Effects of Iron from an Amino Acid Complex on the Iron Status of Neonatal and Suckling Piglets

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ABSTRACT : This experiment was conducted to investigate the effects of iron from an amino acid complex (Availa-Fe®) on the iron status of neonatal and suckling piglets. A total of 24 gestating sows (Landrace×Large White) were randomly allocated to three dietary treatments. The control diet contained 80 mg kg^{-1} Fe from ferrous sulfate heptahydrate ($FeSO_4·7H_2O$), while the two experimental diets were supplemented with an additional 120 mg kg^{-1} Fe from Availa-Fe® or $FeSO_4·7H_2O$, respectively. The lactating sows remained the same iron treatments as gestating sows, while neonatal piglets of 24 litters born from the above sows were allotted to another three treatments. Piglets from the sows of the control treatment were fed basal diet with no supplemental Fe as control treatment, but were injected with 100 mg Fe as Fe dextran at birth. Piglets from the sows of Availa-Fe® or $FeSO_4·7H_2O$ treatments were supplemented with 120 mg kg^{-1} iron from Availa-Fe® or $FeSO_4·7H_2O$, respectively. The total born alive and weaned, and the average piglets weight at birth and at weaning were not significantly affected by the sow's dietary treatments ($p>0.05$). Iron from Availa-Fe® did not demonstrate a statistically significant improvement in hemoglobin concentration, hematocrit and plasma iron of sows on day 90 and 105 of pregnancy and the milk iron of sows during lactation ($p>0.05$). Neonatal piglets in the Availa-Fe® treatment had a significantly higher hemoglobin concentration ($p<0.05$) and higher hematocrit and plasma iron ($p>0.05$) than those in the other two treatments, respectively. The hemoglobin of suckling piglets in the Availa-Fe® treatment was higher than that of piglets in $FeSO_4·7H_2O$ treatment on day 28 ($p<0.05$). The total iron binding capacity of piglets in Availa-Fe® treatment was lower than that of piglets in the control and $FeSO_4·7H_2O$ treatment on day 14 ($p<0.05$), but there was not a statistically significant difference among three treatments on day 28 ($p>0.05$). However, the hemoglobin and hematocrit of suckling piglets injected with Fe were higher than those of piglets in the other two treatments ($p<0.05$). This study indicated that the addition of 120 mg kg^{-1} iron from amino acid complex into the diets improved iron status of neonatal and nursing piglets more effectively than the addition of 120 mg kg^{-1} iron from $FeSO_4·7H_2O$, however, this improvement of the organic Fe was not sufficient to replace the Fe injection for prevention of iron-deficiency anemia. ***(Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 10 : 1485-1491)***

Key Words : Iron-amino Acid Complex, Ferrous Sulfate, Hemoglobin, Milk Iron, Sow, Piglet

INTRODUCTION

Iron has important functions in the body as a component of hemoglobin and numerous other iron-containing proteins. Iron-deficiency anemia is a serious problem in piglets, because body stores at birth are small (Ekman and Jwanska, 1966) and amounts of iron in sow milk is insufficient compared with the need of piglets during the first weeks of life. It is well established that iron dextran (100 to 200 mg) injected intramuscularly into piglets within several days of birth will prevent iron-deficiency anemia (Barber et al., 1955; Browrilie, 1955; McDonald et al., 1955). Once injected into the piglets, the iron dextran complex is presumed to be slowly removed from the injection site and then incorporated into essential body iron or storage (Ku et al., 1983).

Oral supplementation would be less invasive and potentially less stressful than injectable Fe for neonatal pigs. During recent years, attempts have been made to increase the transfer of iron from the sow to her offspring, either by placental transfer or by mammary secretion, but results have led to conflicting conclusions. Prevention of Fe deficiency continues to be a challenge to the swine industry. 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. Brady et al. (1978) revealed that a high level of iron during late gestation or parenteral administration of iron dextran to gestating sows did not substantially increase placental transfer of iron to fetuses. But, 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 mg kg^{-1} Fe in the gestation diet, significant quantities crossed the placenta and were incorporated into the fetuses. This

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Table 1. Feed ingredients and nutrient composition of the basal diets for gestating and lactating sows and basal creep diet for suckling piglets

Ingredients	Gestating sows (%)	Lactating sows (%)	Suckling piglets (%)
Corn	70.00	60.00	42.00
Extruded soybean (38.0%, CP)	-	-	20.00
Dried whey powder	-	-	15.00
Menhaden fish meal	-	-	10.00
Sprayed dried plasma protein	-	-	4.00
Dried whole milk powder	-	-	5.00
Soybean meal	13.14	30.00	-
Wheat bran	13.50	6.58	2.00
Dicalcium phosphate	1.8	1.74	-
Limestone	0.95	0.90	0.80
Salt	0.25	0.35	0.20
L-lysine.HCL	0.06	0.13	-
Mineral/vitamin premix	0.30 [a]	0.30 [a]	1.00 [b]
Total	100.00	100.00	100.00
Calculated nutrients composition			
Digestible energy (MJ/kg)	12.97	13.14	14.85
Crude protein (%)[c]	14.34	20.18	23.48
Lysine (%)	0.61	1.01	1.52
Methionine (%)	0.20	0.28	0.40
Methionine+cysteine (%)	0.48	0.62	0.84
Threonine (%)	0.49	0.76	1.02
Calcium (%)[c]	1.05	1.03	1.15
Avail. phosphorus (%)	0.39	0.40	0.55
Fe (mg/kg) [c]	256	278	144

[a] Mineral/vitamin premix supplied per kilogram diet: 9,000 IU vitamin A; 1,500 IU vitamin D_3; 30 IU vitamin E; 2.00 mg vitamin K_3; 1.20 mg thiamin; 4.00 mg riboflavin; 15.00 mg D-pantothenic acid; 16.00 mg niacin; 1.00 mg vitamin B_6; 21.00 μg vitamin B_{12}; 0.80 g choline (choline chloride); 0.21 mg D-biotin; 1.00 mg folic acid; 80 mg Fe from $FeSO_4 \cdot 7H_2O$; 8 mg Cu from $CuSO_4 \cdot 5H_2O$; 70 mg Zn from $ZnSO_4 \cdot 7H_2O$; 30 mg Mn from $MnSO_4 \cdot H_2O$; 0.50 mg I from KI; 0.20 mg Se from Na_2SeO_3.

[b] Mineral/vitamin premix supplied per kilogram diet: 9,000 IU vitamin A; 1,500 IU vitamin D_3; 30 IU vitamin E; 2.00 mg vitamin K_3; 1.20 mg thiamin; 4.00 mg riboflavin; 15.00 mg d-pantothenic acid; 16.00 mg niacin; 1.00 mg vitamin B_6; 21.00 μg vitamin B_{12}; 0.60 g choline (choline chloride); 0.21 mg D-biotin; 1.00 mg folic acid; 140 mg ethocyquin; 250 mg Cu from $CuSO_4 \cdot 5H_2O$; 200 mg Zn from $ZnSO_4 \cdot 7H_2O$; 40 mg Mn from $MnSO_4 \cdot H_2O$; 1.00 mg I from KI; 0.35 mg Se from Na_2SeO_3; 80 mg olaquindox; 500 mg calcium propionate.

[c] Measured value.

resulted in significantly reduced mortality as well as heavier piglets at birth and at weaning (Close, 1998).

Most of the dietary iron for pigs are from feed and inorganic iron supplements. These iron sources vary widely in their bioavailability to the animal (Henry and Miller, 1995). The most commonly used iron dietary supplement is inorganic in the form of ferrous sulfate. Feed ingredients can greatly influence iron solubility in the intestinal lumen, which will eventually influence iron absorption. Iron reaching the fetus is limited by gut uptake (Hallberg, 1981), metabolism of the liver and other tissues (Huebers and Finch, 1987; Theil, 1987), and secretion rate of uteroferrin by the uterus (Roberts et al., 1986; Vallet et al., 1998). Interest in using organic mineral complexes as mineral sources for animals has increased because they have higher bioavailability than inorganic mineral sources. The reported relative availability of chelated or proteinated sources of Fe is 125 to185% relative to $FeSO_4$ (Henry and Miller, 1995). Availa-Fe® manufactured by Zinpro, USA, is an iron amino acid complex and the bioavailability of it was significantly better than that of ferrous sulfate supplementation in weanling pigs (Yu et al., 2000).

Therefore, the objectives of this study were to evaluate the effect of iron from an amino acid complex on the iron status of neonatal and suckling piglets, and to determine whether it is sufficient to prevent anemia when the iron from amino acid complex is fed the sow during gestation or lactation and suckling piglets.

MATERIALS AND METHODS

Experimental design, animals and diets

The experiment was divided into two phases, including a gestating and a lactating phase. Three dietary treatments were used in gestating phase. The control diet included 80 mg kg^{-1} Fe from ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) and a corn-soybean meal-wheat bran basal diet, whereas the other dietary treatment was supplemented additional 120 mg kg^{-1} Fe from Availa-Fe® into the control diet. An additional diet supplemented with 120 mg kg^{-1} Fe from

Table 2. Effect of dietary iron-amino acid complex on the reproductive performance of gestating sows

Item	Treatments[1]			SEM[2]
	Control	Iron-amino acid complex	Ferrous sulfate	
Added Fe (mg/kg)	0	120	120	
Dietary Fe[3] (mg/kg)	256	365	357	
Feed intake (kg/d)	2.80	2.80	2.80	0
Total born alive[4]	10.6	11.8	10.9	1.50
Total weaned[4]	9.67	10.63	9.85	2.15
Average piglet weight at birth[5] (kg)	1.56	1.50	1.52	0.18
Average piglet weight at weaning[5] (kg)	5.54	5.81	5.19	0.22

[1] Control diet included 80 mg kg^{-1} Fe from $FeSO_4·7H_2O$ in basal diet; Iron-amino acid complex treatment supplemented additional 120 mg kg^{-1} Fe from Availa-Fe® into the control diet; Ferrous sulfate treatment supplemented additional 120 mg kg^{-1} Fe from $FeSO_4·7H_2O$ into the control diet as positive control treatment .

[2] Standard error of mean. [3] Measured value. [4] Data represent mean of eight litters per treatment.

[5] Data represent mean of all piglets of eight litters per treatment.

$FeSO_4·7H_2O$ into the control diet was used as a positive control. During the lactating phase, sows remained the same iron treatment as gestating sows.

However, neonatal piglets of 24 litters born from the above sows were allotted to another three treatments. Piglets from the sows of the control treatment were fed corn-soybean meal-dried whey meal-fish meal basal diet with no supplemental Fe as control treatment, but were injected with 100 mg Fe as Fe dextran at birth. Piglets from the sows of Availa-Fe® treatment were fed basal diet supplemented with 120 mg kg^{-1} iron from Availa-Fe® as organic iron treatment, while piglets from the sows of positive control were fed basal diet supplemented with 120 mg kg^{-1} iron from $FeSO_4·7H_2O$ as inorganic iron treatment. Suckling piglets were fed on their respective creep feeds from day 5 throughout weanling on day 28. Availa-Fe® (Zinpro Corp., USA) contains 60.0 g iron/kg and 139.3 g total amino acids/kg. The experiment basal diets were formulated to meet or exceed the NRC (1998) nutrient requirements for gestating and lactating sows and nursing piglets (Table 1).

A total of 24 gestating sows (Landrace×Large White) crossbred to Duroc boars were randomly allocated into three dietary treatments. The sows were at day 70 of pregnancy. Eight replicates with one sow per replicate were used for each treatment. Sows were housed in pens (180 cm×120 cm, one sow per pen) with concrete floor during gestation and were brought into farrowing crates with plastic coated slatted floors just before farrowing where they remained with their litters until weaning in an environmentally controlled building. Each sow was fed 2.5 to 4.5 kg daily according to the sow's appetite. The feeder was made of wood to prevent iron contamination. Water was provided with free access from a bowl type drinker. The spilled feed from the sows feeder and the sows feces in the farrowing crates were cleaned thoroughly every day. The piglets from sows fed on the control diet were injected intramusculally with 100 mg Fe as Fe-dextran at birth, whereas the piglets from sows in another two treatments received no Fe injection. Piglets had free access to their mothers milk, water and pelleted diets.

Blood samples were drawn from all sows per treatment on day 70, 90 and 105 of pregnancy. Six piglets per litter were bled via venipuncture from the jugular vein at birth before Fe injection, and on day 14 and 28. The blood sample collected was placed into heparinized vacuum tubes for analysis. At day 14 and 21 post-partum, approximately 20 to 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 collected by manual expression into plastic vials and stored at -20°C for Fe analysis. Litter size and piglet weights at birth and at weaning were recorded.

Chemical and statistical analyses

Hemoglobin concentration was determined using the cyanmethemoglobin method described by Crosby et al. (1954). Hematocrit was measured using the microcapillary method. Plasma iron and total iron binding capacity were determined according to the method of Ramsay (1957). The iron content of the milk was determined as described by McDowell (1947).

Individual sows and piglets within litters were used as experimental units. One-way analysis was performed using the General Linear Models Procedures of SAS software (1989). Differences among means were tested using Duncan's multiple range tests. A significant level of 0.05 was used.

RESULTS AND DISCUSSION

Reproductive performance

The total born alive and weaned, and the average piglets weight at birth and at weaning were not significantly affected by the sow's dietary treatments ($p>0.05$) (Table 2). The result supported the reports by Acda and Chae (2002)

Table 3. Effect of dietary iron-amino acid complex on blood hemoglobin, hematocrit and plasma iron of gestating sows

Treatments[1]	Hemoglobin[2] (g/dl)			Hematocrit[2] (%)			Plasma iron[2] (μg/dl)		
	Day 70	Day 90	Day 105	Day 70	Day 90	Day 105	Day 70	Day 90	Day 105
Control	12.2	11.1	12.2	39.7	36.9	40.5	328	372	395
Iron-amino acid complex	12.3	12.1	11.1	38.4	39.3	36.3	346	403	455
Ferrous sulfate	13.4	12.6[3]	11.5	43.1	41.7[3]	37.3	308	327[3]	432
SEM[4]	0.4	0.5	0.4	1.3	1.6	1.4	59	59	64

[1] Control diet included 80 mg kg^{-1} Fe from $FeSO_4\cdot 7H_2O$ in basal diet; Iron-amino acid complex treatment supplemented additional 120 mg kg^{-1} Fe from Availa-Fe® into the control diet; Ferrous sulfate treatment supplemented additional 120 mg kg^{-1} Fe from $FeSO_4\cdot 7H_2O$ into the control diet as positive control treatment.

[2] Data represent mean of eight sows per treatment.

[3] Data represent mean of six sows (due to two blood samples hemolysis). [4] Standard error of mean.

Table 4. Effect of dietary iron-amino acid complex on milk iron of lactating sows

Treatments[1]	Added Fe (mg/kg)	Dietary Fe[2] (mg/kg)	Feed intake (kg/d)	Milk iron[3] (μg/dl)	
				Day 10	Day 21
Control	0	278	4.24	580	552
Iron-amino acid complex	120	383	3.90	612	633
Ferrous sulfate	120	393	4.04	471[4]	494
SEM[5]			0.24	60	66

[1] Control diet included 80 mg kg^{-1} Fe from $FeSO_4\cdot 7H_2O$ in basal diet; Iron-amino acid complex treatment supplemented additional 120 mg kg^{-1} Fe from Availa-Fe® into the control diet; Ferrous sulfate treatment supplemented additional 120 mg kg^{-1} Fe from $FeSO_4\cdot 7H_2O$ into the control diet as positive control treatment.

[2] Measured value. [3] Data represent mean of eight sows per treatment.

[4] Data represent mean of six sows (the volume of two milk samples was too little to be measured). [5] Standard error of mean.

that the sows' reproductive and neonates' growth performance were affected neither by the source nor by the level of trace minerals. But, Fehse and Close (2000) reported the improved sow performance in terms of the 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 mg kg^{-1} organic Fe to gestating sows some 7 days before farrowing resulted in heavier pigs at birth and at weaning.

Blood constituents of gestating sows

The effects of Availa-Fe® supplementation on the blood constituents of gestating sows are shown in Table 3. Feed intake of each gestating sow was at the same amounts (2.8 kg/day). At the beginning of trial (on day 70 of pregnancy), the initial hemoglobin concentration and hematocrit of sows in positive control treatment were higher than those of the other two treatments ($p>0.05$). As the experimental feeding progressed, there was not a significant difference in hemoglobin concentration and hematocrit among the three treatments on day 90 and105 of pregnancy ($p>0.05$). The plasma iron concentration was increased in the sows of each treatment from 70 to 105 day of pregnancy, and it was higher in Availa-Fe® treatment than in another two treatment during gestation ($p>0.05$).

Milk iron of lactating sows

The effects of Availa-Fe® supplementation on milk iron of lactating sows are shown in Table 4. During lactation, the experimental sows received the same iron treatment as gestating sows. The milk iron of sows in Availa-Fe® treatment was higher than that of sows in the other two treatments during lactation ($p>0.05$). The additional 120 mg kg^{-1} iron from $FeSO_4\cdot 7H_2O$ decreased milk iron compared with 80 mg kg^{-1} iron from $FeSO_4\cdot 7H_2O$ in the control treatment. The increased concentration of Fe in milk suggested efficient absorption and utilization of Fe in organic form, which was eventually transferred to the mammary gland. Paul et al. (1978) found that supplementation with 3,000 mg kg^{-1} Fe from amino acid iron chelate in sows diet significantly improved the milk iron. However, during the gestating and lactating phase, the addition of 700 mg kg^{-1}Fe from ferrous sulfate did not significantly improve milk iron of sows (Spruill et al., 1971). Pond et al. (1961) conclusively stated that whether Fe sources are administered to sows orally or via injection, Fe concentration in milk is not increased sufficiently to prevent anemia.

Blood constituents of neonatal piglets

The effects of Availa-Fe® supplementation in the gestating sows on the blood constituents of their neonatal piglets are shown in Table 5. Neonatal piglets in the Availa-Fe® treatment had a significantly higher hemoglobin concentration than those in the other two treatments ($p<0.05$). The different source of iron did not significantly influence the plasma iron, total iron binding capacity and hematocrit of neonatal piglets ($p>0.05$).

Table 5. Effect of dietary iron-amino acid complex on hemoglobin, hematocrit, plasma iron and total iron binding capacity of neonatal piglets and suckling piglets

Treatments [1]	Dietary Fe[2] (mg/kg)	Hemoglobin[3] (g/dl)			Hematocrit[3]. (%)			Plasma iron[3] (μg/dl)			Total iron binding capacity[3] (μg/dl)		
		At birth	Day 14	Day 28	At birth	Day 14	Day 28	At birth	Day 14	Day 28	At birth	Day 14	Day 28
Control	144	9.01^{a}	8.79^{a}	8.12^{a}	34.9	35.8^{a}	23.5^{a}	90.1	76.4	75.3	571	671^{a}	709
Iron-amino acid complex	288	10.14^{b}	6.06^{b}	6.95^{b}	38.1	20.0^{b}	12.3^{b}	97.9	69.6	72.5	579	620^{b}	712
Ferrous sulfate	285	9.44^{a}	$7.26^{4,c}$	6.43^{c}	37.6	$25.5^{4,b}$	13.3^{b}	93.2	70.5^{4}	76.1	581	$718^{4,c}$	733
SEM[5]		0.28	0.22	0.25	1.2	1.2	1.7	4.3	2.4	2.8	21	13	16

[1] Piglets from the sows of the control treatment fed the basal diet with no supplement Fe as control group, but injected with 100 mg Fe as Fe dextran on day one after birth; Piglets from sows of iron-amino acid complex treatment supplemented 120 mg kg^{-1} Fe from Availa-Fe® into the basal diet as organic iron treatment; Piglets from sows of positive control treatment supplemented 120 mg kg^{-1} Fe from $FeSO_4{\cdot}7H_2O$ into the basal diet as inorganic iron treatment.

[2] Measured value. [3] Data represent mean of eight litters (six piglets/L) per treatment.

[4] Data represent mean of eight litters (five piglets/L) per treatment (due to one blood sample/litter hemolysis). [5] Standard error of mean.

[a, b, c] Means within a column with the different superscripts differ significantly ($p<0.05$).

Previous researchers have speculated that organically chelated and complexed metals are more efficiently utilized by the animal than those of similar minerals in their inorganic forms. Addition of 700 mg kg^{-1} Fe from ferrous sulfate in the gestation sow diet did not improve hemoglobin concentration and plasma iron of newborn piglets (Spruill et al., 1971). It has been suggested that the iron solubility of Availa-Fe® is significantly better than ferrous sulfate at pH 6.0 (Yu et al., 2000). Groen et al. (1947) reported that amino acids and certain other organic acids increase iron absorption by buffering the pH of the intestinal contents and delaying the rise in pH in the intestinal contents toward neutrality. In the small intestine (pH 7.0 or higher), ionic ferrous iron is probably oxidized into the ferric form, which would be expected to form insoluble ferric hydroxide, unless the ferric iron was kept in a soluble form by complex or chelating agents.

Blood constituents of suckling piglets

The effects of Availa-Fe® supplementation on the blood constituents of nursing piglets are shown in Table 5. The newborn piglets in the control treatment were injected with 100 mg Fe as Fe dextran at birth. Suckling piglets were fed on their respective creep feeds from day 5 throughout weaning on day 28, but the average feed intake per piglet is 4.19 to 4.82 g/d, which is lower than what we expected. Hot weather in summer and an outbreak of diarrhea may influence the feed intake of piglets during experimental period. The hemoglobin concentration and hematocrit of piglets injected Fe were higher than those of piglets in the organic and inorganic treatments on day 14 and 28 ($p<0.05$). The hemoglobin concentration of piglets in the organic treatment was lower than that of piglets in the inorganic treatment on day 14 but was higher on day 28 ($p<0.05$), respectively. The total iron binding capacity of piglets in the organic treatment was lower than that of piglets in the control and inorganic treatments on day 14 ($p<0.05$), but, there was not a statistically significant difference in total iron binding capacity among the three treatments on day 28 ($p>0.05$).

In evaluating the biological response to iron, hemoglobin and hematocrit levels are sensitive criteria (Amine et al., 1972). The plasma iron concentration is a warning signal of iron deficiency, whereas the level of total iron binding capacity is a criterion for iron metabolism (Furugouri, 1972a, b). Hemoglobin concentrations of 10 g/dl are considered normal, 8 g/dl indicates borderline anemia, while 6 g/dl indicates severe anemia (McDowell, 1992). According to this criterion, it was used in this study.

The injection of iron was an effective way to prevent anemia in piglets during the first days of life. In this study, the result was in accordance with numerous previous studies in piglets. It is necessary that a suckling pig retains 7 to16 mg of iron daily or 25 mg of iron/kg of body weight to maintain adequate levels of hemoglobin and storage iron (Braude et al., 1962). The method of oral administration of large doses of iron supplementation to the sows was used to maintain normal hemoglobin levels in piglets, and it was on the basis that, first, increased iron intake by the sow during late gestation would increase the iron stores in the fetus which would serve as a reserve during the critical suckling period and, second, increased iron intake by the sow during lactation would increase the iron content of the milk. However, 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).

With the exception of iron in the sows milk and creep diets, post-partum, suckling piglets in the organic and inorganic treatment would have to rely on the iron reserves in the body at birth. This study indicated that the addition of Availa-Fe® to the diets of gestating and lactating sows and suckling piglets improved Fe status of suckling piglets more effectively than the addition of iron from ferrous sulfate, but neither placental nor mammary transfer of iron fed to the sow during gestation or lactation was of sufficient magnitude to prevent anemia with a source of iron during the suckling period.

IMPLICATIONS

This study indicated that the addition of 120 mg kg^{-1} iron from an amino acid complex into the diets of gestating and lactating sows and nursing piglets improved iron status of neonatal and nursing piglets more effectively than 120 mg kg^{-1} iron from ferrous sulfate heptahydrate, which may have resulted from the better absorption, metabolism or placental and mammary transfer of iron. However, this improvement of the organic Fe was not sufficient to replace the Fe injection commonly practised in swine production for prevention of iron-deficiency anemia.

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