Mineral accretion in nursing piglets in relation to sow performance and mineral source

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ABSTRACT: The present study investigated the effect of a moderate substitution of inorganic mineral sources with chelated mineral sources from four weeks prior to parturition throughout lactation on sow and litter performance. In addition, the aims were to determine whether the mineral source and litter performance affect mineral status and accretion in piglets at birth and at weaning. Forty gestating sows in a commercial pig herd were selected and randomly assigned to two experimental groups, with part of the Cu, Mn, Zn and Fe content of the feed added as either an inorganic mineral source or a chelated mineral source. From each sow, one piglet was randomly selected at birth and at weaning for total body mineral analysis. Neither the performance of the sows and the piglets nor the total body mineral concentrations of the piglets at birth and at weaning were significantly different between the two diet groups ($P > 0.05$). Fe, Na and P content of piglets at birth were inversely correlated with birth weight ($r = –0.447$, $P = 0.004$ for Fe; $r = –0.431$, $P = 0.005$ for Na; $r = –0.340$, $P = 0.032$ for P). Daily accretion rate of K and Ca of piglets was positively correlated with piglet growth performance during the entire lactation period ($r = 0.469$, $P = 0.008$ for K; $r = 0.581$, $P < 0.001$ for Ca), and negatively correlated with number of liveborn piglets ($r = –0.424$, $P = 0.014$ for K, and $r = –0.405$, $P = 0.027$ for Ca). In conclusion, the study documented that partial substitution of inorganic minerals with a chelated mineral source failed to exert significant effects on performance and total body mineral concentrations. The importance of the influence of sow milk production on mineral body stores in piglets warrants further investigation.

Keywords: sow; chelated minerals; piglet growth; mineral accretion

It is known that trace minerals, namely zinc (Zn) (Hambridge et al., 1986), copper (Cu) (Hambridge et al., 1986), iron (Fe) (Beard and Dawson, 1997) and manganese (Mn) (Leach and Harris, 1997) have an important role in metal-containing enzymes (metalloenzymes), provide structural integrity to proteins and/or may directly participate as catalysts in biochemical reactions. Trace minerals are also essential for proper immune function, as both innate and acquired immunity is compromised during Zn and Cu deficiencies (Failla, 2003).

During past years, a considerable number of studies have been conducted to investigate the effects of chelated versus inorganic mineral sources in pig diets, especially in growing pigs. In the chelated mineral sources, the minerals are bound to organic ligands. The organic ligands usually comprise a mixture of amino acids, and consequently mineral chelates can utilize amino acid uptake mechanisms in the intestine (Ashmead et al., 1985; Ashmead, 1993; Power and Horgan, 2000). The mineral within the complex is perceived to be protected from physiochemical factors or from negative interactions with dietary components, as phytate, which binds cations making them unavailable for absorption (Fairweather-Tait, 1996).

In sows, many macro- and micro-elements can be stored in body tissues, so that during periods of high nutritional demand, the sow can mobilize and utilize them (Mahan, 1990). Minerals in sows are essential for the growth of foetuses, mammary secretions, growth and maintenance (Mahan, 1990). Therefore, increasing the bioavailability of dietary minerals may improve the performance of the sow. Mirando et al. (1993) found that partial substitution of inorganic mineral sources with chelated mineral sources (25% of the minerals supplied from chelated sources) was beneficial for sows' reproductive performance. More sows on the chelated diet became pregnant and had more live foetuses and less dead foetuses than the sows fed the inorganic diet (Mirando et al., 1993).

Previous research has shown that most trace minerals increase at a rapid rate in piglet tissues during the nursing period, implying that the maternal mineral tissue stores are transferred to milk and then onto the tissue (Mahan and Shields, 1998). Body Mg, Zn, Fe and Mn have been observed to increase from birth until weaning, while Cu decrease (Mahan and Shields, 1998). Minerals other than trace elements, like Ca and P meanwhile, increase from birth to weaning. Body Na has been measured as high at birth and then been seen to decline postnatal, while the opposite has been observed for the amount of K (Mahan and Shields, 1998). It has been demonstrated previously that lactating sows nursing larger litters exhibit a greater extent of bone demineralization (Maxson and Mahan, 1986). However, information is limited regarding the relationship between the mineral accretion by the piglets, from birth until weaning, and performance parameters, such as piglet and litter growth and litter size.

The aim of the present study was to evaluate the effect of a partial supplementation of an inorganic mineral source with a chelated mineral source during the last weeks of gestation and throughout lactation, on sow performance and on mineral accretion in piglets. Another aim of this study was to investigate whether the mineral source and litter performance could affect mineral status and accretion in piglets at birth and at weaning. Because of the present economical constraints to including high levels of chelated minerals, only a moderate substitution (on average 26%) was deliberately chosen.

MATERIAL AND METHODS

Experimental design and diets

The present study included forty (40) multiparous sows (Hypor). The experimental period started four weeks before the expected farrowing date. The sows were divided into two equal groups. As treatments, 27%, 20%, 36% and 23% of total dietary Cu, Zn, Mn, and Fe, respectively, were provided either as a chelated mineral source (Optimins, Nordos-Nutreco) or as an inorganic mineral source (composition Table 1). The sows received the same type of diet from the beginning of the experiment until weaning (Table 2). From the start of the experimental period up until two days after parturition, the sows in both groups received a 150 g mineral supplement. After the 2nd day of lactation and until weaning, the sows received 220 g/day. Feed allowance until farrowing was 3 kg/day. After parturition, the amount of feed increased gradually up to a maximum daily feed allowance of 5.5 kg after the 5th day of lactation was reached. The sows were fed twice a day; feed intake was monitored throughout the experimental period and feed refusals were weighed each day before morning feeding. One week before the expected farrowing, sows were transferred to the farrowing rooms. Water was provided *ad libitum* during the last week of gestation and throughout the entire lactation period.

At birth and at weaning (within 12 hours after initiation of farrowing) piglets were individually weighed on a digital scale with an accuracy of 0.01 kg. Also at these points, one piglet was randomly selected from each sow. These piglets were euthanized by IM injection with T61® (Intervet-Schering-Plough), and stored at –20°C until analysis. Afterwards, the piglets were autoclaved, and homogenised prior to total body mineral analysis. In total, 20 piglets were analysed per diet group at birth and at weaning (80 piglets).

Analytical procedures

Concentrations of Ca, P, Mn, Zn, Mg, K, Na, Cu, Fe, and S were analysed by induction-coupled plasma spectrophotometry (ICP) at the University College of Ghent using the ICP-AES Iris Intrepid II XSP simultaneous emission spectrophotometer with dual-view, wavelength range 165–1 050 nm. The emission wavelength was specific for each element analysed.

Statistical analysis

The mineral concentration of the sacrificed piglets at birth and at weaning, the daily mineral accretion of piglets during lactation, the performance parameters of the sows (number of liveborn and stillborn piglets) and the piglets (piglet and

Table 1. Concentrations of Zn, Mn, Cu and Fe in the premix, supplements, and final feed

Mineral (mg/kg)	Premix 2.25%	Supplement (chelated/inorganic)	Raw materials	Total
Zn	75	40	35	150
Mn	38	20	40	98
Cu	8	10	10	28
Fe	113	60	85	258

litter growth, individual piglet weight at birth and at weaning, litter weight at birth and at weaning, daily rate of accretion of minerals during lactation per piglet) were analysed using analyses of variance with the mineral source (organic versus inorganic) as the fixed factor. The mineral accretion rate per piglet was calculated using the following equation:

$$\text{mineral accretion rate} = (\text{min}_{\text{concw}} \times \text{weight}_{\text{w}} - \text{min}_{\text{concb}} \times \text{weight}_{\text{b}})/28$$

where:

$\text{min}_{\text{concw}}$ = the concentration of minerals in the piglet at weaning

weight_{w} = the piglet weight at weaning

$\text{min}_{\text{concb}}$ = the concentration of minerals in the piglet at birth

weight_{b} = the piglet weight at birth

28 = the days of the lactation period

The associations between mineral content at birth or at weaning and the daily accretion rate of minerals with performance parameters were investigated with Pearson's correlation. The level of significance was set at $P < 0.05$. Statistical analyses were performed with SPSS 15.0 (Chicago IL, USA).

RESULTS

The mineral content of the piglets of the two study groups did not differ significantly between the two diets at birth and at weaning (Table 3). Also with respect to the performance parameters of the piglets, only numerical differences were obtained between the two experimental groups (Table 4). No significant differences were found in mineral accretion rates throughout lactation between the two experimental groups (Table 5).

As the mineral source did not affect the studied parameters, data from both groups were pooled for studying correlations between performance parameters and mineral accretion. Total body Fe, Na, and P content of piglets at birth were inversely correlated with birth weight ($r = -0.447$, $P = 0.004$ for Fe; $r = -0.431$, $P = 0.005$ for Na; $r = -0.340$, $P = 0.032$ for P). There was no significant association between mineral content of piglets at weaning and performance parameters. The daily accretion rate of K and Ca of the piglets were positively correlated with piglet growth over the entire lactation period ($r = 0.469$, $P = 0.008$ for K; $r = 0.581$, $P < 0.001$ for Ca). The number of liveborn piglets was negatively correlated with the daily accretion rate of K ($r = -0.424$, $P = 0.014$) and of Ca ($r = -0.405$, $P = 0.027$).

Table 2. Composition of the experimental diet fed to the sows during late gestation and the entire course of lactation. The two experimental groups received the same basal diet

Main ingredients (%)	
Wheat	28.8
Wheat meal	10.0
Barley	10.0
Peas	10.0
Sugar beet pulp	9.9
Palm meal	5.0
Rapeseed	5.0
Maize	2.5
Fat	1.62
L-Lysine	0.2
L-Threonine	0.05
L-Methionine	0.03
Calcium phosphate	0.13
Nutrient composition	
Crude protein (g/kg)	148
Crude ash (g/kg)	57
Crude fat (g/kg)	46
Sugars (g/kg)	47
Starch (g/kg)	355
Net energy (MJ/kg)	9.1

Table 3. Mean total body mineral concentrations (± SD) at birth and at weaning in piglets from sows supplemented with either chelated or inorganic trace elements

	At birth			At weaning		
	chelated	inorganic	*P*-value	chelated	inorganic	*P*-value
Ca (g/kg)	3.72 ± 0.65	3.97 ± 0.66	0.240	2.75 ± 0.44	2.73 ± 0.30	0.900
Cu (mg/kg)	1.9 ± 0.38	2.2 ± 1.0	0.230	1.7 ± 0.8	2.2 ± 1.7	0.260
Fe (mg/kg)	29 ± 9.9	29 ± 1.4	0.950	0.016 ± 0.005	0.021 ± 0.010	0.070
K (g/kg)	1.00 ± 0.22	0.98 ± 0.24	0.710	0.82 ± 0.23	0.86 ± 0.37	0.660
Mg (g/kg)	0.10 ± 0.016	0.11 ± 0.03	0.400	0.095 ± 0.021	0.10 ± 0.051	0.400
Mn (mg/kg)	0.47 ± 0.14	0.41 ± 0.14	0.160	0.39 ± 0.13	0.45 ± 0.19	0.240
Na (g/kg)	0.96 ± 0.36	0.84 ± 0.29	0.220	0.41 ± 0.11	0.43 ± 0.11	0.580
P (g/kg)	0.51 ± 0.15	0.53 ± 0.13	0.620	0.37 ± 0.08	0.36 ± 0.12	0.730
S (g/kg)	0.2 ± 0.01	0.019 ± 0.011	0.790	0.01 ± 0.006	0.012 ± 0.01	0.590
Zn (mg/kg)	10 ± 3	8.8 ± 3	0.110	9 ± 2.8	10 ± 4	0.360

Table 4. Mean performance parameters (piglet and litter growth, piglet weight at birth and at weaning, litter weight at birth and at weaning) of piglets born to sows belonging either to the group fed on diets supplemented with chelated or in the group fed on diets supplemented with inorganic trace elements

	Chelated	Inorganic	*P*-value
Piglet growth (g/day)	204 ± 32	204 ± 36	0.970
Litter growth (g/day)	2 171 ± 370	1 962 ± 674	0.280
Weight at weaning (kg)	7.3 ± 1.0	7.2 ± 1.0	0.810
Litter weight at weaning (kg)	70 ± 10	63 ± 16	0.110
Litter weight at birth (kg)	20 ± 4	19 ± 3	0.490
Birth weight (kg)	1.59 ± 0.29	1.50 ± 0.24	0.330

Table 5. Daily accretion rate per piglet (μg/day) throughout the lactation period. The differences between the two experimental groups were not statistically significant

Mineral accretion rate (μg/day)	Chelated	Inorganic
Zn	1.8	1.8
S	1.5	1.0
P	67	50
Mn	0.07	0.07
Mg	18	14
K	154	154
Fe	2.4	2.5
Cu	0.34	0.22
Ca	488	483

DISCUSSION

Partial supplementation of sow diet with chelated minerals generated no significant effects on performance and total body mineral concentration in the present study. The reasons for the absence of any effects are not clear but could be multiple. In the first instance, it could be attributed to the fact that chelated minerals were supplemented only during the last four weeks of gestation and throughout lactation. Although porcine foetal growth accelerates significantly during the last trimester of pregnancy (McPherson et al., 2004), and the mineral composition of foetal pigs follows the same pattern (Wu et al., 1999), the accretion of minerals by the piglets in utero and the build up of maternal tissues might already be influenced by supplementation at earlier stages.

Second, the nature of the chelate itself could also explain the absence of significant differences. A recent study on broiler chickens (Huang et al., in press), reveals differences in bio-availability according to the chelation strength of zinc chelates. Since only one chelate type was tested in the present study, we cannot discern whether this has been a reason for the lack of effect.

Third, all sows in this study were fed restrictively equal amounts of feed and, therefore, mineral supplement (chelated or inorganic). This restricted feeding possibly did not meet the nutritional demands of the sow during late gestation and early lactation, as factors such as body weight and/or parity of the sow were neglected. Mahan and Newton (1995) have shown that the body mineral contents of gilts at 24 months of age were higher than at nine months and that this difference may be attributed to additional hard and soft tissue growth, which resulted in higher quantities of the minerals being deposited in the body. In addition, Peters and Mahan (2008a) demonstrated that the trace mineral intake of lactating sows increased quadratically to parity 4 and declined afterwards.

The negative correlation between the Fe, Na, and P levels at birth with birth weight may be interpreted to signify that piglets which are heavier at birth will have less Fe, Na, and P content in comparison to their lighter littermates. That is, what may be occurring is a possible dilution of the levels of these minerals in relation to a higher body mass of the piglets. As described previously, the quantity of body Fe probably reflected the quantity of heme and non-heme Fe compounds in body muscle mass relative to total body weight, while body Na was high at birth and then declined after birth (Mahan and Shields, 1998). Moreover, the existence of this negative correlation is of particular importance for the Fe status during early stages of lactation. As postnatal growth increases, the need for Fe especially increases, because of the greater volume of blood necessary to maintain the greater amount of tissue being formed (Peters and Mahan, 2008b). Thus, heavier piglets at birth may exhibit signs of anaemia sooner than their littermates (Peters and Mahan, 2008b). Moreover, it becomes evident that the Fe stores of the sow available for transfer to foetuses or to the mammary tissue should be increased, probably by increasing the bioavailability of Fe from dietary sources.

Furthermore, higher daily accretion rates of K and Ca by piglets corresponded with higher piglet growth during the lactation period. Piglet growth is considered as an indicator of milk production levels of sows (Lewis et al., 1978). Maxson and Mahan (1986) found that, in lactating sows that nurse larger litters, a greater amount of bone demineralization occurred. It could be hypothesised in the same manner, that the higher the piglet growth, the higher the mobilisation of Ca from the sow's tissues and as a result the higher the excretion in the sow's milk. Moreover, as reported elsewhere, the relative amount of K in the neonatal pig was low, increased dramatically during lactation, and then increased with increasing pig weight, resulting in an overall quadratic response (Mahan and Shields, 1998). The findings of the present study are consistent also with previous findings of our research group (Papadopoulos et al., 2008), in which milk production of sows during mid-lactation could be predicted by variations in the urinary levels of K and Ca in sows during mid-lactation. Furthermore the negative correlation between litter size and mineral accretion rate of K and Ca may indicate a dilution of these minerals in the milk of the sow, when litter size is increasing. It should be noted that the correlations derived from the present study require further investigation in order to elucidate the nature of the underlying mechanisms involved and to exert the maximum benefit for the productivity of the sow and growth of the progeny.

Results suggest that under the present field conditions, partial substitution of inorganic by chelated minerals exerted no significant effects on the mineral content of piglets at birth or at weaning, and on performance parameters. The fact that the literature reveals a potential for beneficial effects of chelated minerals, indicates that they act through mechanisms and on parameters which have not been completely elucidated to date. The study further suggests that high piglet growth and increased litter size might be associated with decreased mineral accretion in piglets, and hence might hamper their further development in cases of marginal mineral provision by the sow.

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REFERENCES

Ashmead H.D. (1993): Comparative intestinal absorption and subsequent metabolism of metal amino acid chelates and inorganic metal salts. In: The Roles of Amino Acid Chelates in Animal Nutrition. Noyes Publishers, New Jersey. 306–319.

Ashmead H.D., Graff D.J., Ashmead H.H. (1985): Intestinal absorption of metal ions and chelates. C.C. Thomas, Springfield, Illinois. 251 pp.

Beard J.L., Dawson H.D. (1997): Iron. In: O'Dell B.L., Sunde R.A. (eds.): Handbook of Nutritionally Essential Mineral Elements. Marcel Dekker, Inc. New York, NY. 275–334.

Failla M.L. (2003): Trace elements and host defense: Recent advances and continuing challenges. Journal of Nutrition, 133, 1443S–1447S.

Fairweather-Tait S.J. (1996): Bioavailability of dietary minerals. Biochemical Society Transactions, 24, 775–780.

Hambridge K.M., Casey C.E., Krebs N.F., (1986): Zinc. Mertz W. (ed.): Trace Elements in Human and Animal Nutrition. Vol. 2. Academic Press, Inc. New York, NY. 137 pp.

Huang Y.L., Lu L., Li S.F., Luo X.G., Liu B.: Relative bioavailabilities of organic zinc sources with different chelation strengths for broilers fed a conventional corn-soybean meal diet. Journal of Animal Science, in press. doi:10.2527/jas.2008–1212.

Leach R.M., Harris E.D. (1997): Manganese. In: O'Dell B.L., Sunde R.A. (eds.): Handbook of Nutritionally Essential Mineral Elements. Marcel Dekker, Inc. New York, NY. 335–355.

Lewis A.J., Speer V.C., Haught D.G. (1978): Relationship between yield and composition of sows' Milk and weight gains of nursing pigs. Journal of Animal Science, 47, 634–638.

Mahan D.C. (1990): Mineral nutrition of the sow: a review. Journal of Animal Science, 68, 573–582.

Mahan D.C., Newton E.A.: Effect of initial breeding weight on macro- and micromineral composition over a three-parity period using a high-producing sow genotype. Journal of Animal Science, 73, 151–158.

Mahan D.C., Shields R.G. (1998): Macro- and micromineral composition of pigs from birth to 145 kilgrams of body weight. Journal of Animal Science, 76, 506–512.

Maxson P.F., Mahan D.C. (1986): Dietary calcium and phosphorus for lactating swine at high and average production levels. Journal of Animal Science, 63, 1163–1172.

McPherson R.L., Ji F., Wu G., Blanton J.R., Jr., Kim S.W. (2004): Growth and compositional changes of fetal tissues in pigs. Journal of Animal Science, 82, 2534–2540.

Mirando M.A., Peters D.N., Hostetler C.E., Becker W.C., Whiteaker S.S., Rompala R. E. (1993): Dietary supplementation of proteinated minerals influences reproductive performance of sows. Journal of Animal Science, 71 (suppl. 1), 180. (abstract).

Papadopoulos G.A., Maes D.G.D., Van Weyenberg S., Verheyen A., Janssens G.P.J. (2008): Selected parameters in urine as indicators of milk production in lactating sows: A pilot study. The Veterinary Journal, 177, 104–109.

Peters J.C., Mahan D.C. (2008a): Effects of dietary organic and inorganic trace mineral levels on sow reproductive performances and daily mineral intakes over six parities. Journal of Animal Science, 86, 2247–2260.

Peters J.C., Mahan D.C. (2008b): Effects of neonatal iron status, iron injections at birth, and weaning in young pigs from sows fed either organic or inorganic trace minerals. Journal of Animal Science, 86, 2261–2269.

Power R., Horgan K. (2000): Biological chemistry and absorption of inorganic and organic trace minerals. In: Lyons T.P., Jacques K.A. (eds): Biotechnology in the Feed Industry, Proceedings of Alltech's 16th Annual Symposium, Nottingham University Press, UK, 277–292.

Wu G., Ott T.L., Knabe D.A., Bazer F.W. (1999): Amino acid composition of the fetal pig. Journal of Nutrition, 129, 1031–1038.

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