Mineral Sources for Swine Diets

The mineral content of grains and oilseeds commonly used in swine diets is often found at low concentration and availability. Consequently, it is essential to balance the diets using supplemental mineral sources to meet the requirements. The sources of macrominerals and trace minerals used in swine diets are discussed in this fact sheet.

Macrominerals

Macrominerals or major minerals need to be supplied in larger amounts in swine diets. The requirements for and dietary concentrations of macrominerals are generally expressed as a percentage (%) of the diet. Calcium, phosphorus, sodium, and chloride are the typical macrominerals added to swine diets.

Calcium and phosphorus

Calcium and phosphorus are essential in skeletal structure development and maintenance, lean tissue deposition, muscle contraction, and many other physiological functions. Calcium and phosphorus are the most abundant minerals in the pig and about 99% of the calcium and 80% of the phosphorus in the body are found in the skeleton. Consequently, deficiency of calcium and phosphorus results in impaired bone mineralization, reduced bone strength, and decreased growth. Clinical signs of deficiency include rickets in growing pigs and osteoporosis in sows, which are manifested as lameness and fractures. The deficiency is exacerbated during lactation as sows mobilize calcium from bone reserves to meet the demand for milk production, which can result in 'downer sows' in late lactation and post-weaning.

To prevent deficiency, swine diets must supply the individual requirements of calcium and phosphorus but also to provide an adequate ratio of one mineral to the other. The calcium:phosphorus ratio greatly influences the absorption and retention of both minerals. In general, wide calcium:phosphorus ratios or excessive calcium and deficient phosphorus concentrations interfere with phosphorus absorption (Reinhardt and Mahan, 1986).

Grains and oilseeds used in swine diets are typically low in calcium and have most of the phosphorus unavailable to the pig. Phytate is the storage form of phosphorus in feedstuffs of plant origin and the enzyme phytase is required to release phosphorus from phytate for absorption (Cowieson et al., 2016). As endogenous phytase activity is negligible in swine, exogenous microbial phytase is commonly used in swine diets to enhance phosphorus release from phytate. Phytase also releases calcium that can be bound to phytate. Furthermore, both calcium and phosphorus are supplemented in the diet by inorganic sources. Importantly, many inorganic sources supply both calcium and phosphorus, which require simultaneous adjustments of the amount of each source in the diet.

Sodium and chloride

Sodium and chloride are involved in nutrient absorption, electrolyte balance, and regulation of pH. Salt or sodium chloride is the most common source of sodium and chloride, composed of approximately 40% sodium and 60% chloride. The supplementation of diets with salt is essential because sodium and chloride are low in grains and oilseeds used in swine diets. However, dietary supplementation of salt is usually reduced in diets with spray-dried blood products, dried whey, or co-products from the food or pet food industry due to the high concentration of sodium and chloride in these ingredients.

The requirements for sodium and chloride are greater for nursery pigs and abruptly decrease for grow-finish pigs and sows (NRC, 2012; Shawk et al., 2018a,b). Diets deficient in salt result in decreased growth performance because of reduced feed intake and poor feed efficiency. Diets with high levels of salt are generally well tolerated if drinking water is available. However, toxicity quickly develops if drinking water is not available.

Magnesium and potassium

Grains and oilseeds used in swine diets typically provide magnesium and potassium in sufficient quantities to meet the requirements. Therefore, no other sources of magnesium and potassium are commonly used in swine diets.

Trace minerals

Microminerals or trace minerals need to be supplied in smaller amounts in swine diets, with the requirements for and dietary concentrations of trace minerals generally expressed as parts per million (ppm or mg/kg) or milligrams per pound (mg/lb) of diet. Because of the smaller amounts, trace minerals are often added in the diets in the form of a trace mineral premix. Zinc, copper, iron, manganese, iodine, and selenium are the typical trace minerals included in a trace mineral premix for swine. Iron is also provided via injectable iron in young piglets.

Zinc

Zinc is an important component of many enzymes and participates in the metabolism of carbohydrates, proteins, and lipids. Zinc is found in grains and oilseeds at low concentration and mostly associated with phytate, which makes zinc unavailable to the pig. Zinc deficiency is characterized by a skin condition called parakeratosis, low growth rate, and impaired reproductive performance. Zinc toxicity depends upon source, dietary level, and duration of feeding, but generally the maximum tolerable dietary level for swine is set at 1,000 ppm with the exception of zinc oxide, which may be included at higher levels (NRC, 2012) for short periods of time immediately after weaning.

Pharmacological levels of dietary zinc between 2,000 and 3,000 ppm is a common recommendation to nursery diets to reduce post-weaning diarrhea and improve growth performance (Hill et al., 2000; Shelton et al., 2011). These effects have been consistently demonstrated with dietary zinc provided as zinc oxide (ZnO) (Hill et al., 2001; Hollis et al., 2005; Walk et al., 2015), while zinc sulfate ($ZnSO_4$) has greater potential to induce toxicity (Hahn and Baker, 1993). Organic sources of zinc with greater bioavailability have not consistently demonstrated the same benefits as zinc oxide when organic zinc is added at lower levels (Hahn and Baker, 1993; Carlson et al., 2004; Hollis et al., 2005).

Copper

Copper is an important component of many enzymes and participates in iron absorption and synthesis of hemoglobin. Copper is found in grains and oilseeds probably at adequate quantities to meet the requirements, but determination of copper requirements of pigs is scarce. Copper deficiency signs include anemia and low growth rate. Copper toxicity occurs at levels above 250 ppm when fed for a long period of time (NRC, 2012).

Pharmacological levels of dietary copper between 125 and 250 ppm is commonly used in the diet to enhance fecal consistency in nursery pigs and improve growth performance in both nursery and grow-finish pigs (Bikker et al., 2016; Coble et al., 2017). The most commonly used source of dietary copper is copper sulfate ($CuSO_4$) (Cromwell et al., 1998), but tribasic copper chloride (TBCC) is as effective as copper sulfate in promoting growth performance (Cromwell et al., 1998; Coble et al., 2017). Organic sources of copper with greater bioavailability, such as Cu-amino acid chelate, also seem to have the potential to influence growth performance (Pérez et al., 2011; Carpenter et al., 2018).

Iron

Iron is an important component of many enzymes and is essential for synthesis of hemoglobin. Iron is low in grains and thereby commonly supplemented from inorganic sources in a trace mineral premix. Newly born piglets develop iron deficiency during lactation and have to be provided with injectable iron.

Injectable iron

Piglets develop iron deficiency in the first week of life due to limited iron storages at birth, low levels of iron in sow milk, and the rapid growth rate that occurs during this early stage of life. Iron deficiency is characterized by anemia, and anemic piglets evidence low growth rate, lethargy, pale skin, and rough hair coats. Iron in excess is also prejudicial, as iron affects gut health, stimulates proliferation of bacteria, and causes diarrhea (Li et al., 2016).

Hemoglobin and hematocrit are commonly used as reliable blood criteria to indicate iron status in pigs. Hemoglobin levels of 11 g/dL or above indicate adequate blood iron status, levels of 9 to 11 g/dL indicate borderline anemia, and levels of 9 g/dL or below indicate an anemic condition (Bhattarai and Nielsen, 2015). For hematocrit, values above 30% indicate adequate blood iron status (Perri et al., 2016).

Iron injection in piglets is a well-stablished practice to prevent iron deficiency and anemia. The injection is administered intramuscularly and preferentially in the neck area of piglets. The most commonly used sources of iron are iron dextran and gleptoferron, which have shown similar efficacy in preventing iron deficiency in piglets (Morales et al., 2018). However, absorption of iron seems to be greater with gleptoferron due to its potentially greater iron bioavailability (Morales et al., 2018).

A single dose of 200 mg of injectable iron around 4 or 6 days after birth maximizes growth performance and improves blood iron status at weaning and in the nursery (Williams et al., 2018a,b). On the other hand, providing an iron injection too soon (day 2) or too late (days 8 or 10) after birth seems to restrict pig performance (Williams et al., 2018b). The need for a second iron injection depends on the amount of iron given in the first injection. When using an injection of 200 mg of iron at 2 days of birth, an additional booster dose of 100 mg of iron midway through lactation can improve blood iron status, but it does not provide further benefits in growth performance (Williams et al., 2018a).

Manganese

Manganese is a component of many enzymes and is involved in bone development. Manganese is found in grains and oilseeds at low concentration. Manganese deficiency signs include impaired skeleton development, lameness, and low growth rate.

Iodine

Iodine is an important component of thyroid hormones and thereby is involved in regulation of metabolic rate. Feedstuffs grown in low-iodine soil, as in the case of sandy areas, are deficient in iodine. Also, canola or rapeseed may contain increased levels of goitrogenic compounds called glucosinolates that interfere with iodine metabolism. Iodine deficiency is characterized by goiter (thyroid enlargement), lethargy, and low growth rate.

Selenium

Selenium is an important component of enzymes involved in antioxidant defense. Selenium and vitamin E have closely related functions, but requirements are independent of one another. Feedstuffs grown in low-selenium soil, as is the case of many areas in the United States, are deficient in selenium. Selenium deficiency signs are similar to signs of vitamin E deficiency, which includes white muscle disease, mulberry heart disease, sudden death, and impaired reproduction. Selenium toxicity at levels of 5 to 10 ppm selenium is characterized as chronic selenosis, with signs of low growth rate and separation of the hoof at the coronary band (NRC, 2012; Gomes et al., 2014). Selenium toxicity at levels above of 10 to 20 ppm selenium is characterized as acute selenosis, with signs of posterior paralysis and lesions in the central nervous system (NRC, 2012; Gomes et al., 2014). The amount of selenium inclusion is regulated in the United States and restricted to a maximum of 0.3 ppm added selenium in any swine diet.

KSU Trace mineral premix

A suggested trace mineral premix is available at KSU Premix & Diet Recommendations. This single premix can be used in diets for all stages of production by adjusting the inclusion rate for sow, nursery, grower, and finisher diets. A sow add pack is also available for sow diets to supply the specific vitamins to enhance reproduction.

Trace minerals can be combined with vitamins in a VTM premix, but it is recommended to have separate premixes because trace minerals can affect the vitamin stability. Otherwise, VTM premix age must be monitored to ensure it is used before excess vitamin loss.

Dietary electrolyte balance

Dietary electrolyte balance represents the ratio of cations and anions in a diet and is important for acid-base status of pigs. The dietary ions that mostly influence electrolyte balance are sodium, chloride, and potassium. Dietary electrolyte balance is determined by the difference between cations and anions in the diet: Na + K - Cl. However, more comprehensive estimation of dietary electrolyte balance also takes into account the contribution of divalent ions, such as calcium, magnesium, sulfur, and potassium.

Traditionally, the optimal dietary electrolyte balance for swine is reported to be approximately 250 mEq/kg (NRC, 2012).

Mineral sources

Minerals are available in inorganic or organic forms to add in swine diets. Inorganic minerals are provided as inorganic salts like sulfates, carbonates, chlorides, and oxides. Organic minerals are provided as a complex with an organic agent like amino acids, proteins, and carbohydrates, and are therefore also called complexed or chelated minerals.

Inorganic minerals release free ions that are reactive and likely to bind to other dietary components. This characteristic can affect the stability of vitamins and minerals in the premix, as well as interfere in the absorption of minerals by the pig during digestion. Organic minerals are less likely to bind to other dietary components because the minerals are already in a complex with organic agents. The organic forms are supposed to minimize the interactions and enhance the absorption and bioavailability of minerals (Liu et al., 2014). However, greater bioavailability of organic minerals does not always result in improvements in growth (Creech et al., 2004; Ma et al., 2012) or reproductive performance (Peters and Mahan, 2008; Peters et al., 2010; Ma et al., 2014). Typically, the use of organic mineral sources is more prevalent in diets for sows and nursery pigs (Flohr et al., 2016).

Decisions on which source of mineral to use should be based primarily on price per unit of bioavailable element, with organic minerals usually being more bioavailable but inorganic minerals are typically more economical. A list of the chemical forms in which inorganic macrominerals and trace minerals are available is shown in **Table 1 and 2** (NRC, 2012).

Table 1. Inorganic sources of trace minerals and respective mineral content

Inorganic mineral	Source	Mineral content, %	Relative bioavailability, %
Zinc	Zinc sulfate (monohydrate)	35.5	100*
	Zinc oxide	72.0	50-80
	Zinc sulfate (heptahydrate)	22.3	100
	Zinc carbonate	56.0	100
	Zinc chloride	48.0	100
Copper	Cupric sulfate (pentahydrate)	25.2	100*
	Cupric chloride, tribasic	58.0	100
	Cupric oxide	75.0	0-10
	Cupric carbonate (monohydrate)	50-55	60-100
	Cupric sulfate (anhydrous)	39.9	100
Iron	Ferrous sulfate (monohydrate)	30.0	100*
	Ferrous sulfate (heptahydrate)	20.0	100
	Ferrous carbonate	38.0	15-80
	Ferric oxide	69.9	0
	Ferric chloride (hexahydrate)	20.7	40-100
	Ferrous oxide	77.8	---
Manganese	Manganous sulfate (monohydrate)	29.5	100*
	Manganous oxide	60.0	70
	Manganous dioxide	63.1	35-95
	Manganous carbonate	46.4	30-100
	Manganous chloride (tetrahydrate)	27.5	100
Iodine	Ethylenediamine dihydroiodide (EDDI)	79.5	100*
	Calcium iodate	63.5	100
	Potassium iodide	68.8	100
	Potassium iodate	59.3	---
	Cupric iodide	66.6	100
Selenium	Sodium selenite	45.0	100*
	Sodium selenate (decahydrate)	21.4	100

Adapted from NRC (2012). The inorganic mineral sources listed in italic are less commonly used sources.
*Mineral source used as standard to which other sources were compared to determine relative bioavailability.
--- No data available.

Table 2. Inorganic sources of macrominerals and respective mineral content					
Source	Calcium, %	Phosphorus, %[1]	Sodium, %	Chloride, %	Potassium, %
Bone meal, steamed	29.8	12.5	0.04	---	0.2
Calcium carbonate	38.5	0.02	0.08	0.02	0.08
Limestone	35.8	0.01	0.06	0.02	0.11
Calcium phosphate (dicalcium)	24.8	18.8	0.20	0.47	0.15
Calcium phosphate (monocalcium)	16.9	21.5	0.20	---	0.16
Calcium phosphate (tricalcium)	34.2	17.7	6.0	---	---
Phosphate, defluorinated	32.0	18.0	3.27	---	0.10
Phosphate, rock curacao, ground	35.1	14.2	0.20	---	---
Phosphate, rock, soft	16.1	9.05	0.10	---	---
Sodium chloride	0.30	---	39.5	59.0	0
Sodium carbonate	---	---	43.3	---	---
Sodium bicarbonate	0.01	---	27.0	---	0.01
Potassium chloride	0.05	---	1.0	46.9	51.4

Adapted from NRC (2012). The inorganic mineral sources listed are more commonly used sources.
[1]Values for total phosphorus. Standardized total tract digestibility (STTD) is 88.3, 81.4, and 53.4% for monocalcium, dicalcium, and tricalcium phosphate, respectively.
--- No data available.

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