ORIGINAL RESEARCH PEER REVIEWED

A survey of vitamin and trace mineral ranges for diagnostic lab reporting from conventionally raised swine

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Summary

Objective: The purpose of this study was to survey the vitamin and mineral levels in various pig tissues at different phases of the life cycle.

Materials and methods: Forty-eight healthy pigs of different stages of production were used for sampling of different tissues. Seven sows and a minimum of 10 animals from each phase of production (suckling, nursery, and finishing) were selected for sampling. A blood sample was collected via sterile venipuncture for serum vitamin and mineral analysis. After euthanasia, the diaphragm and liver were collected. Samples were submitted to the Iowa State University Veterinary Diagnostic Laboratory for analysis. Data were analyzed using SAS (version 9.4; SAS Institute Inc) and presented as minimum and maximum concentrations with standard error. The experimental unit was the animal.

Results: Levels of vitamin A, vitamin E, copper, zinc, selenium, iron, and manganese were higher in liver tissues than in serum and diaphragm tissues. Diaphragm muscle had similar levels of phosphorus as the liver tissue. Serum had similar levels of calcium as the liver tissue.

Implications: These data provide a sampling of vitamin and mineral levels present in tissues and serum of commercial pigs and suggests that vitamin and mineral levels differ between sampling sites.

Keywords: swine, vitamin, mineral, tissue

Received: September 14, 2021
Accepted: March 10, 2022

Resumen - Una encuesta de los rangos de vitaminas y minerales traza para los reportes de laboratorio de diagnóstico de cerdos criados convencionalmente

Objetivo: El propósito de este estudio evaluar fue estudiar los niveles de vitaminas y minerales en varios tejidos de cerdos en diferentes fases del ciclo de vida.

Materiales y métodos: Para el muestreo en diferentes tejidos se utilizaron 48 cerdos sanos de diferentes etapas de producción. Para el muestreo se seleccionaron siete cerdas y un mínimo de 10 animales de cada fase de producción (lechones lactantes, destete, y finalización). Se tomó una muestra de sangre mediante venopunción estéril para el análisis de vitaminas y minerales en suero. Después de la eutanasia, se recolectó el diafragma y el hígado. Para su análisis las muestras se enviaron al Laboratorio de Diagnóstico Veterinario de la Universidad Estatal de Iowa. Los datos se analizaron utilizando el SAS (versión 9.4; SAS Institute Inc) y los resultados se presentaron como concentraciones mínimas y máximas y el error estándar de la media. La unidad experimental fue el animal.

Resultados: Al compararlos, los niveles de vitamina A, vitamina E, cobre, zinc, selenio, hierro, y manganeso fueron más altos en los tejidos del hígado, en el suero y los tejidos del diafragma. El músculo del diafragma tenía niveles de fósforo similares a los del tejido hepático. El suero tenía niveles de calcio similares a los del tejido hepático.

Implicaciones: Estos datos proveen una muestra de los niveles de vitaminas y minerales presentes en tejidos y suero de cerdos comerciales e indican que los niveles de vitaminas y minerales difieren entre los sitios de muestreo.

Résumé - Une enquête sur les intervalles de vitamines et d'oligo-éléments pour les rapports de laboratoire de diagnostic des porcs élevés de manière conventionnelle

Objectif: Le but de cette étude était d'étudier les taux de vitamines et de minéraux dans divers tissus de porc à différentes phases du cycle de vie.

Matériels et méthodes: Quarante-huit porcs sains de différents stades de production ont été utilisés pour l'échantillonnage de différents tissus. Sept truies et un minimum de 10 animaux de chaque phase de production (allaitement, pouponnière, et finition) ont été sélectionnés pour l'échantillonnage. Un échantillon de sang a été prélevé par ponction veineuse stérile pour l'analyse des vitamines et minéraux sériques. Après l'euthanasie, le diaphragme et le foie ont été prélevés. Les échantillons ont été soumis au laboratoire de diagnostic vétérinaire de l'Iowa State University

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Greiner L, Elefson S, Radke S, Hagen C, Humphrey D, Becker S. A survey of vitamin and trace mineral ranges for diagnostic lab reporting from conventionally raised swine. *J Swine Health Prod*. 2022;30(5):282-291. **https://doi.org/10.54846/jshap/1286.**

pour analyse. Les données ont été analysées à l'aide de SAS (version 9.4 ; SAS Institute Inc.) et présentées sous forme de concentrations minimales et maximales avec écart-type de la moyenne. L'unité expérimentale était l'animal.

Résultats: Les taux de vitamine A, de vitamine E, de cuivre, de zinc, de sélénium, de fer, et de manganèse étaient plus élevés dans les tissus hépatiques que dans le sérum et le tissu diaphragmatique. Le muscle diaphragme avait des taux de phosphore similaires à ceux du tissu hépatique. Le sérum avait des concentrations de calcium similaires à celles du tissu hépatique.

Implications: Ces données fournissent un échantillonnage des concentrations de vitamines et de minéraux présents dans les tissus et le sérum des porcs commerciaux et suggèrent que les taux de vitamines et de minéraux diffèrent entre les sites d'échantillonnage.

Over the years, nutritionists have continued to evaluate the vitamin and mineral requirements of swine. Recently, it was documented that US swine nutritionists feed a margin of safety above the 2012 NRC recommendations to offset any potential vitamin degradation or manufacturing challenges.[1,2] Little information has been compiled over the last 15 years to document current vitamin and mineral concentrations present in healthy swine of modern genetics. A widely used publication for mineral and vitamin reference values was published in 1994.[3,4] Modern hog production has changed greatly in the last 20 years particularly in reference to intensively raised, indoor swine as well as genetics and growth rate. In addition, vitamin D levels of hogs raised indoors have noticeably different levels compared to outdoor raised hogs.[5]

Therefore, sampling healthy swine being raised indoors would be important to establish reference values for vitamins and minerals to assist diagnostic laboratories, veterinarians, and nutritionists in discerning potential nutritional differences when assessing modern day pigs. However, the process of creating new reference values is costly. The objective of this study was to survey the vitamin and mineral levels in various tissues from healthy swine of modern genetics in different production phases to assess if new reference values need to be generated.

Animal care and use

The study was conducted on 6 different farms located across the United States. All animal care practices were conducted by following the routine farm management procedures and Pork Quality Assurance guidelines.[6] Additionally, the trial was approved by the Iowa State University Animal Care Committee (IACUC #19-340).

Materials and methods

Samples

The 6 farms used in this study were selected based on voluntary participation from written communication with companies identified within the top 25 largest production systems and with individual producers based on timeframe available for study personal to collect the samples. Selected farms verified that the animals were fed vitamins and minerals at levels that met or exceeded the 2012 NRC recommendations.[2] The farms had to verify that the pigs used for sample collection were free of acute illness. Animals selected for sample collection were identified as animals with a physical abnormality (eg, hernia or prolapse) that would prevent the animal from completing the production life cycle, were scheduled for euthanasia (eg, growth study sampling), or were being harvested. The number of animals selected from each farm varied due to the number of animals available on the day that sampling personnel were present on the farm. Seven sows and a minimum of 10 animals from each phase of production (suckling, nursery, and finishing) were selected for sampling. The suckling phase was defined as day 1 through 21 of age. The nursery and finisher phases were defined as day 22 to 64 of age and 65 to 165 days of age, respectively. Euthanasia was conducted using methods approved for swine by the American Veterinary Medical Association.[7] Injectable euthanasia agents were not used in this study. After euthanasia, the diaphragm and liver were collected and placed into a sterile bag and a blood sample was collected using sterile methods. Samples were placed on ice and transported to the Iowa State University Veterinary College and submitted to the Iowa State University Veterinary Diagnostic Laboratory (ISUVDL) to be held in a -20°C freezer until analysis.

Sample analysis

Samples were analyzed for vitamin and mineral concentrations using procedures outlined by ISUVDL (Vitamin A and E in serum – ISUVDL 9.833; Vitamin A in tissue – ISUVDL 9.2429; Vitamin E in tissue – ISUVDL 9.2430; Trace mineral in tissue – ISUVDL 9.2420). Serum and tissue samples were stored at -80°C. Vitamin A and E analyses of both serum and tissues were conducted following the established standard operating procedure (SOP) using internally validated methods. A 0.5 mL aliquot of serum was placed in a 15 mL screw-top tube. Two milliliters of 95% ethanol and 4 mL of 95/5 hexane/chloroform were added. Samples were gently shaken to mix and then centrifuged for 5 minutes at 2000 rpm. Following centrifugation, 2 mL of the hexane/chloroform was transferred to a 7 mL glass vial encased in foil.

One gram of fresh liver for each vitamin A and E analysis was weighed into 50 mL polypropylene tubes and 0.2 g of celite was added. For vitamin A, 5 mL of 0.01% butylated hydroxy toluene in 95% ethanol was added, followed by 1 mL of 50% sodium hydroxide. Samples were placed in an oven at 60°C for 30 minutes, and then chilled for 10 minutes at -20°C. Samples were vortexed at 2000 rpm for 10 minutes, and then centrifuged for 5 minutes at 2000 rpm. Following centrifugation, 1 mL of the hexane/chloroform was transferred to a 7 mL glass vial encased in foil. For vitamin E, 5 mL of 0.01% butylated hydroxytoluene in 95% ethanol was added, followed by 10 mL of 95/5 hexane/chloroform. The sample was vortexed at 2000 rpm for 10 minutes and then centrifuged for 5 minutes at 2000 rpm. Following centrifugation, 5 mL of the hexane/chloroform was transferred to a 7 mL glass vial encased in foil.

Serum and tissue extracts were dried using a nitrogen stream. Serum extracts were dissolved in 250 µL high-performance liquid chromatography (HPLC)-grade methanol while tissue extracts for vitamins A and E were dissolved in 1 mL of 0.09% hydrochloric acid in methanol and 500 µL HPLC-grade methanol, respectively. Following the extraction process, both serum and tissue extracts were analyzed using ultra HPLC. Serum vitamin D was analyzed by liquid chromatography tandem mass spectrometry (LC/MS/MS) through Heartland Assays. Samples were processed and analyzed for mineral content following the established SOP on a wet weight basis.

A National Institute of Standards and Technology liver standard was included in the run. An in-house laboratory control liver was also used to ensure quality control and to verify instrument accuracy. Serum samples were analyzed for calcium, copper, iron, magnesium, manganese, molybdenum, phosphorus, potassium, selenium, and zinc using inductively coupled plasma mass spectrometry (ICP-MS; Analytik Jena Inc) in CRI mode with hydrogen as the skimmer gas. Analysis of tissues was performed by the same instrument but also included cadmium, cobalt, chromium, and sodium per laboratory method. Standards for elemental analyses were obtained from Inorganic Ventures while 15 mL centrifuge tubes, 50 mL digestion vessels, trace mineral grade nitric acid, and hydrochloric acid were obtained from Fisher Scientific. Serum samples were diluted in 1% nitric acid. Serum samples were transferred to 15 mL tubes in 0.25 mL portions and 4.75 mL of 1% nitric acid was added and then analyzed by ICP-MS. Tissue samples were digested using a microwave digestor by placing 0.5 g samples into 50 mL digestion tubes and adding 10 mL of 70% nitric acid. After digestion, all samples were diluted to 25 mL using 1% nitric acid with 0.5% hydrochloric acid. An additional 1:10 dilution using 1% nitric acid was made and then analyzed by ICP-MS. For quality control, bismuth, scandium, indium, lithium, yttrium, and terbium were used as internal standards for the ICP-MS.

Data analysis

Data were analyzed using SAS (version 9.4; SAS Institute Inc) and were presented as minimum and maximum concentrations with standard error. If the element of analysis was below the detectable limit, the lower limit threshold was divided by 2 to provide a value.[8] The experimental unit was the animal. Tables were generated to demonstrate the different concentrations of each vitamin and mineral by sample type along with phase of growth.

Results

Vitamins and minerals are stored in different locations of the body and dictates which locations are more ideal for analysis (Table 1). Liver tissue levels of vitamin A, vitamin E, copper, zinc, selenium, and iron were higher than those in serum and diaphragm tissue (Table 2). Vitamin A and E levels were not detectable in the diaphragm tissue at any phase of production (Tables 2, 3, and 4). Most mineral concentrations tended to be higher in tissues (diaphragm and liver) compared to serum. Serum had similar levels of calcium as the liver tissue (Table 4). Median data were provided for each sampling location in Tables 5, 6, and 7. Data from previously published references were compiled for further evaluation of current findings (Table 8).

Table 1: Preferred sampling sites for common vitamins and minerals tested in swine*

Nutrient	Preferred biological sample
Vitamin A	Liver
Vitamin E	Serum
Vitamin D3	Serum
Calcium	Serum
Cobalt	Liver
Copper	Liver
Iron	Liver
Magnesium	Serum
Manganese	Liver
Molybdenum	Liver
Phosphorus	Serum
Potassium	Serum
Selenium	Liver/Serum/Blood
Sodium	Serum
Zinc	Liver

* Preferred sample sites such as serum may not reflect true nutrient status. Samples should be collected from locations of vitamin and mineral storage to best assess status.

Discussion

Vitamin and mineral concentrations do differ across production phases and sample types. Some of this variation can be associated with dietary ingredients or immune status, which can influence antioxidant status. In addition, vitamin and mineral analysis conducted in tissues or serum which do not adequately reflect common stores can result in misinterpretation of results. Understanding where vitamins and minerals are stored within the body is important when determining the appropriate sample to assess for concentration status. Iron, copper, manganese, selenium, zinc, and vitamins A, D, and E are stored in the liver. Although predominately stored in adipose tissue, vitamin E is stored in the liver in a limited capacity. Lastly, minerals such as magnesium, phosphorus, and calcium are typically found in the bone. These macrominerals are tightly regulated within the body as evidenced by the maintenance of serum concentrations.

Samples derived from the liver had higher concentrations of certain vitamins and minerals compared to other samples. For example, most of the body's vitamin A is stored in the liver as retinyl esters and therefore, the liver would be the primary sample site when testing for a vitamin A deficiency.[9] When sampling, personnel must not only understand the correct sample type to collect, but also the health status of the animal and the manner and condition in which samples are collected to allow for adequate interpretation. For example, minerals such as iron and zinc may be sequestered in the liver during inflammatory or infectious processes resulting in elevated concentrations. Conversely in serum samples, the degree of hemolysis may result in elevated concentrations of iron and potassium but decreased vitamin E concentrations resulting from degradation. Furthermore, some vitamin and mineral concentration ranges are different from the values presented in Puls.[3,4] Serum

Table 2: Vitamin and mineral concentrations in the liver of suckling, nursery, and finisher pigs and lactating sows

	Phase of production											
	Suckling piglet[†]			Nursery[†]			Finisher[†]			Lactating sow[†]		
Nutrient, ppm*	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**
Vitamin A[‡§]	29	18-63	3	13	0.5-25.0	2	71	47-90	4	262	80-530	56
Vitamin E	8.5	3.3-17.1	1.0	4.2	0.9-8.0	0.6	5.9	3.4-9.7	0.5	9.5	6.1-12.5	0.9
Cadmium[§]	0.004	0.001-0.030	0.002	0.010	0.002-0.021	0.002	0.027	0.014-0.062	0.004	0.026	0.012-0.041	0.004
Calcium	98	59-145	7	96	63-128	5	100	67-118	5	89	60-121	8
Chromium	10.97	0.09-181.00	10.63	0.17	0.06-0.53	0.04	0.11	0.04-0.16	0.01	0.08	0.03-0.18	0.02
Cobalt§	0.013	0.001-0.150	0.009	0.009	0.002-0.017	0.001	0.018	0.013-0.022	0.001	0.016	0.008-0.025	0.002
Copper	44	16-104	6	12	7-21	1	10	4-16	1	158	11-435	59
Iron	1091	134-3458	242	114	74-195	10	263	115-474	34	226	143-352	27
Magnesium	195	174-227	4	221	191-267	6	194	158-233	9	154	121-189	10
Manganese	2.2	1.2-3.4	0.2	3.3	2.4-4.2	0.1	3.3	2.2-4.9	0.3	1.8	1.3-2.3	0.1
Molybdenum	0.47	0.29-0.65	0.03	0.66	0.14-1.10	0.08	1.43	0.97-1.69	0.07	1.28	0.97-1.47	0.07
Phosphorus	2907	2546-3456	62	3729	3083-4319	120	3468	2742-4490	167	2485	1678-3519	244
Potassium	2745	868-3487	142	3647	3182-4176	80	2782	1481-3386	166	2548	1695-3434	217
Selenium	0.55	0.45-0.80	0.03	0.72	0.56-0.87	0.02	0.98	0.75-1.19	0.04	1.01	0.67-1.72	0.16
Sodium	1425	128-2187	127	967	798-1227	35	1275	751-1864	92	1314	821-1695	130
Zinc	70	27-120	7	163	42-562	53	131	51-313	25	62	38-91	6

* Values presented as per unit of wet tissue weight.

† Suckling piglets were 1-21 days of age (n = 17); Nursery pigs were 22-64 days of age (n = 13); Finisher pigs were 65-165 days of age (n = 11); and Lactating sows (n = 7).

‡ Represented as retinol.

§ When the element of analysis was below the detectable limit, the lower limit threshold was divided by 2 to provide a value.[8]

Table 3: Vitamin and mineral concentrations in the diaphragm of suckling, nursery, and finisher pigs and lactating sows

	Phase of production											
	Suckling piglet†			Nursery†			Finisher†			Lactating sow†		
Nutrient, ppm*	Mean	Range	SE	Mean	Range	SE	Mean	Range	SE	Mean	Range	SE
Vitamin A‡	NA	NA	NA	§	§	§	§	§	§	§	§	§
Vitamin E	NA	NA	NA	¶	¶	¶	¶	¶	¶	¶	¶	¶
Cadmium**	0.005	0.001-0.012	0.001	0.002	0.001-0.005	0.0004	0.002	0.001-0.006	0.0005	0.005	0.001-0.019	0.0025
Calcium	132.8	76.000-229.171	10.081	103	75-118	4	90	57-146	7	137	78-308	30
Chromium	0.126	0.058-0.365	0.020	0.110	0.067-0.164	0.010	0.115	0.041-0.201	0.012	0.106	0.034-0.189	0.019
Cobalt**	0.001	0.001-0.005	0.0003	0.001	0.001-0.003	0.0002	0.002	0.001-0.004	0.0003	0.003	0.000-0.013	0.0017
Copper**	2.01	1.10-5.01	0.231	2.3	0.5-4.0	0.4	2.0	0.5-4.0	0.3	7.30	0.00-43.12	5.980
Iron	56.1	29.0-139.3	8.113	25	17-31	1	29	18-61	4	43.2	7.0-100.2	10.83
Magnesium	190	156-223	4	168	10-249	27	287	183-996	71	738	153-1539	215
Manganese	0.354	0.142-0.627	0.036	0.2	0.1-0.3	0.0	0.2	0.1-0.3	0.0	0.191	0.100-0.340	0.037
Molybdenum**	0.066	0.018-0.570	0.032	0.03	0.02-0.06	0.00	0.02	0.01-0.04	0.00	0.075	0.020-0.272	0.034
Phosphorus	1737	1362-2005	34	2033	1647-2581	88	1989	1665-2418	75	1536	1427-1825	54
Potassium	2816	2415-3388	69	3090	2699-3766	117	3371	2701-3941	117	2986	2567-3617	139
Selenium	0.195	0.135-0.300	0.010	0.31	0.23-0.43	0.02	0.92	0.26-5.00	0.41	0.32	0.28-0.44	0.02
Sodium	1094.3	838.9-1373.3	36.679	1166	1016-1546	47	818	651-996	33	1238	862-1539	93
Zinc	21	14.000-26.000	1	23	18-30	1	30	20-35	1	37	28-42	2

* Values presented per unit of wet tissue weight.

† Suckling piglets were 1-21 days of age (n = 17); Nursery pigs were 22-64 days of age (n = 13); Finisher pigs were 65-165 days of age (n = 11); Lactating sows (n = 7).

‡ Represented as retinol.

§ Vitamin A analysis was below the detectable level of < 1 ppm.

¶ Vitamin E analysis was below the detectable level of <0.5 ppm.

** When the element of analysis was below the detectable limit, the lower limit threshold was divided by 2 to provide a value.[8]

NA = not measured in suckling pigs.

Table 4: Vitamin and mineral concentrations in the serum of suckling, nursery, and finisher pigs and lactating sows

	Phase of Production											
	Suckling piglet*			Nursery*			Finisher*			Lactating sow*		
Nutrient	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**
Vitamin A, ppm†‡	0.12	0.02-0.280	0.02	0.26	0.01-0.39	0.03	0.16	0.10-0.21	0.01	0.13	0.03-0.32	0.04
Vitamin E, ppm‡	3.8	1.100-10.100	0.6	1.07	0.05-3.20	0.27	1.8	1.1-3.3	0.2	2.4	0.9-4.4	0.5
Vitamin D2, ng/mL‡	0.75	0.750-0.750	0.00	0.75	0.750-0.750	0.00	0.75	0.750-0.750	0.00	0.750	0.750-0.750	0.00
Vitamin D3, ng/mL‡§	3.95	0.75-8.60	0.57	16.75	9.20-27.50	1.43	42.74	18.40-115.80	9.35	35.73	9.50-53.00	5.46
Calcium, ppm	106.5	75.1-134.7	3.0	87.1	50.1-120.4	6.5	93.9	83.5-100.9	1.7	97.9	75.9-133.4	6.9
Copper, ppm	1.9	1.000-3.1	0.1	1.3	1.0-1.9	0.1	2.0	1.3-2.4	0.1	1.8	1.4-2.2	0.1
Iron, ppm	39.5	0.4-604.7	35.3	9.7	1.2-59.5	4.8	1.5	0.8-2.2	0.1	4.2	0.8-14.6	1.9
Magnesium, ppm	45.6	4.0-180.0	11.0	19.9	13.7-24.9	1.1	18.9	14.8-26.7	1.1	33.0	17.2-56.9	6.2
Manganese, ppm‡	0.047	0.003-0.180	0.015	0.007	0.002-0.037	0.003	0.002	0.001-0.004	0.0003	0.014	0.001-0.034	0.006
Molybdenum, ppm‡	0.003	0.001-0.010	0.001	0.012	0.006-0.015	0.001	0.004	0.002-0.007	0.0004	0.010	0.004-0.015	0.001
Phosphorus, ppm‡	84.4	46.5-187.4	7.8	49.3	33.0-66.0	2.4	79.6	2.5-444.4	36.7	91.2	35.0-179.1	23.1
Potassium, ppm	583.5	249.8-1124.3	66.5	362.8	248.0-733.3	39.1	255.8	218.6-313.7	9.8	521.7	176.8-1033.7	138.5
Selenium, ppm	0.123	0.088-0.160	0.005	0.124	0.084-0.190	0.010	0.241	0.200-0.278	0.009	0.255	0.133-0.355	0.032
Zinc, ppm	1.5	0.3-10.4	0.6	0.8	0.5-1.2	0.1	0.9	0.5-2.0	0.1	1.8	0.6-4.4	0.6

* Suckling piglets were 1-21 days of age (n = 17); Nursery pigs were 22-64 days of age (n = 13); Finisher pigs were 65-165 days of age (n = 11); Lactating sows (n = 7).

† Represented as retinol.

‡ When the element of analysis was below the detectable limit, the lower limit threshold was divided by 2 to provide a value.[8]

§ Represented as 25(OH)D3.

Table 5: Median vitamin and mineral concentrations in the liver of suckling, nursery, and finisher pigs and lactating sows

Nutrient, ppm†	Suckling piglet*	Nursery*	Finisher*	Lactating sow*
Vitamin A‡	25	14	72	250
Vitamin E	7.3	4.6	5.7	10.2
Cadmium§	0.003	0.012	0.021	0.023
Calcium	91	96	105	95
Chromium	0.235	0.122	0.104	0.062
Cobalt§	0.001	0.009	0.019	0.014
Copper	38	11	10	108
Iron	577	113	241	192
Magnesium	197	224	188	159
Manganese	2.3	3.3	2.9	1.8
Molybdenum	0.46	0.64	1.53	1.33
Phosphorus	2811	3702	3287	2592
Potassium	2770	3590	2720	2688
Selenium	0.52	0.74	0.99	0.72
Sodium	1585	941	1187	1415
Zinc	66	79	97	62

* Suckling piglets were 1-21 days of age (n = 17); Nursery pigs were 22-64 days of age (n = 13); Finisher pigs were 65-165 days of age (n = 11); and Lactating sows (n = 7).

† Values presented as per unit of wet tissue weight.

‡ Represented as retinol.

§ When the element of analysis was below the detectable limit, the lower limit threshold was divided by 2 to provide a value.[8]

vitamin A and selenium levels from the current study are lower than previously published values. Previously reported vitamin A ranges were 0.4 to 0.5 ppm in suckling and nursery pigs and 0.25 to 0.40 ppm in sows compared to the current ranges of 0.01 to 0.39 ppm and 0.03 to 0.32 ppm, respectively.[4] Serum selenium was reported to be 0.14 to 0.30 ppm with no specific age, while the current study documented serum selenium levels to be 0.080 to 0.194 ppm for the suckling/nursery pig and 0.133 to 0.355 ppm for the sow.[3] In addition, vitamin D3 concentrations in the current study were lower in the suckling and nursery pigs compared to the published values of 8 to 23 ng/mL and 25 to 30 ng/mL, respectively. Furthermore, more recent work conducted by Flohr et al[10] reported serum vitamin D3 levels in suckling age pigs were between 0.0 and 5.7 ng/mL depending upon maternal dietary consumption and nursery pig serum levels were 22.7 to 30.8 ng/mL. However, the levels in this study were slightly lower than those documented by Flohr et al.[10] Other vitamins and minerals were slightly higher than the referenced values, such as calcium and zinc in the liver. Elevated zinc levels may be associated with feeding higher levels of zinc in the nursery to aid in controlling pathogenic organisms.

This study demonstrates that while some vitamin and mineral concentrations in modern commercial swine are not different than previously published ranges, concentrations in other samples are either higher or lower than previously published work. In addition, previously published reference values did not completely identify the different phases of production. This study demonstrates the need for additional studies focused on the analysis of multiple biological samples from healthy pigs to best determine the appropriate vitamin and mineral ranges for the modern pig.

Implications

Under the conditions of this study:

- Select sample tissue type based on vitamin or mineral of interest.
- Vitamin and mineral levels vary based on age of the animal.
- Further sampling of both healthy and acutely ill animals is needed.

Acknowledgements

The authors would like to acknowledge Iowa Pork Producers Association for funding this project. The authors would also like to thank Olha Ivanytska, Angela Jensen, and Thomas Olsen for analysis of samples.

Conflict of interest

None reported

Disclaimer

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Table 6: Median vitamin and mineral concentrations in the diaphragm of suckling, nursery, and finisher pigs and lactating sows

Nutrient, ppm†	Suckling piglet*	Nursery*	Finisher*	Lactating sow*
Vitamin A‡	NA	§	§	§
Vitamin E	NA	¶	¶	¶
Cadmium**	0.003	0.001	0.001	0.002
Calcium	125.3	105	82	119
Chromium	0.087	0.104	0.107	0.111
Cobalt**	0.001	0.001	0.001	0.001
Copper**	1.85	2.5	2.0	1.00
Iron	45.3	27	25	38.0
Magnesium	187.4	195	218	862
Manganese	0.342	0.2	0.2	0.200
Molybdenum**	0.027	0.03	0.03	0.030
Phosphorus	1725	1935	1905	1468
Potassium	2786	2995	3300	2910
Selenium	0.189	0.30	0.51	0.30
Sodium	1121	1139	850	1272
Zinc	21	23	32	39

* Suckling piglets were 1-21 days of age (n = 17); Nursery pigs were 22-64 days of age (n = 13); Finisher pigs were 65-165 days of age (n = 11); Lactating sows (n = 7).

† Values presented per unit of wet tissue weight.

‡ Represented as retinol.

§ Vitamin A analysis was below the detectable level of < 1 ppm.

¶ Vitamin E analysis was below the detectable level of < 0.5 ppm.

** When the element of analysis was below the detectable limit, the lower limit threshold was divided by 2 to provide a value.[8]

NA = not measured in suckling pigs.

References

1. Flohr JR, DeRouchey JM, Woodworth JC, Tokach MD, Goodband RD, Dritz SS. A survey of current feeding regimens for vitamins and trace minerals in the US swine industry. *J Swine Health Prod*. 2016;24(6):290-303.

2. National Research Council. *Nutrient Requirements of Swine*. 11th ed. National Academy Press; 2012.

3. Puls R. *Mineral Levels in Animal Health: Diagnostic Data*. 2nd ed. Sherpa International; 1994.

4. Puls, R. *Vitamin Levels in Animal Health*. 2nd ed. Sherpa International; 1994.

5. Arnold J, Madson DM, Ensley SM, Goff JP, Sparks, C, Stevenson GW, Crenshaw T, Wang C, Horst RL. Survey of serum vitamin D status across stages of swine production and evaluation of supplemental bulk vitamin D premixes used in swine diets. *J Swine Health Prod*. 2015;23(1):28-34.

*6. National Pork Board. Pork Quality Assurance Plus Handbook. Version 4.0. National Pork Board; 2019.

*7. American Veterinary Medicine Association. *Guidelines for Euthanasia of Animals: 2020 Edition*. American Veterinary Medical Association; 2020. Accessed January 5, 2022. **https://www.avma.org/sites/default/files/2020-01/2020-Euthanasia-Final-1-17-20.pdf**

8. Cohen MA, Ryan PB. Observations less than the analytical limit of detection: A new approach. *JAPCA*. 1989;39(3):328-329. **https://doi.org/10.1080/08940630.1989.10466534**

9. Thorbjarnarson T, Drummond JC. Conditions influencing the storage of vitamin A in the liver. *Biochem* J. 1928;32(1):5-9. **https://doi.org/10.1042/bj0320005**

10. Flohr JR, Woodworth JC, Bergstrom JR, Tokach MD, Dritz SS, Goodband RD, DeRouchey JM. Evaluating the impact of maternal vitamin D supplementation: I. Sow performance, serum vitamin metabolites, and neonatal muscle characteristics. *J Anim Sci*. 2016;94:4629-4642. **https://doi.org/10.2527/jas.2016-0409**

* Non-refereed references.

Table 7: Median vitamin and mineral concentrations in the serum of suckling, nursery, and finisher pigs and lactating sows

Nutrient, unit[†]	Suckling piglet*	Nursery*	Finisher*	Lactating sow*
Vitamin A, ppm[‡§]	0.12	0.30	0.17	0.08
Vitamin E, ppm§	2.8	0.70	1.6	2.3
Vitamin D2, ng/mL[§]	0.75	0.75	0.75	0.750
Vitamin D3, ng/mL[§¶]	3.1	18.3	31.3	35.5
Calcium, ppm	106.0	82.7	94.8	94.7
Copper, ppm	1.8	1.1	2.0	1.9
Iron, ppm	2.9	2.0	1.4	1.4
Magnesium, ppm	32.1	20.1	18.3	32.9
Manganese, ppm[§]	0.015	0.003	0.002	0.003
Molybdenum, ppm[§]	0.002	0.012	0.004	0.011
Phosphorus, ppm[§]	85.3	50.3	46.3	63.1
Potassium, ppm	479.1	331.3	248.0	402.5
Selenium, ppm	0.123	0.109	0.235	0.273
Zinc, ppm	0.9	0.7	0.7	0.7

* Suckling piglets were 1-21 days of age (n = 17); Nursery pigs were 22-64 days of age (n = 13); Finisher pigs were 65-165 days of age (n = 11); and Lactating sows (n = 7).

† Values presented per unit of wet tissue weight.

‡ Represented as retinol.

§ When the element of analysis was below the detectable limit, the lower limit threshold was divided by 2 to provide a value.[8]

¶ Represented as 25(OH)D3.

Table 8: Previously published reference values for vitamins and minerals in the serum of swine*

Nutrient, ppm	No specified age	Fetus	Weanling/ Nursery	Growing	Adult	Lactating sow
Vitamin A	.	0.100-0.200	0.400-0.500	0.400-0.500	0.400-0.500	0.250-0.400
	.	.	0.080-0.268†	.	.	0.128-0.393†
Vitamin E	.	.	1.000-5.200	0.800-2.100	0.900-2.000	1.200-3.000
Vitamin D_3	.	.	0.005-0.023	.	.	0.050-0.095
	.	.	0.004-0.016†	.	.	0.025-0.111†
Calcium	90-130	.	.	.	.	.
Copper	1.3-3.0	.	.	.	.	.
Iron	1.0-1.5	.	.	.	.	.
Magnesium	18-39	.	.	.	.	.
Manganese	0.04	.	.	.	.	.
Molybdenum	.	.	.	.	.	.
Phosphorus	60-107	.	.	.	.	.
Potassium	136.84-207.22	.	.	.	.	.
Selenium	0.14-0.30	.	.	.	.	.
Sodium	3218.57-3448.47	.	.	.	.	.
Zinc	0.7-1.5	.	.	.	.	.

* Vitamin and mineral reference values from Puls.[3,4]

† Reference values from Flohr[10] were converted from ng/mL to ppm.