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Effects of Sources and Levels of Selenium on Physiological Responses, Litter Performance, Blood Profiles, Milk Composition and Tissue Concentration in Lactating Sows and Their Progeny

포유돈 사료 내 셀레늄 형태 및 첨가수준이 모돈 및 자돈의 생리적 변화, 포유능력, 혈액성상, 돈유성분 및 조직 내 셀레늄 농도에 미치는 영향

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Summary

Recently, in a situation where consumers' interest in well-being is increasing, many foods fortified with bioactive substances are being released according to this trend. In nature, selenium exists in two chemical forms: organic and inorganic. Among them, organic selenium has a higher retention rate, higher tissue accumulation and antioxidant bioavailability, and low toxicity and environmental pollution than inorganic selenium. So, replacing the conventional inorganic Se with organic Se in animal feed has recently attracted by feed industry although organic form of selenium is much more expensive. However, production of selenium fortified animal products is not well developed in market of animal food because supplementation level of selenium in feed is very low and bioavailability of selenium is different by levels and sources. Therefore, this study was conducted to investigate the effect of selenium benefits on lactating sows on physiological responses, litter performance, blood profiles and milk composition when mixed form of selenium was provided in lactation diet. A total of 45 F1 multiparous sows (Yorkshire × Landrace) with average body weight (BW) of 241.8 ± 3.57 kg, backfat thickness of 18.9 ± 1.76 mm, and parity of 3.50 ± 0.440 were allotted to one of 4 treatments considering BW, backfat thickness, and parity in a complete randomized design (CRD) with 15 replicates. Treatments were 1) Con; corn-SBM based diet; 2) ISOS15; corn-SBM based diet + inorganic selenium 0.15 ppm + organic selenium 0.15 ppm; 3) ISOS25; corn-SBM based diet + inorganic selenium 0.25 ppm + organic selenium 0.25 ppm. As a result, during the lactation period, the mixing levels of organic and inorganic selenium did not show difference in body

weight and backfat thickness of lactating sows. In addition, litter weight and piglet weight were not changed by different levels of dietary selenium in sow's diet. Additionally, the milk composition of lactating sows was not altered by different levels of dietary selenium. When sows were fed ISOS15 and ISOS25 treatment diet, ADFI was increased numerically compared to control but there were no differences in body weight and backfat thickness of sows. When sows were fed selenium treatment diets, selenium in blood was clearly increased at 7 d of lactation both in sow and piglets ($P<0.01$) and maintained plateau after time. Liver selenium in piglets tended to increase when dietary selenium was provided to sows. However, selenium contents in kidney and muscle were higher as dietary selenium was increased, respectively ($P=0.03$, $P=0.04$). This experiment demonstrated that dietary selenium can be transferred efficiently from sows to piglets subsequently adequate level and source of selenium should be suggested. Moreover, selenium fortified pork can be produced if adequate level and source of selenium is utilized in diets for grower-finisher pigs.

Keywords : Selenium, Blood profiles, Litter performance, Piglets, Lactating sow

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List of Abbreviations

ADG	:	Average daily gain
ADFI	:	Average daily feed intake
ANOVA	:	Analysis of variation
BF	:	Backfat
BW	:	Body weight
CRD	:	Completely randomized design
GLM	:	General linear model
LSD	:	Least significance difference
MCP	:	Monocalcium phosphate
ME	:	Metabolic energy
NRC	:	National Research Council
SAS	:	Statistical analysis system
SBM	:	Soybean meal
SEM	:	Standard error of the mean
WEI	:	Weaning to estrus interval

I. Introduction

Due to the recent FTA agreement with foreign countries, the supply and demand situation of feed raw materials is deteriorating, which is causing great difficulties in enhancing the competitiveness of the domestic livestock industry due to the rise in domestic feed prices. As part of countermeasures against the difficulties of domestic livestock farms, pig farms have increased interest in meat production with enhanced functional physiological active substances of high added value. Among the functional substances added in livestock feed, Selenium (Se), as well as vitamin C and E, which have been proven to have antioxidant ability in the animal body, is under the spotlight. Although selenium has long been recognized as a toxic substance (Wendel, 1989), Rotruck et al. (1973) began to draw more attention after selenium was identified as an essential component of glutathione peroxidase (GSH-Px), a metal-containing enzyme that plays an important role in the intracellular antioxidant defense system.

In nature, selenium exists in two chemical forms: organic and inorganic. Inorganic selenium is found not only in metal form but also in selenite, selenate, and selenide form. In contrast, selenium in feed, grains, and oilmeals is mainly found in the form of an organic selenium as selenomethionine. Therefore, livestock mainly consume selenium in the form of SeMet (Surai, 2006). When livestock is supplied with selenium sources (organic and inorganic), it is reported that organic selenium has higher absorption and accumulation efficiency in the intestines than inorganic selenium (Ortman and Pehrson, 1999; Lawler et al., 2004). As a result,

organic selenium is used to produce selenium-reinforced livestock products, but organic selenium products are not only highly dependent on imports, but also have a small amounts of addition, so if they are paid excessively at the site, they are at risk of addiction and expensive.

Therefore, in this study, when selenium was mixed in different sources and levels of addition to lactation diets, it was conducted to investigate the effect of selenium benefits on lactation sows on responses, litter performance, blood profiles and milk composition.

II. Review of Literature

1. Introduction

In a situation where consumers' interest in well-being is increasing recently, many foods with enhanced physiologically active substances are on the market according to this trend. In particular, in livestock foods, research is actively being conducted to produce foods with fortified physiologically active substances by providing physiologically active substances to livestock to satisfy consumers' consumptions need. In Korea, omega eggs (Chung et al., 1992), CLA-reinforced pork and eggs (Park et al., 1999; Lee et al., 2003), selenium-reinforced eggs and pork are being produced, and interest in trace nutrients is increasing overseas (Reddy, 1996).

In the field of food science, antioxidants are used in a limited sense of inhibition or delay of maintenance, but in recent years, it has been reported that oxidation inhibition or delay functions are also found to be expressed in vivo and are involved in suppressing various physiological disorders (Giese, 1996; Frankel, 1996). Selenium enhancement in livestock products can be produced by supplementing organic and inorganic selenium in feed consumed by livestock to induce metastasis by metabolism in the body, or by raising selenium above nutritional levels to deposit in muscle tissue for a certain period of time.

2. Requirements of selenium

Most of the nutritional requirements for trace minerals in pigs were determined with a focus on avoiding nutritional deficiencies and go as far back as the 1990s. The NRC in 1973 did not recognize a supplemental need for selenium, but 0.15 ppm Se was inserted in the NRC tables for all swine production phases in 1979. In 1998, the NRC requirement for selenium increasing to 0.30 ppm in the nursery period. NRC requirements are generally based on optimal growth, environmental and health conditions and reflect the minimum requirements for achieving optimal performance. The requirement of selenium was decreased a little in nursing and weaning pigs in NRC 2012 compared with that of 1998 (Table 1). However, in many pig farms, many environmental and health problems that are not present in research facilities can modify pig requirements.

The dietary requirement for selenium ranges from 0.3 ppm for weanling pigs to 0.15 ppm for finishing pigs and sows (Groce et al., 1971, 1973a,b; Ku et al., 1973; Mahan et al., 1973; Ullrey, 1974; Young et al., 1976; Glienke and Ewan, 1977; Wilkinson et al., 1977a,b; Mahan and Moxon, 1978a,b, 1984; Piatkowski et al., 1979; Meyer et al., 1981; Lei et al., 1998), but in commercial conditions this should be increased depending on the level of stress (Surai and Fisinin, 2015). The requirement for selenium is affected by dietary phosphorus (Lowry et al., 1985b), but not dietary calcium (Lowry et al., 1985a). Several forms of selenium, including selenium-enriched yeast, sodium selenite, and sodium selenate, are effective in

meeting dietary requirements (Mahan and Magee, 1991; Suomi and Alaviuhkola, 1992; Mahan and Parrett, 1996; Mahan and Kim, 1996).

Table 1. Dietary selenium requirements for swine (90% DM, NRC 2012)

Pigs	Requirements of selenium (amount/kg of diet)	
	NRC, 1998	**NRC, 2012**
Growing pigs	0.30 mg/kg	0.30 mg/kg
5-7 (kg)	0.30 mg/kg	0.25 mg/kg
7-11 (kg)	0.25 mg/kg	0.20 mg/kg
11-25 (kg)	0.15 mg/kg	0.15 mg/kg
25-50 (kg)	0.15 mg/kg	0.15 mg/kg
50-75 (kg)	0.15 mg/kg	0.15 mg/kg
75-100 (kg)	0.15 mg/kg	0.15 mg/kg
100-135 (kg)	0.15 mg/kg	0.15 mg/kg
Gestating sows	0.15 mg/kg	0.15 mg/kg
Lactating sows	0.15 mg/kg	0.15 mg/kg
Boars	0.15 mg/kg	0.15 mg/kg

3. Characteristics of selenium

For health, growth and biochemical and physiological functions, essential trace elements are necessary in diets of the animals (Scott et al., 1982). Selenium (Se) is an essential trace element for human and animal health (Schrauzer, 2003; Surai, 2006). It is a component of at least 25 selenoproteins participating in the maintenance of redox balance and antioxidant defense. Selenium was not considered important until Eggert et al. (1957) reported that selenium is an essential nutrient for pigs because it helps prevent hepatosis diaetetica. One of the main biochemical functions of selenium is the component of glutathione peroxidase (GPx). GPx removes hydrogen peroxide but utilizes glutathione (GSH), which must be regenerated with glutathione reducing enzyme that eliminates the toxicity of lipid peroxides and protects cells and organs from damage caused by peroxide (Rotruck et al., 1973).

Selenium is the only micronutrient regulated by the Food and Drug Administration (FDA) as feed additives due to its potential toxic effects. The FDA first approved the supplementation of selenium for feed in 1974, but it was only available for swine, chicken, and turkey diets. The FDA permits manufactured premixes to contain no more than 200 mg Se/kg. In general, selenium is provided as a supplement to the swine diet in the form of an inorganic (sodium selenite) or organic (enriched Se yeast). Numerous experimental studies have proven that organic selenium is suitable for nutritional selenium supplementation.

3.1 Functions of selenium

The functions and roles of various immune enhancements to selenium benefits have been identified (Arthur et al., 1993), and selenium intake at levels above the recommended dose exhibits anti-disease (Neve, 1996) and anticancer effects (Greeder and Melner, 1980). Selenium is reported to have a positive effect on blood lipid metabolism by reducing blood cholesterol content (Jun and Choi, 2002). Also, it has reported that there are anti-stress effects such as antidepressant and anti-anxiety by increasing the production and activity of sperm and exhibiting antidepressant effects (David and Richard, 1991). Selenium plays an important role in pig nutrition via participating in selenoprotein synthesis, which is central for the antioxidant system regulation in the body (Gopalakrishna et al., 2016).

3.2 Deficiency of selenium

Selenium deficiency is associated with skeletal muscular dystrophy and reproductive dysfunction (Mehdi et al., 2013), Mulberry heart disease (MHD) in pigs and Keshan disease in humans (Oropeza-Moe et al., 2015). Mulberry heart disease in young pigs is still dominant in some pigs due to selenium deficiency. Deficiency usually occurs within a few weeks of postweaning, but the outbreak can occur at the stage before weaning (Mahan, 1991, 1994). Progressive selenium deficiency was associated with morphological changes of spermatids and spermatozoa with subsequent complete disappearance of mature germinal cell. Damaged spermatogenesis due to selenium deficiency has been reported in several animal species, including pigs (Marin-Guzman et al., 1997, 2000).

3.3 Toxicity of selenium

The toxic (selenosis) level of selenium depends on the chemical form of the element, the age of the animal, and how it is administered. Responses to selenosis are classified into chronic (long-term effects) and acute (short-term effects). When excessive selenium is administered, the body attempts to remove excessive selenium through multiple pathways (mainly urine, bile, lungs) or by trapping it in various tissues (muscle, hair), making it biologically less available for biological purposes. The overwhelming part of this excretion system produces toxic effects in various tissues.

Chronic selenosis normally occurs when feedstuffs or diets contain 5 to 20 ppm Se (Kim, 1999). Symptoms are primarily characterized in growing pigs by reduced growth rates and feed intakes, and later by the loss of hair and separation of the hoof at the coronary band site (Goehring et al., 1984a,b; Mahan and Moxon, 1984). Chronic selenosis in reproducing sows results in lower conception rates, smaller litter size, weaker pigs, and a higher percentage of stillborn.

Acute selenosis occurs after ingesting a large amount of selenium from seleniferous feeds or injecting a large amount of inorganic selenium. Ingestion of large amounts of selenium resulted in feed rejection, weight loss, respiratory distress, spinal paralysis, incoordination, loss of hair, and ultimately death (Miller, 1938; Miller and Williams, 1940; Herigstad et al., 1973; Harrison et al., 1983; Mahan and Moxon, 1984). Acute selenosis can occur under conditions of errors in weighing of selenium premixes or incorrect application conditions of injectable selenium.

4. Different sources of selenium

Selenium exists in two forms: inorganic (selenite and selenate) and organic (selenomethionine and selenocysteine). Both forms can be good dietary sources of selenium. Soils contain inorganic selenites and selenates that plants accumulate and convert to organic forms, mostly selenocysteine and selenomethionine and their methylated derivatives. Selenium in the feed is most likely in the form of selenomethionine or selenocysteine. It is an amino acid containing selenium. Thus, in the process of absorption and utilization, the animal body treats it with amino acids, making the organic form of selenium more available to tissues.

Since selenomethionine is found in livestock feed, the amount of selenium held through livestock products increases. Selenomethionine must be converted into selenocysteine for protein synthesis. On the other hand, the inorganic selenium form, selenite or selenate is effective in preventing selenium deficiency in livestock, but not in the synthesis of selenocysteine containing selenocysteine found in meat, milk and eggs. Selenide, selenite and selenate are inorganic types of selenium in the feed.

Organic selenium has a higher absorption rate, higher tissue accumulation and antioxidant bioavailability, and lower toxicities and environmental pollution (Swanson, 1991; Vendeland, 1994). Therefore, replacing the traditional inorganic selenium with an organic selenium has recently attracted more attention.

4.1 Organic selenium

Various sources of organic selenium such as Se-enriched yeast, Se-amino acid and Se-proteinate were introduced in the animal feed industries. Yeast was used because it can be produced in large quantities under controlled conditions and is known to contain a highly bioactive organic form of selenium (Gerhard, 2001). The use of selenium yeast in pig diets has been approved by the FDA since 2001. Another organic selenium sources were developed to improve the bioavailability of selenium products in animals, and Se-proteinate is one of the organic selenium sources produced from enzymatically hydrolyzed soybean proteins. The organic form includes selenomethionine and selenocysteine and is found in plants (Schrauzer, 2000) and animals respectively (Kincaid et al., 1999; Boldizarova et al., 2004).

Initially, all the dietary selenomethionine is incorporated into protein. Hoffman et al. (1970) and McConnell and Hoffman (1972). The selenomethionine may be metabolized into Se-adenosyl methionine (SeAM) and further into Se-adnosyl homocysteine (SeAH) (Markham et al., 1980). SeAH is then converted into selenocysteine by enzyme activity of cystathionine β-synthase and cystathionine γ-lyase. Subsequently, selenocysteine can be incorporated into proteins or degraded, releasing the selenite or it can be degraded by selenocysteine lyase enzyme, releasing elemental Se which can be reduced to selenide (Esaki et al., 1982). Another fate of selenomethionine is transferred to methylselenol (Steele and

Benevenga, 1979) and then methylselenol can be converted into selenide via Smethyltransferase (Sunde, 1997).

4.2 Inorganic selenium

In 1987, the FDA approved 0.3 mg/kg of inorganic selenium (sodium selenite or selenate) added to animal feed, and limited the selenium added to free mixed products to 200 mg/kg. Sodium selenite and sodium selenate had similar effects on animals but considering the cost, sodium selenite is preferred (Mahan, 2001). Among the inorganic forms (i.e., selenates, selenides and selenite), the selenide form is more frequently found in the food supply.

First, selenate is converted to selenite (Axley and Stadtman, 1989). The selenite is then non-enzymically reduced by forming selenodiglutathione (GS-Se-SG) to selenide (Ganther, 1996; Hsieh and Ganther, 1977; Foster and Sumar, 1997). Selenide can have several different options. Selenide plays an important role in mixed function oxidase systems of microsomal and other cellular membranes (Chatterjea and Shinde, 2002). The methylation of selenide forms methylselenol (CH_3SeH) which then form dimethylselenide or trimethylselenonium ion (((CH_3) xSeH) (Hsieh and Ganther, 1977). Selenide can also bind to the Se-binding proteins or it can be a substrate for selenophosphate synthestase for the tRNA-mediated synthesis of selenoproteins (Sunde, 1997). This final step converts the inorganic selenium into an organic selenium found in mammalian tissues.

4.3 Comparison of organic and inorganic selenium

Selenium is generally added to the pig diet with sodium selenite (Na2SeO3) in inorganic form. However, due to its high absorption rate and biological effects in pigs, interest in organic selenium has been increasing in recent years (Mahan et al., 1999, 2014; Jang et al., 2010). Organic selenium has also been reported to have higher antioxidant activity, but inorganic selenium may act as a prooxidant (Spallholz, 1994) and particularly toxic effects at high levels (Seko et al., 1989). Since selenomethionine is found in livestock feed, the amount of selenium held through livestock products increase. On the other hand, the inorganic selenium form, selenite or selenate is effective in preventing selenium deficiency in livestock, but not in the synthesis of selenocysteine containing selenoprotein found in meat, milk and eggs.

Several studies have demonstrated that selenium conditions at birth of pigs can be affected by dietary selenium concentration and the sources of selenium (Mahan et al., 1974; Mahan, 2000; Mahan and Peters, 2004). It has been shown that the selenium content in newborn piglet tissues and sow colostrum was higher when organic vs. inorganic selenium was fed (Mahan and Kim, 1996). The sow fed with organic selenium had a higher selenium status than the sow fed with inorganic selenium (Mahan, 1994). In addition, studies conducted on growth-finishing pigs (Mateo et al., 2007) have shown that inorganic selenium is not as effective in accumulating selenium in tissue as organic selenium.

5. Effects of supplementation of selenium in lactating sow and their progeny

5.1 Maternal effect on progeny

Newborn piglets suffer severely from oxidative stress because of their naive antioxidant system (Yin et al., 2013). Meanwhile, weaning stress has also been proven to cause oxidative stress (Zhu et al., 2013; Yin et al., 2014). Oxidative stress is a major concern in newborn piglets early in the postnatal period. For example, intrauterine growth-restricted (IUGR) pigs had worse oxidative status and lower antioxidant capacity (Che et al., 2015), Nogales et al. (2013) suggested that liver oxidation is considered as one of the mechanisms involved in low birth weight. Improving the antioxidant defenses of piglets during these critical times is critical to their health and growth performance (Surai and Fisinin, 2016). In recent years, maternal nutrition has received widespread attention (Pappas et al., 2008), and adding antioxidants to the maternal diet has proven to be a viable strategy to enhance the antioxidant capacity of offspring (Zhan et al., 2011). The importance of selenium in animal nutrition is related to its participation in maintaining the antioxidant status of animals. Neonatal pigs (Mahan and Kim, 1996; Mahan, 2000; Mahan and Peters, 2004; Yoon and McMillan, 2006) and nursery pigs (Mahan and Kim, 1996; Mahan, 2000; Mahan and Peters. 2004; Zhan et al., 2011) born to sows fed diets containing selenium from organic sources were reported to have higher selenium content than pigs born to sows fed diets containing selenium from inorganic sources.

The selenium element can be passed from sow to offspring. As more maternal selenium is passed on to the fetus and newborn, the maternal selenium status may be affected during pregnancy and lactation. This could lead to depletion of selenium stocks in sows (Lyons and Oldfield, 1996), and the antioxidant status of sows was reduced. Therefore, the health and productivity of sows may be affected.

Prenatal selenium supplementation in sows should not only meet the need for sow to piglet transfer, but also maintain maternal selenium concentrations. Different selenium sources showed a wide variety of selenium transport and conservation capacity of sows (Mahan and Kim, 1996; Yoon and McMillan, 2006). Selenomethionine was passed more effectively to offspring via milk than the inorganic selenium (Anan et al., 2009). Numerous studies have suggested that selenomethionine prevents a decrease in plasma selenium and glutathione peroxidase (GSH-Px) activity in lactating sows and a decrease in selenium in milk during lactation (McGuire et al., 1993; Alaejos and Romero, 1995). This indicates that selenomethionine can provide an efficient source of organic selenium for both sows and their offspring.

5.2 Secretion in milk or colostrum

Selenium is very important for the proper development of newborn animals, and its deficiency negatively affects growth, health and fertility (Schwarz and Foltz, 1957). During pregnancy, selenium crosses the placental barrier and the newborn receives an adequate supply of selenium, even if the animal is moderately selenium deficient (Gunter et al., 2003). During the first few weeks of life, milk is the only

dietary source of selenium for newborn animals (Ortman and Pehrson, 1997, 1999). Selenium status in animals at birth and weaning can be affected by the dam's body selenium reserves, dietary selenium concentration, and selenium source (Mahan, 2000; Mahan and Peters, 2004). There are studies in pigs that show that selenium concentrations in milk or colostrum increase in both inorganic and organic matter (Acda and Chae, 2000; Mahan and Peters, 2004; Yoon and McMillan, 2006; Svoboda et al., 2008), but are much greater when dams are fed organic selenium (Mahan, 1994; Mahan and Kim, 1996; Mateo et al., 2007). The growth rate is between 34% (Juniper et al., 2006) and 90% (Ortman and Pehrson, 1997).

III. Effects of Sources and Levels of Selenium on Physiological Responses, Litter performance, Blood Profiles, Milk Composition and Tissue Concentration in Lactating Sows and Their Progeny

ABSTRACT: This study was conducted to investigate the effects of sources and levels of selenium in lactating sow diet on physiological responses, litter performance, blood profiles, milk composition and tissue concentration. A total of 45 F1 multiparous sows (Yorkshire × Landrace) with average body weight (BW) of 241.8 ± 3.57 kg, backfat thickness of 18.9 ± 1.76 mm, and parity of 3.50 ± 0.440 were allotted to one of 3 treatments considering BW, backfat thickness, and parity in a complete randomized design (CRD) with 15 replicates. Treatments were 1) Con; corn-SBM based diet; 2) ISOS15; corn-SBM based diet + inorganic selenium 0.15 ppm + organic selenium 0.15 ppm; 3) ISOS25; corn-SBM based diet + inorganic selenium 0.25 ppm + organic selenium 0.25 ppm. As a result, during the lactation period, the mixing levels of organic and inorganic selenium did not significantly differ in body weight and backfat thickness of lactating sows. In addition, the mixing levels of organic and inorganic selenium were not significantly different in litter weight and piglet weight. Additionally, the milk composition of lactating sows was not altered by selenium admixture levels. When organic and inorganic selenium were mixed and added in lactating sow diet, ADFI tended to increase in ISOS15 and ISOS25 treatments compared to control. In blood profiles of lactating sows and piglets, there was a significant difference in concentration of serum selenium at 7 day of lactation ($P<0.01$) and maintained

plateau after that time. Selenium concentration of kidney and muscle was increased at 21 day of lactation, respectively (P=0.03, P=0.04), however liver selenium tended to increase by dietary selenium treatment. This experiment demonstrated that dietary selenium can be transferred efficiently from sows to piglets subsequently adequate level and source of selenium should be suggested. Moreover, selenium fortified pork can be produced if adequate level and source of selenium is utilized in diets for grower-finisher pigs

Key words: Selenium, Blood profiles, Litter performance, Piglets, Lactating Sow

Introduction

Recently, as interest in public health has increased, research on the development of functional livestock foods containing physiologically active substances beneficial to the human body is being actively conducted (Garnier et al., 2003), there is a growing interest in processed meat products containing high value-added functional physiologically active substances that meet the needs.

Selenium concentrated in livestock products supplements organic and inorganic selenium in feed consumed by livestock to induce metastasis by body metabolism, or supplies selenium with more than nutritive value and accumulates it in muscle tissue for a certain period to produce selenium-rich livestock products. Studies on selenium deposition in pig muscle are known to increase selenium content in meat by supplying organic/inorganic selenium (Mahan and Parrett, 1996; Mahan et al., 1999), and selenium from livestock products is Se-Met and Se-Cys, and selenium is substituted at the sulfur position exists in a complex form, so its utilization in the body is superior to that of other plant foods and fish (Finley, 2000). On the other hand, depending on the chemical form of selenium, the utilization rate of livestock varies greatly. Lawler et al. (2004) reported that the organic selenium form has higher intestinal absorption and internal accumulation efficiency than the inorganic selenium form. Most selenium is excreted in the urine, and it has been reported that selenium accumulation in tissues is limited (Hidiroglou et al., 1968).

However, the organic selenium preparations used by farms to produce selenium-enriched livestock products are expensive imported products, and the level of addition is also very small, so it is not easy to use them in the actual field. Therefore, in this study, when selenium was mixed in different sources and levels of addition to lactation diets, it was conducted to investigate the effect of selenium benefits on lactation sows on physiological responses, litter performance, blood profiles and milk composition.

Materials and Methods

Experimental animals

All experimental procedures involving animals were conducted in accordance with the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Care and Use Committee.

A total of 45 F1 multiparous sows (Yorkshire × Landrace) with average body weight (BW) of 241.8 ± 3.57 kg, average backfat thickness of 18.9 ± 1.76 mm, and an average parity of 3.50 ± 0.440 was used in a 3-wk trial at a research farm located in Eum-seong, Korea. All sows were allotted to one of three treatments considering BW, backfat thickness, and parity in completely randomized design (CRD) with 15 replicates.

Experimental design and diets

All experimental diets for lactating sows were formulated based on corn-soybean meal and selenium was supplemented by sources and levels. Treatments are as followed: 1) Control : corn-SBM based diet, 2) ISOS15 : corn-SBM based diet + inorganic selenium 0.15 ppm + organic selenium 0.15 ppm, 3) ISOS25 : corn-SBM based diet + inorganic selenium 0.25 ppm + organic selenium 0.25 ppm.

All other nutrients in experimental diets were formulated to meet or exceed the NRC requirements (2012).

The formula and chemical composition of experimental diets in lactation was presented in Table 1.

Animal management

A total of 45 pregnant sows were washed and moved into farrowing crates (2.40 × 1.80 m^2) on day 110 of gestation. The gestation diet was decreased gradually 0.2 kg per day during 5 days before farrowing. Delivery inducer was not used during farrowing and all sows were taken an assistance when dystocia was happened. After farrowing, the experimental lactation diet was increased gradually from 1.0 kg/d until 5 days postpartum and then provided *ad libitum* during the lactation period. Each farrowing crate was equipped with a feeder and a nipple waterer for sows and a heat lamp for newborn piglets. The temperature of lactating barn was kept 28 ± 2℃ and baby house under heating lamp was kept 32 ± 2℃. Air condition of lactating barn was regulated automatically by ventilation system and air-conditioner. After farrowing, piglets were cross-fostered within treatment until 24 hrs postpartum to balance suckling intensity of sows with equalization of litter size, and thus to minimize any effect of initial litter size potentially affecting litter growth. Cutting umbilical cord and tail and castration were conducted 3 days after birth, and piglets were injected with 150 ppm Fe-dextran (Gleptosil®, Alstoe, UK)

injection. All piglets were not fed creep feed during whole lactation period. Weaning was performed at approximately 21 d.

Body weight, backfat thickness, lactation feed intake

Live body weight and backfat thickness of sows were measured at 24 hrs postpartum, 7^{th} day of lactation and 21^{st} day of lactation, respectively. Body weight of sow was measured by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) and backfat thickness was measured at P_2 position (mean value from both sides of the last rib and 65 mm away from the back bone) by Ultra-sound device (Lean Meter®, Renco Corp., Minneapolis, MN, USA). Daily feed waste was recorded during lactation to identify physiological effects on sows.

Litter performance

The number and body weight of piglets was measured at 24 hrs postpartum, 7^{th} day of lactation and 21^{st} day of lactation for calculating litter weight, piglet weight and both weight gain by electric scale (CAS CO. Ltd., Yangju-si, Gyeonggi-do, Korea). At measuring the body weight of piglets, ear notching was practiced for experiment. ADG of piglets was calculated to identify their growth performance and lactating performance after farrowing.

Blood profiles

Blood samples (n=4 for each treatment) were collected from jugular vein of sows using 10 ml disposable syringes at 24 hrs postpartum, 7th day of lactation and 21st day of lactation, respectively. Also, blood samples were collected from anterior vena cava of piglets using 3 mL disposable syringes at 24 hrs postpartum and 5 mL disposable syringes at 7th day of lactation and 21st day of lactation. All serum from blood samples were moved in serum tube (SST^{TM}II Advance, BD Vacutainer, Becton Dickinson, Plymouth, UK) and EDTA tube (BD Vacutainer K_2E, Becton Dickinson, Plymouth, UK). Individual sample was centrifuged at 3,000 rpm, 4℃ for 15 minutes (Eppendorf centrifuge 5810R, Hamburg, Germany) and the supernatant serum was separated to a microtube (Axygen, UnionCity, CA, USA) and stored at –20℃ deep freezer until analysis.

The concentration of selenium in blood was measured by fluorometric method of AOAC (2000).

Milk composition

Colostrum samples were collected from functional mammary glands at 24 hrs postpartum (n=4) and milk samples (n=4 for each treatment) were taken at 7th day of lactation and 21st day of lactation. One mL of oxytocin (Komi oxytocin inj., Komipharm International Co., Ltd., Siheung-si, Gyeonggi-do, Korea) was injected into the blood vessels of the sow's ear to collect colostrum and milk in a 50mL

conical tubes (SPL Life Sciences Co., Ltd., Pocheon-si, Gyeonggi-do, Korea) from the first and second teats. Collected samples were stored in a freezer (−20 °C) until further analysis. Proximate analysis for fat, protein, lactose, and solids not fat of milk as well as colostrum was determined using a Milkoscan FT 120 (FOSS, Hillerod, Denmark). Also, the concentration of selenium in milk was measured by fluorometric method of AOAC (2000).

Tissue concentration

Piglets were killed and samples from liver, kidney, muscle were taken at 24 hrs postpartum (n=4), 7^{th} day of lactation and 21^{st} day of lactation (n=3 for each treatment). Individual samples were stored at –20°C deep freezer until analysis. The concentration of selenium in blood was measured by fluorometric method of AOAC (2000).

Statistical analysis

All collected data were analyzed as a completely randomized design using the General Linear Model (GLM) procedure in SAS (SAS Institute, 2004). Individual sows and their litters were used as the experimental unit in physiological response, litter performance, blood profiles, milk composition and tissue concentration. The differences among means were declared significant at $P<0.05$ and highly significant at $P<0.01$ and the determination of tendency for all analysis was $P\geq0.05$

and $P<0.10$. When the significance was declared, fisher's least significance difference (LSD) method was used to separate the means.

Results and Discussion

Physiological responses

The effects of mixed addition levels of organic and inorganic selenium on body weight, backfat thickness and average feed daily gain of lactating sows were shown in Table 2. Body weight, backfat thickness and lactation feed intake of sows were not affected by mixed addition levels of Se during lactation.

Previous studies that mixed additions of organic and inorganic selenium reported that the sources and levels of selenium did not affect the body weight, backfat thickness and average daily feed intake of lactating sows (Mahan, 2000; Mahan and Peters, 2004). In agreement with the above, the present study indicated that dietary selenium source and level could not have influence on physiological responses of sows during whole experimental periods.

In this study, when organic and inorganic selenium were mixed and added in lactating sow diet, ISOS15 and ISOS25 treatments were numerically higher in average daily feed intake than control. The reason for the higher ADFI observed in ISOS15 and ISOS25 compared with control remained uncertain. It could be related to the smell of the feed. The olfactory system of pigs is a fairly large, highly organized structure and highly developed (Nguyen et al., 2012; Brunjes et al., 2016). As smell is an initial attractant to feed, sows fed organic and inorganic selenium may have consumed more feed due to attractive smell perception.

Nutrients supplied as feed are insufficient to maintain the sow's body shape, develop body shape, and produce milk (Nobler et al., 1990). Decreased feed intake during lactation period can lead to excessive weight loss and problems related to the reproduction of the next parity, resulting in delays WEI (Reese et al., 1982; Baidoo et al., 1992), no estrus (Kirkwood et al., 1987), low ovulation rates (Zak et al., 1997) and decrease in fertility (Kirkwood et al., 1987). Therefore, Eissen et al. (2000) reported that the feed intake of sows during lactation should be increased as much as possible for continuous reproduction.

Litter performance

The effects of mixed addition levels of organic and inorganic selenium on the number of piglets, litter weight, litter weight gain, average BW of piglet, and average BW gain of piglet were shown in Table 3. The number of piglets, litter weight, litter weight gain, average BW of piglet, and average BW gain of piglet were not affected by mixed addition levels of Se during lactation.

Organic Se supplementation during lactation has potential for improving the growth performance of offspring (Zhan et al., 2011; Falk et al., 2019, Mou et al., 2020). Also, Falk et al (2020) reported that growth performance of piglets was positively influenced by both dietary Se source and level. Previous studies that mixed additions of organic and inorganic selenium reported that the sources and levels of selenium did not affect the litter performance (Mahan, 2000; Mahan and Peters, 2004).

As with the results of previous studies, the mixed addition of selenium to lactation sow diet during the 4-week lactation period did not negatively affect the litter performance of the lactating sows. However, when organic and inorganic selenium were mixed, there were not many studies on the reproductive performance of the lactating sows and growth performance of their progeny. In addition, most of the experimental periods were during whole-gestation or late gestation, and there were few experiments simply on the lactation period (Surai and Fisinin, 2016). In this experiment, there was no significant difference in the growth performance of piglets, despite the addition of organic and inorganic selenium to the diet, this result is considered to be because the experimental period was simply set to the lactation period.

Blood profiles

The effects of mixed addition levels of organic and inorganic selenium on serum Se concentration in sows and piglets were shown in Table 4. The serum Se concentrations of sows and piglets at 7 day of lactation were significantly higher when sows were fed organic and inorganic Se than control ($P<0.01$; $P<0.01$; respectively). However, there was no significant difference between the ISOS treatment groups.

Selenium can be passed on to offspring in the placenta and pig milk (Burk et al., 2013; Hill et al., 2014). In addition, higher selenium concentrations in sow milk increased selenium status in weaning pigs (Mahan and Kim, 1996), and higher

selenium status may mainly help reduce post-weaning mortality (Mahan et al., 1975). Organic selenium is more effective than inorganic selenium in increasing the selenium content in the blood and persists longer in the body of animals (Duntas and Benvenga, 2015).

Previous studies have shown that serum Se concentrations in sows and piglets fed a selenium mixture (0.15 ppm organic + 0.15 ppm inorganic) were similar to those treated with 0.15 ppm organic selenium (Mahan and Peters, 2004), and the Se concentration in the serum increased as the level of addition increased (Mahan, 2000).

In this study, ISOS15 and ISOS25 treatments were significantly higher in serum selenium concentration in sows and piglets than control group, there was no significantly difference between the ISOS treatment groups. This result means that selenium concentration in piglet serum was increased by ingesting colostrum and milk secreted by lactating sows regardless of the level of mixed addition of organic and inorganic selenium to lactating sows.

Milk composition

The effects of mixed addition levels of organic and inorganic selenium on the chemical composition of colostrum and milk were shown in Table 5. Fat, protein, lactose, total solid and solid not fat contents both in colostrum and milk were not affected by mixed addition levels of Se during lactation.

Newborn piglets receive selenium from sow's milk and colostrum, and the sources and levels of selenium in the sow's diet influences the selenium status of nursing and weaning piglets (Mahan et al., 1974). Selenium concentrations in mammary secretions can be increased by dietary supplementation of minerals, and the organic form of selenium used in dietary supplements is more effective at increasing selenium concentrations in colostrum and milk than the inorganic form (Kim and Mahan, 2001; Mahan and Peters, 2004; Quesnel et al., 2008; Yoon and McMillan, 2006; Zhan et al., 2011).

Previous studies have shown that selenium concentrations in sows fed a selenium mixture (0.15 ppm organic + 0.15 ppm inorganic) were similar to those treated with 0.15 ppm organic selenium. In addition, as the amount of selenium added increased, the selenium concentration of sow milk increased (Mahan, 2000; Mahan and Peters, 2004).

In the present study, there was no significant difference in selenium concentrations in milk, despite the addition of organic and inorganic selenium to the diet. This is considered to be because the experimental period was simply set as the lactation period as above.

Tissue concentration

The effects of mixed addition levels of organic and inorganic selenium on tissue Se concentration in piglets were shown in Table 6. The kidney and muscle Se concentrations of piglets at 21 day of lactation were significantly higher when

sows were fed organic and inorganic Se than control (P=0.03; P=0.04; respectively). However, there was no significant difference between the ISOS treatment groups.

In general, selenium concentrations in porcine tissues vary significantly from tissue to tissue (Seboussi, 2010), and according to previous studies, it was reported that selenium's ability to accumulate in tissues gradually decreased in the order of kidney, liver, and muscle (Combs, 1986; Lawler et al., 2004). Mahan and Peters (2004) reported that selenium supplementation in sow diet during pregnancy or lactation increased selenium content in sow and piglet tissues. Additionally, supplementation of selenium in the diet of gestating sows has been reported to increase selenium concentrations in piglet tissues by 50-130%. (Mahan and Kim, 1996). It is known that liver selenium tended to increase like kidney and muscle when dietary selenium is provided although it did not show any significant difference. Presumably contrary result might be obtained because experimental period was very short compared to previous experiments. Moreover, liver is a kind of labile tissue subsequently delivered selenium in liver directly pass through to various tissues such as muscle and kidney.

In the present study, ISOS15 and ISOS25 treatments were significantly higher in tissue selenium concentration in piglets than control group, there was no significantly difference between the ISOS treatment groups. This result demonstrated that selenium concentration in piglet tissue was increased by ingesting colostrum and milk secreted by lactating sows regardless of the level of mixed addition of organic and inorganic selenium to lactating sows.

Conclusion

During the lactation period, the mixing levels of organic and inorganic selenium did not significantly differ in body weight and backfat thickness of lactating sows. In addition, the mixing levels of organic and inorganic selenium were not significantly different in litter weight and piglet weight. Additionally, the milk composition of lactating sows was not altered by dietary selenium supplementation. In blood profiles of lactating sows and piglets, there was a significant difference in concentration of serum selenium at 7 day of lactation and it was maintained plateau after that time. Also, there were significant differences in selenium concentration of kidney and muscle at 21 day of lactation by dietary selenium of sows.

This experiment demonstrated that dietary selenium can be transferred efficiently from sows to piglets subsequently adequate level and source of selenium should be suggested. Moreover, selenium fortified pork can be produced if adequate level and source of selenium is utilized in diets for grower-finisher pigs.

Table 1. The chemical composition of the experimental diet for lactating sow

Item	Treatments		
	Con	ISOS15[1)]	ISOS25[2)]
Ingredient (%)			
Corn	75.48	75.48	75.48
SBM	15.53	15.53	15.53
Wheat bran	3.00	3.00	3.00
Tallow	1.72	1.72	1.72
Limestone	1.28	1.28	1.28
MCP	1.49	1.49	1.49
L-methionine (90%)	0.04	0.04	0.04
L-lysine Sulfate (50%)	0.59	0.59	0.59
Threonine (98.5%)	0.17	0.17	0.17
Vitamin premix[3)]	0.10	0.10	0.10
Mineral premix[4)]	0.10	0.10	0.10
Choline chloride-50	0.10	0.10	0.10
Salt	0.40	0.40	0.40
Sum	100.00	100.00	100.00
Chemical composition[5)]			
ME (kcal/kg)	3300.00	3300.00	3300.00
CP (%)	13.43	13.43	13.43
Lysine (%)	0.96	0.96	0.96
Methionine (%)	0.26	0.26	0.26
Threonine (%)	0.65	0.65	0.65
Ca (%)	0.76	0.76	0.76
Total P (%)	0.65	0.65	0.65

[1)] ISOS15: Basal diet + Inorganic selenium 0.15 ppm + Organic selenium 0.15 ppm

[2)] ISOS25: Basal diet + Inorganic selenium 0.25 ppm + Organic selenium 0.25 ppm

[3)] Provided the following per kilogram of diet: vitamin A, 12,000 IU; vitamin D3, 1,200 IU; vitamin E, 68 IU; vitamin K, 5.0 mg; thiamine (vitamin B1), 2.60 mg; riboflavin (vitamin B2), 7.8 mg; niacin (vitamin B3), 60 mg; pyridoxine (vitamin B6), 6.00 mg; d-biotin, 0.5 mg; folic acid, 6.0 mg; vitamin B12, 0.02 mg

[4)] Provided the following per kilogram of diet, control diet: Se, 0 mg; I, 0.75 mg; Mn, 60 mg; Cu, 60 mg; Fe, 120 mg; Zn, 46 mg; Co, 0.4 mg; ISOS15: inorganic Se, 0.15 ppm; organic Se. 0.15 ppm; I, 0.75 mg; Mn, 60 mg; Cu, 60 mg; Fe, 120 mg; Zn, 46 mg; Co, 0.4 mg; ISOS25: inorganic Se, 0.25 ppm; organic Se. 0.25 ppm; I, 0.75 mg; Mn, 60 mg; Cu, 60 mg; Fe, 120 mg; Zn, 46 mg; Co, 0.4 mg

[5)] Calculated values

Table 2. Effects of dietary selenium in lactation diet on body weight and backfat thickness of sows during lactation

Criteria	Treatment[1)]			SEM[2)]	P−value
	Con	ISOS15	ISOS25		
Body weight, kg					
24 hrs postpartum	239.85	246.00	239.78	5.266	0.86
7th day of lactation	248.10	254.76	248.98	5.265	0.82
21st day of lactation	234.33	240.86	235.00	5.668	0.79
Changes (21-0d)	-5.51	-5.13	-4.78	2.496	0.99
Backfat thickness, mm					
24 hrs postpartum	19.08	20.58	17.25	1.051	0.39
7th day of lactation	18.41	20.25	17.66	0.983	0.55
21st day of lactation	17.41	18.33	17.41	0.910	0.89
Changes (21-0d)	-1.66	-2.25	0.16	0.689	0.30
ADFI, kg	5.40	5.87	6.00	0.212	0.41

[1)] Treatment: Con: corn-soybean meal(SBM) based diet, ISOS15: corn-soybean meal based diet with inorganic selenium 0.15 ppm + organic selenium 0.15 ppm, ISOS25: corn-soybean meal based diet with inorganic selenium 0.25 ppm + organic selenium 0.25 ppm

[2)] Standard error of means.

Table 3. Effects of dietary selenium in lactation diet on performance of sows during lactation

Criteria	Treatment[1)]			SEM[2)]	P-value
	Con	ISOS15	ISOS25		
No. of piglets					
After cross-fostering[3)]	----------12.00----------			-	-
7th day of lactation	11.50	11.66	11.50	0.120	0.75
21st day of lactation	11.16	11.16	11.33	0.206	0.94
Litter weight, kg					
After cross-foster	16.93	15.88	15.69	0.700	0.29
7th day of lactation	29.63	29.81	28.97	1.128	0.95
21st day of lactation	63.73	59.30	61.90	1.857	0.66
Litter weight gain	46.79	40.72	46.20	1.675	0.32
Piglet weight, kg					
After cross-foster	1.40	1.54	1.30	0.058	0.29
7th day of lactation	2.58	2.55	2.51	0.091	0.96
21st day of lactation	5.74	5.38	5.47	0.168	0.70
Piglet weight gain	4.33	3.84	4.16	0.150	0.41

[1)] Treatment: Con: corn-soybean meal(SBM) based diet, ISOS15: corn-soybean meal based diet with inorganic selenium 0.15 ppm + organic selenium 0.15 ppm, ISOS25: corn-soybean meal based diet with inorganic selenium 0.25 ppm + organic selenium 0.25 ppm

[2)] Standard error of means.

[3)] After cross-fostering day within 24 hrs postpartum.

Table 4. Effects of dietary selenium in lactation diet on serum selenium in piglet at birth and 21 d during lactation

Criteria	Treatment[1)]			SEM[2)]	P-value
	Con	ISOS15	ISOS25		
Sow					
Selenium, ppm					
24 hrs postpartum	---------- 0.13 ----------			-	-
7th day of lactation	0.11[a]	0.26[b]	0.21[b]	0.021	<0.01
21st day of lactation	0.24	0.29	0.27	0.013	0.52
Piglet					
Selenium, ppm					
24 hrs postpartum	---------- 0.03 ----------			-	-
7th day of lactation	0.06[a]	0.11[b]	0.19[b]	0.008	<0.01
21st day of lactation	0.13	0.14	0.18	0.011	0.08

[1)] Treatment: Con: corn-soybean meal(SBM) based diet, ISOS15: corn-soybean meal based diet with inorganic selenium 0.15 ppm + organic selenium 0.15 ppm, ISOS25: corn-soybean meal based diet with inorganic selenium 0.25 ppm + organic selenium 0.25 ppm

[2)] Standard error of means.

[ab] Means with different superscripts in the same row significantly differ (P<0.05)

Table 5. Effects of dietary selenium in lactation diet on milk composition of sows during lactation

Criteria	Treatment[1)]			SEM[2)]	P-value
	Con	ISOS15	ISOS25		
Fat, %					
Colostrum	---------- 8.14 ----------			-	-
7th day of lactation	6.82	6.91	6.77	0.028	0.52
21st day of lactation	6.75	6.83	6.75	0.026	0.66
Protein, %					
Colostrum	----------11.86 ----------			-	-
7th day of lactation	4.42	4.57	4.46	0.178	0.51
21st day of lactation	4.38	4.44	4.47	0.459	0.27
Lactose, %					
Colostrum	---------- 3.98 ----------			-	-
7th day of lactation	5.98	5.68	5.75	0.032	0.48
21st day of lactation	5.94	5.75	5.63	0.132	0.26
Total solid, %					
Colostrum	----------26.50 ----------			-	-
7th day of lactation	17.25	17.38	17.19	0.258	0.45
21st day of lactation	17.65	17.53	17.43	0.543	0.58
Solid not fat, %					
Colostrum	----------15.46 ----------			-	-
7th day of lactation	10.55	10.68	10.64	0.058	0.58
21st day of lactation	10.49	10.54	10.61	0.081	0.25
Selenium, ppm					
Colostrum	----------0.10 ----------			-	-
7th day of lactation	0.07	0.07	0.08	0.003	0.58
21st day of lactation	0.07	0.07	0.08	0.005	0.50

[1)] Treatment: Con: corn-soybean meal(SBM) based diet, ISOS15: corn-soybean meal based diet with inorganic selenium 0.15 ppm + organic selenium 0.15 ppm, ISOS25: corn-soybean meal based diet with inorganic selenium 0.25 ppm + organic selenium 0.25 ppm

[2)] Standard error of means.

Table 6. Effects of dietary selenium in lactation diet on tissue selenium concentration in piglet at birth and 21 d during lactation

Criteria	Treatment[1)]			SEM[2)]	P-value
	Con	ISOS15	ISOS25		
Selenium, ppm					
Liver					
24 hrs postpartum	---------- 0.37 ----------			-	-
21st day of lactation	0.41	0.46	0.53	0.063	0.84
Kidney					
24 hrs postpartum	---------- 0.33 ----------			-	-
21st day of lactation	0.34[a]	0.38[b]	0.42[b]	0.156	0.03
Muscle					
24 hrs postpartum	---------- 0.31 ----------			-	-
21st day of lactation	0.13[a]	0.34[b]	0.43[b]	0.120	0.04

[1)] Treatment: Con: corn-soybean meal(SBM) based diet, ISOS15: corn-soybean meal based diet with inorganic selenium 0.15 ppm + organic selenium 0.15 ppm, ISOS25: corn-soybean meal based diet with inorganic selenium 0.25 ppm + organic selenium 0.25 ppm

[2)] Standard error of means.

[ab] Means with different superscripts in the same row significantly differ ($P<0.05$)

Literature Cited

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

Alaejos, M. S., Romero, C. D. 1995. Selenium in human lactation. Nutr. Rev. 53:159–166.

Anan, Y., Ogra, Y., Somekawa, L., Kazuo, T., Suzuki, K. T. 2009. Effects of chemical species of selenium on maternal transfer during pregnancy and lactation. Life Sci 84:888–893.

AOAC. 2000. Official Methods of Analysis. 17th Edition, The Association of Official Analytical Chemists, Gaithersburg, MD, USA. Methods 925.10, 65.17, 974.24, 992.16.

Arthur, J. R., Nicol, F., and Beckett. G. J. 1993. Selenium deficiency, thyroid hormone metabolism, and thyroid hormone deiodinases. Am. J. Clin. Nutr. 57:236-239.

Axley, M. J. and T. C. Stadtman. 1989. Selenium metabolism and selenium dependent enzymes in microorganisms. Annu. Rev. Nutr., 9: 127-137.

Baidoo S. K., F. X. Aherne, R. N. Kirkwood, and G, R. Foxcroft. 1992. Effect of feed intake during lactation and after weaning on sow reproductive performance. Can. J. Anim. Sci. 72(4):911-917.

Boldizarova, K., L. Gresakova, S. Faix and L. Leng. 2004. Antioxidant status of lambs fed on diets supplemented with selenite or se-yeast. J. Anim. Feed. Sci., 14: 245-253.

Brunjes, P. C., S. Feldman, S. K. Osterberg. 2016. The pig olfactory brain: a primer, Chem.Senses. 41:5,415-425

Burk, R. F., G. E. Olson, K. E. Hill, V. P. Winfrey, A. K. Motley, and S. Kurokawa. 2013. Maternal-fetal transfer of selenium in the mouse. FASEB J. 27:3249–3256.

Chatterjea, M. N. and R. Shinde. 2002. Metabolism of Minerals and Trace Elements: Text Book of Medical Biochemistry. 5th Edn., Jaypee Brothers Med Pub Ltd., New Delhi, India, pp: 526-531.

Che, L., Xuan, Y., Hu, L., Liu, Y., Xu, Q., Fang, Z., Lin, Y., Xu, S., Wu, D., Zhang, K., Chen, D. 2015. Effect of postnatal nutrition restriction on the oxidative status of neonates with intrauterine growth restriction in a pig model. Neonatology 107 (2), 93–99.

Chung, I. K., Park, K. M., Yoon, H. S., Kim, H. W., and Kim, M. T. 1992. Effects of omega-3 fatty acids supplementation on the contents of omega-3 fatty acids of egg yolk. Kor. J. Anim. Nutr. Feed 16(1), 7-11.

Combs G. F. J., Combs S. B (eds). 1986. The role of selenium in nutrition. Academic, Orlando.

David, B. and Richard, C. 1991. The impact of selenium supplementation on mood. Biol. Psych. 29, 1092-1098.

Duntas, L. H and Benvenga, S. 2015. Selenium: an element for life. Endocrine 48, 756–775

Eggert, R. C., Patterson, E., Akers, W. T., Stokstad, E. I. R. 1957. The role of vitamin E and selenium in the nutrition of the pig [abstract]. J. Anim. Sci. 16:1037.

Eissen J. J., E. Kanis, and B. Kemp. 2000. Sow factors affecting voluntary feed intake during lactation. Livestock Production Science 64: 147-165.

Esaki, N., H. Tanaka, S. Uemura, T. Suzuki and K. Soda. 1982. Selenocysteine lyase, a novel enzyme that specifically acts on selenocysteine: Mammalian distribution and purification and properties of pig liver enzyme. J. Biol. Chem., 257: 4386-4391.

Falk, M., Bernhoft, A., Reinoso-Maset, E., Salbu, B., Lebed, P., Framstad, T., Fuhrmann, H., Oropeza-Moe, M. 2020. Beneficial antioxidant status of piglets from sows fed selenomethionine compared with piglets from sows fed sodium selenite. Journal of Trace Elements in Medicine and Biology. 58(126439).

Finley, J. W. 2000. Does selenium accumulation in meat confer a health benefit to the consumer? Proc. Soc. Anim. Sci. pp. 1-10.

Foster, L. H. and S. Sumar. 1997. Selenium in health and disease. A review. Crit. Rev. Food Sci. Nut., 37: 211-228.

Frankel, E. N. 1996. Antioxidants in lipid foods and their on food quality. Food Chem. 57(1), 51-55.

Ganther, H. E. 1966. Enzymic synthesis of dimethyl selenide from sodium selenite in mouse liver extracts. Biochemistry, 5: 1089-1098.

Garnier, J. P., Klont, R., and Plastow, G. 2003. The potential impact of current animal research on the meat industry and consumer attitudes towards meat. Meat Sci. 63, 79-88.

Gerhard N. Schrauzer. 2001. Nutritional selenium supplements: product types, quality, and safety. J. Am. Coll. Nutr. 20:1-4.

Giese, J. 1996. Antioxidants: Tools for preventing lipid oxidation. Food Technol. 50(11), 73-78.

Glienke, L. R., and R. C. Ewan. 1977. Selenium deficiency in the young pig. J. Anim. Sci. 45: 1334–1340.

Goehring, T. B., I. S. Palmer, O. K. Olson, G. W. Libal, and R. C. Wahlstrom. 1984a. Effects of seleniferous grains and inorganic selenium on tissue and blood composition and growth performance of rats and swine, J. Anim. Sci., 59:725.

Goehring, T. B., I. S. Palmer, O. K. Olson, G. W. Libal, and R. C. Wahlstrom. 1984b. Toxic effects of selenium on growing swine fed corn–soybean meal diets, J. Anim. Sci., 59:733.

Gopalakrishna, R., U. Gundimeda, S. Zhou, K. Zung, K. Forell, and A. Holmgren. 2016. Imbalance in protein thiol redox regulation and cancer-preventive efficacy of selenium, Reactive Oxygen Species, vol. 2, no. 4.

Greeder, G. A. and Milner, J. A. 1980. Factors influencing the inhibitory effect of selenium on mice, inoculated with Ehrlich ascites tumor cells. Science 209:825-826.

Groce, A. W., E. R. Miller, K. K. Keahey, D. E. Ullrey, and D. J. Ellis. 1971. Selenium supplementation of practical diets for growing-finishing swine. J. Anim. Sci. 32:905–911.

Groce, A. W., E. R. Miller, D. E. Ullrey, P. K. Ku, K. K. Keahey, and D. J. Ellis. 1973a. Selenium requirements in corn-soy diets for growing-finishing swine. J. Anim. Sci. 37:948–956.

Groce, A. W., E. R. Miller, J. P. Hitchcock, D. E. Ullrey, and W. T. Magee. 1973b. Selenium balance in the pig as affected by selenium source and vitamin E. J. Anim. Sci. 37:942–947.

Gunter, S. A., Beck, P. A., Phillips, J. K. 2003. Effects of supplementary selenium source on the performance and blood measurements in beef cows and their calves. J. Anim. Sci., 81: 856-864.

Harrison, L. H., B. M. Colvin, B. P. Stuart, L. T. Sangster, E. J. Gorgacz, and H. S. Gosser. 1983. Paralysis in swine due to focal symmetrical poliomalacia: Possible selenium toxicosis, Vet. Pathol., 20:265.

Herigstad, R. R., C. K. Whitehair, and O. K. Olson. 1973. Inorganic and organic selenium toxicosis in young swine: comparison of pathologic changes with those in swine with vitamin E-selenium deficiency, Am. J. Vet. Res., 34:1227.

Hidiroglou, M. D., Heanley, P., and Jenkins, K. J. 1968. Metabolism of inorganic selenium in rumen bacteria. Can. J. Physiol. Pharm. 46, 229-232.

Hill, K. E., A. K. Motley, V. P. Winfrey, and R. F. Burk. 2014. Selenoprotein P is the major selenium transport protein in mouse milk. PLoS One 9:e103486.

Hoffman, J. L., K. P. McConnell, and D. R. Carpenter, 1970. Aminoacylation of *Escherichia coli*. Biochem. Biophys. Acta., 199: 531-534.

Hsieh, H. S. and H. E. Ganther. 1977. Biosynthesis of dimethyl selenide from sodium selenite in rat liver and kidney cell-free systems. Biochem. Biophys. Acta., 497: 205-217.

Jang, Y. D., H. B. Choi, S. Durosoy, P. Schlegel, B. R. Choie, and Y. Y. Kim. 2010. Comparison of bioavailability of organic selenium sources in finishing pigs. Asian- Australas. J. Anim. Sci. 23:931–936.

Jun, Y. S. and Choi, M. K. 2002. Effect of copper and selenium supplementation on lipid contents in rats. J. East Asian Soc. Dietary Life. 12:100-106.

Juniper, D. T., Phipps, R. H., Jones, A. K., and Bertin, G. 2006. Selenium supplementation of lactating dairy cows: Effect on selenium concentration in blood, milk, urine and feces. J. Dairy Sci., 89: 3544-3551.

Kim, Y. Y. 1999. Selenium Metabolism and Toxicity of Inorganic and Organic Selenium Sources and Levels on Growth, Reproduction and Other Mineral Nutrients in Swine, Ph.D. thesis, Ohio State University, Columbus, 149 pp.

Kincaid, R. L., M. Rock and F. Awadeh. 1999. Selenium for Ruminants: Comparing Organic and Inorganic Selenium for Cattle and Sheep. In: Biotechnology in the Feed Industry, Lyons, T.P. and K.A. Jacques (Eds.). Nottingham University Press, Nottingham, UK, pp: 537-545.

Kirkwood, R. N., Baidoo, S. K., Aherne, F. X., Sather, A. P., 1987. The influence of feeding level during lactation on the occurrence and endocrinology of the post weaning estrus in sows. Can. J. Anim. Sci. 67, 405–415.

Ku, P. K., W. T. Ely, A. W. Groce, and D. E. Ullrey. 1973. Natural dietary selenium, a-tocopherol and effect on tissue selenium. J. Anim. Sci. 37:501–505.

Lawler, T. L., Taylor, J. B., Finley, J. W., and Caton, J. S. 2004. Effect of supranutritional and organically bound selenium on performance, carcass characteristics, and selenium distribution in finishing beef steers. J. Anim. Sci. 82, 1488- 1493.

Lee, J. I., Ha, Y. J., Kwack, S. C., Lee, J. D., Kim, D. H., Kang, G. H., Hur, S. J., and Park, G. B. 2003. Effects of conjugated linoleic acid (CLA) feeding levels and periods on textural property and fatty acid composition of pork. J. Anim. Sci. & Technol. 45(6), 1047-1060.

Lei, X. G., H. M. Dann, D. A. Ross, W. H. Cheng, G. F. Combs, Jr., and K. R. Roneker. 1998. Dietary selenium supplementation is required to support full expression of three selenium-dependent glutathione peroxidases in various tissues of weanling pigs. Journal of Nutrition 128:130-135.

Lowry, K. R., D. C. Mahan, and J. R. Corley. 1985a. Effect of dietary calcium on selenium retention in postweaning swine. J. Anim. Sci. 60:1429–1437.

Lowry, K. R., D. C. Mahan, and J. R. Corley. 1985b. Effect of dietary phosphorus on selenium retention in postweaning swine. J. Anim. Sci. 60:1438–1446.

Lyons, T. P., and Oldfield, J. E. 1996. The case for organic selenium. In: Bulletin Selenium-Tellurium Development Association (Grimbergen Belgium), 1996 June Issue, pp. 1–3.

Mahan, D. C., J. E. Jones, J. H. Cline, R. F. Cross, H. S. Teague, and A. P. Crifo, Jr. 1973. Efficacy of selenium and vitamin E injections in the prevention of white muscle disease in young swine. J. Anim. Sci. 36:1104–1108.

Mahan, D. C., Penhale, L. H., Cline, J. H., Moxon, A. L., Fetter, A. W., Yarrington, J. T. 1974. Efficacy of supplemental selenium in reproductive diets on sow and progeny performance. J. Anim. Sci. 39:536–543.

Mahan, D. C., A. L. Moxon, and J. H. Cline. 1975. Efficacy of supplemental selenium in reproductive diets on sow and progeny serum and tissue selenium values. J. Anim. Sci. 40:624–631.

Mahan, D. C., and A. L. Moxon. 1978a. Effect of adding inorganic or organic selenium sources to the diets of young swine. J. Anim. Sci. 47:456–466.

Mahan, D. C., and A. L. Moxon. 1978b. Effect of increasing the level of inorganic selenium supplementation in the postweaning diets of swine. J. Anim. Sci. 46:384–390.

Mahan, D. C., and A. L. Moxon. 1984. Effect of inorganic selenium supplementation on selenosis in postweaning swine, J. Anim. Sci., 58:1216.

Mahan, D. C., and P. L. Magee. 1991. Efficacy of dietary sodium selenite and calcium selenite provided in the diet at approved, marginally toxic, and toxic levels to growing swine. J. Anim. Sci. 69:4722–4725.

Mahan, D. C., and N. A. Parrett. 1996. Evaluating the efficacy of selenium-enriched yeast and sodium selenite on tissue selenium retention and serum glutathione peroxidase activity in grower and finisher diets. J. Anim. Sci. 74:2967–2974.

Mahan, D. C., and Y. Y. Kim. 1996. Effect of inorganic selenium at two dietary levels on reproductive performance and tissue selenium concentrations in first-parity gilts and their progeny. J. Anim. Sci. 74:2711–2718.

Mahan, D. C., T. R. Cline, and B. Richert. 1999. Effects of dietary levels of selenium- enriched yeast and sodium selenite as selenium sources fed to growing- finishing pigs on performance, tissue selenium, serum glutathione peroxidase activity, carcass characteristics, and loin quality. J. Anim. Sci. 77:2172–2179.

Mahan D. C., Peters J. C. 2004. Long-term effects of dietary organic and inorganic selenium sources and levels on reproducing sows and their progeny. J. Anim. Sci. 82:1343−1358.

Mahan, D. C., M. Azain, T. D. Crenshaw, G. L. Cromwell, C. R. Dove, S. W. Kim, et al. 2014. Supplementation of organic and inorganic selenium to diets using grains grown in various regions of the United States with differing natural Se concentrations and fed to grower- finisher swine. J. Anim. Sci. 92:4991–4997.

Mahan, D. C. 1991. Assessment of the influence of dietary vitamin E on sows and offspring in three parities: Reproductive performance, tissue tocopherol, and effects on progeny. J. Anim. Sci. 69:2904-2917.

Mahan, D. C. 1994. Effects of dietary vitamin E on sow reproductive performance over a five-parity period. J. Anim. Sci. 72:2870-2879.

Mahan, D. C. 2000. Effect of organic and inorganic selenium sources and levels on sow colostrum and milk selenium content. J. Anim. Sci. 78:100−105.

Mahan, D. C. 2001. Selenium and Vitamin E in swine nutrition. In: Lewis AJ, Southern LL (eds), Swine Nutrition, 2nd edn. CRC Press LLC, Boca Raton, FL, pp. 281–314.

Marin-Guzman, J., D. C. Mahan, and R. Whitmoyer. 2000. Effect of dietary selenium and vitamin E on the ultrastructure and ATP concentration of boar spermatozoa, and the efficacy of added sodium selenite in extended semen on sperm motility. J. Anim. Sci. 78:1544-1550.

Marin-Guzman, J., D. C. Mahan, Y. K. Chung, J. L. Pate, and W. F. Pope. 1997. Effects of dietary selenium and vitamin E on boar performance and tissue responses, semen quality, and subsequent fertilization rates in mature gilts. J. Anim. Sci. 75: 2994-3003.

Markham, G. D., E. W. Hafner, C. W. Tabor and H. Tabor. 1980. S-Adenosylmethionine synthetase from Escherichia coli. J. Biol. Chem., 255: 9082-9092.

Mateo, R. D., Spallholz, J. E., ELder, R., Yoon, I., Kim S. W. 2007. Efficacy of dietary selenium source on growth and carcass characteristics of growing-finishing pigs fed diets containing high endogenous selenium. J. Anim. Sci. 85: 1177-1183.

McConnell K. P., Hoffman J. L. 1972. Methionine-selenomethionine parallels in rat liver polypeptide chain synthesis. FEBS Lett 24: 60-62.

McGuire, M. K., Burgert, S. L., Milner, J. A., Glass, L., Kummer, R., Deering, R., Boucek, R., Picciano, M. F. 1993. Selenium status of lactating women is affected by the form of selenium consumed. Am J Clin. Nutr. 58:649–652.

Mehdi Y., Hornick J.-L., Istasse L., Dufrasne I., 2013. Selenium in the environment, metabolism and involvement in body functions. Molecules 18, 3292–3311.

Meyer, W. R., D. C. Mahan, and A. L. Moxon. 1981. Value of dietary selenium and vitamin E for weanling swine as measured by performance and tissue selenium and glutathione peroxidase activities. J. Anim. Sci. 52:302–311.

Miller, W. T. 1938. Toxicity of selenium fed to swine in the form of sodium selenite, J. Agric. Res., 56:831.

Miller, W. T., and K. T. Williams. 1940. Minimum lethal dose of selenium, as sodium selenite, for horses, mules, cattle and swine, J. Agric. Res., 60:163.

Neve, J. 1996. Selenium as a risk factor for cardiovascular diseases. J. Cardiovasc. Risk 3:42-47.

Nguyen, D. T., K. Lee, H. Choi, M. K. Choi, M. T. Le, N. Song, J. H. Kim, H. G. Seo, J. W. Oh, K. Lee, T. H. Kim, C. Park. 2012. The complete swine olfactory subgenome: ex-pansion of the olfactory gene repertoire in the pig genome, BMC Genomics 13(1), 584–595.

Nobler J., J. Y. Dourmad, and M. Etienne. 1990. Energy utilization in pregnant and lactating sows: modeling of energy requirements. J. Anim. Sci. 68(2):562-572.

Nogales, F., Ojeda, M. L., Fenutria, M., Murillo, M. L., Carreras, O. 2013. Role of selenium and glutathione peroxidase on development, growth, and oxidative balance in rat offspring. Reproduction 146, 659–667.

NRC. 1973. Nutrient Requirements of Swine, 7th ed., National Academy Press, Washington, D.C.

NRC. 1979. Nutrient Requirements of Swine, 8th ed., National Academy Press, Washington, D.C.

NRC. 1998. Nutrient Requirements of Swine (10th Ed.). National Academy Press, Washington, D. C.

NRC. 2012. Nutrient requirement of pigs. National Research Council, Academy Press.

Oropeza-Moe, M., Wisløff, H., Bernhoft, A. 2015. Selenium deficiency associated porcine and human cardiomyopathies. J. Trace Elem. Med. Biol. 31, 148–156.

Ortman, K. and Pehrson, B. 1997. Selenite and selenium yeast as feed supplements for dairy cows. J. Vet. Med. Ser. A, 44: 373-380.

Ortman, K. and Pehrson, B. 1999. Effect of selenate as a feed supplement to dairy cows in comparison to selenite and selenium yeast. J. Anim. Sci. 77:3365-3370.

Pappas, A. C., Zoidis, E., Surai, P. F., Zervas, G., 2008. Selenoproteins and maternal nutrition. Comp. Biochem. Physiol. B Biochem. Mol. Biol. 151, 361–372.

Park, G. B., Lee, J. I., Park, T. S., Kim, J. H., Shin, T. S., Kang, S. J., Ha, Y. L., and Joo, S T. 1999 Effects of dietaty conjugated linoleic acid (CLA) on cholesterol and CLA content of egg yolks. Kor. J. Anim. Sci. 41(1), 65-74.

Piatkowski, T. L., D. C. Mahan, A. H. Cantor, A. L. Moxon, J. H. Cline, and A. P. Grifo, Jr. 1979. Selenium and vitamin E in semipurified diets for gravid and nongravid gilts JAnimSci48:1357–1365.

Reddy, B. S. 1996. Micronutrients as chemopreventive agents. IARC Sci. Publ. 139, 221-235.

Reese, D. E., Moser, B. D., Peo, E. R., Lewis, A. J., Zimmerman, D. R., Kinder, J. E., and Stroup, W. W. 1982. Influence of energy intake during lactation on subsequent gestation, lactation and postweaning performance of sows. J. Anim. Sci. 55(4), 867-872.

Rotruck, J. T., A. L. Pope, H. E. Canther, A. B. Swanson, D. C. Hafeman, and W. G. Hoekstra. 1973. Selenium: Biochemical role as a component of glutathione peroxidase. Science 179:588-590.

Schrauzer G. N. 2000. Selenomethionine: a review of its nutritional significance, metabolism and toxicity. J. Nutr 130: 1653-1656.

Schrauzer, G. N. 2003. The nutritional significance, metabolism and toxicology of selenomethionine. Adv Food Nutr Res 47:73–112.

Schwarz, K. and Foltz, C. M. 1957. Selenium as an integral part of factor 3 against dietary liver degeneration. J. Am. Chem. Soc., 79: 3292-3293.

Scott, M. L., M. C. Nesheim and R. J. Young. 1982. Nutrition of the Chicken. 3rd Edn., ML Scott and Associates, Ithaca, New York.

Seboussi R., Faye B., Alhadrami G., Askar M., Ibrahim W., Mahjoub B., Hassan K., Moustafa T., Elkhouly A. 2010. Selenium distribution in camel blood and organs after different level of dietary selenium supplementation. Biol Trace Elem Res. 133(1):34−50.

Seko, Y., Y. Saiti, J. Kitahara, and N. Imura. 1989. Active oxygen generation by the reaction of selenite with reduced glutathione in vitro. Pp. 33–70 in A.

Wendel, ed. Selenium in biology and medicine. Springer-Verlag, Berlin, Germany.

Spallholz, J. E. 1994. On the nature of selenium toxicity and carcinostatic activity. Free Radic. Biol. Med. 17:45–64.

Steele, R. D. and N. J. Benevenga. 1979. The metabolism of 3-methylthiopropionate in rat liver homogenates. J. Biol. Chem., 254: 8885-8890.

Sunde, R. A. 1997. Selenium. In: Handbook of Nutritionally Essential Mineral Elements, O'Dell, B. L. and R. A. Sunde (Eds.). Marcel Dekker Inc., New York, pp: 493-556.

Suomi, K., and T. Alaviuhkola. 1992. Responses to organic and inorganic selenium in the performance and blood selenium content of growing pigs. Ag. Sci. Finland 1:211.

Surai, P. F. 2006. Selenium in Nutrition and Health. Nottingham University Press, Nottingham, UK.

Surai, P. F. and Fisinin, V. I. 2015. Selenium in pig nutrition and reproduction: boars and semen quality – A review. Asian-Australasian Journal of Animal Sciences 28:730-746.

Surai, P. F., Fisinin, V. I. 2016. Selenium in sow nutrition. Anim. Feed Sci. Technol. 211:18–30.

Svoboda, M., Ficek, R., and Drabek, J. 2008. Efficacy of organic selenium from se-enriched yeast on selenium transfer from sows to piglets. Acta Vet. Brno, 77: 515-521

Swanson, C. A. 1991. Human (74se) selenomethionine metabolism: a kinetic model. Am J. Clin. Nutr. 54:917–926.

Ullrey, D. E. 1974. The selenium-deficiency problem in animal agriculture. Pp. 275–293 in Trace Element Metabolism in Animals, Volume 2, W. C. Hoekstra, J. W. Suttie, H. E. Ganther, and W. Mertz, eds. Baltimore: University Park Press.

Vendeland, S. C. 1994. Uptake of selenite, selenomethionine and selenate by brush border membrane vesicles isolated from rat small intestine. Biometals 7:305–312.

Wendel, A. 1989. Selenium in biology and medicine. Springer Verlag, Berlin. pp. 3-325.

Wilkinson, J. E., M. C. Bell, J. A. Bacon, and C. C. Melton. 1977b. Effects of supplemental selenium on swine. II. Growing-finishing. J. Anim. Sci.44:229–233.

Wilkinson, J. E., M. C. Bell, J. A. Bacon, and F. B. Masincupp. 1977a. Effects of supplemental selenium on swine. I. Gestation and lactation. J. Anim. Sci. 44:224–228.

Yin, J., Ren, W., Liu, G., Duan, J., Yang, G., Wu, L., Li, T., Yin, Y. 2013. Birth oxidative stress and the development of an antioxidant system in newborn piglets. Free Radic. Res. 47, 1027–1035.

Yin, J., Wu, M., Xiao, H., Ren, W., Duan, J., Yang, G., Li, T., Yin, Y. 2014. Development of an antioxidant system after early weaning in piglets. J. Anim. Sci. 92,612–619.

Yoon, I., McMillan, E. 2006. Comparative effects of organic and inorganic selenium on selenium transfer from sows to nursing pigs. J. Anim. Sci. 84:1729–1733.

Young, L. G., J. H. Lumsden, A. Lun, J. Claxton, and D. E. Edmeades. 1976. Influence of dietary levels of vitamin E and selenium on tissue and blood parameters in pigs. Can. J. Comp. Med. 40:92–97.

Zak, L. J., Cosgrove, J. R., Aherne, F. X., and G. R. Foxcroft. 1997. Pattern of feed intake and associated metabolic and endocrine changes differentially affect postweaning fertility in primiparous lactating sows. J. Anim. Sci. 75, 208−216.

Zhan, X., Qie, Y., Wang, M., Li, X., Zhao, R. 2011. Selenomethionine: an effective selenium source for sow to improve Se distribution, antioxidant status and growth performance of pig offspring. Biol. Trace. Elem. Res. 142, 481–491.

Zhu, L. H., Zhao, K. L., Chen, X. L., Xu, J. X. 2013. Impact of weaning and an antioxidant blend on intestinal barrier function and antioxidant status in pigs. J. Anim. Sci. 91, 1522.

V. Summary in Korean

본 연구는 포유돈 사료 내 셀레늄 형태 및 첨가수준이 모돈 및 자돈의 생리적 변화, 포유능력, 혈액성상, 돈유성분 및 조직 내 셀레늄 농도에 미치는 영향을 조사하여 포유돈 사료 내 셀레늄의 적용 가능성을 규명하기 위해 수행되었다. 본 실험은 평균체중이 241.8 ± 3.57kg 인 2 원교잡종 (Yorkshire × Landrace) F1 모돈 45 두를 공시하여 3 처리, 15 반복, 반복 당 1 두씩, 체중과 등지방 두께에 따라 완전임의배치법 (CRD; Completely randomized design)으로 구배치하여 실험을 수행하였다. 실험의 처리구는 포유돈 사료 내 셀레늄의 혼합 첨가수준에 따라 1) Control: basal diet; 2) ISOS15: basal diet + organic Se 0.15 ppm + inorganic Se 0.15 ppm; 3) ISOS25: basal diet + organic Se 0.25 ppm + inorganic Se 0.25 ppm 로 나뉘었다.

전체 실험기간동안 모돈의 체중 및 등지방 두께 변화에는 처리구에 따른 유의적인 영향이 나타나지 않았으며, 포유자돈의 성장성적에 있어서 이유두수, 자돈체중 및 증체량 등에서도 처리구간 유의적인 차이가 나타나지 않았다. 또한, 혈액성상에서 포유돈 사료 내 유기태 셀레늄과 무기태 셀레늄을 혼합 첨가하였을 때, 포유 21 일령 모돈 및 자돈의 혈액 내 셀레늄 농도에서는 유의적인 차이가 나타나지 않았으며, 돈유성분에서는 포유 7 일령 및 포유 21 일령 모돈의 돈유 내 셀레늄 농도에서 처리구간 유의적인 차이가 나타나지 않았다. 하지만, 포유돈 사료 내 유기태 셀레늄과 무기태 셀레늄을 혼합 첨가하였을 때 사료섭취량에서 ISOS15 및 ISOS25 처리구가 대조구와 비교하여 수치적으로 높은 것으로 나타났으며. 포유 7 일령 모돈 및 자돈의 혈액 내 셀레늄 농도에서 처리구간 유의적인 차이가 나타났다 ($P<0.01$). 또한, 포유 21 일령 자돈의 신장 및 근육 내 셀레늄 농도에서 유의적인 차이가 나타났으며 ($P=0.03$; $P=0.04$),

포유 21 일령 자돈의 간 내 셀레늄 농도에서는 유의적인 차이는 나타나지 않았지만 (P>0.10), 셀레늄의 첨가수준이 증가할수록 자돈의 간 내 셀레늄 농도가 수치상으로 증가하였다.

결론적으로, 포유돈 사료 내 셀레늄의 혼합 첨가는 모돈의 셀레늄 상태를 개선시켜 포유자돈으로의 이행을 높였고, 이는 포유기 모돈과 자돈에게 긍정적인 영향을 미칠 것으로 사료된다.