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A Review on the Applications of Organic Trace Minerals in Pig Nutrition

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Abstract: The purpose of this review is to provide an update on recent informations regarding application of organic trace minerals in pig nutrition. Understanding the efficacy of organic trace minerals has been increasingly important over the past few years as a result of increased customer awareness of their benefits and the increase in the number of commercial products available to the consumer. Organically bound trace minerals of interests in pig nutrition specifically include iron, copper, zinc, chromium and selenium. Organic iron, chromium and selenium have been shown to improve reproductive efficiency as measured by increased farrowing rate, reduced mortality, larger litter size and increased litter weight at birth and at weaning. Additional benefits derived from organic chromium supplementation include improved carcass quality and increased nitrogen retention. Reviews presented reveal no consistent effect of organic copper and zinc on growth performance but could provide the needs of pigs at lower inclusion rate without compromising performance of animals while maintaining serum concentration, and substantially reducing fecal excretions of these elements.

Key words: Organic sources, chelates, reproductive efficiency, growth performance

Introduction

With the increasing number of commercial organic trace mineral products available to the consumer and the increasing use of these products by the pig industry, it is of interest to briefly review the application characteristics of organic trace minerals. The most prudent selection and use of organic trace minerals result from increased customer awareness on the current production performance. So it is very likely that benefits as well as the non-beneficial effects of application be known.

Trace minerals play a vital and important role in nutrition, being part of structural materials, constituents of the soft tissues and cells, and regulate many of the vital biological processes. They occur naturally in most feed ingredients but the amount and bio availability varies considerably. Although trace minerals are traditionally included in the diet at very small amount in the form of premix of inorganic salts such as sulphates, chlorides, carbonates and oxides, there are several factors that may reduce their availability when ingested by the animals. Some researches in mineral nutrition have shown that the availability of trace minerals can be improved by binding them to organic ligands, usually a mixture of amino acids or small peptides and thus, the so- called organic trace minerals.

A ligand is a molecule containing an atom which has a lone pair of electrons. In the process of chelation, the ligand acts as chelating agent and encircles the metal atom to form a heterocyclic ring structure. That is, the metal atom is bonded to the ligand through donor atoms such as the oxygen of the carboxyl group , nitrogen or sulfur of the amino acid or peptide. As reviewed by Hynes and Kelly (1995), ligands that contain only one donor atom are termed "monodentate" ligands and those that contain two or more donor atoms capable of bonding to a metal ion are termed bi, tri- or tetradentate ligands. When such ligands bond to a metal ion via two or more donor atoms, the complex formed contains one or more heterocyclic rings and such species are called "chelates". Chelates may have four, five- six- and seven-membered rings but it has been shown that chelates having five-membered rings have the greatest stability (Graddon, 1968). There are various categories of organic trace minerals as defined by the Association of American Feed Control Officials (AAFCO,1998) such as:

Metal amino acid chelate - is the product resulting from the reaction of a metal ion from a soluble metal salt with amino acids with a mole of metal to one to three (preferably two) moles of amino acids to form coordinate covalent bonds. The average weight of the hydrolyzed amino acids must be approximately 150 and the resulting molecular weight of the chelate must not exceed 800.

Metal amino acid complex - is the product resulting from complexing of a soluble metal salt with an amino acid(s).

Metal polysaccharide complex - is the product resulting from complexing of a soluble metal salt with a polysaccharide solution.

Metal proteinate - is the product resulting from the chelation of a soluble metal salt with amino acids and/or partially hydrolyzed protein.

Absorption and bioavailability of organic trace minerals: Absorption of trace minerals is often a major limitation of their utilization. Oftentimes absorption is coined with availability because a trace mineral must be certainly absorbed before it can be utilized. However, a trace mineral can also be absorbed but not necessarily be utilized thus making its bioavailability low. During digestion the mineral ions from inorganic sources are released and may re-combine with other digesta components in the intestine forming insoluble complexes and thereby excreted, reducing their absorption across the small intestine. This indicates that the degree to which these dietary minerals are available for absorption depends on the extent to which they form complex molecules in the gut. Whereas the organic minerals utilize peptide and/or amino acid uptake mechanisms in the intestine (Ashmead *et al*., 1985; Ashmead, 1993). The mineral within the complex or chelate is in a chemically inert form due to the coordinate covalent and ionic bonding by the amino ligands hence, more stable and less prone to interactions. The mineral is protected from physiochemical factors or from negative interactions with dietary components such as phytate, which binds cations making them unavailable for absorption (Fairweather-Tait, 1996). In addition, the organic trace minerals remained to be electrically neutral at certain pH conditions. Thus, the mineral chelate/complex is absorbed intact through the intestinal mucosa, traversing the mucosal cell membrane into the plasma (Power and Horgan, 2000). Organic trace minerals have stability constants at such magnitude as to allow the metal ions to be released and transferred to the host's bio logical system (Hynes and Kelly,1995). Minerals using either amino acid or peptide uptake mechanism would therefore be expected to be absorbed and circulated to target tissues very efficiently (Power and Horgan, 2000) hence, highly bioavailable. However, bioavailability could be influenced by several factors. These include host-related factors such as age and species of the animal, sex, stage of growth, pregnancy, lactation, nutritional status, disease, gastrointestinal secretions and microflora as well as gastrointestinal transit time (Johnson, 1989; Fairweather-Tait,

Table 1: The effect of supplementing the breeder diet with 200 ppb chromium picolinate on reproductive performance

Location	Performance trait	Chromium (ppb)		
		0	200	P-value
Site 1	Sow number	831.0	775.0	
	Farrowing rate,%	82.0	86.3	0.125
	Born alive	12.3	12.4	0.325
	Still births,%	7.2	7.1	0.584
Site 2	Sow number	197.0	222.0	
	Farrowing rate,%	85.0	84.0	0.900
	Born alive	10.9	11.1	0.345
	Still births,%	9.1	8.3	0.885

Adapted from: Campbell (1998)

Table 2: Effect of chromium from chromium chloride and chromium picolinate on growth and serum and carcass traits of growing-finishing pigs

Item	Basal	Cr chlorideb	Cr picolinateb
Gain, kg/d	0.69 0.73	0.72	
Feed intake, kg/d	2.09	2.08	2.25
Gain/feed	0.33	0.35	0.32
Cholesterol, mg/dl	72.30	80.40	68.00
Growth hormone, ng/ml	2.61	2.37	1.55
Insulin, U/ml	19.50	20.60	22.50
10th rib fat, cm	3.07	2.90	2.39
Loin eye area, cm	31.50	31.20	38.40
Percentage of muscling	52.30	52.30	55.70
Dressing percentage	74.60	74.60	74.20

a-Data are means of four replicates of four pigs each. Pigs averaged 22.4 kg initially and the experimental period was 98 d. b-Chromium, 200 ppb. Adapted from: Page, 1991.

Table 3: Effect of source and level of copper on performance of weanling pigs

Item	Control	Cu-lys		$CuSO_4$	
		100	200	100	200
Daily gain, g	364.00	406.00	392.00	391.00	394.00
Daily feed, g	717.00	776.00	745.00	733.00	747.00
Feed:gain ratio	1.97	1.91	1.89	1.88	1.89
Liver Cu, ppm[1]	23.00	33.00	337.00	34.00	272..00

[1]Basal vs all other treatments (p < .001); 200ppm of Cu vs 100ppm of Cu (< 0.001). Adapted from: Coffey *et al*. (1994)

1996). The physiochemical factors may also affect nutrient uptake from the intestinal lumen and the incorporation of nutrients into biochemical pathways within the cellular environment (Power and Horgan, 2000). Such factors include the chemical form in which the mineral is ingested, and the amounts and proportions of other dietary components (phytate, phosphate, amino acids, sugars, other metals, etc.) with which it competes and/or interacts metabolically.

Organic iron (Fe) in sows diets: Baby pigs are very susceptible to Fe deficiency anemia because of lack of placental or mammary Fe transfer from the dam to offspring. Pond *et al*. (1961) showed conclusively that whether Fe sources are administered to dams orally or via injection, neither pig stores at birth nor Fe concentration in milk is increased sufficiently to prevent anemia in the offspring. However, with the reported relative availability of chelated or proteinated sources of Fe as 125 - 185% (Henry and Miller, 1995), this has prompted interest in their inclusion and use in sows and piglets diets. According to Ashmead and Graff (1982) iron linked to amino acid increased the transfer of Fe across the placenta and into the embryo. Thus, when provided organic Fe at 200 ppm 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 (Close, 1998). More recently, Close (1999) reported that addition of organic iron to a normal lactation diet fed some 7 days before farrowing and throughout a 26-day lactation, improved feed intake of the sow as well as the weaning weights of the piglets. These indicate that more iron crossed the placenta and transferred into the fetuses which then have higher blood haemoglobin and immunoglobulin levels at birth. This higher immune status and viability resulted to a stronger piglet, consuming more milk and hence, performed better. This observation also provided evidence that organic iron was transported through the body by a different mechanism from normal iron metabolic mechanism (Vandergrifft, 1993).

Organic iron (Fe) in weanling pigs diets: Very little information is available to demonstrate the effects of organic Fe supplementation on the performance of weanling pigs. There was no concrete evidence showing positive response of weanling pigs to organic forms of iron compared with iron sulfate. Lewis *et al*. (1995) reported that the iron in iron-methionine was less bioavailable than the iron in ferrous sulfate but the iron from iron-proteinates was similar to iron in ferrous sulfate (Lewis *et al*., 1999).

Organic chromium (Cr) in sows diets: There are quite a number of studies indicating positive effect of organic chromium in female reproduction. In experiment conducted by Lindemann *et al*. (1995a) wherein gilts fed diets with 200 ppb Cr from Cr picolinate throughout growth and gestation had larger and heavier litters at birth and at 21 days of age than the controls. Similar experiment was carried out by Campbell (1998) and showed that supplementing the diet with 200 ppb organic chromium fed during gestation and lactation improved fertility through increased litter size and farrowing rate (Table 1). According to Close (1999), the higher number of piglets born alive probably resulted from the action of insulin which influenced follicular development, LH and FSH secretions and hence, increased ovulation rate. Progesterone concentration in the plasma may also change and this affects the action of uterine secretory proteins (uteroferrin and retinol-binding protein) which control embryo survival.

Organic chromium (Cr) in growing-finishing diets: For the past years, efforts are being made to improve carcass quality and organic Cr may be a valuable tool in this respect. In experiments done by Page *et al*. (1991; 1993) in growing/finishing pigs, organic Cr from Cr picolinate significantly increased feed intake, decreased feed efficiency (G/F), reduced 10th rib fat, increased loin eye areas and percentage muscling and reduced serum cholesterol level (Table 2). The work of Lindemann *et al* (1995b) demonstrated a similar response of decreased backfat and increased loin eye area when 200 ppb of Cr from Cr picolinate was fed in diets with 100 or 120% of NRC (1998) lysine requirement for growing-finishing pigs. Similar findings were also reported by Mooney and Cromwell (1995). These beneficial effects of Cr are probably mediated through the action of the growth-promoting hormones which repartition nutrients are in favor of lean rather than fat deposition (Close, 1999).

Positive effects of Cr supplementation were also noted on growth performance of young pigs. Harper *et al*. (1995) examined the effect of adding 200 ppb Cr from Cr picolinate to diets of pigs weaned at 29 days of age. In the first 35 days postweaning, Cr supplementation resulted to an improvement in daily gain ($p < 0.05$) and feed utilization ($p < 0.09$). Wenk, 1994 evaluated multiple forms of Cr such as Cr chloride, Cr yeast and Cr picolinate and reported no performance effects of Cr in the growing period (27-60 kg), but Cr increased growth rates in the finishing period (60-106 kg). The increased growth rate in the finishing period indicated to some extent an improvement on nutrient utilization. This was confirmed when Wang (1995) conducted four nutrient retention experiments to assess the effect of feeding 200 ppb Cr as Cr picolinate on dry matter digestibility and nitrogen balance of growing-finishing pigs. Organic Cr increased the nitrogen absorption ($p < 0.05$), nitrogen retention ($p < 0.10$) and dry matter digestibility ($p < 0.01$). Due to improvement in nitrogen utilization,

Table 4: The growth performance of entire male pigs individually housed and offered diets ad libitum containing either no added copper (control: 20ppm Cu), copper sulphate (150ppm) or organic copper complex(40 ppm)

Feeding period	Parameter	Control	$CuSO_4$	Org.Cu	P-value
Growers	Growth rate, kg/d	0.902	0.957	0.942	0.077
(30-60 kg)	Feed intake, kg/d	1.94	2.05	2.08	0.044
	FCR, feed:gain	2.15	2.16	2.21	0.470
	Faecal Cu, ppm DM	130.00	853.00	275.00	
Finishers	Growth rate, kg/d	0.845	0.871	0.836	0.660
(60-90kg)	Feed intake, kg/d	2.39	2.59	2.65	0.730
	FCR, feed:gain	2.84	2.98	3.02	0.002
	Faecal Cu, ppm DM	108.00	776.00	199.00	

Adapted from: Smits and Henman, 2000.

Table 5: Performance and serum Zn concentration of weanling pigs fed diets with high concentration of zinc (3000 mg/kg) from different sources

Item	ZnO	Zn-met	Zn-lys	$ZnSO_4$
ADG,kg *	0.15a	0.13ab	0.12ab	0.09b
ADFI. kg *	0.26a	0.26a	0.21ab	0.18b
Gain:feed	0.56	0.49	0.58	0.47
Serum concentration, mg/l*	0.98b	1.09b	1.25ab	1.42a

* Means on the same row without common letter differ significantly ($P < 0.05$). Adapted from: Schell and Kornegay, 1996.

organic Cr has been regarded of having the potential of positive environmental impact (Lindemann, 1996).

Organic copper (Cu) in weanling pigs diets: Copper is widely used in the pig industry to promote growth. It is normally added at 100 - 250 ppm to pigs diets in the form of inorganic salt. Although limited research with Cu-amino acids and Cu-proteinates suggesting somewhat greater absorption of Cu than that obtained with copper sulfate ($CuSO_4$) (Baker, 1995), several experiments have been done to evaluate the performance of weanling pigs fed diets supplemented with Cu either as $CuSO_4$ or as organic Cu.

Some of the previous reports have shown that addition of Cu from Cu-lys resulted in improved performance of pigs. Zhou *et al*. (1994) compared $CuSO_4$ with Cu-lys when provided in the diet to weanling piglets over a 24 day period. The piglets on the Cu-lys diet consumed more feeds and had significantly higher growth rates than those fed the $CuSO_4$ diets. Similar results were reported by Coffey *et al*. (1994) who evaluated the efficacy of Cu-lys as growth promotant for weanling pigs (Table 3). Averaged across levels of Cu supplementation, the percentage improvements from Cu-lys additions were greater than those of copper sulphate for growth rate (16.8 vs 11.5%; $P < 0.03$), and feed intake (14.1 vs 8.7%; $P < 0.01$) but not for efficiency of feed utilization (2.2 vs 2.4%). According to Apgar and Kornegay (1996), ADG tended to be higher for pigs fed Cu-lys than pigs fed $CuSO_4$ and at similar levels of feed intake growth rate was 14.3% higher for the pigs fed Cu-lys than $CuSO_4$.

More recently, Smits and Henman (2000) reported that improvement on growth rate was only in the grower stage by increasing feed intake but not at the finishing period (Table 4). However, Close (1999) stated that even though pigs fed diets supplemented with organic copper recorded similar level of performance as those fed diets supplemented with inorganic Cu, there was considerable reduction on coefficient of variation of the growth rate of piglets and a substantial reduction on the amount of copper excretions when organic Cu was provided (Smits and Henman, 2000; Lee *et al*., 2001a).

Earlier studies done by Kirchgessner and Grassmann (1970), and Grassmann and Kirchgessner (1974) have also shown that absorption rate of Cu in the form of Cu-amino acid complexes was higher than that in the inorganic forms for rats and for cattle (Kincaid *et al*., 1986) In agreement to this, Du *et al*. (1996) reported that Cu utilization from Cu proteinate and Cu-lys were higher ($P < 0.05$) based on the liver Cu content. Moreso, the rats fed Cu complexes had higher liver Fe or Zn content than the rats fed $CuSO_4$, suggesting that Cu complexes are absorbed via another mechanism that differs from that of inorganic Cu and does not interfere with Fe and Zn.

On the other hand, some studies in which organically boundCu has been added to swine diets revealed that they are as effective as $CuSO_4$ in improving performance and Cu status in pigs(Bunch *et al*., 1965; Zoubek *et al*., 1975; Stansbury *et al*., 1990; van Heughten and Coffey, 1992; Coffey, *et al*., 1994; Apgar *et al*., 1996), in chicks (Baker *et al*., 1991; Aoyagi and Baker, 1993) and in cattle (Wittenberge *et al*. 1990; Ward *et al*., 1993). Even at growth-stimulative levels of Cu, $CuSO_4$ the absorption and retention of Cu was similar for both and Cu-lys (Apgar and Kornegay, 1996).

Organic zinc (Zn) in pigs diets: Inorganic zinc supplement in the form of zinc oxide is normally included at high rate (3 kg/ton) in pigs diets due to its pharmacological effects. However, much of this dietary zinc is excreted because the availability of zinc oxide is low (Ammerman *et al*., 1995). Enhancing therefore, the availability of zinc from sources would reduce the amount of this mineral to be added in animals diets. The use of organically bound zinc such as Zn-lys and Zn-met have received much attention because of their potential of providing readily available zinc. But several researches have been reported with conflicting results. Hahn and Baker (1993) observed no improvement on ADG of weanling pigs fed 3000 ppm Zn from chelated Zn-lys and Zn-met. This report was confirmed by Schell and Kornegay (1996) who investigated the feeding of high concentrations of Zn in pigs to improve postweaning performance and to compare the availability of Zn from several sources when fed to pigs at high concentrations. These previous results showed that the performance of pigs was not generally improved by feeding 3000 mg Zn /kg from any of the Zn sources (Table 5). The serum concentration of Zn was greater ($P < 0.05$) for pigs fed $ZnSO_4$ rather than ZnO and Zn-met. Thus, when used as measurement, the bioavailability of Zn was lowest for ZnO and intermediate for Zn-lys and Zn-met. But when based on plasma concentrations of zinc, equivalent bioavailabilities have been reported for zinc sulfate, zinc-lys and zinc-met (Hahn and Baker, 1993).

Contrary to these reports, Cheng *et al*. (1998) demonstrated that $ZnSO_4$ and Zn-lys complex seemed to be equally effective not only in promoting growth but also in Zn absorption, and tissue stores of young pigs even when diets contained deficient, adequate or slightly more than adequate level of lysine. This was consistent with the previous reports of Kornegay and Thomas (1975); Hill *et al*. (1986); Likewise, Wedekind *et al*. (1994); Swinkels, *et al*., 1996 reported that Zn from both $ZnSO_4$ and Zn-met were equally effective, in contrast to the findings of Wedekind *et al*. (1992) that Zn-met complex was more available than $ZnSO_4$ or ZnO as measured by the Zn content of the tibia of chicks. Ward *et al*. (1996) reported that the growth response of weanling pigs was similar between those fed 250 ppm of zinc from zinc-met complex and 2000 ppm zinc from zinc oxide, which suggests an increase

Table 6: Growth performance and copper (Cu) and zinc (Zn) concentrations in serum and feces of weanling pigs1

Treatment*	A	B	C	D	E	SE
ADG(g)	573.00	571.00	601.00	594.00	597.00	25.06
ADFI(g)	988.00	962.00	934.00	974.00	964.00	46.54
FCR	1.72a	1.68a	1.55b	1.64ab	1.62ab	0.09
Serum(mg/l)						
Cu						
2nd w	1.60b	1.76ab	1.98a	1.75ab	2.02a	0.21
4th w	1.49bc	1.38c	1.70a	1.66ab	1.80a	0.18
Zn						
2nd w	1.44b	1.50ab	1.55ab	1.52ab	1.74a	0.16
4th w	1.64ab	1.60b	1.72ab	1.61b	1.83a	0.13
Feces(mg/kg)						
Cu	1,870.00a	615.00d	1,165.00b	785.00c	1,240.00b	451.90
Zn	1,555.00a	795.00c	1,240.00b	1,155.00b	1,560.00a	297.36

*Treatment: A, $ZnSO_4$ 120ppm, $CuSO_4$ 170ppm; B, ZAC 60ppm,CAC 85ppm; C, ZAC 120ppm, CAC 170ppm; D, ZM 60ppm, CL 85ppm; E, ZM 120ppm, CL 170ppm. 1Values with different superscripts of the same row are significantly different ($p < 0.05$). Adapted from: Lee *et al*., 2001b.

Table 7: Effect of Se sources and levels fed to sows during late gestation on litter and postpartum milk Se concentration

	Inorganic Se		Organic Se		
Item	0.15	0.30	0.15	0.30	SEM
Colostrum Se ug/mL	0.061a	0.093a	0.131b	0.188c	0.016de
Milk Se, ug/mL					
7 d	0.032f	0.036g	0.077h	0.111i	0.002dj
14 d	0.027f	0.036g	0.072h	0.105i	0.003dj
Litter Se measurements					
7 d					
GSH-Px, units/mL	0.128	0.130	0.109	0.110	0.019
Serum Se, ug/mL	0.015b	0.061ab	0.057b	0.072a	0.005d
14 d					
GSH-Px, units/mL	0.147	0.206	0.215	0.217	0.021
Serum Se, ug/mL	0.072c	0.076c	0.086b	0.104a	0.004dk

a,b,c,Means within each row with different superscripts differ ($p < 0.05$). d-Linear increase ($p < 0.01$) .15 and .30 ppm organic Se level. e-Se level x Se source interaction ($p < 0.01$). f,g,h,i-Means within each row with different superscripts differ ($p < 0.01$). j-Se level x Se source interaction ($p < 0.05$). k-Linear response ($p < 0.01$) .15 and .30 ppm inorganic Se levels. Adapted from: Mahan (2000).

Table 8. Effect of dietary Se sources and levels on growing-finishing pig performances

	Inorganic Se				Organic Se				
Item	0.05	0.10	0.20	0.30	0.05	0.10	0.20	0.30	SEM
Final weight, kga	107.6	104.3	105.5	104.2	106.6	108.0	106.1	106.7	1.4
Daily gain, g									
20 to 55 kg	772	764	780	763	770	782	783	804	20
55 to 105 kg	916	853	880	854	895	900	885	857	15
Overall	852	812	838	813	838	847	837	835	13
Daily feed, g									
20 to 55 kg	1,730	1,691	1,768	1,707	1,715	1,735	1,734	1,774	41
55 to 105 kg	2,695	2,546	2,698	2,523	2,688	2,644	2,628	2,615	57
Overall	2,248	2,147	2,273	2,141	2,232	2,219	2,210	2,228	38
Gain:feed, g/kg									
20 to 55 kg	446	451	445	447	449	451	452	453	6
55 to 105 kg	340	335	326	339	333	340	337	329	6
Overall	379	378	369	380	375	383	379	375	4

a-Each mean represents 39 pigs per treatment group with an average initial body weight of 20.4 kg. Adapted from: Mahan, *et al*., 1999.

in the bioavailability of zinc in zinc-met. More recently, Lee *et al*. (2001a) demonstrated higher ADG in pigs fed diet with 120 ppm Zn from zinc-met than the control group ($ZnSO_4$).

Organic zinc (Zn) and copper (Cu) in pigs diets: Because of the positive response of weanling pigs to the pharmacological levels of Zn and Cu, there has been interest in determining whether Zn and Cu act synergistically. This was first initiated by Smith *et al*. (1997), who evaluated the potential interactive or additive effects of growth-promotional levels of Zn and Cu on weanling pig performance. They observed decreased ADG ($p < 0.01$) and ADFI ($p < 0.05$) in pigs fed the diets with 250 ppm Cu, with or without 3,000 ppm Zn compared with pigs fed either the control diet or the diet with only 3,000 ppm added Zn. The lack of an additive response to Zn and Cu at pharmacological levels could be attributed to Cu:Zn imbalance. In collaboration with this finding Spears *et al*. (1999) showed that the levels of Zn and Cu normally added to pig diets can be greatly reduced without affecting performance from weaning to slaughter. Substantial reduction of Zn and Cu in fecal excretions were obtained by replacing a portion of the reduced inorganic trace minerals in the diet with organic trace minerals. Similar results were also obtained by Lee *et al*. (2001b) wherein the effects of feeding different chelated Zn and Cu sources on growth performance and fecal excretions of weanling pigs were evaluated. Results indicated that the efficacy of chelated Zn and Cu sources at low levels are not statistically different ($p > 0.05$) in terms of growth performance and in maintaining serum concentrations from that of high levels of inorganic Zn and Cu sources. The fecal excretions for Zn and Cu were reduced in pigs fed low level of these minerals using organic sources (Table 6).

Organic selenium (Se) in sows diets: It has been a tradition to supplement swine diets with Se in the form of sodium selenite particularly in sows diets. A deficiency in Se may lead to problems at farrowing which may include high piglet mortality, lethargic and weak piglets as well as mulberry heart disease. In addition, low Se intake can lead to reduced muscle tone and strength in sows which may eventually prolong the farrowing process with a greater incidence of stillborn piglets (Close, 1998).

With organic Se having more availability of 120 to 150% to sodium selenite (Close,1998), research report of Mahan and Kim (1996) showed the beneficial effects of adding Se-enriched yeast to a gestating diet. First parity gilts fed diets with organic Se had increased milk Se content and when fed .3 ppm Se from Se-enriched yeast source subsequently increased the piglet tissue Se concentrations. In line with these findings, Mahan (2000) evaluated the short-term effects of feeding two dietary Se sources at various levels on the transfer of Se to the dam's milk and nursing pig. Similar responses were observed that organic Se increased milk Se content 2.5 to 3 times that of inorganic source and subsequently increased the nursing pig's serum Se (Table 7), a clear indication that Se is transferred through placental and mammary tissue (Mahan *et al*., 1977). These results have important implications for the young piglets which are often deficient in Se at weaning, a deficiency that can predispose them to mulberry heart disease (Close, 1998). Hence, pigs of poor Se status may encounter Se deficiency sooner after weaning (Mahan *et al*., 1975).

Organic selenium (Se) in growing/finishing diets: Inclusion of Se in grower/finisher pig diets is also important in improving the Se status of the various organs in the animal's body as well as the activity of glutathione peroxidase (GSH-Px). GSH-Px functions for the prevention of cell membrane oxidation and a deficiency of Se will therefore leave membrane vulnerable to oxidation and precipitate drip loss in meat (Close, 1999). Mahan *et al*.(1999) evaluated the efficacy of inorganic and organic Se sources for growing/finishing pigs, as measured by performance and various tissue, serum, carcass, and loin quality traits. The performance results of pigs during growing, finishing, and overall experimental period demonstrated no effect ($p > 0.05$) of Se source or level on pig gain, feed intake and gain:feed ratio (Table 8). But both Se source and level positively affected the Se concentration in the various pig tissues at the end of the growing and finishing periods and the magnitude of increase was substantially greater when organic Se source was fed. No carcass measurement benefit resulted from either Se source or level. However, there was a trend for higher drip loss and increased loin paleness; low carcass quality when inorganic Se level increased. These results were consistent with the work of Mahan and Parrett (1996) who demonstrated no growth or feed responses when either inorganic or organic form of Se was added at various levels to growing-finishing cereal grain-based diets for pigs. When organic Se was added there was higher deposition of Se in muscle but with higher GSH-Px activity when the inorganic form of element was provided.

Conclusion: The practical use of organic trace minerals will depend on the performance response, health status of animals and environmental impact. These responses will determine the cost-effectiveness of organic trace minerals in pig production. Positive responses to organic Fe, Cr and Se have been reported in relation to swine reproductive efficiency. Improved carcass quality and increased nitrogen retention are added benefits that could be derived from organic Cr supplementation. However reviews presented revealed no consistent effect of organic sources for Cu and Zn on performance variables and concentrations in serum and soft tissues. Most of the research results demonstrated that organic sources of Cu and Zn at low levels could substantially decrease the concentrations of Cu and Zn excreted compared to inorganic sources at pharmacological levels.

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