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Effect of increasing levels of fat-soluble and water-soluble vitamins on improving performance and plasma vitamin concentration in modern hybrids pig's growth and finishing phase

[*Efeito do aumento dos níveis de vitaminas lipossolúveis e hidrossolúveis na melhoria do desempenho e na concentração plasmática de vitaminas em suínos híbridos modernos nas fases de crescimento e terminação*]

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ABSTRACT

The objective was to evaluate the supplementation of fat-soluble and water-soluble vitamins on the performance and plasma concentrations of vitamins in modern hybrids pigs. A total of 144 commercial hybrid castrated male, 43.531 ± 1.099kg, were used in a randomized block design with six treatments, eight replicates and three animals per pen. The experimental treatments were different vitamin supplementation levels – 0, 25, 50, 75, 100, and 125% of the recommended by Rostagno *et al*. (2011) for male pigs in growth I (40 to 50kg), growth II (50 to 70kg), and finishing I (70 to 90kg) phases. For growth phases I and II, a linear effect (P<0.05) due to increase in vitamin supplementation was observed on performance. For finishing phase I and total phase, a linear effect (P<0.05) was observed with increased final average weight (FAW) and improved feed conversion ratio (FCR). For average daily weight gain (ADWG) and average daily feed intake (ADFI) a quadratic effect was observed (P<0.05). A linear (P<0.05) increase in plasmatic α-tocopherol and B_{12} was observed with the 125%. Thus, it is concluded that the 125% vitamin supplementation improved performance of modern hybrids pigs (40 to 90kg).

Keywords: feed efficiency, micronutrients, requirements of vitamin, swine

RESUMO

Objetivou-se avaliar a suplementação de vitaminas lipossolúveis e hidrossolúveis sobre o desempenho e as concentrações plasmáticas de vitaminas em suínos híbridos modernos. Um total de 144 híbridos machos castrados, 43,531 ± 1,099kg, foram distribuídos em delineamento de blocos ao acaso, com seis tratamentos, oito repetições e três animais por baia. Os tratamentos foram diferentes níveis de vitaminas – 0, 25, 50, 75, 100 e 125% do recomendado por Rostagno et al. *(2011) para suínos machos nas fases de crescimento I (40 a 50kg), crescimento II (50 a 70kg) e terminação I (70 a 90kg). Para as fases de crescimento I e II, observou-se efeito linear (P<0,05) devido ao aumento na suplementação vitamínica sobre o desempenho. Para a fase de terminação I e a fase total, observou-se efeito linear (P<0,05) com o aumento do peso médio final (PMF) e melhoria da conversão alimentar (CA). Já para as variáveis de ganho de peso médio diário (GPMD) e consumo de ração médio diário (CRMD,) observou-se efeito quadrático (P<0,05). Houve aumento linear (P<0,05) em α-tocoferol e cobalamina plasmáticos devido à suplementação de 125%. Assim, conclui-se que a suplementação com 125% de vitaminas melhorou o desempenho de suínos híbridos modernos (40 a 90kg).*

Keywords: feed efficiency, micronutrients, requirements of vitamin, swine

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INTRODUCTION

Vitamins are organic compounds required in small amounts in the diet and participate in numerous metabolic reactions essential to promote performance, health and, consequently, the productive efficiency of pigs. Vitamins are basically classified according to their solubility, being fat-soluble (A, D_3, E and K) when soluble in lipophilic substances and water-soluble (complex B and C vitamins) when soluble in water. Because most of them are not synthesized efficiently by the animal, it is imperative to provide them in the diet.

In general, vitamin A contributes to maintain the epithelial tissue integrity, vision, and immunity while vitamin D_3, considered a hormone, acts in the regulation of calcium and phosphate ion homeostasis, bone mineralization and in increasing macrophage activity (Combs Jr, 2008; Isabel *et al*., 2012). Vitamin E is a natural biological antioxidant and acts at the cell membrane level with effects on the reproductive and immune systems, showing synergism with selenium (McDowell, 2006). Vitamin K, on the other hand, contributes to the blood clotting process (Combs Jr, 2008). Regarding the water-soluble vitamins (B complex), it is possible to state that they act as enzyme cofactors in the energy (mitochondrial and lipidic) and amino acid metabolism, for example, in interconversion processes of compounds, methylation, acetylation, remethylating, electron transport chain, DNA formation and in biosynthesis of intermediary compounds essential for health and performance improvement (McDowell, 2006; Combs Jr, 2008; Isabel *et al*., 2012).

The scientific literature available on the recommendation of vitamin levels in the diet of growing and finishing pigs is very variable. While the average recommendation of vitamins (fat-soluble and water-soluble) for growing and finishing pigs increased by 1.51% according to the National Research Council (Nutrient…, 1988, 1998, 2012), Rostagno *et al*. (2005, 2011) increased by an average of 7.07%. However, when comparing the levels recommended by Rostagno *et al*. (2017), there is an average increase of up to 2.9 times in relation to the levels recommended by Rostagno *et al*. (2011) for some specific vitamins and at certain rearing stages.

Based on this, Dalto and Silva (2020) reviewed the vitamin levels recommended by nutritionists in the Brazilian swine industry. These authors noted that the average supplementation values for fat-soluble and water-soluble vitamins can reach up to 1.4 and 2.2 times when compared to the levels recommended by Rostagno *et al*. (2017) for the growing and finishing phases, respectively. The difference between the vitamin recommendations can be explained by the fact that companies with high productivity rates are adopting the concept of diet formulation with higher vitamin inclusions. Thus, the objective is not only to provide the minimum vitamin requirements to avoid deficiency symptoms in pigs. There is also an interest in maximizing performance associated with increased lean meat content in the carcass, reduced lipid peroxidation of the meat, improved immune status against stressors in the production of confined pigs, among other factors that are related mainly to the genetic advances of the adopted lines, which are constantly evolving.

Given the above, the objective was to evaluate the effect of fat-soluble and water-soluble vitamin supplementation on the performance and plasma concentrations of α-tocopherol and B_{12} in growing and finishing modern pigs.

MATERIAL AND METHODS

All methods involving the handling of the animals were performed in accordance with the regulations approved by the Ethics Committee on Animal Use (CEUA) of the Federal University of Viçosa (UFV) under protocol number 119/2014. The study was carried out in the Swine Production Sector of the Animal Science Department of the Agricultural Sciences Center at the UFV, in Viçosa, Minas Gerais, Brazil.

A total of 144 castrated male pigs, commercial hybrids of high genetic potential for meat deposition (AGPIC 426 x Camborough), with initial average weight of 43.531±1.099kg were used, distributed in a randomized block design with six treatments, eight repetitions, and three animals per experimental unit.

The treatments were 0, 25, 50, 75, 100, and 125% supplementation of fat-soluble and water-soluble vitamins. The treatment with 100% vitamin supplementation was based on the

Brazilian Tables for Poultry and Swine (Rostagno *et al*. 2011) recommendations for castrated male pigs in the phases from 30 to 50kg, from 50 to 70kg and from 70 to 100 kg live weight, the inclusion levels being 1.000, 0.880 and 0.750kg/ton of feed, respectively (Table 1). The experimental diets for these production phases (Growth I, Growth II, and Finishing I) were formulated based on corn and soybean meal according to Rostagno *et al*. (2011), being isoprotein and isoenergetic (Table 2).

The animals were housed in masonry stalls (2 x 2m) with concrete feeders (60 x 30 cm) and nipple drinkers, located in a masonry shed with a concrete floor and covered with clay roof tiles. The facilities were cleaned daily during the experimental period.

Experimental feed and water were provided ad libitum throughout the experimental period. Feed, leftovers, and animals were weighed at the beginning and end of each production phase and during the total experimental period to verify the final average weight (FAW), average daily feed intake (ADFI), average daily weight gain (ADWG), and feed conversion ratio (FCR) of the pigs.

Blood samples were collected from the pigs on the final experimental period to measure vitamin E and vitamin B_{12} in the plasma of one pig per pen. The pigs were transferred to a cage and 20mL of blood were collected through the jugular vein. Vitamin E concentration (α-tocopherol) were determined with HPLC (Van Kempen *et al*., 2016) and Vitamin B_{12} were determined according to Yang *et al*. (2020).

The experimental data were submitted to normality tests (Shapiro-Wilk test) and analysis of variance (ANOVA) and subsequent regression, at 5% level of significance, using the SAS program (SAS, 2002). To assess the fit of the models, values of the root mean square of the residuals (RMSE) and the coefficients of determination (R^2) were considered.

Table 1. Vitamin supplementation levels for swine (amount per kg feed)[1]

Phase		Growth I and II		Finishing I
Age (kg)		30-50 kg	50-70 kg	70-100 kg
Vitamin A	UI	5500	4840	4125
Vitamin D_3	UI	1200	1056	900
Vitamin E	UI	32.000	28.200	24.000
Vitamin K_3	mg	2.400	2.110	1.800
Vitamin B_1	mg	0.800	0.700	0.600
Vitamin B_2	mg	2.500	2.200	1.880
Nicotinic Acid	mg	24.000	21.000	18.000
Pantothenic Acid	mg	12.000	10.600	9.000
Vitamin B_6	mg	1.600	1.410	1.200
Vitamin B_{12}	mg	0.016	0.014	0.012
Biotin	mg	0.080	0.070	0.060
Choline	mg	160.000	141.000	120.000
Folic Acid	mg	0.240	0.211	0.180

[1] Amount recommended (kg) per ton of feed: Growth I (30-50kg), 1.000kg/ton; Growth II (50-70kg), 0.880kg/ton; Finishing I (70-100kg), 0.750kg/ton.

Table 2. Centesimal and calculated composition of the experimental basal diets without inclusion of vitamins levels (0%)

	Experimental Phases		
Ingredients	Growth I (40 to 50 kg)	Growth II (50 to 70 kg)	Finishing (70 to 90 kg)
Corn	71.985	75.990	79.050
Soybean meal, 45%	24.050	20.361	17.596
Soybean oil	1.000	1.000	1.000
Dicalcium phosphate	1.161	1.036	0.783
Calcite limestone	0.706	0.600	0.574
Starch	0.300	0.300	0.300
Mineral mix[1]	0.100	0.088	0.075
Vitamin mix[1]	0.000	0.000	0.000
Choline chloride[1]	0.000	0.000	0.000
Salt	0.358	0.337	0.314
BHT	0.010	0.010	0.010
L-lysine-HCl 78%	0.245	0.232	0.238
DL-methionine 99%	0.034	0.008	0.011
L-Threonine 98,5%	0.053	0.037	0.050
ME (Mcal/kg)	3257.4	3273.30	3288.8
CP (%)	16.82	15.43	14.438
Dig. lysine, %	0.927	0.834	0.777
Dig. met + Cys, %	0.547	0.494	0.475
Dig. methionine, %	0.290	0.250	0.241
Dig. threonine, %	0.603	0.542	0.521
Dig. valine, %	0.690	0.636	0.596
Dig. tryptophan, %	0.174	0.155	0.140
Dig. histidine, %	0.428	0.398	0.375
Dig. leucine, %	1.435	1.358	1.301
Dig. isoleucine, %	0.632	0.573	0.528
Dig. phenylalanine, %	0.758	0.697	0.650
Total Ca, %	0.630	0.552	0.474
Available P, %	0.311	0.282	0.231

[1] Amount per kg feed: 5500 IU Vitamin A, 1200 IU Vitamin D3, 32 IU Vitamin E, 0.8 mg Vitamin B1, 2.5 mg Vitamin B2, 0.016 mg Vitamin B12, 1.6 mg Vitamin B6, 12 mg Calcium pantothenate, 24 mg Nicotinamide, 0. 08 mg Biotin, 0.24 mg Folic Acid, 2.4 mg Vitamin K3, 64 mg Fe, 9.6 mg Cu, 88 mg Zn, 32 mg Mn; 0.80 mg I, 0.29 mg Se, 160 mg Choline chloride.

RESULTS

Table 3 shows the performance data of pigs in growth phases I and II. The duration of growth phase I, II, and total growth (I and II) were 11, 15, and 26 days, respectively. A linear effect ($P<0.05$) was observed for growth phase I (40-50 kg), with higher FAW and ADWG and improved FCR because of increasing vitamin supplementation levels. However, no effect ($P>0.05$) was observed on ADFI.

A linear effect ($P<0.05$) was observed for growth phase II (50-70 kg), with higher FAW and improved FCR. However, no effect ($P>0.05$) was observed on ADFI and ADWG. When analyzing the total growth phase (I and II, 40-70 kg), a linear effect ($P<0.05$) was observed with higher ADWG and improved FCR. Thus, an improvement in performance was found because of the 125% vitamin supplementation in the diet of pigs in growth phase I and II.

Table 3. Performance of pigs fed diets with increasing levels of vitamin supplementation

40-50 kg	Vitamin supplementation levels (%)						CV	P value	
	0	25	50	75	100	125	(%)	L	Q
FAW[1], kg	53.185	53.862	53.590	54.350	54.036	54.877	1.48	0.0002	0.8022
ADFI[2], kg	2.214	2.230	2.187	2.235	2.197	2.257	4.30	0.5687	0.4345
ADWG[3], kg	0.882	0.940	0.964	0.979	0.955	1.028	6.76	0.0002	0.0990
FCR[4], kg/kg	2.509	2.370	2.280	2.289	2.305	2.195	4.93	<0.0001	0.1358
50-70 kg									
FAW[1], kg	67.410	69.243	68.817	69.627	69.352	70.132	2.43	<0.0001	0.3987
ADFI[2], kg	2.548	2.621	2.606	2.612	2.603	2.575	4.11	0.7799	0.1738
ADWG[3], kg	0.948	1.025	1.015	1.018	1.021	1.045	8.58	0.0712	0.4613
FCR[4], kg/kg	2.701	2.575	2.570	2.582	2.553	2.470	5.99	0.0120	0.8184
40-70 kg									
ADFI[2], kg	2.381	2.425	2.396	2.423	2.400	2.416	3.40	0.6060	0.6587
ADWG[3], kg	0.915	0.982	0.989	0.998	0.989	1.037	6.40	0.0017	0.4299
FCR[4], kg/kg	2.604	2.474	2.424	2.435	2.432	2.332	4.27	<0.0001	0.3269

[1]FAW = final average weight; [2]ADFI = average daily food intake; [3]ADWG = average daily weight gain; [4]FCR = feed conversion ratio; CV (%) = coefficient of variation; L = linear effect; Q = quadratic effect.

Table 4 shows the performance data of the pigs in finishing phase I (70-90kg) and total experimental period (40-90kg). The duration of finishing phase I and total experimental period were 21 and 47 days, respectively. For finishing phase I and total experimental period (growth I, II and finishing I) a linear effect ($P<0.05$) was also observed with increase in FAW, ADWG, ADFI and improvement in FCR due to increasing the vitamin supplementation levels in the pigs' diet. A quadratic effect ($P<0.05$) was also observed on ADFI and ADWG for the mentioned experimental periods.

Table 4. Performance of pigs fed diets with increasing levels of vitamin supplementation

70-90 kg	Vitamin supplementation levels (%)						CV (%)	P value	
	0	25	50	75	100	125		L	Q
FAW[1], kg	86.189	92.047	93.045	93.826	93.045	95.822	3.37	<0.0001	0.0133
ADFI[2], kg	2.777	3.259	3.247	3.291	3.214	3.252	4.34	<0.0001	<0.0001
ADWG[3], kg	0.894	1.085	1.153	1.152	1.128	1.223	6.65	<0.0001	0.0011
FCR[4], kg/kg	3.120	3,006	2,817	2,859	2,866	2,658	6.36	<0.0001	0.6037
40-90 kg									
FAW[1], kg	86.189	92.047	93.045	93.826	93.045	95.822	2.89	<0.0001	0.0133
ADFI[2], kg	2.513	2.703	2.680	2.713	2.671	2.695	2.93	0.0008	0.0010
ADWG[3], kg	0.908	1.017	1.044	1.050	1.035	1.099	5.46	<0.0001	0.0376
FCR[4], kg/kg	2.772	2.661	2.568	2.589	2.584	2.453	4.04	<0.0001	0.4688

[1]FAW = final average weight; [2]ADFI = average daily food intake; [3]ADWG = average daily weight gain; [4]FCR = feed conversion ratio; CV (%) = coefficient of variation; L = linear effect; Q = quadratic effect.

Table 5 shows the pigs' plasma levels of α-tocopherol and vitamin B12 at the end of the experimental period. There was a linear increase ($P<0.05$) in the plasma concentrations of α-tocopherol and vitamin B_{12} because of increasing the vitamin supplementation in the diet of pigs (40-90kg).

Table 5. Plasma concentrations of α-tocopherol and vitamin B_{12} in pigs at the end of the experimental period

	Vitamin supplementation levels (%)						CV	P value	
	0	25	50	75	100	125	(%)	L	Q
α-tocopherol[1], μg/mL	0.813	1.075	1.138	1.155	1.775	1.998	20.43	<0.0001	0.0612
Vit. B_{12}[2], pg/mL	50.250	53.880	61.630	73.880	84.500	92.630	18.29	<0.0001	0.0928

CV (%) = coefficient of variation; L = linear effect; Q = quadratic effect. [1]α-tocopherol: $Y = 0.0092x + 0.7512$; $r^2 = 88.52\%$. Vitamin B_{12}: $Y = 0.3612x + 46.8901$; $r^2 = 98.21\%$.

Table 6 shows the regression equations of the significant variables as shown by ANOVA, for all the evaluated experimental phases. It was found that the 125% vitamin supplementation, as recommended by Rostagno *et al*. (2011) (100%), improved the FCR improvement of pigs in all evaluated phases. For the FAW, ADFI, and ADWG variables of the pigs, there was a linear and quadratic effect in the finishing phase I (70-90kg) and total phase (40-90kg). To choose the model to be adopted, the most adequate RMSE and r^2 values were found for the quadratic adjustment. Thus, for finishing phase I, the estimated vitamin levels were 108, 81 and 105% for best FAW, ADFI and ADWG values, respectively. When analyzing the total experimental period, the estimated vitamin supplementation levels were 109, 80 and 116% for best FAW, ADFI and ADWG values, respectively.

Table 6. Regression equations, root of the mean square of error (RMSE), standard error of the mean (SEM) and coefficient of determination (r^2) of the pig's performance variables at different phases, fed diets with increasing levels of vitamin supplementation

Variables	Regression Equations	RMSE	SEM	r^2 (%)
	Growth I, 40-50 kg			
FAW[1]	Y = 0.011136x + 53.287560	0.0641	0.283	77.79
ADWG[3]	Y = 0.000906x + 0.901863	0.0004	0.023	77.82
FCR[4]	Y = -0.002013x + 2.450804	0.0020	0.040	78.02
	Growth II, 50-70 kg			
FAW[1]	Y = 0.016852 + 68.043899	0.2092	0.594	71.19
FCR[4]	Y = -0.001382x + 2.661685	0.0011	0.054	75.92
	Growth I and II, 40-70 kg			
ADWG[3]	Y = 0.000726x + 0.940089	0.0003	0.022	73.74
FCR[4]	Y = -0.001683x + 2.555458	0.0014	0.037	78.54
	Finishing I, 70-90 kg			
FAW[1]	Y = 0.059362x + 88.619375	1.4978	0.942	72.38
FAW[1]	Y = -0.000643x^2 + 0.139791x + 87.278884	1.4444		83.72
ADFI[2]	Y = 0.002614x + 3.010542	0.0195	0.049	39.01
ADFI[2]	Y = -0.000071x^2 + 0.011472x + 2.862915	0.0072		77.22
ADWG[3]	Y = 0.002023x + 0.979887	0.0042	0.026	70.06
ADWG[3]	Y = -0.000024x^2 + 0.005060x + 0.929277	0.0023		83.53
FCR[4]	Y = -0.003076x + 3.080494	0.0039	0.064	81.26
	Total experimental period, 40-90 kg			
FAW[1]	Y = 0.059362 + 88.619375	2.4511	0.942	72.38
FAW[1]	Y = -0.000643x^2 + 0.139791x + 87.278884	1.4448		83.72
ADFI[2]	Y = 0.000969x + 2.602280	0.0029	0.027	36.69
ADFI[2]	Y = -0.000026x^2 + 0.004201x + 2.548411	0.0013		71.53
ADWG[3]	Y = 0.001160x + 0.953292	0.0009	0.019	72.31
ADWG[3]	Y = -0.000011x^2 + 0.002562x + 0.929930	0.0006		81.32
FCR[4]	Y = -0.002065x + 2.733637	0.0016	0.037	82.93

[1]FAW = final average weight; [2]ADFI = average daily feed intake; [3]ADWG = average daily weight gain; [4]FCR = feed conversion ratio.

DISCUSSION

In the present study, was observed that increasing dietary vitamin supplementation for pigs provided improvement in performance parameters, especially FCR. Similarly, Chae *et al*. (2000) observed a linear effect on ADWG and FCR of growing pigs with the inclusion of 150% vitamins in relation to the NRC (Nutrient…, 1998) recommendations. Choi *et al*. (2001) also observed a quadratic effect on ADWG and FCR due to supplementation up to 200% of the NRC requirements (Nutrient…, 1998) for pigs four weeks before slaughter.

Cho *et al*. (2017) conducted three separate experiments with different ages, types, and vitamin levels. In experiment 1, a linear effect was found in ADWG and ADFI due to increased supplementation of fat-soluble and B-complex vitamins up to 28 days post-weaning of piglets. However, in experiment 2 the increase in vitamin supplementation did not influence the performance of pigs until 67 days of age. However, in experiment 3 a quadratic effect was observed on ADWG and feed efficiency of pigs fed diets containing up to 470% of the NRC requirements (Nutrient…, 1988) for B-complex vitamins. Similarly, Mahan *et al*. (2007) observed improvement of ADWG, ADFI and feed efficiency of pigs in the phase from 23 to 55kg, due to an increase of B-complex vitamins in the diet. According to these authors, there was also an increase in the FAW, ADWG, and ADFI of the pigs in the subsequent phase, from 55 to 85kg. However, for the final phase, with pigs from 85 to 120kg, no performance improvement was observed.

Currently, the NRC (Nutrient…, 2012) vitamin recommendations may not reflect the requirements of modern commercial hybrids for the expression of their maximum genetic potential (Isabel *et al*., 2012; Dalto & Silva, 2020). Based on this, Yang *et al*. (2020) observed that supplying vitamins above the levels recommended by the NRC resulted in an increase in ADWG and feed efficiency of piglets during a period of 28 days post weaning. However, Shaw *et al*., (2002), Gaudré and Vautier (2009) and Silva *et al*., (2015) did not observe improved performance due to de increase of vitamins in the diet of pigs in the growth phase. For the finishing phase, Mavromichalis *et al*. (1999), Tian *et al*. (2001) and Groesbeck *et al*. (2007) did not observe positive effect on pig performance due to the increase of vitamin supplementation.

In the present study, an increase in vitamin plasma levels and performance of pigs was observed due to increase of vitamin in the diets. Among the fat-soluble vitamins, vitamin A acts beyond the interconversion processes of rhodopsin by light uptake, improved phospholipid membranes and stimulates osteoclasts and can accelerate bone development (Isabel *et al*., 2012). However, Ching *et al*. (2002) found that excess of vitamin A in the diet reduced by 30% of blood tocopherol. Regarding the antioxidant effect of vitamin E, Silva-Guillen *et al*. (2020) observed a reduction in malonaldehyde and a tendency to reduce the interleukins (1β, 1ra, 2 and 4) in piglets fed a diet containing peroxidized oil and supplemented with 33 IU/kg DL-α-tocopherol. Thus, the increase in plasma levels of α-tocopherol observed in our study may have contributed to the improved immune status of pigs. Furthermore, it can be inferred that the concentration of vitamin A provided in the diet did not impair the vitamin E absorption, indicating that there was a balance between the supplementation levels of these vitamins.

Vitamin D_3 is another that can positively impact performance, calcium and phosphorus homeostasis, bone mineralization, and immune system, especially, for pigs raised in confinement without access to sunlight (Kolp *et al*., 2017). According to Witschi *et al*. (2011) and Panisson *et al*. (2021) the supplementation of 50µg/kg of vitamin D_3 or 25(OH)D_3 in the diet of pregnant sows provided improvement in bone characteristics and increase in performance of piglets. Regarding vitamin K, Monegue (2013) observed an increase in prothrombin activity with the supplementation of 0.5 ppm of vitamin K_3 in pig diets formulated with corn containing mycotoxins.

As described earlier, B-complex vitamins are enzyme cofactors of numerous metabolic reactions. Vitamin B_1 (thiamine) acts on the decarboxylation of α-ketoacids and glucose metabolism accelerating the Krebs cycle (Isabel *et al*., 2012). And vitamin B_2 (riboflavin) optimizes the transport of electrons and protons in the respiratory chain in the enzymatic form of flavin adenine dinucleotide and removes nitrogen from amino acids making the carbon chain available to be used as an energy source (Combs Jr, 2008). Based on this, Lutz and Stahly (1998) observed an increase in ADWG, feed efficiency and lean meat content in the carcass of pigs fed diets containing 3.7 to 7.4 mg/kg riboflavin.

Although it can be synthesized from tryptophan, vitamin B_3 (nicotinic acid) also acts in electron transport by converting nicotinamide adenine dinucleotide (Isabel *et al*., 2012). Its efficacy, however, depends on the combination between vitamin B_2 and vitamin B_6 (pyridoxine). Real *et al*. (2002) found an increase in ADWG and feed efficiency of growing and finishing pigs fed diets supplemented with niacin at 13 to 55 mg/kg.

According to Saddoris *et al*. (2005), using the ideal protein concept in formulating diets increases the requirements of B vitamins, especially in diets formulated with wheat and sorghum. According to these authors, supplementation of 13.2 ppm of pantothenic acid (vitamin B_5) in pig diets increased the loin area and reduced the last rib fat, producing higher lean meat content in the carcass. This is because pantothenic acid is part of coenzyme A with a direct influence on basal metabolism, with increase in protein acetylation, on Krebs cycle reactions for glucose synthesis and, consequently, increases lipid breakdown.

Folic acid, pyridoxine (B_6) and cyanocobalamin (B_{12}) are also mainly linked to protein and amino acid metabolism. Vitamin B_6 influences transaminations, glycogenolysis and synthesis of neurotransmitters (serotonin and noradrenaline) (Isabel *et al*., 2012). For its activation, vitamin B_{12} depends on microbial synthesis and presence of cobalt. In its active form, vitamin B_{12} acts in the recycling of folic acid, in the synthesis of methionine from homocysteine with isomerization of the methyl-malonyl coA enzyme, which, in turn, will act in the degradation of amino acids and fatty acids with odd number of carbon (Combs Jr, 2008; Isabel *et al*, 2012). Folic acid, on the other hand, participates in methylation reactions and receives carboxyl groups from serine, glycine, and histidine for the synthesis of other amino acids. The increase in vitamin B_{12} concentration in swine plasma due to increasing vitamin supplementation indicates optimization in amino acid metabolism, especially sulfur amino acids.

As to vitamin B_6 supplementation, Woodworth *et al*. (2000) reported an increase in ADWG of piglets fed diets with 3.3 mg/kg. In contrast, Yu *et al*. (2010) observed increased ADWG and ADFI of piglets fed diets supplemented with 2.5 mg/kg folic acid. Wang *et al*. (2021) also found a linear increase in ADWG and ADFI with folic acid supplementation of piglets in the post-weaning phase.

Although it is not considered to be a vitamin, choline also has a synergistic effect with B vitamins with acetyl co A formation and donation of methyl groups for synthesis of homocysteine, for example. Li *et al*. (2018) reported that choline chloride supplementation for pigs from weaning to slaughter reduced serum concentrations of free fatty acids, triglycerides, and lipoprotein lipase expression, indicating optimization in lipid metabolism.

In the production process countless variations coexist regarding the commercial hybrid adopted, sex, management, age, rearing density, environmental factors (temperature, humidity, and health challenges), stressors, feed quality, and combination of ingredients in the formulation, storage and physical form of the diet, processing of ingredients and, mainly, source and vitamin supplementation levels (Combs Jr 2008; Isabel *et al*., 2012). The variation among the aforementioned factors and the differences in the experiments performed to determine vitamin supplementation requirements explain the divergence among the studies.

Table 7 shows the recommendation for vitamin supplementation for modern hybrid swine in the growing phase (I and II) and finishing I. In general, the average vitamin levels suggested in the latest edition of the Brazilian Tables for Poultry and Swine (Rostagno *et al*., 2017) are, on average, 3.86% higher than the levels in the present study. When analyzing the vitamin classes separately, it turns out that Rostagno *et al*. (2017) recommend an increase of 1.98 and 4.70% for fat-soluble and water-soluble vitamins, respectively, in relation to the levels observed in the present study. When separately comparing the data from the present study with the levels of Rostagno *et al*. (2017), the fat-soluble vitamins with higher increase were D_3 and E, 2.03 and 4.23%, respectively. As for the water-soluble vitamins, the ones that increased the most were folic acid and vitamin B_2, 8.65 and 21.61%, respectively. Thus, recent research and recommendations from independent nutritionists indicate that vitamin requirements based on higher levels may be a trend aimed not only at improving performance, but also to increase gut health, immune status, and meat quality of modern pigs that directly impact the productive efficiency of animals.

In conclusion, vitamin supplementation of modern hybrids pig feeds is recommended for growth phase I (40-50kg), growth phase II (50-70kg), finishing phase I (70-90kg) and for total phase (40-90kg) at 125%.

Table 7. Recommendation of vitamins levels for swine (per kg of feed)

		Phase (kg body weight)		
Vitamins		40-50 kg	50-70 kg	40-90 kg
Vitamin A	UI	6875.000	6050.000	6027.083
Vitamin D_3	UI	1500.00	1320.000	1315.000
Vitamin E	UI	40.000	35.250	35.083
Vitamin K_3	mg	3.000	2.637	2.629
Vitamin B_1	mg	1.000	0.875	0.875
Vitamin B_2	mg	3.125	2.750	2.741
Nicotinic Acid	mg	30.000	26.250	26.250
Pantothenic Acid	mg	15.000	13.250	13.166
Vitamin B_6	mg	2.000	1.762	1.754
Vitamin B_{12}	mg	0.020	0.017	0.018
Biotin	mg	0.100	0.087	0.088
Choline	mg	200.000	176.250	175.416
Folic Acid	mg	0.300	0.264	0.262

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