Influence of a Single Dose of Fe Dextran Administration with Organic Trace Mineral Supplementation on the Performance of Piglets**

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ABSTRACT : This study was designed to evaluate the influence of a single or double dose of Fe dextran with organic trace mineral supplementation on the performance of piglets from dams fed diets with either inorganic (ITM) or organic trace minerals (OTM). It also determined the effect of the source of the trace minerals on the reproductive performance of sows. The trace mineral premixes were prepared using metal proteinates and the corresponding inorganic salts for the OTM and the ITM, respectively. Each mineral premix provided 100 ppm Fe/175 ppm Fe, 35 ppm Cu/170 ppm Cu, 90 ppm Zn/120 ppm Zn, and 40 ppm Mn/35 ppm Mn when added at 0.20% in sows /weaned pigs' diets, respectively. The first dose of Fe dextran was administered to piglets at 3 d and the second dose at 10 d after birth. One dose of Fe dextran supplied 100 mg of Fe. A total of 16 gestating sows (Landrace×Yorkshire) in parities 2 to 4 were randomly allocated to four treatments: 1) diet with ITM/one dose of Fe dextran to piglets, 2) diet with ITM/two doses of Fe dextran to piglets, 3) diet with OTM/one dose of Fe dextran to piglets, and 4) diet with OTM/two doses of Fe dextran to piglets. The total born alive, weaned, body weight at birth and at weaning were not affected by the sow's dietary treatment. Although organic trace mineral supplementation tended to increase the milk Fe content ($p<0.10$) at 7 d postpartum, piglets in all treatments performed equally from birth to weaning. The double doses of Fe dextran neither improved the average daily gain (ADG) nor influenced the survival of piglets from birth to weaning (21 d). Results suggest that a single dose of Fe dextran given to suckling pigs is adequate to sustain their needs for growth throughout the lactation period (21 d). Furthermore, there was a 21% improvement in both the ADG and the average daily feed intake (ADFI) ($p<0.05$) in weaned pigs fed diets with OTM. Cu and Fe in the liver ($p<0.01$), and Zn in both the bone ($p<0.01$) and the serum ($p<0.01$) were higher in piglets fed OTM than in those fed ITM. It would be concluded that single dose of Fe dextran administration with organic trace mineral supplementation show similar growth performance compared to 2 dose Fe dextran administration with inorganic mineral supplementation in young pigs. ***(Asian-Aust. J. Anim. Sci. 2002. Vol 15, No. 10 : 1469-1474)***

Key Words : Organic Mineral, Fe Dextran, Performance, Piglet

INTRODUCTION

Suckling pigs are very susceptible to iron deficiency due to low concentration of Fe in the milk (Hill and Spears, 2001). Pigs receiving only milk as a source of iron rapidly develop anemia, because sow's milk contains only an average of 1 mg of iron per liter (Brady et al., 1978) or <1 mg Fe per kg DM (Underwood and Suttle, 1999). To prevent the deficiency, Fe supplements such as injectable Fe dextran are given to suckling pigs. It is necessary that a suckling pig retains 7 to 16 mg of iron daily or 25 mg of iron/kg of body weight gain to maintain adequate levels of hemoglobin and storage iron (Braude et al., 1962).

During recent years, attempts have been made to increase transfer of iron from the dam to her offspring, either by placental transfer or by mammary secretion but results have led to conflicting conclusions. Spruill et al. (1971) reported that feeding gestation diets with high iron levels resulted in a slight but non-significant increase in placental transfer of iron as measured by liver iron stores, serum iron and hemoglobin and hematocrit levels of the newborn pig. The secretion of iron by the mammary gland was not influenced by feeding diets high in iron during gestation and lactation. Other researchers, however, reported otherwise, namely that a high level of iron fed to sows during late gestation (Brady et al., 1978) or parenteral administration of iron dextran to gestating sows did not substantially increase placental transfer of iron to fetuses. Neither pig stores at birth nor Fe concentration in milk was increased sufficiently to prevent anemia in the offspring (Pond et al., 1961; Ducsay et al., 1984).

The reported relative availability of chelated or proteinated sources of Fe as 125-185% relative to $FeSO_4$ (Henry and Miller, 1995) has prompted interest in their inclusion and use in sows' diets. Ashmead and Graff (1982) stated that Fe linked to an amino acid increased the transfer of Fe across the placenta and into the embryo. Thus, when provided at 200 ppm Fe in the gestation diet, significant quantities crossed the placenta and were incorporated into the fetuses. This resulted in significantly reduced mortality as well as heavier piglets at birth and at weaning (Ashmead, 1996; Close, 1998). More recently, Close (1999) reported

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that the addition of organic Fe to a normal lactation diet fed some 7 days before farrowing, and throughout a 26-day lactation, improved the feed intake of the sow as well as the weaning weights of the piglets. Close (1999) suggested that more Fe crossed the placenta and was transferred into the fetuses, which then had higher blood haemoglobin and immunoglobulin levels at birth. This higher immune status and viability results in a stronger piglet, consuming more milk and hence performing better.

Some of the previous reports have shown that the addition of organic mineral resulted in improved performance of pigs. Zhou et al. (1994) demonstrated that weanling pigs provided with Cu-lys in the diet over a 24-d period consumed more feed and had a significantly higher growth rate than those fed the $CuSO_4$ diet. Du et al. (1996) reported that Cu utilization from Cu proteinate and Cu-lys was higher, based on the liver Cu content. More recently, Lee et al. (2001a,b) revealed that the efficacy of chelated Zn and Cu sources at low levels was not statistically different from that of high levels of inorganic Zn and Cu sources, in terms of growth performance and maintaining serum concentrations. In addition, as reviewed by Acda and Chae (2002), most of the research on organic minerals indicated that the fecal excretions for Zn and Cu were substantially reduced in pigs fed lower levels of these minerals using organic sources, compared with inorganic sources, when used at a pharmacological level.

The purpose of this research was to investigate the influence of a single dose of Fe dextran with organic trace minerals supplementation on the performance of piglets from dams fed diets with different sources of trace minerals, from birth to 2 wk after weaning. It also determined the effect of organic trace minerals supplementation on the reproductive performance of sows.

MATERIALS AND METHODS

Experimental procedure, animals and diets

Trace mineral premixes were prepared using metal proteinates and the corresponding inorganic salts for organic trace mineral (OTM) and inorganic trace mineral (ITM), respectively. When the mineral premix was incorporated in sow's/weaned pigs' diets at the rate of 0.20%, it provided 100 ppm Fe/175 ppm Fe, 35 ppm Cu/170 ppm Cu, 90 ppm Zn/120 ppm Zn, and 40 ppm Mn/35 ppm Mn, respectively. The dietary levels of Cu and Zn were the maximum levels permitted by the Ministry of Agriculture in Korea for sows/weanling pigs. The metal proteinates used in this study (Fe, Cu, Zn and Mn) were manufactured and provided by Tongwoo TMC Co. in Korea. Metal proteinate is defined by the Association of American Feed Control Officials (AAFCO, 1998) as the product resulting from the chelation of a soluble metal salt with amino acids and/or partially hydrolyzed protein.

Sixteen gestating sows of the same blood line (Landrace ×Yorkshire) in parities 2 to 4 were used in this study. Sows were randomly allocated to the following 4 dietary treatments with the corresponding dose of injectable Fe dextran received by the suckling pigs (Landrace×Yorkshire ×Duroc): 1) diets with ITM/one dose of Fe dextran, 2) diets with ITM/two doses of Fe dextran, 3) diets with OTM/one dose of Fe dextran, and 4) diets with OTM/two doses of Fe dextran. One dose Fe dextran supplied 100 mg of Fe. Treatments were replicated 4 times.

The sows' diet was formulated to meet or exceed the NRC (1998) recommendations for all nutrients (Table 1). At 7 d prepartum through 21 d postpartum, each sow received 3.5-5.0 kg feed daily according to appetite. At 7 d and 14 d postpartum, approximately 20-30 ml milk was collected from the functional glands of each sow following intravenous injection of oxytocin to facilitate milk let-down. The milk samples were placed into plastic vials, stored at -20°C, and later analyzed for Fe and Zn.

Suckling pigs, on the other hand, received 1 dose of Fe dextran (100 mg Fe) intramuscularly 3 days after birth. Seven days after, a second dose was administered to the piglets in treatments 2 and 4. The suckling pigs were weaned at 21 d of age. The weekly body weights and survival rate were recorded.

Subsequently, the piglets from each dam were evaluated through 14 d post weaning. The weaned pigs were housed in pens (1.9×2.3 m) with partially slotted floors (55.5%) following the same dietary treatments as that in their dams. The feed and nutrient composition of the diets is presented in Table 1. In the piglet diet, metal proteinates for Fe, Cu, Zn and Mn also were used for the organic mineral group. The pigs were allowed ad libitum access to the diets from self feeders and to water from nipple waterers. The piglets' body weights and feed intake were recorded at 21 d and 35 d.

At 28 d, one pig from each replicate of each treatment was stunned by electrocution. The pig was bled via venipuncture from the jugular vein. The blood sample collected was placed into heparinized vacuum tubes and stored at -20°C for Fe analysis. The pig was immediately incised to obtain liver and bone samples for trace mineral analyses.

Chemical and statistical analyses

Bone samples were cleaned of all soft tissues. Samples except for blood serum were dry-ashed at 550°C and then wet-ashed with 1:1 HCl. Digested samples were diluted with deionized distilled water; with 2% HCl for blood serum as necessary for trace mineral determination. The Fe and Zn concentrations in milk and in blood serum, Cu and Fe in liver, and Mn and Zn in bone were determined by flame atomic absorption spectrophotometry (Model 094AA,

Table 1. Feed ingredient and nutrient composition of basal diets

	Lactation	Prestarter	Starter
Ingredient (%)			
Corn, ground	51.17	-	22.22
Extruded corn	-	47.18	-
Whey powder	-	30.00	25.00
Soybean meal (44%)	30.64	-	19.56
Bakery by-product	-	7.40	10.00
Lactose	-	-	5.00
Blood plasma protein	-	5.00	5.00
Fish meal (68%)	-	4.00	4.00
Sucrose	-	2.00	4.00
Wheat bran	5.00	-	-
Soy oil	-	2.70	2.00
Animal fat	4.73	-	-
Molasses	3.00	-	-
Tricalcium phosphate	2.00	-	-
Mono calcium phosphate	-	0.11	0.95
Rapeseed meal (38%)	2.00	-	-
Salt	0.55	0.10	0.10
Limestone	0.34	-	0.40
Mineral premix [1]	0.20	0.20	0.20
Vitamin premix [2]	0.12	0.25	0.30
Probiotics	0.15	-	-
L-lysine (78%)	0.04	0.06	0.18
DL-methionine (50%)	0.02	0.06	0.30
ZnO	-	0.34	0.34
Acidifier	-	0.15	-
Apramycin (100g/kg)	-	0.15	0.15
CTC (100g/kg)	-	0.10	0.10
Mecadox (50g/kg)	-	0.10	0.10
Choline chloride (25%)	-	0.10	0.10
Total	100.00	100.00	100.00
Calculated nutrient composition			
ME, kcal/kg	3,300	3,400	3,400
Crude protein, %	19.15	24.00	21.69
Calcium, %	0.90	0.80	0.80
Avail. phosphorus, %	0.45	0.50	0.54
Lysine, %	1.10	1.60	1.50
Met+cys, %	0.66	0.84	0.84

[1] Supplied per kg diet: (sow) 100 mg Fe, 35 mg Cu, 90 mg Zn, 40 mg Mn, 0.75 mg Co, 0.75 mg I, 0.23 mg Se, (piglet) 175 mg Fe, 170 mg Cu, 120 mg Zn, 35 mg Mn, 0.05 mg Co, 0.25 mg Se, 0.75 mg I.

[2] Supplied per kg diet: 12,000 IU vitamin A, 3,000 IU vitamin D_3, 30 IU vitamin E, 3.45 mg vitamin K_3, 1.8 mg vitamin B_1, 14.4 mg vitamin B_2, 3 mg vitamin B_6, 0.045 mg vitamin B_{12}, 30 mg pantothenic acid, 90 mg niacin, 0.105 mg biotin, 0.75 mg folic acid.

GBC, Australia).

Individual sows and piglets/weaned pigs within litters were used as experimental units. Data were statistically analyzed using the GLM procedure of SAS (1985). The mean differences between treatments and the main effects of source and dose were detected using Duncan's multiple range tests (Duncan, 1955).

RESULTS

Performance of sows and suckling piglets

The number of pigs farrowed (total born alive) and the body weight at birth and at weaning were not affected by the sow's dietary treatment (Table 2). The survival rate of suckling pigs was low for all treatments. This was partially caused by an outbreak of diarrhea, and some suckling pigs were laid on by the dam. However, supplementation of the sow's diet with organic trace minerals tended to increase the Fe content in the milk at 7 d of lactation ($p<0.10$). There was no significant difference in the concentration of Zn in the milk ($p>0.10$) of sows fed the trace minerals of either source. The growth performance of suckling pigs was unaffected by sow's dietary treatment and by the number of doses of iron dextran (Table 3). No interaction effect was observed. The suckling pigs in all treatments performed equally from birth to weaning. The second dose of iron dextran failed to improve the ADG ($p>0.05$) or the weight of the pigs at 21 d postpartum ($p>0.05$).

Performance of weaned pigs

There was no interaction effect observed between the source of trace minerals and the number of doses of Fe dextran on the growth performance of weaned pigs (Table 3). However, the growth performance of weaned pigs fed diets supplemented with organic trace minerals was improved. Both the ADG and the ADFI were improved by 21% ($p<0.05$). These groups of weaned pigs were farrowed by dams fed diets supplemented with organic trace minerals. The results also showed that the second dose of injectable Fe dextran received by the suckling pigs during their early life had no additional advantage for the improvement of growth after weaning.

Mineral concentration in the liver, bone and serum

As presented in Table 4, one dose of injectable Fe

Table 2. Effect of organic trace mineral supplementation on the reproductive performance of sows and on mineral concentration in milk

Parameter	ITM[1]	OTM[1]	SE
Total born alive	9.84	9.67	2.05
Total weaned	7.17	7.00	2.15
Average piglet weight at birth, kg	1.60	1.44	0.19
Average piglet weight at weaning, kg	6.06	5.72	0.45
Mineral concentration in milk, ppm[2]			
d 7 Fe[3]	1.67^b	1.73^a	0.11
Zn	1.66	1.71	0.11
d 14 Fe	1.83	1.84	0.03
Zn	1.82	1.84	0.04

[1] ITM=Inorganic trace minerals; OTM=Organic trace minerals.

[2] On fresh basis.

[3] Values with different superscripts of the same row differ ($p<0.10$).

Table 3. Effect of Fe dextran administration and trace minerals supplementation of either source on the performance of weaned pigs (21-35 d)

Parameter	ITM[1]		OTM[1]		SE	Probability[2]		
	1-dose	2-dose	1-dose	2-dose		Source	Dose	S×D
ADG, g	245	224	268	301	39.51	0.02	NS	NS
ADFI, g	304	311	382	364	41.80	0.01	NS	NS
F/G	1.26	1.40	1.45	1.22	0.21	NS	NS	NS

[1] ITM=Inorganic trace minerals; OTM=Organic trace minerals.
[2] NS=Not significant (p>0.10).

Table 4. Effect of Fe dextran administration and trace minerals supplementation of either source on mineral concentration in the liver, bone and the serum of weaned pigs

Mineral, ppm[2]	ITM[1]		OTM[1]		SE	Probability[3]		
	1-dose	2-dose	1-dose	2-dose		Source	Dose	S×D
Liver Cu[4]	20.24^{b}	20.34^{b}	23.20^{a}	21.29^{b}	1.46	0.01	0.07	0.04
Fe	367.40	355.40	405.55	403.33	24.67	0.01	NS	NS
Bone Zn	72.03	69.43	77.37	72.98	3.31	0.01	0.01	NS
Mn	1.38	1.21	1.36	1.29	0.13	NS	0.08	NS
Serum Fe	1.23	1.16	1.28	1.20	0.09	NS	NS	NS
Zn	0.89	0.81	1.01	0.90	0.09	0.01	0.01	NS

[1] ITM=Inorganic trace minerals; OTM=Organic trace minerals.
[2] On fresh basis.
[3] NS=Not significant (p>0.10).
[4] Values with different superscripts of the same row significantly differ (p<0.05).

dextran given to weaned pigs fed diets with organic trace minerals gave a higher Cu content in the liver ($p<0.05$), compared with those fed diets with inorganic trace minerals. Cu and Fe in the liver, and Zn in both the bone and the serum, were significantly increased ($p<0.01$) in weaned pigs fed organic trace minerals, regardless of the number of doses of Fe dextran received by the pigs. But there was a significant reduction in the concentration of Zn in both the bone and the serum ($p<0.05$), and a tendency toward decreased Cu in the liver ($p<0.10$) of weaned pigs given 2 doses of injectable Fe dextran. A double dose of Fe dextran administration failed to increase further the Fe concentration in the liver or the serum ($p>0.10$).

DISCUSSION

The non-significant effect of the source of trace minerals on the reproductive performance of sows could be attributed to the duration of feeding the dietary variables to sows. In this study, sows received their dietary treatments 7 d prepartum which was not long enough to influence the reproductive processes in the sows. Considering the reproductive benefit that could be derived from using organic minerals, such as improved female reproduction via reduced embryonic death loss, improved uterine environment, reduced incidence of cystic ovaries and increased estrus intensity (Vandergrift, 1993), a longer feeding period seems necessary before any positive response is observable. Fehse and Close (2000) reported improved sow performance in terms of total number of pigs born, born alive and weaned from their experiment covering the whole reproductive cycle of sows, whereas Close (1998, 1999) reported that providing 200 ppm organic Fe to gestating sows some 7 days before farrowing resulted in heavier pigs at birth and at weaning. These improved performance levels of sows were not obtained in this study. However, the results suggest that the capacity of the sow to utilize trace minerals for incorporation in milk tended to be high with the organic source. Nevertheless, Pond et al. (1961) conclusively stated that, whether Fe sources are administered to dams orally or via injection, Fe concentration in milk is not increased sufficiently to prevent anemia. The increased concentration of Fe in milk suggests efficient absorption and utilization of dietary Fe in organic form, which was eventually transferred to the mammary gland. Results further indicate that the magnitude of the differences between the two sources could probably be related to differences in availability of the element from the source.

Like any other minerals, Fe is absorbed according to need (Underwood and Suttle, 1999). It is absorbed with high efficiency in milk-fed animals. Neonatal pigs are born with relatively low body Fe content (e.g., 35 to 50 mg), and the postnatal need for this element is relatively high (e.g., 7 to 16 mg/d; Braude et al., 1962; NRC, 1998) to support rapid growth. The results indicate that one dose of Fe dextran and the iron available in milk is sufficient to maintain adequate hemoglobin levels and to support growth throughout the suckling period. According to Caperna et al. (1987), the red blood cells turnover in pigs is approximately

62 d. Therefore, one dose of injectable Fe dextran could adequately sustain hemoglobin concentration until creep was fed at 21 d of age. The ADG of suckling pigs throughout the lactation period was not further improved by the second dose of injectable Fe dextran. Similar results were demonstrated by Hill et al. (1999) in their experiments, indicating that one Fe injection for pigs from sows fed adequate vitamin E will result in adequate growth and hemoglobin concentration with today's improved genetics. The single Fe injection described by Hill et al. (1999) provided 200 mg Fe, in contrast to the dose containing 100 mg Fe used in this study.

Furthermore, supplementing sows with organic trace minerals had no significant influence on the growth performance of the suckling pigs. The results suggest that minerals stored in the body of piglets from sows supplemented with either source of trace minerals are adequate to support their rapid rate of growth during this period. However, extending the feeding with dietary variables such as that of the dam to weaned pigs showed significant improvement in the ADG and ADFI ($p<0.05$). An improvement of 21% in both the ADG and the ADFI was recognized in weaned pigs fed diets with organic trace minerals. This degree of increment in both ADG and ADFI suggests that increased feed intake may have been the major influence on the improvement of ADG. This improved performance could also be associated with the significant increase in iron stores in the liver, blood serum and bone ($p<0.01$). The high concentration of Fe in the liver and the serum, and of Zn in both the bone and the serum, may have resulted from the improved dietary intake in addition to that acquired from the dam. From these results it appears that Fe, Zn and Cu in organic forms are better absorbed and retained in the body than those in inorganic salts. This is consistent with the previous reports that Cu-amino acid complexes had higher availability than $CuSO_4$ for rats (Kirchgessner and Grassmann, 1970). Apgar et al. (1995) reported increased Cu deposition in the livers of pigs fed 200 mg/kg of Cu from Cu-lys as compared with livers of pigs fed $CuSO_4$. Perhaps the organic Cu source is metabolized differently compared to $CuSO_4$. Also, using rats as the experimental model, Du et al. (1996) showed that Cu utilization from Cu proteinate and Cu-lys was higher based on the liver Cu content. The rats fed Cu complexes had higher liver Fe or Zn content than those fed the $CuSO_4$, suggesting that Cu complexes are absorbed via another mechanism that differs from that of inorganic Cu and does not interfere with Fe and Zn. However, in experiments conducted by Coffey et al. (1994) using Cu-lys as the sole source of Cu and as growth promotant for weanling pigs, it was reported that liver Cu concentrations in pigs fed the highest level of the Cu-lys were lower than those in pigs fed the same concentration using $CuSO_4$. Cheng et al. (1998) also showed that Zn concentrations in serum, liver, kidney and rib were similar between pigs supplemented with $ZnSO_4$ and those fed Zn-lys, which suggests that the availability of Zn is similar between Zn-lys and $ZnSO_4$ (Kornegay and Thomas, 1975; Hill et al., 1986; Wedekind et al., 1994; Swinkels et al., 1996).

In the present study, the second dose of Fe dextran was given 11 d before weaning, and it was expected that the benefit due to available Fe would be discerned at weaning and even extended up to post weaning, but the opposite was observed. It neither improved growth at weaning and/or weight post weaning nor influenced the Fe concentration in the liver or serum of the weaned pigs. The concentration of Zn in both the bone and the serum appeared to be depressed by the second dose of Fe dextran, and tended to reduce the bone Mn. As reviewed by Henry (1995) in her research on Mn interactions using rats, Fe supplementation at 140 ppm decreased absorption of ^{54}Mn, compared with the basal diet containing 10 ppm Fe. In addition, Hill and Spears (2001) cited that in human, an excessive Fe also inhibits Zn absorption, regardless of form. It is therefore concluded that a second dose of Fe dextran given in early life may not be necessary to further improve the growth of weaned pigs.

IMPLICATIONS

One dose (100 mg) of injectable Fe dextran given to piglets at 3 d of age is adequate to sustain their needs for growth throughout the suckling period. The second dose of Fe dextran may not be necessary to further improve growth. The results also showed that supplementing weaned pigs with organic trace minerals could improve the ADG and ADFI. These groups of weaned pigs were farrowed by dams fed the diet supplemented with organic trace minerals.

REFERENCES

AAFCO. 1998. Official Publication of the Association of American Feed Control Officials Incorporated. (Ed. P. M. Bachman). pp. 237-238.

Acda, S. P. and B. J. Chae. 2002. A review on the applications of organic trace minerals in pig nutrition. Pakistan J. Nutr. 1:25-30.

Apgar, G. A., E. T. Kornegay, M. D. Lindemann and D. R. Notter. 1995. Evaluation of copper sulfate and a copper lysine complex as growth promoters for weanling swine. J. Anim. Sci. 73:2640-2646.

Ashmead, H. D. and D. J. Graff. 1982. Placental transfer of chelated iron. Proceedings of the International Pig Veterinary Society Congress, Mexico. p. 207.

Brady, P. S., P. K. Ku, D. E. Ullrey and E. R. Miller. 1978. Evaluation of an amino acid iron chelate hematinic for the baby pig. J. Anim. Sci. 47:1135-1140.

Braude, R., A. G. Chamberlain, M. Kotarbinska and K. G. Mitchell. 1962. The metabolism of iron in piglets given labeled iron either orally or by injection. Brit. J. Nutr. 19:427-449.

Caperna, T. J., M. L. Failla, N. C. Steele and M. P. Richards. 1987. Accumulation and metabolism of iron-dextran by hepatocytes, kupffer cells and endothelial cells in the neonatal pig liver. J. Nutr. 117:312-320.

Cheng, J., E. T. Kornegay and T. Schell. 1998. Influence of dietary lysine on the utilization of zinc from zinc sulphate and zinc-lysine complex by young pigs. J. Anim. Sci. 76:1064-1074.

Close, W. H. 1998. The role of trace mineral proteinates in pig nutrition. In: Biotechnology in the Feed Industry (Ed. T. P. Lyons and K. A. Jacques). Nottingham University Press. Nottingham, UK. pp. 469-483.

Close, W. H. 1999. Organic minerals for pigs: An update. In: Biotechnology in the Feed Industry (Ed. T. P. Lyons and K. A. Jacques). Nottingham University Press. Nottingham, UK. pp. 51-60.

Coffey, R. D., G. L. Cromwell and H. J. Monegue. 1994. Efficacy of a copper-lysine complex as a growth promotant for weanling pigs. J. Anim. Sci. 72:2880-2886.

Du, Z., R. W. Hemken, J. A. Jackson and D. S. Trammel. 1996. Utilization of copper in copper proteinate, copper lysine and cupric sulfate using rat as experimental model. J. Anim. Sci. 74:1657-1663.

Ducsay, C. A., W. C. Buhi, F. W. Bazer, R. M. Roberts and C. F. Camba. 1984. Role of uteroferrin in placental iron transport: Effect of maternal iron treatment on fetal iron and uteroferrin content and neonatal hemoglobin. J. Anim. Sci. 59:1303-1308.

Duncan, D. B. 1955. Multiple F tests. Biometric. 11:1-12.

Fehse, R. and W. H. Close. 2000. The effect of the addition of organic trace elements on the performance of a hyper-prolific sow herd. In: Biotechnology in the Feed Industry (Ed. T. P. Lyons and K. A. Jacques). Nottingham University Press. Nottingham, UK. pp. 309-325.

Henry, P. R. 1995. Manganese bioavailability. In: Bioavailability of Nutrients for Animals (Ed. C. B. Ammerman, D. H. Baker and A. J. Lewis). Academic Press. New York. pp. 239-256.

Henry, P. R. and E. R. Miller. 1995. Iron bioavailability. In: Bioavailability of Nutrients for Animals (Ed. C. B. Ammerman, D. H. Baker and A. J. Lewis). Academic Press, New York. pp. 169-194.

Hill, D. A., E. R. Peo, Jr., A. J. Lewis and J. D. Crenshaw. 1986. Zinc-amino acid complexes for swine. J. Anim. Sci. 63:121-130.

Hill, G. M. and J. W. Spears. 2001. Trace and ultratrace elements in swine nutrition. In: Swine Nutrition, 2nd ed. (Ed. A. J. Lewis and L. L. Southern). CRC Press, Washington, DC. pp. 229-262.

Hill, G. M., J. E. Link, L. Meyer and K. L. Fritsche. 1999. Effect of vitamin E and selenium on iron utilization in neonatal pigs. J. Anim. Sci. 77:1762-1768.

Kirchgessner, M. and E. Grassmann. 1970. The dynamics of copper absorption. In: Trace Element Metabolism in Animals (Ed. C. F. Mills). Proc. WAAP/IBP Int. Symp. Abeerden, Scotland. pp. 277-287.

Kornegay, E. T. and H. R. Thomas. 1975. Zinc-proteinate supplement studied. Hog Farm Manage. Aug. pp. 50-52.

Lee, S. H., S. C. Choi, B. J. Chae, S. P. Acda and Y. K. Han. 2001a. Effect of feeding different chelated copper and zinc sources on growth performance and fecal excretions of weanling pigs. Asian-Aust. J. Anim. Sci. 14:1616-1620.

Lee, S. H., S. C. Choi, B. J. Chae, J. K. Lee and S. P. Acda. 2001b. Evaluation of metal-amino chelates and complexes at various levels of copper and Zn in weanling pigs and broiler chicks. Asian-Aust. J. Anim. Sci. 14:1734-1740.

MAF. 1999. A guide for quality control in animal feeds. Ministry of Agriculture and Forestry. Seoul, Korea.

National Research Council. 1998. Nutritional requirements of swine. National Academy Press, Washington, DC.

Pond, W. C., R. S. Lowrey, J. H. Mane and J. K. Loosli. 1961. Parenteral iron administration to sows during gestation and lactation. J. Anim. Sci. 20:747-750.

SAS. 1985. SAS user's guide: Statitics, SAS Inst. Inc. Cary. NC.

Spruill, D. G., V. W. Hays and G. L. Cromwell. 1971. Effects of dietary protein and iron on reproduction and iron-related blood constituents in swine. J. Anim. Sci. 33:376-384.

Swinkels, J. W. G. M., E. T. Kornegay, W. Zhou, M. D. Lindemann, K. E. Webb, Jr. and M. W. Verstegen. 1996. Effectiveness of a zinc amino acid chelate and zinc sulfate in restoring serum and soft tissue zinc concentrations when fed to zinc-depleted pigs. J. Anim. Sci. 74:2420-2439.

Underwood, E. J. and N. F. Suttle. 1999. The Mineral Nutrition of Livestock. 3rd ed. CABI Pulishing, New York.

Vandergrift, B. 1993. The role of mineral proteinates in immunity and reproduction. What do we really know about them? In: Biotechnology in the Feed Industry (Ed. T. P. Lyons). Alltech Technical Publications. Nicholasville, Kentucky. pp. 27-34.

Wedekind, K. J., A. J. Lewis, M. A. Giesemann and P. S. Miller. 1994. Bioavailability of zinc from inorganic and organic sources for pigs fed corn-soybean meal diets. J. Anim. Sci. 72:2681-2689.

Zhou, W., E. T. Kornegay, H. van Laar, J. W. G. M. Swinkels, E. A. Wong and M. D. Lindemann. 1994. The role of feed consumption and feed efficiency in copper-stimulated growth. J. Anim. Sci. 72:2385-2394.