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True Mineral Digestibility Values in Diet Formulation: Impacts on Performance, Economic and Environmental Benefits

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Abstract. Animal production, especially swine production is projected to increase in response to the increasing demand for animal protein. In this regard, there is the need to significantly improve production in terms of performance, cost and environmental sustainability. At present, one of the nutritional problems militating against these standards of production is the high levels of nutrients in the pig manure causing eutrophication due to high minerals' contents of the pig manure with particular emphasis on phosphorus. Minerals are very essential nutrients for the pig as they are involved in many physiological functions, including the structural integrity of the animal in enhancing growth performance. As with other nutrients, minerals are provided to the animal via their rations. However, their high concentrations in the animal manure at present is generating a lot of concerns to all stakeholders, including the nutritionists and environmentalists. To overcome this, it is recommended that dietary mineral contents should be based on their true digestible values instead of their apparent digestible values as to avoid excess inclusions levels of minerals in the diet. In doing so, the negative impacts of fibre and particularly phytate on mineral digestibility and retentions are significantly minimized leading to better animal performance, economic benefits and reduction in the degree of eutrophication, thereby supporting environmental sustainability. These concepts are cleared expatiated on in this paper using corn-SBM-based diet as an example for swine.

Key words: Minerals, Apparent and True Digestible values, Retention, Chelation and Swine

Introduction

Corn and soybean meal (SBM) are usually used as energy, protein, amino acids (AAs) and mineral sources in swine rations. There is nutritional, economic and environmental benefits in the use of corn and SBM in swine nutrition. These benefits include: low fibre contents in corn compared with barley and wheat leading to the provision of more of the dietary energy being made available to the pigs (NRC, 2012). Economically, corn has a very high yielding value within a short growing period indicating that it can quickly be translated into more pounds of pork per acre than barley and wheat. Nevertheless, it has low calcium (Ca) and phosphorus (P) contents compared with barley and wheat (NRC, 2012).

However, SMB plays a complementary role in corn/SBM-based diets for swine. This is because SBM is also low in fibre and serves as a very excellent source of energy, protein and some essential AAs that are limiting in corn (NRC, 2012). More importantly, the low contents of Ca and P in corn are compensated for by the high contents of these minerals in SBM. Due to the low fibre contents in corn and SBM, corn-SBM-based diets enable nutrients to be more digestible primarily as a result of reduced effect of fibre during fibre-nutrient interactions which are known to encapsulate nutrients and thus significantly reduce substrate-enzyme interactions (Low, 1985). To this point therefore, in corn-SBM-based diet, the negative effects of fibre-nutrient interaction on nutrient digestion, absorption and bioavailability are significantly reduced in the pig, particularly in weanling and growing pigs (Low, 1985). This results in enhanced nutrient bioavailability to the animals, especially minerals (Cavert, 1991). Furthermore, this is expected to reduce nutrient concentrations in the excreted manure into the environment in swine-producing areas.

To date, the reduction of nutrients' levels in manure, particularly minerals has not been fully achieved and at present has become a serious source of concern to all stakeholders. The major concerns relate mostly to the high levels of P in the manure resulting in eutrophication (Mallin, 2000). Additionally, the high levels of trace-minerals in the pig manure is gradually becoming another source of concern to the swine industry (Dourmad & Jondreville, 2007). This is also thought to be related to high dietary mineral contents antagonizing absorption and the presence of phytate (an effective chelator) of minerals relating to P and other cations, such as Ca, magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) which renders the minerals unavailable to the animal. Therefore, the objectives of this paper are to guide on the uses of the true digestible values (TDVs) of minerals as against the use of their apparent digestible values (ADVs) in swine nutrition to enable reduction in cost of production and environmental pollution resulting from the high levels of dietary mineral contents in the pig manure while simultaneously improving animal performance, respectively.

Influence of Dietary Fibre and Phytate

Irrespective of the complementary roles existing between corn and SBM in corn/SBM-based diets for pigs, the presence of dietary fibre and phytate aid in explaining the high mineral content levels in the pig manure (Lei & Porres, 2003). The overall resultant effects of these further aggravate the antagonisms amongst dietary minerals as they induce nutritional distortions leading to physiological mineral imbalances during the process of mineral flux from their dietary source to the animal (Peo, 1991; Petersen, 2010). This observation becomes worse when dietary minerals are included in the diet based on their ADVs. To this point therefore, based on mineral wheel study interactions/interrelations it has been reported that when dietary minerals are provided based on the mineral true dietary requirements, that is, TDVs, they would show mineral-ion synergy relationship during their normal course of metabolism thereby physiologically leading to the majority of the minerals being made bioavailable to the animal for absorption and assimilation (Knowlton et al., 2004).

Animal production and particularly that of swine production has been projected to be on the increase (Tamminga, 2003). Therefore, although nutrient release via animal manure to the environment is inevitable the possibility exists from nutritional standpoint to significantly reduce manure nutrient levels into the environment. This is possible by improving swine diets according to their phases in production by fortifying their diets with true dietary nutrient requirements, including minerals. This is true because it results in favoring improved mineral metabolism by triggering mineral synergies in the course of their normal metabolisms and thus significantly minimizes the formations of insoluble-phytate-mineral-complexes (Lei & Porres, 2003; Knowlton et al., 2004) that impede mineral solubility for absorption. Minerals' antagonisms especially by phytate inducing the formations of insoluble-phytate-mineral-complexes has been identified as one of the major factors responsible for the high levels of mineral levels in the pig manure causing eutrophication (Mallin, 2000; Lei & Porres, 2003).

The main strategy in dealing with the above problem of mineral metabolism therefore is by the fortification of swine diets based on the TDVs of individual minerals in the diets. Traditionally, swine diets are formulated based on the animal's mineral ADV. The ADVs of minerals from nutritional standpoint of view underestimates the TDVs of the dietary minerals (Johnson et al., 2012). Nutrients' supplies, including minerals beyond requirements ultimately give rise to the excretion of the excess in the pig manure as they are beyond the animal digestive capacity (NRC, 2012; Knowlton et al., 2004). This is majorly why the use of TDVs is to the rescue as it digestibility value is always higher compared with the ADV. Furthermore, TDVs are more accurate and reliable and therefore better match or meet the animal true requirements (Ammerman, 1995). This is also true because ADV is defined as the difference between the total intake of a mineral and the total fecal excretion of the mineral. The value obtained by this difference usually expressed as a percentage of the intake. On the other hand, TDV corrects for the portion of the mineral which has been absorbed into the animal's body but subsequently excreted back ("inevitable loss" or "endogenous loss") into the gastrointestinal tract as a component of the physiological consequence involving the metabolism of the mineral. Different independent studies referred to this portion of the mineral as the total endogenous fecal excretion (Ammerman, 1995; Rudehutscord, Haverkamp & Pfeffer, 1998). Therefore, TDV is derived by the difference between the mineral total intake minus the total fecal and total endogenous excretions combined of total intake multiplied by 100. This thus makes TDVs always higher compared with ADVs. This thus also explains why TDV is more accurate estimate of the mineral presented to the body tissues for metabolic purposes. It is therefore, recommended that for the effective utilization and better management of ingested dietary mineral for non-ruminants, such as the pig and poultry, the TDV of the mineral should be determined and employed in diet formulations to better support mineral metabolisms and assimilations, thereby improving retention of the ingested dietary minerals by the animal (NRC, 2012; Knowlton et al., 2004; Rudehutscord, Haverkamp & Pfeffer, 1998). Adsorptions of minerals by dietary fibres using TDVs of dietary minerals are also significantly reduced (NRC, 2012). Overall, these result in improved performance of the animals as a result of enhanced mineral retentions ensuring the structural integrity of the animal; results in the least-cost concepts of diet formulation, thereby significantly reducing the total cost of production and eutrophication. In these ways make animal production more environmentally-friendly.

From the fore-discussed therefore, the complex interactions and interrelationships that occur amongst minerals, including trace-minerals also support the determination and use of the TDVs of the minerals as schematically depicted in Figure 1. The figure briefly shows three trace-mineral wheel diagrams and the nature of the extremely large complex relationships of mineral-ion interactions could be with diverse effects on their metabolism with huge significant negative effects on animal performance/welfare and the environment. It further gives more insights of the extent of the complexity when all dietary minerals are involved. Again, it also emphasizes that dietary mineral intake should nutritionally be based on maintaining proper mineral balance strictly based on their TDVs for enhanced performance, reduce cost of production and eutrophication (NRC, 2012; Knowlton et al., 2004).

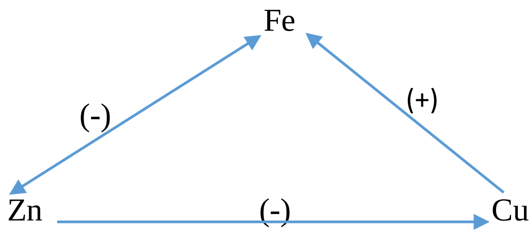

Figure 1. Typical types of ion interactions (positive, negative and multiple) that affect bioavailability

Figure 1 demonstrates that there two major types of interactions; positive and negative. The former is usually synergistic whereas the latter is commonly antagonistic. Additionally, within these two types there may be multiple or one-on-one interactions. Here, the latter may be one-way or even reciprocal. In Figure 1, Zn interacts negatively with both Cu and Fe while Cu interacts positively with Fe. This indicates that the relationship when Cu and Fe dietary concentrations are in their true animal requirements' states Cu shows a positive (synergistic) effect on the metabolism of Fe. Furthermore, there is a reciprocal interaction between Zn and Fe. The multiple nature of interactions existing amongst dietary minerals also demonstrated in Figure 1 by the fact that if Zn dietary digestibility is antagonized as shown in this example, Zn would in turn antagonistically affect the digestibility and thus the assimilation of Cu which in fact is essential for the effective utilization of Fe.

Phytate-P as the Chief Chelator of Minerals

Overall, since mineral nutrients cannot be considered separately and because of the known interacting forces existing amongst them in addition to their additive effects there is a need to ensure that the dietary supply pattern does not inhibit their solubility and subsequently impede their absorption and utilization. To this point therefore, dietary fibre and phytate-P levels of the diet should be largely known based on the dietary ingredients involved in compounding the diet as in this case corn and SBM. This would largely enable the bioavailability of the minerals, including phytate-P to the animal. This is true as phytate is a very strong chelator being a polyanion triggering phytate-mineral-complexes with dietary minerals (NRC, 2012; Lei & Porres, 2003) as demonstrated in Figure 2. Figure 2 gives more insights on the commonly recognized in-vivo interactions involving the essential trace-minerals, particularly in the presence of phytate and dietary P and Ca. The absorption and assimilation of Fe are negatively affected by the use of ADVs of Zn, Mn and Cu. Phosphate in both its inorganic and organic (phytate) forms interact with other minerals as well, such as Fe with huge implications on mineral absorption and retention. Cu bioavailability is negatively affected by Zn, Fe, including the Cu-Mo-S complex. Additionally, the use of ADVs of Cu or Zn can induce Se deficiency. Therefore, it is not a gainsaying that the determination and use of the TDVs of these minerals in diet formulation for swine significantly contribute to better management of the nutrition of mineral nutrients, including other nutrients for the swine industry (Figure 2).

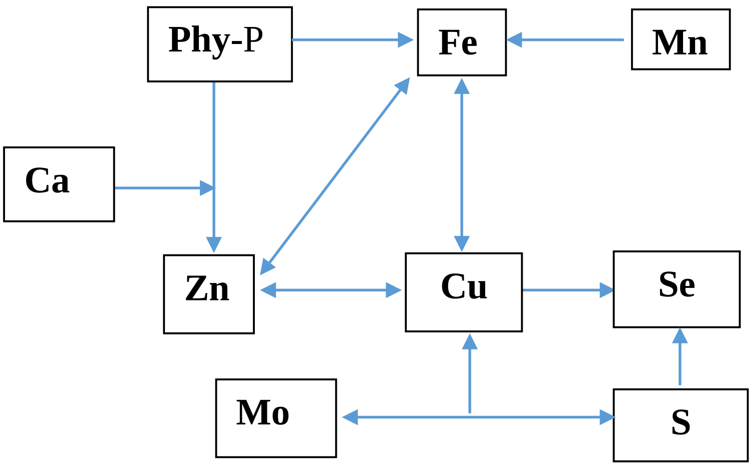

Figure 2. Implication of phytate-P on essential micro-minerals interactions

Note: Phytate-P designates both phytate and inorganic phosphate. The effect of phytate on Zn is accentuated by Ca

According to NRC (2005) projections, ten minerals (micro-and macro-minerals) that would be of main concern on the environment and subsequently have significant impacts on crop production and environmental pollution have been identified. These minerals include: Cd, Cu, Hg, Fe, Se, Zn, Na, K, P and S. Amongst these minerals P and the trace-minerals (Cu, Fe, Se and Zn) are presently identified as causing environmental pollution. This is further compounded by phytate associated P from grains and legumes which normally form the bulk of swine diets. This situation has resulted in federal, state and counties in most countries promulgating environmental regulations that swine producers should conform to regarding the concentrations of nutrients in the pig manure in order to protect the environment from pollution and for the sustainability of the ecosystem (Petersen, 2010). These policies when properly harnessed no doubt would aid optimize mineral digestion and retention by pigs and thus better enhance animal health and therefore better support animal performance. Furthermore, it would increase hog farmers profit margins due to reduction in cost of production as excess use of minerals particularly that of P are avoided while also minimizing P and trace-minerals' excretions in the pig manure leading to better mineral and other nutrients' management on the farm. Again, the use of the TDVs of these minerals would help to reduce the odour menace associated with pig production. This is because the use of TDVs results in improvements of dietary nutrients digestibility and retention resulting in less or minimized dietary nutrient components entering the hindgut of the pig. Since pungent odours emanating from pig feces are principally associated with the fermentation of undigested feed materials in the large intestine, the use of TDVs have great potential to reduce odour emissions since less feed residues used by the micro-flora in the large intestine would be available for fermentative activities by the microbes' resident in the large intestine.

Conclusions

ADV of a mineral is defined as the difference between the total intake of a mineral and the total fecal excretion of the mineral leading to overestimation of the mineral retained by the animal. However, the TDV of the mineral corrects for the portion of the mineral which has been absorbed into the animal's body but subsequently excreted back ("inevitable loss") into the gastrointestinal tract as a component of the physiological consequence involving the metabolism of the mineral. Therefore, TDV is derived by the difference between the mineral total intake minus the total fecal and total endogenous excretions combined of total intake. This always makes TDVs higher than their ADVs counterparts and thus better match requirement with animal need; improve performance, reduce cost of production and subsequently minimized eutrophication, thereby making animal production eco-friendlier.

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