explain the lowered insulin sensitivity of tissue at the beginning of lactation (Kronfeld *et al.*, 2005). Although cortisol was not measured in this study, it could be a possible explanation for the observed lower glucose clearance in early lactation. Hence, interference of cortisol with glucose metabolism could mask a possible effect of DMG on the glucose metabolism in early lactation in sows. This could also explain the lack of influence of DMG supplementation on the preprandial glucose, insulin and fructosamine levels, all these parameters being related to the glucose metabolism.

Despite the anti-oxidative properties of DMG reported in rats (Hariganesh and Prathiba, 2000), no influence on the oxidative parameters TBARS and FRAP were reported in this study. However, the doses used by Hariganesh and Prathiba (2000) were much higher than the dose used in the present trial (25 or 35 mg/kg BW in rats, in contrast to at the highest approximately 15 mg/kg BW for sows consuming the maximum of 3.5 kg feed/day in the present trial). In addition, the rats in this study suffered gastric ulceration resulting in a physiologically different status than sows on day one *post partum*.

Research on leptin in many different species, including humans, has revealed that this hormone is related to energy metabolism (Barb *et al.*, 2001; Budak *et al.*, 2006). Moreover, levels of leptin in sows can vary in relation to the feeding level (Quesnel *et al.*, 2009), feed composition, time after transition from one feed to another (Papadopoulos *et al.*, 2009) and body condition, mostly measured as back fat thickness (Prunier *et al.*, 2001). In this study, both feeding scheme and body condition of all sows were similar, resulting in similar fasting leptin levels at the first day of lactation for both treatment groups. Given the inducing role of leptin in insulin resistance, as reviewed by Barb *et al.* (2001), these similar leptin levels likely reduced the chance of finding differences in glucose tolerance induced by different dietary treatments. Fasting NEFA levels were also similar between treatments, indicating a similar amount of energy mobilized from fat reserves in both treatment groups. The absence of an influence of DMG supplementation on leptin combined with lack of effect on fasting NEFA concentration, the equal feed intake and similar body condition of all sows indicates that the present DMG supplementation over a period of 10 days did not affect the lipid metabolism of sows in the peripartal period. Although no influence on lipid metabolism could be recorded, the slight increase in TG blood levels and the significant improvement in AFD of CFAT indicate

that DMG supplementation over a longer period of time or at a higher dose might have a beneficial influence on lipid metabolism. Indeed, the results of AFD in this study indicate that DMG may act as an external emulsifier in pig feed (Wieland *et al.*, 1993; Dierick and Decuypere, 2004). The emulsifying effect of DMG incorporation in the sow's diet not only resulted in improvement of CFAT digestibility, but also improved digestibility of CP and NFE. These findings corroborate with the results of a previously published study on the addition of emulsifying agents to pig feed (Dierick and Decuypere, 2004). Studies on the effects of emulsification of fat sources in piglet feed indicate that the addition of emulsifiers to piglet feed improve nutrient digestibility, resulting in a reduction of feed costs (Jones *et al.*, 1992; Odle *et al.*, 1994). Seeing the limited number of studies published on the effects of addition of emulsifiers to the diets for sows, it would be worthwhile to do further research on the effect of DMG on nutrient digestibility.

Results of colostrum analyses in this study indicate that the technique used is not sensitive enough to measure small amounts of DMG in the colostrum samples. The low DMG levels detected in both groups indicate that little DMG is transferred into the colostrum. This finding is in line with previous studies reporting that most DMG is eliminated from the organism by demethylation rather than by excretion (Lever *et al.*, 2005) or in this case by secretion in the colostrum.

No direct effect of DMG supplementation on reproductive performance parameters was noted, except for a numerical decrease in the number of stillborn piglets in litters of sows fed diets supplemented with DMG. The incidence of piglet mortality at or shortly after farrowing may be linked to an increased glucose intolerance of sows during late gestation (Kemp *et al.*, 1996).

In conclusion, this study showed that short-term supplementation of DMG had an emulsifying effect that resulted in an improved nutrient digestibility. However, neither a significant influence on glucose clearance one day after parturition nor improved reproductive performance parameters could be substantiated in the present trial. Further research, in which DMG is supplemented for a longer period and/or at a higher dose, is warranted to investigate the possible beneficial effects of DMG on energy and lipid metabolism, health and performance of the sow and the piglets.

Acknowledgments

The authors thank Taminco N.V. (Ghent, Belgium) for financial support and providing the DMG, AVEVE N.V. (Leuven, Belgium) for providing the feed and the use of their experimental study farm, Koen Van Criekingen for the animal care and his help during blood sampling, Steven Galle for making feed mixtures and Herman De Rycke, Inge Vaesen and Annelies Callewaert for the analyses.

References

Alsop JE, Hurnik D and Bildfell RJ 1994. Porcine ketosis: a case report and literature summary. Journal of Swine Health and Production 2, 5–8.

Ayoade GO 2003. Lactation failure in sows – case report. African Journal of Medicine and Medical Sciences 32, 321–322.

Barb CR, Hausman GJ and Houseknecht KL 2001. Biology of leptin in the pig. Domestic Animal Endocrinology 21, 297–317.

Benzie IFF and Strain JJ 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Analytical Biochemistry 239, 70–76.

Budak E, Fernández Sánchez M, Bellver J, Cerveró A, Simón C and Pellicer A 2006. Interactions of the hormones leptin, ghrelin, adiponectin, resistin, and PYY3-36 with the reproductive system. Fertility and Sterility 85, 1563–1581.

Close WH, Noblet J and Heavens RP 1985. Studies on the energy-metabolism of the pregnant sow. 2. the partition and utilization of metabolizable energy-intake in pregnant and non-pregnant animals. British Journal of Nutrition 53, 267–279.

Dierick NA and Decuypere JA 2004. Influence of lipase and/or emulsifier addition on the ileal and faecal nutrient digestibility in growing pigs fed diets containing 4% animal fat. Journal of the Science of Food and Agriculture 84, 1443–1450.

Eklund M, Mosenthin R and Piepho HP 2006. Effects of betaine and condensed molasses solubles on ileal and total tract nutrient digestibilities in piglets. Acta Agriculturae Scandinavica, Section A-Animal Science 56, 83–90.

Friesen RW, Novak EM, Hasman D and Innis SM 2007. Relationship of dimethylglycine, choline, and betaine with oxoproline in plasma of pregnant women and their newborn infants. Journal of Nutrition 137, 2641–2646.

Gannon JR and Kendall RV 1982. A clinical evaluation of N,N-dimethylglycine (Dmg) and diisopropylammonium dichloroacetate (Dipa) on the performance of racing greyhounds. Canine Practice 9, 7–13.

Goddard JS and McLean E 2001. Acid-insoluble ash as an inert reference material for digestibility studies in tilapia, *Oreochromis aureus*. Aquaculture 194, 93–98.

Greene HM, Wickler SJ, Bray RE, Burrill MJ and London C 1996. The effect of N,N-dimethylglycine on athletic performance at altitude in horses and mules. Pferdeheilkunde 12, 499–501.

Guan JQ and Tung CH 1998. Dynamics of fluorescence quenching of pyrene in novel micelles of the zwitterionic betaine surfactant N-(3-dodecyloxy-2-hydroxypropyl)-N,N-dimethylglycine. Journal of Colloid and Interface Science 208, 90–95.

Hariganesh K and Prathiba J 2000. Effect of dimethylglycine on gastric ulcers in rats. Journal of Pharmacy and Pharmacology 52, 1519–1522.

Hulten F, Neil M, Einarsson S and Hakansson J 1993. Energy metabolism during late-gestation and lactation in multiparous sows in relation to backfat thickness and the interval from weaning to 1st oestrus. Acta Veterinaria Scandinavica 34, 9–20.

Jin CJ, Park HK, Cho YM, Pak YK, Lee KU, Kim MS, Friso S, Choi SW, Park KS and Lee HK 2007. S-adenosyl-L-methionine increases skeletal muscle mitochondrial DNA density and whole body insulin sensitivity in OLETF rats. Journal of Nutrition 137, 339–344.

Jones DB, Hancock JD, Harmon DL and Walker CE 1992. Effects of exogenous emulsifiers and fat sources on nutrient digestibility, serum-lipids, and growth-performance in weanling pigs. Journal of Animal Science 70, 3473–3482.

Kalmar ID, Cools A, Buyse J, Roose P and Janssens GPJ 2010. Dietary N,N-dimethylglycine supplementation improves nutrient digestibility and attenuates pulmonary hypertension syndrome in broilers. Journal of Animal Physiology and Animal Nutrition, in press, 1–9. doi:10.1111/j.1439-0396.2010.01018.x.

Kemp B, Soede NM, Vesseur PC, Helmond FA, Spoorenberg JH and Frankena K 1996. Glucose tolerance of pregnant sows is related to postnatal pig mortality. Journal of Animal Science 74, 879–885.

Kornegay ET and Meacham TN 1973. Evaluation of supplemental choline for reproducing sows housed in total confinement on concrete or in dirt lots. Journal of Animal Science 37, 506–509.

Kronfeld DS, Treiber KH and Geor RJ 2005. Comparison of nonspecific indications and quantitative methods for the assessment of insulin resistance in horses and ponies. Journal of the American Veterinary Medical Association 226, 712–719.

Lai MH 2008. Antioxidant effects and insulin resistance improvement of chromium combined with vitamin C and E supplementation for type 2 diabetes mellitus. Journal of Clinical Biochemistry and Nutrition 43, 191–198.

Lever M, George PM, Dellow WJ, Scott RS and Chambers ST 2005. Homocysteine, glycine betaine, and N,N-dimethylglycine in patients attending a lipid clinic. Metabolism 54, 1–14.

Lin H, Decuypere E and Buyse J 2004. Oxidative stress induced by corticosterone administration in broiler chickens (*Gallus gallus domesticus*): 1. Chronic exposure. Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology 139, 737–744.

NRC 1998. Nutrient requirements of swine, 10th edition. National Academy Press, Washington DC, USA.

Odle J, Lin X, Wieland TM and van Kempen TATG 1994. Emulsification and fatty acid chain length affect the kinetics of [14C]-medium-chain triacylglycerol utilization by neonatal piglets. Journal of Nutrition 124, 84–93.

Oliviero C, Heinonen M, Valros A, Halli O and Peltoniemi OA 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Animal Reproduction Science 105, 365–377.

Papadopoulos GA, Maes DG, Van WS, van Kempen TA, Buyse J and Janssens GP 2009. Peripartal feeding strategy with different n-6: n-3 ratios in sows: effects on sows' performance, inflammatory and periparturient metabolic parameters. British Journal of Nutrition 101, 348–357.

Pere MC, Etienne M and Dourmad JY 2000. Adaptations of glucose metabolism in multiparous sows: effects of pregnancy and feeding level. Journal of Animal Science 78, 2933–2941.

Prunier A, Guadarrama CA, Mourot J and Quesnel H 2001. Influence of feed intake during pregnancy and lactation on fat body reserve mobilisation, plasma leptin and reproductive function of primiparous lactating sows. Reproduction Nutrition Development 41, 333–347.

Quesnel H, Meunier-Salaun MC, Hamard A, Guillemet R, Etienne M, Farmer C, Dourmad JY and Pere MC 2009. Dietary fiber for pregnant sows: Influence on sow physiology and performance during lactation. Journal of Animal Science 87, 532–543.

Revell DK, Williams IH, Mullan BP, Ranford JL and Smits RJ 1998. Body composition at farrowing and nutrition during lactation affect the performance of primiparous sows: I. Voluntary feed intake, weight loss, and plasma metabolites. Journal of Animal Science 76, 1729–1737.

Sales J and Janssens GP 2003. Methods to determine metabolizable energy and digestibility of feed ingredients in the domestic pigeon (*Columba livia domestica*). Poultry Science 82, 1457–1461.

SKUP (Scandinavian evaluation of laboratory equipment for primary health care) 2006. Precision Xtra^{TM} Plus (G3c) Precision Xceed. SKUP, Bergen, Norway. Retrieved August 3, 2009, from http://www.skup.nu/GetFile.ashx?fileid=331.

SPSS Inc. 2008. SPSS version 17.0. SPSS Inc., Chicago, Illinois, USA.

Thiex N 2002. Feeds. Journal of AOAC International 85, 270–273.

Tonda ME and Hart LL 1992. N,N dimethylglycine and L-carnitine as performance enhancers in athletes. Annals of Pharmacotherapy 26, 935–937.

van der Peet-Schwering CMC, Kemp B, Binnendijk GP, den Hartog LA, Vereijken PFG and Verstegen MWA 2004. Effects of additional starch or fat in late-gestating high nonstarch polysaccharide diets on litter performance anal glucose tolerance in sows. Journal of Animal Science 82, 2964–2971.

Weldon WC, Lewis AJ, Louis GF, Kovar JL, Giesemann MA and Miller PS 1994a. Postpartum hypophagia in primiparous sows. 1. effects of gestation feeding level on feed-intake, feeding-behavior, and plasma metabolite concentrations during lactation. Journal of Animal Science 72, 387–394.

Weldon WC, Lewis AJ, Louis GF, Kovar JL and Miller PS 1994b. Postpartum hypophagia in primiparous sows. 2. effects of feeding level during gestation and exogenous insulin on lactation feed-intake, glucose-tolerance, and epinephrine-stimulated release of nonesterified fatty-acids and glucose. Journal of Animal Science 72, 395–403.

Wieland TM, Lin X and Odle J 1993. Utilization of medium-chain triglycerides by neonatal pigs: effects of emulsification and dose delivered. Journal of Animal Science 71, 1863–1868.