The Role of Vitamins and Minerals in the Production of High Quality Pork* - Review -

D. C. Mahan[1] and Y. Y. Kim
The Ohio State University, Columbus, Ohio 43210, U.S.A.

ABSTRACT : Vitamin and mineral deletion from swine diets can result in reduced growth if done during the period wher muscle and bone development is occurring. Several of the vitamins and minerals decline in the serum during the starter period, suggesting a higher dietary inclusion may be necessary postweaning. Vitamin research with grower-finisher pigs is limited, but results suggest that rapidly growing lean pigs may have a higher dietary requirement for the B vitamins. Several studies have suggested that early weaning and pigs of a lean genotype may have a dietary requirement for vitamin C, Cl and Cr. High dietary vitamin E levels are fortified in the diet and seems to be effective in preventing mulberry heart problems in weanling and grower pigs. Organic Se is more effectively retained in muscle tissue than inorganic Se, approximately 20% less is excreted, but the bioavailability of organic Se for glutathione peroxidase activity is only 80 to 90% to that of sodium selenite. The active form of thyroxine (T4) is dependent upon a Se containing enzyme. Withdrawal of vitamins and minerals during the latter part of the finisher period has not affected pig performance responses, but studies with poultry suggest that the vitamin content of the meat may be reduced if the vitamins are withdrawn prior to marketing. High levels of vitamin E have been shown to improve pork quality, by reducing drip loss. Studies with vitamin C and Se have suggested that they may also be involved in pork quality. (*Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 2 : 287-294*)

Key Words : Swine Diets, Vitamins, Minerals, Dietary Requirement, Pork Quality

INTRODUCTION

The need for providing specific feed ingredients to swine diets has a history which predates the 20th century. During the era of feeding swine formulated complete diets, animal proteins and unidentified factors from various feed products had been routinely added to swine diets. These feeds were reported to contain vital components that enhanced the animals growth rate and feed efficiency responses. The observation that animals had a need for "salt licks" and often had "unnatural cravings" for various materials indicated that there was a dietary need for factors which were also present in soils. The discovery during the last 70 years of the large number of vitamins and minerals has thus revolutionized swine diet formulations.

Although the need for salt was recognized in antiquity, the earliest known mineral experiments were in the 1800's where limestone was found to enhance the bone development and the egg shell quality of birds (Georgievskii et al, 1982). Since the 1920's, the area of mineral nutrition has not only identified most of the minerals that are required by livestock, but mineral forms, bioavailablity, interactions, and the role of these elements in body development and metabolism have greatly expanded our knowledge about the minerals elements. Recent emphasis on discovering the potential need for supplemental Cr, Cl and the use of phytase to increase P bioavailability emphasizes that newer elements and improved usage of existing sources continues to expand the mineral field.

During the era from 1930 to 1950 not only were most of the dietary vitamins identified and requirements established for swine, but their chemical synthesis was also achieved in the laboratory. The identification that vitamin B_{12} could not be provided from grain sources was essential for the dietary elimination of the animal protein factor. The vitamins were manufactured in large quantities in a purified form. This allowed the development of vitamin premix packages where their addition to the diet in low quantities alleviated the need for the more expensive "speciality feeds". Recent research suggests that other vitamins (ascorbic acid, carnitine) may not be adequately synthesized in the young pig which may further enlarge the list of required vitamins for the pig. The current practice of early weaning may further affect the fortification level of vitamins since the digestion and absorption mechanisms of the young pig are physiologically immature.

Trends throughout the world suggest that fewer animal products may be available in the future as potential feed sources for swine. An increasing amount of the feed will be either from an agronomic origin, or be produced by synthetic and bacterial (yeast) processes. In many cases, grains are grown continually on the same land which often results in a lower soil pH. This situation may ultimately affect the quantity and bioavailability of minerals to the plants. With the movement of pigs to complete confinement, removal of the nutrients which were obtained from soil and scavenged forage materials, emphasizes that the need for specific vitamins and minerals in swine diets becomes critical. An excellent example of this is Se, where it was not added to swine diets prior to 1970, but has now become widely recognized throughout the world as

[1] Address reprint request to D. C. Mahan.

* This paper has been presented at Pre-Conference Symposium I entitled "Recent Advances in the Production of High Quality Pork" at the 8th World Conference on Animal Production on June 28, 1998 at Seoul National University, Seoul, Korea. The paper has been reviewed and edited by Prof. P. Bosi (Italy) and Prof. Y. I. Choi (Korea).

a mineral element that is deficient in confinement raised swine. Because some countries are expressing increasing concern about polluting water supplies with Se excesses, the dietary form of this element has also become a factor in regulating its addition to animal diets in many countries.

An experiment conducted with grower-finisher pigs has demonstrated the effectiveness of the need for adding vitamin and minerals to corn-soybean meal based diets (Cline and Mahan, 1972). The data presented in Figure 1 demonstrates that the deletion of vitamins, trace minerals, or the Ca and P sources from the diet had a detrimental effect on pig growth responses. The responses were exacerbated as the feeding period was prolonged. The most profound performance effect was when the vitamin premix and the inorganic Ca:P sources were deleted. In the latter case the bones of the pigs became weakened such that by the end of the trial broken bones, particularly the vertebrae, were demonstrated. Even though pigs were housed where they could practice coprophagy, the deletion of vitamins reduced animal growth responses.

It is clear that both supplemental vitamins and minerals are essential for the normal growth and health of the modern pig. With the emphasis on rapid growth rates, increasing amounts of lean deposition, early weaning, and the increasing use of complete confinement, the value of adequate fortification levels of these nutrients is essential. This manuscript will review the most recent findings for vitamin and mineral requirements in pig diets from weaning through the finisher period, and their effects on pork quality. Because there are approximately 25 nutrients in this category, only those of current prominence or those where recent information is available will be discussed.

REQUIREMENTS FOR GROWTH AND DEVELOPMENT

Vitamins

The vitamins each have specific and vital functions in the body. The fat soluble vitamins are largely involved in tissue growth and maintenance, while the B vitamins and ascorbic acid are generally needed as co-factors for metabolic purposes. Consequently, as more feed is consumed and more nutrients need to be metabolized, supplemental B vitamins are needed in proportion to the quantity of feed consumed, whereas the fat soluble vitamins are needed on a per body weight basis. Because grower-finisher pigs generally consume feed on an ad libitum basis and the amount of feed consumed largely reflects a relatively constant energy consumption per kg body weight, vitamin recommendations are generally expressed on an amount per unit of diet.

The nursing pig is provided an ample supply of vitamins in the colostrum and milk from the dam to meet its nutritional needs (Bowland, 1961). These supplies are adequate to attain a rapid growth rate in the nursing pig. Upon weaning the young pig must, however, rely on their digestive enzymes to either disassociate the vitamins from the dietary gain components or be fed a diet with supplemental sources of highly available vitamins which will meet their metabolic needs. The pig must absorb the vitamins from the intestinal tract in an adequate quantity to support the co-factor functions of these micro-nutrients.

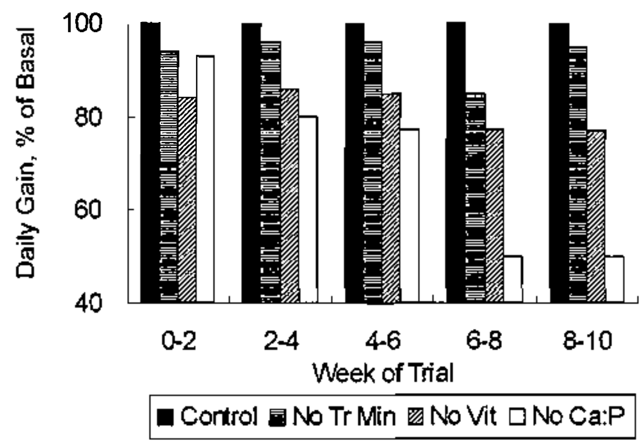

Figure 1. Effect of vitamin or mineral deletion on grower-finisher pig performance

There is evidence demonstrating a decline in the serum concentration of at least some of the vitamins upon weaning (Mahan and Moxon, 1980, Yen et al., 1981, 1985), that there is an interaction between the absorption of vitamins A and E, and that the intestinal absorption sites are changing morphologically in the weaned pig (Cera et al., 1988). These physiological changes in the pig affect the absorption of all nutrients from the intestinal tract and consequently the dietary recommendation for these vitamins. Although one could assume that other vitamins, particularly the B vitamins also decline in the young pig upon weaning such evidence is lacking. The possible decline in vitamins or the smaller relative amounts available for tissue metabolism may therefore compromise the ability of the weaned pig to effectively utilize the absorbed feed nutrients unless the diet is fortified with a higher dietary level of the vitamins. The functions and role of the vitamins in swine nutrition have been recently reviewed (Cook and Easter, 1991; Mahan, 1991; Ullrey, 1991).

The weaned pig demonstrates a decline in both serum α-tocopherol and Se within a week postweaning (Mahan and Moxon, 1980; Meyer et al., 1981). Serum concentrations of α-tocopherol do not increase for a few weeks postweaning unless the diet contains extremely high concentrations of the vitamin. Even when the diet contains high concentrations of vitamin E, evidence suggests that blood concentrations do not vary much between the supplemental dietary levels during the initial weeks postweaning. Absorbed α-tocopherol is readily retained by the liver, suggesting that the absorbed vitamin E is rapidly cleared from the serum (Moriera, unpublished data). Consequently, serum concentrations of α-tocopherol may not be the best criteria to evaluate the body status of vitamin E, particularly in younger swine. As the pig develops tissue the clearance of blood α-tocopherol into tissue maintains a low serum concentration of this vitamin, whereupon when tissue formation declines the blood concentration of the vitamin will rise. Because the vitamin E and Se deficiency is prevalent in much of the world, particularly with rapidly growing animals, adequate supplementation of vitamin E and Se is critical. Criteria to accurately assess the dietary requirements, particularly vitamin E are lacking. Measurement criteria for Se currently use glutathione peroxidase (GSH-Px) as the biological standard for determining the dietary requirement. However, when GSH-Px activities are used as the measurement tool for the weaning, growing and finishing pig, the plateau level is below the dietary level where deficiencies occur in the field.

Because ascorbic acid is amply supplied in sow milk and is considered to be synthesized in the young pig from 1 week of age, the need for its supplementation in the diet of the pig has not been recognized (Braude et al., 1950). Recent evidence suggest that the rate of synthesis may be inadequate for the young weaned pig. Although the research is not consistent, the results seem to suggest that during the early ages postweaning the pig responds to supplemental vitamin C, whereas as the pig matures it seems to synthesize an adequate quantity and does not respond to supplemental supplies of the vitamin (Mahan and Saif, 1983; Mahan et al., 1994; Yen et al., 1981, 1985).

An adequate level of dietary B vitamins is necessary for the pig to achieve maximum growth rates. Both lean tissue development and the amount of stress that the pig encounters will influence the dietary requirement of the B vitamins. Several B vitamins are used in the development of muscle tissue. Consequently, the requirements for these vitamins would be expected to be higher with pigs of a leaner genotype and those with a higher growth rate. Stahley et al. (1995) demonstrated in a recent study that a lean genotype responded to the a higher dietary B vitamin supplementation than a genotype of moderate leanness. Their results demonstrated, however, that the B vitamin requirements for both genotypes was substantially higher (300 to 400%) in the lean genotypes from 5.5 to 10 kg body weight than the NRC (1988) suggested allowances. For the duration of their trial the growth response to B vitamin supplementation was at a 500% level above that of NRC (1988). Their experiment was, however, conducted for varying lengths of time for each treatment group. Growth response were also obtained, to the higher B vitamin levels with the control pigs but has not been confirmed by other research. Although the need for B vitamins would be expected to be higher for leaner genotypes and faster growing pigs, the substantially larger gains at the extreme supplementation levels of the B vitamins which were evaluated by these workers needs to be investigated further.

When one evaluates the fortification levels of the vitamins which are currently being recommended by both university and various nutritional groups, and then comparing them to the NRC (1988), there is often times a substantial difference between these recommendations, particularly vitamins A and D, whereas in other cases, the recommendations are relatively close (table 1).

Table 1. Comparison of NRC (1988) and industry average (IA) fortification vitamin recommendations for growing swine (United States)[a]

Vitamin	Starter		Grower		Finisher	
	NRC	IA	NRC	IA	NRC	IA
	amount g/kg diet					
Vitamin A, IU	1,750	5,200	1,300	3,250	1,300	2,500
Vitamin, D IU	200	1,050	150	600	150	500
Vitamin E, IU	11	22	11	12	11	10
Vitamin K (menadione), mg	0.5	1.6	0.5	1.1	0.5	0.9
Biotin, mg [b]	0.05	0.1	0.05	0.03	0.05	0.03
Choline, g	0.4	NR	0.3	NR	0.3	NR
Folacin, mg [b]	0.3	0.5	0.3	0.1	0.3	0.2
Niacin (avail.), mg	12.5	26.8	10.0	15.5	7.0	11.9
Pantothenate, mg	9.0	15.7	8.0	9.5	7.0	7.4
Riboflavin, mg	3.0	4.0	2.5	2.5	2.0	1.9
Thiamine, mg [b]	1.0	1.0	1.0	0.4	1.0	0.3
Vitamin B_6, mg [b]	1.5	1.3	1.0	0.6	1.0	0.5
Vitamin B_{12}, mg	15.0	19.5	10.0	12.0	5.0	9.5

[a] Source: BASF (1993); NR=Not reported.

[b] Grains contain high concentrations of these vitmains and/or there is evidence of microbial synthesis in the intestinal tract. Therefore, many nutritionists do not recommend supplemental fortification for market swine.

It is well recognized that various factors can affect the stability of vitamins in the final feed mixture and their activity with prolonged storage. Consequently, most nutritionist can justify some degree of higher recommendations, but excesses of many of the vitamins cannot be justified based on published scientific evidence. Excess concentrations of dietary vitamin A and D may be detrimental to the pig. Excess vitamin A has been reported to interfere with vitamin E absorption with the weanling pig (Ching et al. 1995), although it has not been demonstrated with the grower-finisher pig (Anderson et al., 1995). Excessive vitamin D increases the osteoclastic activity of bone cells, which could cause bone decalcification. The major B vitamins which are normally added to swine diets (niacin, pantothenic acid, riboflavin, vitamin B_{12}) are higher in pig starter diets (ca. 60%) compared to NRC (1988) recommendations, while fortification levels in the grower-finisher diets are higher by 25 to 40%, respectively.

Minerals

The role of Ca and P in bone development and P functions in protein metabolism are well established. Diets with an inadequate concentration of these minerals results in lower gains and a weakened bone structure in grower pigs, whereas the response with finisher pigs results in lower recommendations (Fammatre et. al. 1977; Maxon and Mahan, 1983; Koch and Mahan, 1986). The Ca and P requirement for maximum bone mineralization and for replacement gilts is higher than that for maximum growth rate (Nimo et al., 1981).

When phosphorus is inadequately provided, pig growth rate, feed intake, feed conversion, bone mineralization and carcass leanness is reduced (table 2). Grains have a relatively high P content, but much of it is bound with an organic constituent (phytic acid) which reduces its digestibility and availability to the pig. Phytate phosphorus represents 60 to 80% of the total plant seed phosphorus (table 3). Phytase is an enzyme naturally present in grains which hydrolyses this chemical linkage. Cereal grains contain varying quantities of this enzyme (table 3). Consequently, the relative availability of P from the different grains and oilseed product differs (table 3).

Table 2. Performance, bone and leanness responses to grower-finisher swine fed a phosphorus adequate or deficient diet

Item	Diet P level, %	
	Adequate 0.50	Inadequate 0.32
Daily gain, kg	0.77	0.54
Daily feed, kg	2.37	2.06
Feed:gain	3.08	3.82
Bone strength, kg	146	77
Bone ash, %	57.4	52.8
Lean, %	58.5	55.9

[a] Source: Cromwell (1991).

Table 3. Phytate content of various feedstuffs and bioavailability of phosphorus for swine

Feedstuff	Total P (%)[a]	Phytate P (% total P)[b]	Phytase Activity (units/kg)[b]	Bio-availability (%)[ab]
Corn	0.28	72	15	12
Wheat	0.37	69	1193	50
Sorghum	0.28	66	24	42
Barley	0.24	64	582	31
Oats	0.34	67	40	23
Wheat Bran	1.16	71	2957	35
SBM, 48%	0.64	60	8	35
Canola meal	1.17	59	16	21
Sunflower meal	0.94	77	60	NA
Peanut meal	0.61	80	3	12
Cottonseed meal	1.17	70	NA	21

[a] Source: NRC (1988). [b] Source: Komegay (1996).
NA = not available.

Phytase has been produced in the laboratory and the effects of adding this enzyme to the diets of nonruminants was conducted over 25 years ago. The initial research clearly demonstrated an improvement in bone mineralization and animal growth when phytase was added to the diet. The product was, however, not economically feasible because the cost of phytase was higher than the dietary inorganic P sources. Consequently, phytase research was not aggressively continued. With increasing emphasis toward the environmental regulation of P and its subsequent deposition on soil, the increasing concentration of P in the soil and water supplies now makes the incorporation of this enzyme in swine diets more attractive to pig producers. The enzyme is produced from a fungus (*Aspergillus niger*), but with new technology the gene has now been incorporated into a bacterial strain and in the *Aspergillus niger* specie to yield purer and higher concentrations of the enzyme.

The recent approval of phytase in the United States has been shown to result in an increased availability of phosphorus in cereal grain sources for swine (Fandrejewski et al., 1997). Its effectiveness on P digestibility in swine during the grower-finisher period is presented in table 4. Phosphorus digestibility increases dramatically when phytase is added to the diet and was comparable to the results of the positive control diet. Because other minerals are chelated with phytate, their availability is also increased by phytase addition (Cromwell, 1991). Consequently, reducing the total dietary P level by 0.10% and adding the phytase enzyme to grower-finisher swine diets has been shown to restore pig growth and feed conversion to that of the positive control diet (table 5).

Table 4. Effect of phytase on mineral digestibility with grower-finisher swine

Item	Positive	Negative	Negative+Phytase	
Ca/P, G:	0.60/0.50	0.55/0.40	0.55/0.40	0.55/0.40
Ca/P, F:	0.50/0.40	0.45/0.35	0.45/0.35	0.45/0.35
Phytase Units/ kg:	0	0	250	500
Phosphorus digestibility, %				
Grower	60.8	52.7	59.2	63.5
Finisher	55.1	38.4	52.2	49.8
Calcium digestibility, %				
Grower	68.4	62.8	64.4	66.4
Finisher	59.6	66.5	65.7	68.1

(Cromwell, 1991)

Phosphorus which is excreted in swine manure and deposited on soil is not readily mobile and rapidly becomes bound to soil particles and other soil minerals. Phosphorus thus accumulates in soils, lakes and streams in an insoluble form. Phosphorus is important for the growth of algae and other aquatic plant life, and its subsequent accumulation in these plants lowers the oxygen content of water. Because of the potential environmental pollution effects of high soil P concentrations, the amount of swine excrement than can be deposited on soils will be regulated. Phosphorus recommendations by industry and universities have generally exceeded the minimum level needed by approximately 0.10%. When one considers the amount of P from this"over-recommendation" and then adjusting the diet by another 0.10% after the addition of phytase, substantially lower P depositions on agricultural land can be achieved. The potential effects on reducing P excretion from phytase addition are reported in table 6. These calculations demonstrate an approximate 54% reduction in the amount of P excreted when phytase is added to grower-finisher swine diets (Cromwell, 1991).

Table 5. Effect of added phytase on grower-finisher swine performance[a]

Item	Positive	Negative	Negative+Phytase	
Ca/P, G:	0.60/0.50	0.55/0.40	0.55/0.40	0.55/0.40
Ca/P, F:	0.50/0.40	0.45/0.35	0.45/0.35	0.45/0.35
Phytase Units/ kg:	0	0	250	500
No. pigs	45	45	45	45
Grower period				
Daily gain, kg	0.77	0.67	0.75	0.75
Daily feed, kg	1.60	1.46	1.58	1.58
Feed/gain	2.07	2.18	2.11	2.10
Finisher period				
Daily gain, kg	0.94	0.74	0.90	0.92
Daily feed, kg	2.58	2.11	2.51	2.52
Feed/gain	2.75	2.82	2.79	2.74

[a] Phytase source was Natuphos® (BASF)

Chromium. Muscle tissue initially develops in response to the number of muscle cells, but in turn responds to nutrient supply and hormonal stimulation. To facilitate the transfer of nutrients into the muscle cell, insulin and growth hormone are needed to mediate this response. The Glucose Tolerance Factor (GTF) has been postulated to serve as a bridge between the cell membrane, and nutrient transfer where Cr is suggested to be the active constituent (Schwartz and Mertz, 1959). The addition of chromium to swine diets has sometime been shown to increase carcass leanness, decrease back fat thickness in grower-finisher pigs (Page et al., 1993; Lindemann et al., 1995; Min et al., 1997).

Table 6. Calculated Phosphorus (P) Content in the Excrement of Pigs[a]

Item	Current Practice	Requirement (NRC)	Phytase Addition
Dietary P level, %	0.5	0.4	0.3
P intake, g/day	15.5	12.4	9.3
P retained, g/day	4.0	4.0	4.0
P excreted, g/day	11.5	8.4	5.3
P reduction, %			
Current Practice		27	54
NRC			37

(Cromwell, 1991)

Selenium. Although Se's role in the enzyme glutathione peroxidase (GSH-Px) has been well established, there are other selenoproteins and enzyme systems where Se has now been reported. Selenium's involvement with GSH-Px, largely as a constituent of this enzyme, serves as an antioxidant in the cytoplasm of the cell. The enzyme is involved in the metabolic conversion of liberated oxygen (toxic) and its conversion to water (non-toxic). Although Vitamin E has been historically linked with Se, this is because of the similarity of functions and deficiency symptoms, although these nutrients function in different regions of the cell. In contrast to GSH-Px which functions in the cytosol, vitamin E is found in the cellular and subcellular membranes helping to maintain their integrity by preventing lipoprotein oxidation. Total dietary Se levels of 0.15 and 0.10 ppm Se are adequate for the grower-finishing pig, respectively.

The inorganic form of Se (sodium selenite) is not retained by body tissues as much as the organic form (selenomethionine and other seleno amino acid analogs) of the element. When either the inorganic or organic Se sources were fed to grower finisher pigs the Se content of muscle and other tissue increased linearly when the organic form was fed, whereas pigs fed the inorganic form had a lower concentration of the element that did not increase as the dietary levels increased (Mahan and Parrett, 1996). Excess Se is largely excreted via the urine or through the bile into the intestinal tract. Because of the lower retention of Se when the inorganic form was fed, the total excretion of Se (urine and feces) was approximately 20% higher when inorganic Se was fed.

Selenium has also been shown to be involved in an enzyme which converts thyroxine (T_4) to the active form (T_3). Thyroxine contains iodine, and a deficiency of either Se or I can lower the production of T_3 (Arthur, 1993). Because thyroxine regulates growth and nutrient utilization, a deficiency of Se could reduce these performance parameters.

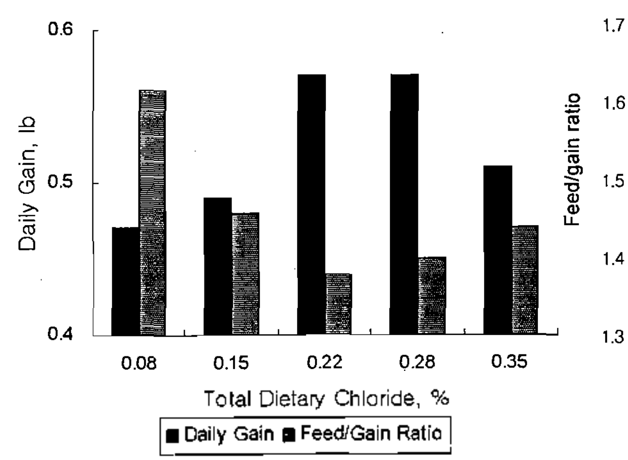

Figure 2. Effect of added chloride in the phase 1 diets of 3-week old weaned pigs

Chloride. This element is secreted in the stomach of the pig having a role in maintaining stomach pH, helps to regulate the species of microbes and their proliferation in the stomach, and activates the pepsinogen proenzyme for subsequent protein digestibility. The secretion of this element is low or absent at birth but increases with pig age, reaching adequate secretory capacity by 5 to 8 weeks of age. Because pigs are being weaned earlier and fed diets which contain feedstuffs that have a high buffering capability (i.e. plant and animal proteins, inorganic minerals), the young pig has a dietary need for Cl. When Cl has been added to weanling pig diets, there has been improvements in pig gain, feed efficiency (figure 2), and in protein digestibility (figure 3). However, the addition of Cl to diets of a later age (>5 weeks) has resulted in a growth depression. These results suggest that the addition of approximately 0.30% Cl, will benefit the young pig for approximately 2 weeks postweaning, but the level of Cl should subsequently be reduced to approximately 0.10%.

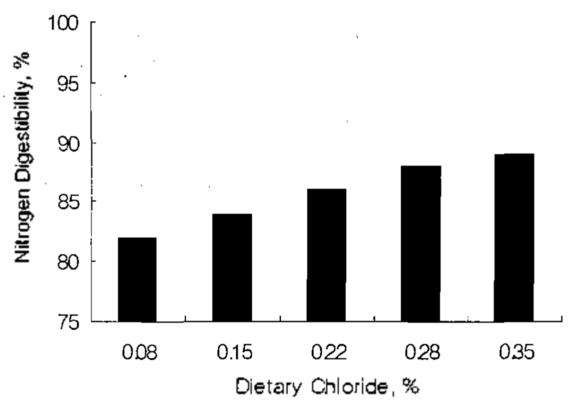

Figure 3. Effect of added chloride on nitrogen digestibility in the phase 1 diets of 3-week old weaned pigs

Zinc. Antibiotics or antibacterial agents added to pig starter diets generally results in growth responses between 10 to 20%. Zinc oxide (3000 ppm) and copper sulfate (250 ppm) added at dietary concentration which exceed the pigs metabolic need has been shown to enhance nursery pig performance (figure 4).

Although there is no known metabolic reason for this response, it is attributable to the inhibiting effect of these minerals on microbial growth in the intestinal tract. Zinc oxide should be the form of zinc fed if the beneficial performance effect is to be realized.

NUTRIENT WITHDRAWAL

There has been interest in withdrawing the vitamin and trace mineral premixes from the diets of swine prior to marketing. The reason for this is largely economical because most of the feed consumed by the pig is during the finishing period.

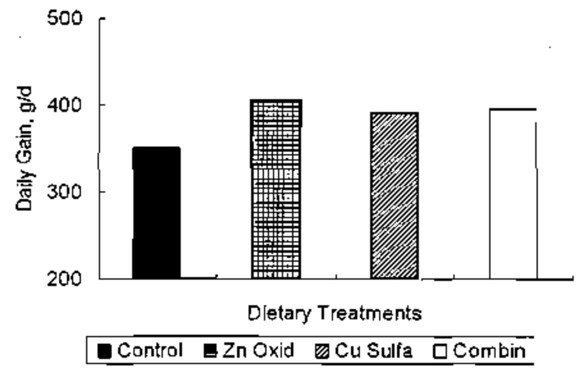

Figure 4. Effect of zinc oxide and copper sulfate and their combination on postweaning performance of weaned pigs

A study recently done by Kansas State (Hancock, unpublished data) suggests that complete removal of the vitamin and trace mineral premix and reducing the Ca and P levels to 0.55 and 0.42%, respectively during the latter part of the finisher period did not effect swine performance responses, and had no effect on the major carcass characteristics. When we combine the interpretations from figure 1, table 1 and their data, it is apparent that when the pig is fed excess concentrations of the micronutrients the pig can retrieve some of these vitamins from its body stores. Muscle and bone development occurs in the finishing pig, albeit at a declining rate, but these tissues continue to have a metabolic need for vitamins and minerals. The premature removal of the vitamins from the diet may result in reduced growth rates. Excessive fortification of diets as done by the industry is costly (table 1), and perhaps needs to be more judicially recommended rather than completely deleting the nutrients from the finisher diets. Because pork contains more than a source of amino acids for humans consuming it, concern about the micro nutrient content has been questioned. A study by Patel et al. (1997) demonstrated that the removal of riboflavin in the diets of growing chicks did not affect growth rate but did effect the riboflavin content of meat tissue. These results imply that the nutritional quality of meat may be compromised without affecting the performance responses of the animal. Before withdrawal of the vitamins and minerals from swine diets, further research needs to be conducted to evaluate the effects on the nutrient content of the meat produced from such animals.

EFFECT ON PORK QUALITY

The results of Patel et al (1997) implies that dietary vitamins can affect meat quality. The consumer prefers to have fresh pork with a reddish-pink color with a minimum loss of water during handling and cooking. Pork which is watery, pale or dark in color is objectionable. Much of the quality of pork and its shelf-life is governed by the oxidative capacity of the product, particularly the lipid component. Several vitamins and minerals have been investigated as to their role in reducing the oxidation of the lipids in the phospholipid component in the membranes of the tissue (Gray and Pearson, 1987). Asghar et al. (1991) and Monohan et al. (1994) demonstrated that high levels of vitamin E reduced the amount of drip loss, improved the color characteristics of loin muscle, and reduced the amount of lipid oxidation. Munoz et al. (1996) demonstrated that a combination of antioxidants (vitamin C, organic Se, vitamin E) fed to growing pigs reduced the drip loss in loin muscle. From these studies, the longer the period of storage the greater was the benefit from the supplemental vitamins or minerals.

Selenium is marginal to low in much of the world for meeting the nutritional requirements of the human. The provision of organic Se in the diet of grower-finisher pigs increases the Se content of pork which should be an avenue of increasing the Se contribution to the human diet.

REFERENCES

Anderson, L. E., R. O. Myer, J. H. Brendemuhl, and L. R. McDowell. 1995. The effect of excessive dietary vitamin A on performance and vitamin E status in swine fed diets varying in dietary vitamin E. J. Anim. Sci. 73:1093.

Arthur, J. R., F. Nicol, and G. J. Rechette. 1990. Hepolic iodothyronine 5'-deiodenase: the role of selenium. Biochem. J. 272:537.

Arthur, J. R. 1993. The biochemical function of selenium: Relationships to thyroid metabolism and antioxidant systems. In: Rowett Research Institute Annual Report. Rowett Research Laboratories, Aberdeen Scotland, U.K.

Asphar, A. J. I. Gray, E. R. Miller, P. K Ku, A. M. Booren, and D. J. Buckley. 1991. Influence of supranutritional vitamin E supplementation in the feed on swine growth, performance and deposition in different tissues. J. Sci. Food Agric. 57:19.

BASF. 1993. Vitamin supplementation rates for U.S. commercial poultry, swine and dairy cattle. Publication KC 9305.

Bowland, J. P. 1961. Swine milk composition - A summary. In L. K. Bustad, R. O. McClellan, and M. P. Burns, Eds., Swine in Biomedical Research. Pacific Northwest Laboratory, Richland, Washington., 97.

Braude, R.,S. K. Kon, and J.W.G. Porter. 195 0. Studies on the vitamin C metabolism of the pig. Br. J. Nutr. 4:186.

Cera, K. R., D. C. Mahan, R. F. Cross, G. A. Reinhjart, and R. E. Whitmoyer. 1988. Effects of age, weaning and postweaning diet on small intestinal growth and jejunal morphology in young swine. J. Anim. Sci. 66:574.

Ching, S., and D. C. Mahan. 1995. Interrelationship of recommended and high dietary vitamin E and vitamin A levels in the postweaning diets of pigs. J. Anim. Sci. 73:71 (Abstr.).

Cline, J. H., and D. C. Mahan. 1972. Effects of nutrient deletion in practical swine diets. J. Anim. Sci. 35:1109 (Abstr.).

Cook, R. A., and R. A. Easter. 1991. The water-soluble vitamins in swine nutrition. In: Swine Nutrition (Ed. E. R. Miller, D. E. Ullrey, A. J. Lewis). p. 235.

Cromwell, G. L. 1991. Phytase appears to reduce phosphorus in feed, manure. Feedstuffs. October 7.

Fammatre, C. A., D. C. Mahan, A. W. Fetter, A. P. Grifo, and J. K. Judy. 1977. Effects of dietary protein, calcium and phophorus levels for growing and finishing swine. J. Anim. Sci. 44:65.

Fandrezewski, H., S. Raj, D. Werenko and T. Zebrowska. 1997. Apparent digestibility of phosphorus in experimental feeds and the effect of commerical phytase. Asian-Aus. J. Anim. Sci. 10(6):665.

Georgieviskii. V. I. 1982. Fundamental concepts. History of the problem. In: Mineral Nutrition of Animals (Ed. Georgievskii, Annenkov, and Samoklin). Butterworths.

Hill, G. M., G. L. Cromwell, T. D. Crenshaw, R. C. Ewan, D. A. Knabe, A. J. Lewis, D. C. Mahan, G. C. Shurson, L. L. Southern, and T. L. Veum. 1996. Impact of pharmacological intakes of zinc and(or) copper on performance of weanling pigs. J. Anim. Sci. 74:181 (Abstr.).

Koch, M. E., and D. C. Mahan. 1986. Biological characteristics for assessing low phosphorus intake in finishing swine. J. Anim. Sci. 62:163.

Lindemann, M. D., C. M. Wood, A. F. Harper, E. T. Kornegay, and R. A. Anderson. 1995. Dietary chromium picolinate additions improve gain:feed and carcass characteistics in growing-finishing pigs and increase litter size in reproducing sows. J. Anim. Sci. 73:457.

Mahan, D. C. 1991. Vitamin E and selenium in swine nutrition. In: Swine Nutrition (Ed. E. R. Miller, D. E. Ullrey, A. J. Lewis).

Mahan, D. C., and A. L. Moxon. 198 0. Effects of dietary selenium and injectable vitamin E-selenium for weanling swine. Nutr. Rpt. Intern. 21:829.

Mahan, D. C., and N. A. Parrett. 1996. Evaluating the efficacy of Se-enriched yeast and inorganic selenite on tissue Se retention and serum glutathione peroxidase activity in grower and finisher swine. J. Anim. Sci. 75:2731.

Mahan, D. C., and L. J. Saif. 1983. Efficacy of vitamin C supplementation for weanling swine. J. Anim. Sci. 56:631.

Mahan, D. C., A. J. Lepine, and K. Dabrowski. 1994. Efficacy of magnesium-L-ascorbyl-2-phosphate for weanling and growing-finishing swine. J. Anim. Sci. 72:2354.

Maxson, P. F., and D. C. Mahan. 1983. Dietary calcium and phosphorus for growing swine from 18 to 57 kilograms body weight. J. Anim. Sci. 56:1124.

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.

Min, J. K., W. Y. Kim, B. J. Chae, I. B. Chung, I. S. Shin, Y. J. Choi and I. K. Han. 1997. Effects of chromium picolinate (CrP) on growth performance, carcass characteristics and serum traits in growing-finishing pigs. Asian-Aus. J. Anim. Sci. 10(1):8-14.

Monohan, F. J., J. I. Gray, A. Asghar, A. Haug, G. M. Strasburg, D. J. Buckley, and P. A. Morrissey. 1994. Influence of diet on lipid oxidation and membrane structure in porcine muscle microsomes. J. Agric. Food Chem. 42:599.

Munoz, A., M. D. Garrido, and M. V. Granados. 1996. Effect of selenium yeast and vitamins C and E on pork meat exudation (personal communication).

Nimmo, R. D., E. R. Peo, Jr., B. D. Moser, and A. J. Lewis. 1981. Effect of level of dietary calcium-phosphorus during growth and gestation on performance, blood and bone parameters of swine. J. Anim. Sci. 52:1330.

N.R.C. 1988 Nutrient Requirements of Swine (9th Ed.). National Academy Press, Washington, DC.

Page, T. G., L. L. Southern, T. L. Ward, and D. I. Thompson. 1993. Effect of chronium picolinate on growth and serum and carcass traits of growing-finishing pigs. J. Anim. Sci. 71:656.

Patel, K. P., H. M. Edwards III, and D. H. Baker. 1997. Removal of vitamin and trace mineral supplements from broiler finisher diets. J. Appl. Poultry Res. 6:191.

Schwartz, K., and W. Mertz. 1959. Chromium (III) and the glucose tolerance factor. Arch. Biophys. 85:292.

Stahley, T. S., N. Williams, S. G. Swenson, R. G. Ewan. 1995. Dietary B vitamin needs of high and moderate lean growth pigs fed from 20 to 62 pounds body weight. Iowa State Swine Research Report. p 19.

Ullrey, D. E. 1991. Vitamins A and K in swine nutrition. In: Swine Nutrition (Ed. E. R. Miller, D. E. Ullrey, A. J. Lewis).

Yen J. T., and W. G. Pond. 1981. Effect of dietary vitamin C addition on performance, plasma vitamin C and hematic iron status in weanling pigs. J. Anim. Sci. 53:1292.

Yen, J. T., P. K. Ku, W. G. Pond, and E. R. Miller. 1985. Response to dietary supplementation of vitamin C and Vitamin E in weanling pigs fed low vitamin E-selenium diets. Nutr. Rep. Int. 31:877.