Fat-soluble vitamins: Beyond nutritional needs

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Introduction

Fat-soluble vitamins A, D, E are vital nutrients for all swine. These vitamins are routinely added to swine feeds at or above National Research Council (NRC) recommended levels. Supplementation via drinking water and injection are also utilized.

Published NRC dietary requirements have not been static. In 1941 requirements for vitamin A, vitamin D and carotene were published and the requirement for vitamin E was first published in 1973 and later increased in 1988. In 1988, carotene was removed as a required dietary nutrient. Vitamin D requirements were increased for sows in the 2011 NRC publication. The primary reasons for changes in fat-soluble vitamin requirements are due to a combination of research findings, husbandry practices (confined vs. non-confined), sow productivity, and improved growth.

The primary emphasis for NRC dietary requirements is minimum daily requirements for animal performance. Research has shown that under certain conditions, higher levels of fat-soluble vitamin-intakes may impact other factors besides average daily gain and feed efficiency.

The purpose of this paper is to review information that shows the impact of strategic use of fat-soluble vitamins on other bodily functions besides generally accepted nutritional needs and also the impact of disease and other factors on fat-soluble vitamin status.

Enhanced immunity ensues when higher than NRC fat-soluble levels are fed or injected

There are several excellent reviews on the impact of fat-soluble vitamins on cell-mediated and humoral immunity.[1,2,3] Research as early as 1931, showed that fat-soluble vitamins had a positive effect on the immune system. As swine husbandry practices have changed from non-confinement to confinement and productivity has increased, the need for adequate fat-soluble vitamin supplementation has become even more paramount.

Several experiments in various species have shown that viral and bacterial infections reduce fat-soluble vitamin status, especially vitamin E. Two studies have shown that there was a negative impact of PRRS on vitamin E status in sows and pigs, but not vitamin D status. L. Bruner, 2013, conducted a field evaluation on the effects of PRRS on vitamin E and vitamin D status of PRRS+ and PRRS- sows and pigs (Personal communication). She found that in nine herds, vitamin D status was not reduced by PRRS, but vitamin E status was dramatically reduced by PRRS virus in both sows and nursing pigs. Tousignant found similar results. He found that PRRS infected weaned pigs had no reduction in vitamin D or selenium status, but a 51.3% reduction in vitamin E status at 14 days post-infection (Table 1) (Personal communication).

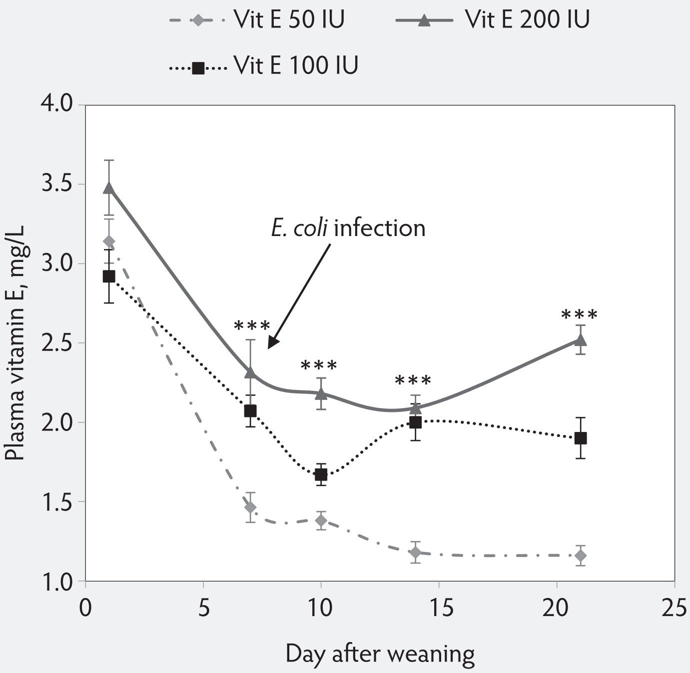
Jensen et al., 1987, reported that for optimum cell-mediated immunity, pig's serum alpha-tocopherol levels should be maintained at levels above 3 ppm.[4] The conundrum with vitamin E is that newly-weaned pigs do not utilize synthetic vitamin E acetate that is in nursery diets. Kim et al., 2016, evaluated the impact of supplementing newly-weaned pigs with either 50, 100, or 200 I.U. dl-alpha-tocopheryl acetate/ kg diet on inflammatory responses.[5] At the start of the experiment (at weaning) average serum vitamin E was 3.2 ppm. Ten days post-weaning, serum alpha-tocopherol levels were 1.4, 1.7 and 2.2 for pigs fed 50, 100 and 200 I.U., respectively (Figure 1). This study supports findings by Moreira

Table 1: Effect of PRRS challenge on vitamin E and selenium serum status in nursery pigs (Tousignant, 2013, personal communication)

	PRRS positive (n = 9)	PRRS negative (n = 10)	*P*-value[1]
Weaning			
Vitamin E (ppm)	3.48	3.72	0.667
25 OH D (ppb)	88	83	0.75
Selenium (ppm)	141.9	110.9	0.0001
14 DPI[2]			
Vitamin E (ppm)	2.3	3.46	0.098
25 OH D (ppb)	38	40	0.72
Selenium (ppm)	140.8 (12.45)	102.5 (22.86)	0.0004

[1] *P*-values calculated using t-test
[2] DPI = Days post-infection

Figure 1: Effect of dietary dl-alpha tocopheryl acetate levels on plasma vitamin E contents after weaning. All pigs were experimentally infected with an enterotoxigenic strain of *E coli* on d 7. ***$P < 0.001$ (Kim, et. al., 2016)



and Mahan, 2002, that nursery pigs are unable to maintain serum vitamin E status after weaning due to lack of ability to utilize synthetic vitamin E acetate at levels up to 200 I.U. per kg (182,000 I.U. per ton).[6]

Hidiroglou et al., 1995,[7] found that pigs injected with d-alpha-tocopherol (VITAL E-500) had dramatically higher plasma alpha-tocopherol concentrations and higher antibody titers to key-hole limpet haemocyanin compared to control pigs. Vitamin E injected pigs also had significantly higher alpha-tocopherol concentrations in spleen, liver, heart, kidney, lung and muscle compared to non-injected pigs.

In a recent experiment at Michigan State University, supplementing the water of newly-weaned pigs with micellized non-esters of *d*-alpha-tocopherol and cholecalciferol reduced oxidative stress. Enzymes superoxide dismutase (SOD) and glutathione peroxide (GPx) were determined in newly-weaned pigs supplemented with vitamin E and D in drinking water (EMCELLE E-D_3 Liquid). SOD was reduced ($P = 0.005$) and GPx activity was reduced due to the water supplementation of vitamins E and D. ($P = 0.0002$).[8]

Another area of interesting research is the impact of vitamin E and selenium deficiencies on enhanced viral pathogenicity. Beck has demonstrated that adequate vitamin E and selenium in rodents reduced viral mutations and subsequent reduction in viral pathogenicity.[9]

Fat-soluble vitamins improve muscle function

No role for vitamin A to improve muscle function has been reported in the literature. Vitamin E has long been shown to be involved in skeletal and cardiac muscle function, and recently smooth muscle function. In the past few years, a growing number of human clinical studies have examined the effects of vitamin D supplementation on muscle function and research on the vitamin D receptor in smooth muscle cells have helped to improve our understanding of the role and actions of vitamin D on smooth muscle function.

In regards to vitamin E deficiencies in nursery pigs, an increase in cardiomyopathy has been associated primarily with vitamin E deficiencies and not selenium.[10] In calves, the fastest growing animals have the lowest vitamin E status.[11] It is interesting that with cardiomyopathy, the fastest growing pigs seem to be affected, therefore supplementing the nursery pig with a biologically available source of vitamin E (EMCELLE TOCOPHEROL) to keep serum vitamin E status above 3-4 ppm is critically important.[12]

Recent university research and field demonstrations has demonstrated that pre-partum injections of vitamins A, D, and E reduces total delivery time approximately one hour (Data on file, Stuart Products, Inc.). Whether the effect is due to enhanced vitamin E and/or vitamin D status has yet to be determined. In the large field study, besides reducing delivery time, stillborns were reduced approximately 30% in the injected sows compared to the non-injected sows. There were 267 sows in the field study. Half were injected with VITAL E-Repro one week pre-farrowing and the other half were not injected. Parities were equally assigned to the two treatments.

Another potential role for elevated levels of vitamin E is sow prolapses. A small survey was conducted in North Carolina to determine if prolapsed sows had different fat-soluble vitamin status compared to cohort sows.[13] The average serum vitamin E status in 10 prolapsed sows was 26% lower when compared to 19 cohort sows (1.30 vs 1.64 ppm), and serum vitamin A and 25 OH D3 were 7 and 6% lower in the prolapsed sows. (Table 2).

Fat-soluble vitamins enhance reproduction

All three fat-soluble vitamins have been shown to impact reproduction in sows.[14] Vitamin A supplementation and/or injection has been shown to improve embryo survival.[15] The form of vitamin A in injectable formulations is critically important. Vitamin A palmitate has been shown to be much more effective on enhancing sow productivity when compared to vitamin A propionate.[16] Jensen and Lauridsen recently presented data on the fat-soluble vitamin needs for highly prolific sows in Denmark.[17] The Danish recommended levels of vitamins A, D and E are dramatically higher than NRC recommendations, especially for the lactating sow (Table 3).[18] As an example, the published vitamin E requirement for lactating sows in Denmark is 165 I.U./kg (150,000 I.U./ton) compared to the NRC requirement of 44 I.U./kg (40,000 I.U./ton).

Table 2: Survey of fat-soluble vitamin status in prolapsed sows and their cohorts. (Riggs and Almond, 2016, unpublished)

Vitamin	Prolapsed sows (n =10)	Cohort sows (n = 19)
Vitamin E (ppm)	1.30	1.64
Vitamin A (ppm)	0.27	0.29
Vitamin D (ppb)	34.84	36.93

Importance of bioavailability of fat-soluble vitamins

Both naturally-occurring and supplemental fat-soluble vitamins go through various steps prior to absorption that is similar to fat metabolism. Prior to absorption, supplemental fat-soluble vitamins A and E need to be de-esterified by the action of intestinal esterases (pancreatic carboxyl ester hydrolase (CEH).[19] The esters are removed from the vitamin molecules prior to absorption. A second step for fat-soluble vitamins is micellization. Micelles are formed by the action of bile salts to create water-soluble droplets that are absorbed. Supplementing water with micellized, non-esterified vitamin E (d-alpha-tocopherol) assists in maintaining adequate vitamin E status of the post-weaned pig.[12] Yang, et al., 2014, compared the utilization of injectable vs oral sources of vitamins A, D and E (VITAL E-Newborn). Injectable sources were utilized approximately twice that of orally administered vitamins[20]

van Kempen et al. reported that the bioavailability for oral *d,l-α*-tocopheryl acetate (normally used in complete feeds) was only 12.5% when administered in nursery pigs. Vitamin E dosed as d-α-tocopherol at one-eighth the level of the synthetic acetate ester showed both a rapid and a very slow pool, whereas orally dosed synthetic vitamin E acetate showed a single slow pool. The authors stated that the use of synthetic vitamin E-acetate brings into question the efficacy of typical use of vitamin E-acetate in swine diets for alleviating oxidative stress.[21]

Conclusions

Of the three fat-soluble vitamins, vitamin E appears to be the most deficient in all post-weaning phases of swine production, while vitamin D supplementation may be most critical in the nursing pig due to low milk content. Reduced farrowing time due to pre-partum injection of fat-soluble vitamins and reduction in mulberry heart are areas affected by inadequate fat-soluble vitamin intake. Esterification of fat-soluble vitamins A and E is done to improve stability in complete feeds, but there are situations in swine production when it is best not to esterify fat-soluble vitamins, especially vitamin E in nursery diets. Stability of esters will be superior, but at the expense of bioavailability.

In general, the NRC recommended levels for fat-soluble vitamins fat-soluble vitamins are too low. The level for gestating and lactating sows should be dramatically increased. For newly-weaned pigs, the source of vitamin E is more critical than inclusion levels. Pigs fed 200 I.U. synthetic acetate/kg diet were still unable to maintain serum tocopherol levels, while pigs supplemented with micellized d-alpha-tocopherol are able to maintain an optimum serum status. The necessity to supplement with a biologically-available source of vitamin E as found in EMCELLE TOCOPHEROL and EMCELLE ED3 Liquid, or VITAL E-injectables is critical to be assured that vitamin levels are more than adequate.

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Table 3: Comparative fat-soluble vitamin recommended use levels (I.U/kg) for swine feeds in Denmark and US (Jensen and Lauridsen, 2017)

		Sows		Nursery pigs	Pigs	Grow/finish
		Gestating	Lactating	6-9 kg	9-30 kg	30-110 kg
Vitamin A	Denmark	8000	8000	8000	5000	4000
	NRC	4000	2000	2200	1750	1300
Vitamin D_3	Denmark	800	800	800	500	400
	NRC	800	800	220	200	150
Vitamin E	Denmark	40	165	140	140	40
	NRC	44	44	16	11	11

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