Original Research

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A survey of current feeding regimens for vitamins and trace minerals in the US swine industry

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Summary

Objective: To describe added vitamin and trace-mineral concentrations used in the US swine industry for breeding and growing pigs.

Materials and methods: A convenience sample survey of nutritionists from 18 US swine production systems representing approximately 2.3 million sows or 40% of the US sow herd was conducted to characterize added vitamin and trace-mineral concentrations in swine diets. Data were compiled by dietary phases to determine descriptive statistics. Nutrients evaluated were vitamins A, D, E, and K; biotin; choline; folic acid; niacin; pantothenic acid; pyridoxine; riboflavin; thiamin; vitamin B12; betaine; vitamin C; carnitine; copper; iodine; iron; manganese; selenium; zinc; cobalt; and chromium. Questions about supplementation of vitamin D from a cross-linked vitamin AD3 beadlet, potential use of natural (d-alpha-tocopherol) vitamin E as a source of vitamin E, and the use of chelated trace minerals were included.

Results: Results indicated variation, but most vitamins and trace minerals were included at concentrations above the total dietary requirement estimates reported by the National Research Council (2012). Chelated sources for partial or complete supplementation of copper, manganese, or zinc ranged from none to 46% and none to 77% for chelated selenium across diet type. The chelated sources were more prevalent in breeding-herd and nursery-pig diets.

Implications: Adding a margin of safety for vitamin and trace-mineral supplementation appears to be standard practice in US swine diets. This survey provides a baseline for supplementation rates of the vitamins and trace minerals used in the US swine industry.

Keywords: swine, trace minerals, vitamins, swine industry, survey

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Resumen - Un estudio sobre los regímenes actuales de alimentación de vitaminas y microminerales en la industria porcina de los EUA

Objetivo: Describir las concentraciones adicionadas de microminerales y vitaminas utilizadas en la industria porcina de EUA para cría y cerdos en crecimiento.

Materiales y métodos: Se realizó un estudio de conveniencia de diferentes nutriólogos de 18 sistemas de producción porcina de EUA representando aproximadamente 2.3 millones de hembras o 40% del hato de hembras de EUA para caracterizar las concentraciones adicionadas de microminerales y vitaminas en las dietas porcinas. Se recopilaron los datos por fases dietéticas para determinar la estadística descriptiva. Los nutrientes evaluados fueron las vitaminas A, D, E, and K; biotina; colina; ácido fólico; niacina; ácido pantoténico; piridoxina; riboflavina; tiamina; vitamina B12; betaína; vitamina C; carnitina; cobre; yodo; hierro; manganeso; selenio; zinc; cobalto; y cromo. Se incluyeron preguntas sobre suplemento de vitamina D de una perla de vitamina AD3 de cadena cruzada, uso potencial de vitamina E natural (d-alpha-tocoferol) como fuente de vitamina E, y el uso de microminerales quelatados.

Resultados: Los resultados indicaron variación, pero la mayoría de las vitaminas y microminerales se incluyeron en concentraciones por encima de los estimados de requerimientos dietéticos totales reportados por el Consejo de Investigación Nacional (NRC, por sus siglas en inglés; 2012). En los diferentes tipos de dieta, las fuentes quelatadas para suplemento completo o parcial de cobre, manganeso, o zinc variaron de nada a 46%, y de nada a 77% en el selenio quelatado. Las fuentes quelatadas fueron más prevalentes en las dietas de hatos de cría y en lechones de destete.

Implicaciones: La adición de un margen de seguridad para la suplementación de microminerales y vitaminas parece ser una práctica estándar en las dietas porcinas de EUA. Este estudio provee un punto de partida para los índices de suplementación de vitaminas y microminerales utilizados en la industria porcina de EUA.

Résumé - Sondage sur les régimes actuels d'alimentation en vitamines et minéraux essentiels dans l'industrie porcine américaine

Objectif: Décrire les concentrations de vitamines et minéraux essentiels utilisées dans l'industrie porcine américaine chez les porcs reproducteurs et les porcs en croissance.

Matériels et méthodes: Un sondage parmi un échantillonnage de convenance de nutritionnistes provenant de 18 systèmes de production porcine américains et représentant environ

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2,3 million de truies ou 40% des troupeaux de truies a été mené afin de caractériser les concentrations de vitamines et de minéraux essentiels ajoutées dans les diètes porcines. Les données ont été compilées par phases d'alimention afin de déterminer des statistiques descriptives. Les nutriments évalués étaient les vitamines A, D, E, et K; la biotine; la choline; l'acide folique; la niacine; l'acide pantothénique; la pyridoxine; la riboflavine; la thiamine; la vitamine B12; la bétaïne; la vitamine C; la carnitine; le cuivre; l'iodine; le fer; le manganèse; le sélénium; le zinc; le cobalt; et le chrome. Des questions sur la supplémentation en vitamine D à partir d'une granule contenant une combinaison en vitamines AD3, l'utilisation potentielle de vitamine E naturelle (d-alpha-tocophérol) comme source de vitamine E, et l'utilisation de minéraux essentiels chélatés étaient incluses.

Résultats: Les résultats indiquaient des variations mais la plupart des vitamines et des minéraux essentiels étaient inclus à des concentrations supérieures aux exigences alimentaires totales estimées rapportées par le Conseil National de la Recherche (2012). Les sources chélatées pour une supplémentation complète ou partielle en cuivre, manganèse, ou zinc variaient de 0% à 46% et de 0% à 77% pour le sélénium chélaté parmi les types de diète. Les sources chélatées étaient plus fréquentes dans l'alimentation des troupeaux reproducteurs et des porcelets en pouponnière.

Implications: L'ajout d'une marge de sécurité pour la supplémentation en vitamines et minéraux essentiels semble être une pratique standard dans les diètes porcines américaines. Ce sondage fourni des valeurs de base pour les taux de supplémentation pour les vitamines et les minéraux essentiels utilisés dans l'industrie porcine américaine.

The proper vitamin and trace-mineral supplementation required to optimize performance, but also minimize unnecessary cost, is an area of limited knowledge for production nutritionists. Most commercial diets are formulated well above NRC (2012)[1] requirement estimates at a margin of safety needed to account for potential ingredient concentration variation and bioavailability, fluctuations in daily feed intake, or degradation of vitamins resulting from unfavorable storage conditions. Another factor influencing the added margin of safety is the added cost of a specific vitamin or trace mineral. A notable survey conducted by Coelho and Cousins[2] examined vitamin supplementation rates from 23 swine entities. From the survey, researchers found that all entities supplied vitamins at concentrations higher than NRC (1998)[3] recommendations. Also, entities in the highest quartile supplied vitamins at rates of two to 10 times that of the lowest quartile. The Coelho and Cousins[2] survey showed that a wide range of supplementation rates were used across commercial systems. Ultimately, since that survey was reported, two NRC publications have been distributed, illustrating the long lapse in time since a survey was conducted to examine industry vitamin supplementation rates. To our knowledge, there has never been a survey of the supplementation rates of trace minerals used in commercial diet formulation. Mahan et al[4] discussed the potential need to express trace-mineral pig requirements on a digestible basis, which would help account for the impact that exogenous enzymes and mineral sources may have on the requirement for the nutrient. Because of the increased usage of phytase and other enzymes, along with the increased availability of chelated trace-mineral sources, there is interest in characterizing trace-mineral usage in the swine industry. With this information, future research examining various vitamin and trace-mineral concentrations for commercially raised pigs could be conducted. Potential for future research, based on findings of the survey, will help determine vitamin and trace-mineral requirements needed to optimize performance and maximize economic return.

Materials and methods

The procedures for this survey were approved by the Kansas State University Committee for Research Involving Human Subjects. The survey information was gathered in an electronic spreadsheet (Excel 2013; Microsoft, Redmond, Washington). The subjects of the survey were swine producers within the United States. A convenience sampling of nutritionists for the swine producers were contacted via e-mail or telephone from the beginning of March to the end of August of 2014 and were asked if they were willing to participate. Of the 22 nutritionists initially contacted, 18 agreed to be involved with the survey. Those willing to participate were provided the survey spreadsheet, or a telephone interview was conducted to collect their information.

The goal of the survey was to identify industry concentrations of added vitamins and trace minerals in complete diets for different phases of production. The phases of production were nursery (weaning to 23 kg), finishing (23 kg to market), gilt development (pre-breeding), and breeding-herd diet formulations. Producers provided approximate weight breaks for feeding phases within each stage of production, along with the premix specifications, inclusion rates, and inclusion rates of any other added vitamin, vitamin-like nutrients, and trace minerals. Specifications were surveyed only for commercial production systems, not for nucleus or multiplier herds.

Results were compiled and pooled to determine descriptive statistics for the supplementation rates. The descriptive statistics used included average, weighted average (determined by the total number of sows), median, minimum, maximum, 25th percentile (lowest quartile), and 75th percentile (highest quartile). Sow inventories were obtained from the *Successful Farming* 2013 Pork Powerhouse list,[5] and producers who were not on the top 25 producers list were asked to provide a current sow inventory. All values were determined using functions in the spreadsheet and included average, standard deviation (STDEV.S), median, minimum (MIN), maximum (MAX), and 25th and 75th percentiles (QUARTILE.EXC). Weighted averages were calculated using the spreadsheet sumproduct function in which producer supplementation rate was multiplied by the size of the producer (sow herd size), then divided by the total number of sows for all participating producers. In addition, the average supplementation rate was calculated as a ratio to the suggested requirement as provided by the NRC.[1] It should be noted that the NRC reports total dietary requirements, while the values we surveyed were those of supplementation rates in vitamin and trace-mineral premixes.

Feeding phases and approximate dietary weight breaks varied from producer to producer; however, results are reported in broad weight ranges that were relatively consistent among all participating producers. Feeding phases were divided into three stages of production, including nursery, finishing, and breeding herd. The nursery diets consisted of phase 1 (weaning to 7 kg), phase 2 (7 to 11 kg), and phase 3 (11 to 23 kg); finishing diets consisted of early-finishing (23 to 55 kg), mid-finishing (55 to 100 kg), late-finishing (100 kg to market), and late-finishing with ractopamine HCl (100 kg to market); and breeding herd diets consisted of gilt development (20 kg to breeding), gestation, lactation, and boar.

Within each dietary phase, the vitamins, vitamin-like substances, and trace minerals of interest were vitamins A, D, E, and K (menadione); betaine; biotin; choline; folic acid; niacin; riboflavin; thiamin; pantothenic acid; pyridoxine; vitamin B12; vitamin C (ascorbic acid); carnitine; copper; iodine; iron; manganese; selenium; zinc; cobalt; and chromium. Participants were also asked to provide the specified source of the nutrient used within each dietary phase in order to distinguish potential differences in the use of vitamin-trace-mineral sources.

Results

In total, 18 US swine production systems participated in the survey, totaling approximately 2,268,900 sows. The systems included the greater Midwest and Southeast regions of the United States. Using the December 2013 US Department of Agriculture sow inventory estimate of 5,760,000 (Quarterly Hogs and Pigs Report, 2013),[6] this survey sampled information from approximately 40% of the US sow herd.

Nursery

Phase 1 (weaning to 7 kg) nursery diet supplementation rates (Table 1) were provided by 13 producers, which represented approximately 19.4% of the US sow inventory. The average

Table 1: Added vitamin and trace-mineral concentrations in phase 1 nursery diets (weaning to 7 kg)*

	N†	Weighted average‡	Average	Ratio to NRC§	Standard deviation	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	13	11,033	10,600	4.8	832.0	8800	9900	9900	11,002	14,630
D (IU/kg)	13	2222	2554	11.6	2303	1542	1705	1995	2200	10,175
E (IU/kg)	13	86.0	73.9	4.6	27.7	44.0	59.6	66.0	77.0	150.0
K (mg/kg)	13	3.7	4.0	7.7	0.53	3.1	3.5	4.0	4.4	4.4
Other vitamins										
Biotin (mg/kg)	11	0.44	0.33	4.2	0.90	0.15	0.22	0.26	0.33	1.06
Choline (mg/kg)	6	202.4	245.5	0.4	167.0	129.8	129.8	166.8	385.0	550.0
Folic acid (mg/kg)	11	1.6	1.6	5.5	4.8	0.77	0.99	1.5	1.7	3.6
Niacin (mg/kg)	13	45.8	49.1	1.6	11.4	36.1	43.6	45.3	52.4	82.5
Pantothenic acid (mg/kg)	13	32.1	30.1	2.5	3.6	25.3	27.5	29.7	33.0	37.6
Riboflavin (mg/kg)	13	9.5	9.0	2.3	1.0	7.7	8.1	8.8	9.9	11.0
Thiamin (mg/kg)	5	2.9	2.9	1.9	0.42	2.2	2.4	3.1	3.3	3.3
Vitamin B6 (mg/kg)	11	4.0	3.7	0.5	0.97	2.2	3.1	4.0	4.4	5.5
Vitamin B12 (μg/kg)	13	41.1	38.9	2.0	0.24	33.0	33.4	38.5	44.0	45.1
Trace minerals										
Copper (mg/kg)	13	157.3	111.4	18.6	96.9	11.2	15.8	157.7	194.0	248.5
Iodine (mg/kg)	13	0.62	0.52	3.7	0.21	0.30	0.34	0.50	0.68	1.0
Iron (mg/kg)	13	104.6	103.5	1.0	15.9	89.8	91.3	99.8	109.9	150
Manganese (mg/kg)	13	38.2	36.6	9.1	7.7	26.5	30.0	34.9	39.8	55.0
Selenium (mg/kg)	13	0.30	0.30	1.0	0.004	0.29	0.30	0.30	0.30	0.30
Zinc (mg/kg)	13	3173	3032	30.3	599.5	1906	2804	2931	3475	4002
Conditionally essential nutrients										
Betaine (mg/kg)	1	960.0	960.0	NA	ND	960.0	ND	960.0	ND	960.0
Carnitine (mg/kg)	1	50.0	50.0	NA	ND	50.0	ND	50.0	ND	50.0
Chromium (mg/kg)	5	0.20	0.20	NA	0.00	0.20	0.20	0.20	0.20	0.20
Vitamin C (mg/kg)	1	250.0	250.0	NA	ND	250.0	ND	250.0	ND	250.0

* Thirteen producers' nutritionists provided information for phase 1 nursery diets, totaling approximately 1,115,400 sows (19.4% of the US sow herd). All reported values are on a complete-feed basis.
† N indicates the number of producers adding concentrations of a nutrient.
‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products, they were divided by the total number of sows for all participating producers.
§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]
NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.
ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

fat-soluble vitamin supplementation rate was 4.6 to 11.6 times that of their NRC[1] requirement estimates. Vitamin D was supplemented at 11.6 times that of the NRC[1] requirement estimate, and a high amount of variation (SD, 2303 IU per kg) occurred in vitamin D supplementation across producers. Other vitamins were supplemented from 0.4 to 5.5 times their NRC[1] requirement estimates. Pyridoxine and choline were supplemented below their requirement estimate, presumably because other ingredients in the diet provide adequate concentrations of these nutrients. One producer supplied betaine as a methyl donor rather than choline, and one producer added vitamin C to the weaning-to-7-kg diet. Trace minerals were supplemented from 1.0 to 30.3 times their requirement estimate. Iron and selenium were supplemented at their requirement estimate, and copper and zinc were supplemented well above their requirement estimate, at 18.6 and 30.3 times, respectively. Carnitine was supplemented by one producer, and five producers supplemented chromium to the weaned pigs during this phase.

Phase 2 (7 to 11 kg) nursery diet supplementation rates (Table 2) were provided by 17 participants, representing 39.0% of the US sow herd. Fat-soluble vitamins were supplemented at rates ranging from 4.0 to 8.1 times their NRC[1] requirement estimates. Other vitamins were supplemented at rates from 0.4 to 7.1 times their respective NRC[1] requirement estimates. Similar to phase 1

Table 2: Added vitamin and trace-mineral concentrations in Phase 2 nursery diets (7 to 11 kg)*

	N†	Weighted average‡	Average	Ratio to NRC§	Standard deviation	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	17	12,129	10,274	4.7	3373	2996	9900	9900	11,002	19,415
D (IU/kg)	17	1912	1773	8.1	527.8	706.2	1487	1760	2160	2849
E (IU/kg)	17	71.3	63.4	4.0	25.1	26.4	44.0	60.1	77.0	125.0
K (mg/kg)	17	4.8	4.0	7.8	1.5	1.2	3.1	4.0	4.4	8.4
Other vitamins										
Biotin (mg/kg)	11	0.37	0.35	7.1	0.22	0.15	0.22	0.29	0.33	0.99
Choline (mg/kg)	4	224.4	209.0	0.4	97.0	129.8	129.8	187.0	308.0	330.0
Folic acid (mg/kg)	11	1.8	1.8	5.9	0.90	0.88	1.1	1.5	2.2	3.5
Niacin (mg/kg)	17	51.3	47.7	1.6	15.2	25.1	41.1	45.1	50.8	82.5
Pantothenic acid (mg/kg)	17	35.6	29.7	3.0	8.6	10.6	26.4	29.3	33.0	54.8
Riboflavin (mg/kg)	17	9.7	8.6	2.5	2	3.3	7.7	8.4	9.9	13.6
Thiamin (mg/kg)	5	2.9	2.9	2.9	0.42	2.2	2.4	3.1	3.3	3.3
Vitamin B6 (mg/kg)	9	4.0	4.0	0.6	0.81	3.1	3.3	4.0	4.6	5.5
Vitamin B12 (μg/kg)	17	46.0	38.5	2.2	11.9	16.5	33.0	38.5	44.0	73.7
Trace minerals										
Copper (mg/kg)	17	169.1	118.2	19.7	96.0	11.2	15.0	156.5	195.1	248.5
Iodine (mg/kg)	17	0.62	0.54	3.9	0.21	0.30	0.34	0.55	0.70	1.0
Iron (mg/kg)	17	118.0	106.4	1.1	29.0	61.1	89.8	99.8	110.1	166.7
Manganese (mg/kg)	17	33.5	35.0	8.8	7.8	24.2	29.1	33.1	39.5	55.0
Selenium (mg/kg)	17	0.29	0.29	1.0	0.02	0.22	0.30	0.30	0.30	0.30
Zinc (mg/kg)	17	2,340	2,081	20.8	751.4	75.0	1,908	2,050	2,527	3,294
Conditionally essential nutrients										
Betaine (mg/kg)	1	960.0	960.0	NA	ND	960.0	ND	960.0	ND	960.0
Chromium (mg/kg)	5	0.23	0.21	NA	0.03	0.20	0.20	0.20	0.24	0.27

* Seventeen producers' nutritionists provided information for phase 2 nursery diets, totaling approximately 2,243,900 sows (39.0% of the US sow herd). All reported values are on a complete-feed basis.
† N indicates the number of producers adding concentrations of a nutrient.
‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.
§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]
NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.
ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

diets, added choline and pyridoxine were supplemented below NRC[1] requirement estimates, presumably because other ingredients provide these nutrients. Trace minerals were supplemented at rates of 1.0 (selenium) to 9.1 times their NRC[1] requirement estimates, except for zinc (20.8) and copper (19.7), which are likely supplemented at high concentrations for growth promotion purposes. One producer supplemented betaine rather than choline as a methyl donor, and five producers supplemented chromium in phase 2 nursery diets.

Phase 3 (11 to 23 kg) nursery diet supplementation rates (Table 3) were provided by all 18 producers who participated in the survey. Fat-soluble vitamins were supplemented at 4.3 to 7.7 times their respective NRC[1] requirement estimates. Other vitamins were supplemented at 1.2 to 6.3 times their respective NRC[1] requirement estimates. No producers who participated in the survey supplemented choline in phase 3 nursery diets. Trace minerals were supplemented at rates of 1.0 to 9.8 times their NRC[1] requirement estimates, except for copper, which was supplemented at a rate of 31.6 times the pig's requirement estimate, probably due to its growth-promotion influences. One producer supplemented cobalt in phase 3 nursery diets.

Finishing

The early-finishing diet (23 to 55 kg) supplementation rates (Table 4) were provided by all 18 survey participants. Fat-soluble vitamins were supplemented at 2.5 to 6.7 times their respective NRC[1] requirement estimates.Other vitamins were supplemented from 0.9 to 2.2 times their respective NRC[1]

Table 3: Added vitamin and trace-mineral concentrations in Phase 3 nursery diets (11 to 23 kg)*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	18	10,954	8868	5.1	3676	3630	5940	9434	11,000	18,698
D (IU/kg)	18	1760	1537	7.7	552.2	825.0	979.0	1478	1984	2748
E (IU/kg)	18	51.5	46.9	4.3	20.5	16.5	36.3	43.8	50.2	100.1
K (mg/kg)	18	4.4	3.5	7.1	1.6	1.3	2.4	4.0	4.4	8.1
Other vitamins										
Biotin (mg/kg)	7	0.26	0.26	5.2	0.07	0.13	0.22	0.26	0.33	0.33
Folic acid (mg/kg)	6	1.9	1.9	0.0	1.1	0.99	0.99	1.4	3.1	3.5
Niacin (mg/kg)	18	46.2	41.6	6.3	17.6	16.5	26.4	39.2	50.4	82.5
Pantothenic acid (mg/kg)	18	32.1	25.7	1.4	9.7	10.8	19.4	25.1	30.6	52.8
Riboflavin (mg/kg)	18	8.6	7.5	2.9	2.4	3.3	5.5	8.1	9.0	13.2
Thiamin (mg/kg)	2	3.1	3.1	2.5	0.16	3.1	ND	3.1	ND	3.3
Vitamin B6 (mg/kg)	5	4.2	3.5	3.2	1.9	0.88	1.8	4.0	5.3	5.5
Vitamin B12 (μg/kg)	18	42.2	33.2	1.2	13.6	16.5	22.9	30.8	39.8	71.3
Trace minerals										
Copper (mg/kg)	18	159.5	158.0	31.6	81.3	11.2	99.5	158.4	200.6	326.5
Iodine (mg/kg)	18	0.55	0.49	3.5	0.25	0.22	0.30	0.36	0.67	1.0
Iron (mg/kg)	18	111.9	104.0	1.0	31.3	60.9	76.7	102.5	122.9	166.7
Manganese (mg/kg)	18	28.0	29.3	9.8	10.9	9.0	24.7	29.8	33.2	55.0
Selenium (mg/kg)	16	0.28	0.29	1.1	0.08	0.14	0.30	0.30	0.30	0.30
Zinc (mg/kg)	18	672.6	401	5.0	959.4	65.8	104.4	120.3	145.8	3030
Conditionally essential nutrients										
Chromium (mg/kg)	2	0.26	0.20	NA	0.09	0.13	ND	0.20	ND	0.27
Cobalt (mg/kg)	1	0.39	0.39	NA	ND	0.39	ND	0.39	ND	0.39

* Eighteen producers' nutritionists provided information for phase 3 nursery diets, totaling approximately 2,268,900 sows (39.4% of the US sow herd). All reported values are on a complete-feed basis.

† N indicates the number of producers adding concentrations of a nutrient.

‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.

§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]

NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.

ND = not done; SD is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

Table 4: Added vitamin and trace-mineral concentrations in early-finishing diets (23 to 55 kg)*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	18	5859	5643	4.3	1057	3630	5104	5533	6600	7480
D (IU/kg)	18	984.9	998.8	6.7	166.5	800.8	825.0	990.0	1102	1320
E (IU/kg)	18	25.1	27.1	2.5	7.7	16.1	20.5	26.4	33.2	39.8
K (mg/kg)	18	2.4	2.4	4.7	0.57	1.3	2.0	2.4	2.9	3.3
Other vitamins										
Biotin (mg/kg)	2	0.07	0.07	1.2	ND	0.07	ND	0.07	ND	0.07
Niacin (mg/kg)	18	24.9	27.5	0.9	6.9	16.5	24.0	26.4	29.7	49.5
Pantothenic acid (mg/kg)	18	17.4	16.9	2.1	2.9	10.8	14.7	16.5	18.9	22.4
Riboflavin (mg/kg)	18	4.8	4.8	2.0	1.3	3.3	4.0	4.8	5.7	8.8
Vitamin B12 (μg/kg)	18	22.9	22.0	2.2	3.1	15.8	19.8	22.4	23.8	26.4
Trace minerals										
Copper (mg/kg)	18	80.8	112.3	28.1	81.3	4.6	66.9	135.7	156.7	242.1
Iodine (mg/kg)	18	0.42	0.42	3.0	0.25	0.22	0.30	0.30	0.45	1.0
Iron (mg/kg)	18	79.8	86.9	1.4	31.3	39.5	70.9	86.0	109.9	123.8
Manganese (mg/kg)	18	21.5	25.2	12.6	10.9	6.6	15.0	29.3	33.0	40.0
Selenium (mg/kg)	18	0.27	0.28	1.4	0.08	0.14	0.27	0.30	0.30	0.30
Zinc (mg/kg)	18	86.0	98.8	1.6	959.4	30.4	78.7	110.0	120.7	150.0
Conditionally essential nutrients										
Cobalt (mg/kg)	1	0.39	0.39	NA	ND	0.39	ND	0.39	ND	0.39

* Eighteen producers' nutritionists provided information for early-finishing diets, totaling approximately 2,268,900 sows (39.4% of the US sow herd). All reported values are on a complete-feed basis.
† N indicates the number of producers adding concentrations of a nutrient.
‡ Weighted averages were calculated using the sumproduct function of Excel (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.
§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]
NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.
ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

requirement estimates. On average, niacin was supplemented below the estimated requirement. Biotin was supplemented in early finishing diets by two producers. Trace minerals were supplemented at rates of 28.1 times copper, 3.0 times iron, 1.4 times iodine, 12.6 times manganese, 1.4 times selenium, and 1.6 times zinc requirement estimates. One producer supplemented cobalt at 0.39 mg per kg.

Mid-finishing (55 to 100 kg) supplementation rates (Table 5) were reported by all 18 producers participating in the survey. Fat-soluble vitamins were supplemented at rates of 2.1 to 5.7 times their respective NRC[1] requirement estimates. Other vitamins were supplemented from 0.8 to 3.8 times their respective NRC[1] requirement estimates. Similar to the previous phase, average niacin supplementation was below the current NRC[1] suggested requirement. Two producers provided added biotin in their mid-finishing diets. Trace minerals were supplemented at rates of 1.6 to 2.7 times the requirement estimate for iodine, iron, selenium, and zinc. Average supplementation rates of copper and manganese were 27.4 and 10.7 times their requirement estimates, respectively.

Late-finishing (100 kg to market) vitamin and trace-mineral supplementation rates (Table 6) were provided by all 18 producers who participated in the survey. Fat-soluble vitamins were supplemented at rates of 3.2 times vitamin A, 5.0 times vitamin D, 1.8 times vitamin E, and 3.6 times vitamin K requirement estimates. Other vitamins were supplemented at rates from 0.7 to 3.3 times their NRC[1] requirement estimates. Niacin, on average, was supplemented at rates below the current NRC[1] requirement. Two producers supplemented biotin in late finishing diets. Trace minerals were supplemented at rates of 1.5 to 2.4 times the requirement estimate for iodine, iron, selenium, and zinc. Average supplementation rates of copper and manganese were 22.0 and 9.3 times their requirement estimates, respectively. One producer only provided added zinc for trace minerals in late-finishing diets.

Supplementation rates of vitamins and trace minerals in late-finishing diets with

ractopamine HCl (Table 7) were reported by seven of the 18 producers. Fat-soluble vitamin supplementation rates were 3.4 times vitamin A, 5.2 times vitamin D, 1.9 times vitamin E, and 3.9 times vitamin K requirement estimates. Other vitamins were supplemented at rates from 0.7 to 3.4 times their NRC[1] requirement estimates. Niacin, on average, was supplemented at rates below the current NRC[1] requirement estimate. Trace minerals were supplemented at rates 1.4 to 2.3 times the requirement estimate for iodine, iron, selenium, and zinc, respectively. Average supplementation rates of copper and manganese were 17.1 and 9.0 times their requirement estimates, respectively. Overall, producers who responded with information on both late-finishing and late finishing diets with ractopamine HCl supplemented 10% more vitamins, 8.5% more trace minerals (copper, iodine, iron, manganese, selenium), and 33% more zinc in those diets that also contained ractopamine HCl.

Breeding-herd diets

Gilt-development diets were provided by 17 producers. When evaluating the gilt developer diets, compared to the suggested growing pig requirements, the average supplementation rates of fat-soluble vitamins were 3.3 times the vitamin A, 4.9 times vitamin D, 2.6 times vitamin E, and 3.0 times vitamin K requirement estimates (Table 8). Compared to gestation requirement estimates, average supplementation rates were 1.1 times vitamin A, 0.9 times vitamin D, 0.6 times vitamin E, and 3.0 times vitamin K requirements. Other vitamins were supplemented at average rates of 2.5 times biotin, 0.8 times choline, 2.5 times folic acid, 0.6 times niacin, 1.4 times pantothenic acid, 1.5 times pyridoxine, 1.3 times riboflavin, 1.0 times thiamin, and 1.5 times vitamin B12 requirement estimates for growing pigs. When evaluating the gilt-developer diets, compared to the suggested gestation requirement estimates, other vitamins were supplemented at an average of 0.6 times biotin, 0.2 times choline, 0.6 times folic acid, 1.8 times niacin, 0.9 times pantothenic acid, 1.5 times pyridoxine, 0.9 times riboflavin, 1.0 times thiamin, and 1.0 times vitamin B12 requirements. One producer supplemented vitamin C at 250 mg per kg. Trace

Table 5: Added vitamin and trace-mineral concentrations in mid-finishing diets (55 to 100 kg)*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	18	5192	4842	3.7	955.2	3520	3852	5280	5603	6162
D (IU/kg)	18	874.9	859.1	5.7	150.7	550.0	790.7	880.0	990.0	1057
E (IU/kg)	18	22.2	23.3	2.1	7.9	16.1	17.4	19.8	27.7	39.8
K (mg/kg)	18	2.2	2.0	4.0	0.46	1.3	1.7	2.2	2.2	2.9
Other vitamins										
Biotin (mg/kg)	2	0.07	0.07	1.1	ND	0.07	ND	0.07	ND	0.07
Niacin (mg/kg)	18	22.0	23.5	0.8	5.1	16.5	20.7	22.0	26.4	34.5
Pantothenic acid (mg/kg)	18	15.4	14.5	2.1	2.4	10.8	12.1	14.5	16.9	17.8
Riboflavin (mg/kg)	18	4.2	4.2	2.1	1.4	2.6	3.3	4.2	4.8	8.8
Vitamin B12 (μg/kg)	18	20.2	18.9	3.8	3.1	13.2	15.8	19.6	22.0	24.2
Trace minerals										
Copper (mg/kg)	18	66.6	82.3	27.4	65.0	3.9	10.1	109.1	146.5	161.7
Iodine (mg/kg)	18	0.39	0.37	2.7	0.25	0.16	0.20	0.30	0.39	1.0
Iron (mg/kg)	18	73.7	75.0	1.9	22.5	32.9	61.5	73.3	88.5	123.8
Manganese (mg/kg)	18	19.4	21.4	10.7	10.5	6.4	15.0	22.0	24.5	40.0
Selenium (mg/kg)	18	0.26	0.24	1.6	0.04	0.11	0.20	0.24	0.30	0.30
Zinc (mg/kg)	18	77.8	84.8	1.7	32.3	30.4	61.5	89.1	100.0	131.2
Conditionally essential nutrients										
Cobalt (mg/kg)	1	0.31	0.31	NA	ND	0.31	ND	0.31	ND	0.31

* Eighteen producers' nutritionists provided information for mid-finishing diets, totaling approximately 2,268,900 sows (39.4% of the US sow herd). All reported values are on a complete-feed basis.

† N indicates the number of producers adding concentrations of a nutrient.

‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.

§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]

NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.

ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

Table 6: Added vitamin and trace-mineral concentrations in late-finishing diets (100 kg to market)*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	18	4616	4187	3.2	999.2	2904	3520	3942	4840	6160
D (IU/kg)	18	781.7	745.8	5.0	209.0	412.5	550.0	756.4	897.6	1078
E (IU/kg)	18	19.6	20.0	1.8	6.6	8.1	16.5	17.6	24.0	33.4
K (mg/kg)	18	1.9	1.8	3.6	0.53	1.0	1.3	1.8	2.2	2.9
Other vitamins										
Biotin (mg/kg)	2	0.04	0.04	1.0	ND	0.04	ND	0.04	ND	0.07
Niacin (mg/kg)	18	19.4	20.2	0.7	4.8	15.0	16.7	18.3	22.4	33.0
Pantothenic acid (mg/kg)	18	13.6	12.5	1.8	3.1	6.8	11.0	12.3	14.5	18.5
Riboflavin (mg/kg)	18	3.7	3.5	1.8	0.95	2.0	3.1	3.3	4.2	5.5
Vitamin B12 (μg/kg)	18	18.0	16.5	3.3	3.5	7.9	15.2	16.5	18.5	22.2
Trace minerals¶										
Copper (mg/kg)	17	56.3	65.9	22.0	71.0	3.1	8.1	10.0	147.2	160.8
Iodine (mg/k)	17	0.37	0.34	2.4	0.24	0.15	0.18	0.24	0.42	1.0
Iron (mg/k)	17	69.3	66.5	1.7	25.2	30.9	54.1	62.9	80.3	103.1
Manganese (mg/kg)	17	17.7	18.6	9.3	9.8	3.3	14.7	19.4	23.0	40.0
Selenium (mg/kg)	17	0.24	0.22	1.5	0.08	0.12	0.17	0.20	0.30	0.30
Zinc (mg/kg)	18	71.7	73.8	1.5	26.8	30.4	55.0	74.9	90.1	131.2
Conditionally essential nutrients										
Cobalt (mg/kg)	1	0.31	0.31	NA	ND	0.31	ND	0.31	ND	0.31

* Eighteen producers' nutritionists provided information for late-finishing diets, totaling approximately 2,268,900 sows (39.4% of the US sow herd). All reported values are on a complete-feed basis.
† N indicates the number of producers adding concentrations of a nutrient.
‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size), and after summing those products they were divided by the total number of sows for all participating producers.
§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]
¶ One producer provided added zinc supplement only for trace minerals in the late-finishing diets.
NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.
ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

minerals were supplemented at average rates of 5.7 times copper, 3.7 times iodine, 1.6 times iron, 18.6 times manganese, 1.4 times selenium, and 2.0 times zinc growing pig requirement estimates. Compared to gestation requirement estimates, developing gilts were supplemented 2.3 times copper, 3.7 times iodine, 1.2 times iron, 1.5 times manganese, 1.9 times selenium, and 1.2 times zinc requirements. Five producers supplemented chromium at 0.20 mg per kg, and one producer supplemented cobalt at 0.39 mg per kg. Two producers supplemented carnitine at a rate of 50 mg per kg of diet.

Gestation diet information (Table 9) was provided by 17 of the producers. Fat-soluble vitamins were supplemented at rates of 2.6 times vitamin A, 2.2 times vitamin D, 1.6 times vitamin E, and 7.3 times vitamin K requirement estimates. Other vitamins were supplemented at rates of 1.4 times biotin, 1.3 times folic acid, 4.6 times niacin, 2.3 times pantothenic acid, 3.4 times pyridoxine, 2.2 times riboflavin, 2.2 times thiamin, and 2.4 times vitamin B12 requirement estimates. Choline was supplemented at 0.5 times its requirement estimate due to partial reliance on choline from other ingredients to meet the animal's requirement. One producer supplemented vitamin C in gestation diets at a rate of 250 mg per kg. Trace-mineral supplementation rates were 1.6 times copper, 3.8 times iodine, 1.3 times iron, 1.5 times manganese, 1.9 times selenium, and 1.2 times zinc requirement estimates. Nine producers supplemented chromium, and one producer supplemented cobalt at 0.39 mg per kg. Two producers supplemented carnitine at a rate of 50 mg per kg.

Lactation diet information (Table 10) was provided by 17 of the producers. Fat-soluble vitamins were supplemented at rates of 5.2 times vitamin A, 2.2 times vitamin D, 1.6 times vitamin E, and 7.3 times vitamin K requirement estimates. Other vitamins were supplemented at rates of 1.4 times biotin, 0.5 times choline, 1.3 times folic acid, 4.6 times niacin, 2.3 times pantothenic acid,

Table 7: Added vitamin and trace-mineral concentrations in late-finishing diets with ractopamine (100 kg to market)*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	7	5247	4473	3.4	1099	3520	3630	3960	5500	6160
D (IU/kg)	7	911.0	774.0	5.2	284.9	440.0	550.0	770.0	1008.3	1078.0
E (IU/kg)	7	25.5	21.1	1.9	7.5	10.1	17.6	20.9	27.5	30.8
K (mg/kg)	7	2.2	2.0	3.9	0.48	1.3	1.7	2.0	2.4	2.9
Other vitamins										
Niacin (mg/kg)	7	20.2	20.5	0.7	2.9	16.5	18.7	20.7	22.0	24.6
Pantothenic acid (mg/kg)	7	15.6	13.6	1.9	3.7	8.6	11.0	13.0	16.5	18.5
Riboflavin (mg/kg)	7	4.4	3.7	1.9	1.2	2.4	3.1	4.0	4.8	5.5
Vitamin B12 (μg/kg)	7	18.5	16.9	3.4	4.4	9.9	13.2	17.6	19.8	22.0
Trace minerals										
Copper (mg/kg)	7	66.2	51.4	17.1	76.6	3.9	8.9	11.5	154.7	159.7
Iodine (mg/kg)	7	0.37	0.29	2.1	0.13	0.20	0.20	0.20	0.37	0.50
Iron (mg/kg)	7	67.1	71.6	1.8	19.6	38.6	64.9	66.5	88.7	99.1
Manganese (mg/kg)	7	19.8	18.0	9.0	10.2	4.1	4.5	20.9	24.9	27.4
Selenium (mg/kg)	7	0.18	0.21	1.4	0.06	0.12	0.15	0.19	0.27	0.28
Zinc (mg/kg)	7	113.9	112.5	2.3	29.6	74.8	99.1	105.2	131.2	160.2
Conditionally essential nutrients										
Cobalt (mg/kg)	1	0.35	0.35	NA	ND	0.35	ND	0.35	ND	0.35

* Seven producers' nutritionists provided information for late-finishing diets with ractopamine, totaling approximately 556,000 sows (9.7% of the US sow herd). All reported values are on a complete-feed basis.
† N indicates the number of producers adding concentrations of a nutrient.
‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.
§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]
NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.
ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

3.4 times pyridoxine, 2.2 times riboflavin, 2.2 times thiamin, and 2.4 times vitamin B12 requirement estimates. One producer supplemented vitamin C in lactation diets at a rate of 250 mg per kg of diet. Trace-mineral supplementation rates were 0.8 times copper, 3.8 times iodine, 1.3 times iron, 1.5 times manganese, 1.9 times selenium, and 1.2 times zinc requirement estimates. Nine producers supplemented chromium at a rate of 0.20 mg per kg, and one producer supplemented cobalt at a rate of 0.39 mg per kg. Two producers supplemented carnitine at a rate of 50 mg per kg of diet.

Boar diet information (Table 11) was provided by 13 of the producers. Fat-soluble vitamins were supplemented at rates of 2.8 times vitamin A, 9.3 times vitamin D, 1.8 times vitamin E, and 7.0 times vitamin K requirement estimates. Other vitamins were supplemented at rates of 1.6 times biotin, 0.6 times choline, 1.4 times folic acid, 4.5 times niacin, 2.3 times pantothenic acid, 3.2 times pyridoxine, 2.2 times riboflavin, 2.0 times thiamin, and 3.1 times vitamin B12 requirement estimates. One producer supplemented vitamin C in boar diets at a rate of 250 mg per kg of diet. Trace-mineral supplementation rates were 4.0 times copper, 4.4 times iodine, 1.4 times iron, 2.3 times manganese, 1.0 times selenium, and 2.8 times zinc requirement estimates. One producer supplemented selenium at a concentration (0.42 mg per kg) above the maximum concentration of 0.30 mg per kg, which was due to an increased inclusion rate of a premix that was also used in other diets. Seven producers supplemented chromium at a rate of 0.21 mg per kg, and one producer supplemented cobalt at a rate of 0.39 mg per kg. One producer supplemented carnitine at a rate of 60 mg per kg of diet.

Nutrient sources

Along with reporting their supplementation rates of vitamins and trace minerals, participants were also asked about the sources of specific nutrients (Table 12) used within the diets. The most distinguishable differences among sources within this survey were associated with supplementation of vitamin D from a cross-linked vitamin AD_3 beadlet, potential use of natural (d-alpha-tocopherol) vitamin E as a source of vitamin E, and the use of chelated trace minerals (copper, manganese, selenium, and zinc). For

Table 8: Added vitamin and trace-mineral concentrations in gilt-development diet (20 kg to breeding)*

	N†	Weighted average‡	Average	Ratio to NRC (grower)§	Ratio to NRC (gestation)§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins											
A (IU/kg)	17	8452	9405	3.3	1.1	2444	4400	9900	9979	11,000	11,986
D (IU/kg)	17	1339	1621	4.9	0.9	497.2	687.5	1320	1760	1996	2218
E (IU/kg)	17	52.1	62.5	2.6	0.6	29.7	16.5	48.4	60.1	66.0	150.0
K (mg/kg)	17	3.1	3.3	3.0	3.0	1.1	1.3	2.4	3.1	4.4	4.8
Other vitamins											
Biotin (mg/kg)	16	0.24	0.29	2.5	0.6	0.09	0.07	0.22	0.26	0.33	0.44
Choline (mg/kg)	13	572.0	541.2	0.8	0.2	132.0	259.6	519.2	519.2	611.6	818.4
Folic acid (mg/kg)	15	1.7	1.7	2.5	0.6	0.73	1.1	1.3	1.5	1.8	3.5
Niacin (mg/kg)	17	34.3	40.3	0.6	1.8	10.8	20.9	38.5	44.0	45.3	55.0
Pantothenic acid (mg/kg)	17	23.5	25.1	1.4	0.9	5.9	15.4	22.0	25.3	28.6	35.0
Riboflavin (mg/kg)	17	6.6	7.5	1.3	0.9	2.0	4.0	5.5	7.7	8.8	9.9
Thiamin (mg/kg)	5	2.0	2.2	1.0	1.0	0.77	1.1	1.7	2.2	2.8	3.3
Vitamin B6 (mg/kg)	12	3.5	3.3	1.5	1.5	1.1	0.88	2.8	3.3	4.0	5.1
Vitamin B12 (μg/kg)	17	30.1	32.1	1.5	1.0	7.7	19.4	27.5	33.0	37.2	44.0
Trace minerals											
Copper (mg/kg)	17	25.1	22.9	5.7	2.3	30.0	8.8	12.2	15.0	16.5	136.8
Iodine (mg/kg)	17	0.50	0.51	3.7	3.7	0.30	0.22	0.33	0.38	0.66	1.3
Iron (mg/kg)	17	88.7	97.8	1.6	1.2	23.1	61.1	89.8	99.8	110.0	149.5
Manganese (mg/kg)	17	30.7	37.2	18.6	1.5	14.4	14.2	26.5	33.1	50.0	70.0
Selenium (mg/kg)	17	0.29	0.29	1.4	1.9	0.03	0.20	0.30	0.30	0.30	0.30
Zinc (mg/kg)	17	105.3	121.5	2.0	1.2	26.8	60.8	110.1	123.8	130.0	173.6
Conditionally essential nutrients											
Carnitine (mg/kg)	2	50.0	50.0	NA	NA	0.00	50.0	ND	50.0	ND	50.0
Chromium (mg/kg)	5	0.20	0.20	NA	NA	0.00	0.20	0.20	0.20	0.20	0.20
Cobalt (mg/kg)	1	0.39	0.39	NA	NA	ND	0.39	ND	0.39	ND	0.39
Vitamin C (mg/kg)	1	250.0	250.0	NA	NA	ND	250.0	ND	250.0	ND	250.0

* Seventeen producers' nutritionists provided information for gilt-development diets, totaling approximately 2,223,600 sows (38.6% of the US sow herd). All reported values are on a complete-feed basis.

† N indicates the number of producers adding concentrations of a nutrient.

‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.

§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1] Since the NRC does not list specific gilt-development requirements, the supplementation rates were compared to the NRC requirements of growing pigs from 25 to 50 kg, as well as to gestation requirements, because most strategies for feeding the developing gilt were related to one of these two diet types.

NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.

ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

Table 9: Added vitamin and trace-mineral concentrations in gestation diets*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	17	9819	10,362	2.6	1026	7698	9900	11,000	11,002	11,986
D (IU/kg)	17	1531	1783	2.2	360.4	1097	1562	1762	2141	2218
E (IU/kg)	17	66.0	70.0	1.6	25.1	44.0	59.0	66.0	73.9	150.0
K (mg/kg)	17	3.5	3.7	7.3	0.99	1.7	2.8	4.0	4.4	4.8
Other vitamins										
Biotin (mg/kg)	17	0.26	0.29	1.4	0.07	0.22	0.22	0.24	0.33	0.44
Choline (mg/kg)	17	645.3	610.7	0.5	114.4	389.8	519.6	571.8	713.0	788.7
Folic acid (mg/kg)	17	1.7	1.7	1.3	0.59	1.1	1.3	1.7	1.7	3.5
Niacin (mg/kg)	17	40.5	45.5	4.6	11.7	24.2	41.1	44.0	49.1	82.5
Pantothenic acid (mg/kg)	17	26.8	27.3	2.3	4.0	22.0	24.4	27.5	29.5	35.0
Riboflavin (mg/kg)	17	7.5	8.1	2.2	1.4	5.5	7.3	8.4	9.5	9.9
Thiamin (mg/kg)	5	2.1	2.2	2.2	0.77	1.1	1.7	2.2	2.8	3.3
Vitamin B6 (mg/kg)	13	4.0	3.5	3.4	1.1	0.88	3.0	3.3	4.4	5.1
Vitamin B12 (μg/kg)	17	34.1	35.2	2.4	4.8	27.3	33.0	33.9	38.5	44.0
Trace minerals										
Copper (mg/kg)	17	15.0	16.1	1.6	6.0	6.8	13.2	15.0	16.5	35.0
Iodine (mg/kg)	17	0.56	0.53	3.8	0.30	0.16	0.31	0.50	0.68	1.3
Iron (mg/kg)	17	101.8	102.2	1.3	28.8	45.4	89.9	100.0	115.1	165.0
Manganese (mg/kg)	17	32.5	37.6	1.5	13.2	21.2	25.7	38.5	50.0	70.0
Selenium (mg/kg)	17	0.29	0.29	1.9	0.04	0.14	0.30	0.30	0.30	0.30
Zinc (mg/kg)	17	112.9	123.0	1.2	28.3	56.7	108.0	125.0	147.2	165.0
Conditionally essential nutrients										
Carnitine (mg/kg)	2	50.0	50.0	NA	0.0	50.0	ND	50.0	ND	50.0
Chromium (mg/kg)	9	0.20	0.20	NA	0.0	0.20	0.20	0.20	0.20	0.20
Cobalt (mg/kg)	1	0.39	0.39	NA	ND	0.39	ND	0.39	ND	0.39
Vitamin C (mg/kg)	1	250.0	250.0	NA	ND	250.0	ND	250.0	ND	250.0

* Seventeen producers' nutritionists provided information for gestation diets, totaling approximately 2,223,600 sows (38.6% of the US sow herd). All reported values are on a complete-feed basis.
† N indicates the number of producers adding concentrations of a nutrient.
‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.
§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]
NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.
ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

vitamin D_3, more than 50% of participants supplemented at least 25% of vitamin D from a vitamin AD_3 cross-linked beadlet, across all surveyed diet types. The use of natural (d-alpha-tocopherol) vitamin E as a potential source of vitamin E ranged from 29% to 62% across all surveyed diet types. It is important to note that this question addresses only producers that specifically note natural vitamin E as a possible source when ordering premix from premix blenders. It does not distinguish whether natural vitamin E was used within their premixes or complete diets. Use of chelated sources for partial or complete supplementation of copper, manganese, or zinc ranged from 0% to 46% across surveyed diet types. Chelated selenium for partial or total selenium supplementation ranged from 0% to 77% of respondents across the different diets. Most chelated trace-mineral supplementation occurred in breeding-herd and early-nursery diets.

Discussion

Presumably, the high inclusion rates for copper and zinc reported for some producers were used for growth promotion, as discussed previously by Reese and Hill.[7] This led to a large variation in copper and zinc supplementation rates in the nursery phases. In the finishing phase, in general the only vitamin or trace mineral supplemented below the requirement was niacin. It is speculated this may be due to the increase (10 to 30 mg per kg) in niacin requirement from the 1998[3] to the 2012 NRC[1] publication, while the other requirements were unchanged. Again in the finishing phase, similar to the nursery, there was a high ratio relative to the NRC suggestions and a wide variability in copper supplementation rates. Again, we speculate this is due to the use by some producers of high levels for growth promotion versus others that only included concentrations to meet the nutritional requirement. Also, in general, manganese supplementation concentrations were high relative to NRC suggestions in the finishing phases, and we do not have a good explanation for this discrepancy.

Large differences in weight categories were associated with gilt-development diets across

Table 10: Added vitamin and trace-mineral concentrations in lactation diets*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	17	9997	10,404	5.2	918.5	8415	9900	11,000	11,002	11,986
D (IU/kg)	17	1557	1789	2.2	348.7	1100	1562	1762	2141	2218
E (IU/kg)	17	67.1	70.2	1.6	24.9	44.0	59.0	66.0	73.9	150.0
K (mg/kg)	17	3.5	3.7	7.3	0.99	1.7	2.8	4.0	4.4	4.8
Other vitamins										
Biotin (mg/kg)	17	0.29	0.29	1.4	0.07	0.22	0.22	0.24	0.33	0.44
Choline (mg/kg)	17	478.5	533.9	0.5	108.5	259.8	519.6	519.6	609.6	675.6
Folic acid (mg/kg)	17	1.7	1.7	1.3	0.59	1.1	1.3	1.7	1.8	3.5
Niacin (mg/kg)	17	41.4	45.8	4.6	11.7	24.2	41.1	44.0	49.1	82.5
Pantothenic acid (mg/kg)	17	27.3	27.5	2.3	3.7	22.0	24.6	27.5	29.5	35.0
Riboflavin (mg/kg)	17	7.7	8.1	2.2	1.4	5.5	7.3	8.4	9.5	9.9
Thiamin (mg/kg)	5	2.1	2.2	2.2	0.77	1.1	1.7	2.2	2.8	3.3
Vitamin B6 (mg/kg)	13	4.0	3.5	3.4	1.1	0.88	3.0	3.3	4.4	5.1
Vitamin B12 (μg/kg)	17	34.8	35.4	2.4	4.6	27.5	33.0	33.9	38.5	44.0
Trace minerals										
Copper (mg/kg)	17	15.0	16.1	0.8	6.0	6.8	13.2	15.0	16.5	35.0
Iodine (mg/kg)	17	0.56	0.53	3.8	0.30	0.16	0.31	0.50	0.68	1.3
Iron (mg/kg)	17	101.8	102.2	1.3	28.8	45.4	89.9	100.0	115.1	165.0
Manganese (mg/kg)	17	32.5	37.6	1.5	13.2	21.2	25.7	38.5	50.0	70.0
Selenium (mg/kg)	17	0.29	0.29	1.9	0.04	0.14	0.30	0.30	0.30	0.30
Zinc (mg/kg)	17	112.9	123.0	1.2	28.3	56.7	108.0	125.0	147.2	165.0
Conditionally essential nutrients										
Carnitine (mg/kg)	2	50.0	50.0	NA	0.0	50.0	ND	50.0	ND	50.0
Chromium (mg/kg)	9	0.21	0.20	NA	0.0	0.20	0.20	0.20	0.20	0.22
Cobalt (mg/kg)	1	0.39	0.39	NA	ND	0.39	ND	0.39	ND	0.39
Vitamin C (mg/kg)	1	250.0	250.0	NA	ND	250.0	ND	250.0	ND	250.0

* Seventeen producers' nutritionists provided information for lactation diets, totaling approximately 2,223,600 sows (38.6% of the US sow herd). All reported values are on a complete-feed basis.

† N indicates the number of producers adding concentrations of a nutrient.

‡ Weighted averages were calculated using the sumproduct function of Excel 2013 (Microsoft) in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.

§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]

NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.

ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

Table 11: Added vitamin and trace-mineral concentrations in boar diets*

	N†	Weighted average‡	Average	Ratio to NRC§	SD	Low	25%	Median	75%	High
Fat-soluble vitamins										
A (IU/kg)	13	10,549	11,249	2.8	1898	7698	9957	11,000	12,558	15,400
D (IU/kg)	13	1608	847	9.3	442.9	1097	1541	1760	2141	2614
E (IU/kg)	13	72.2	77.4	1.8	31.0	44.0	59.0	66.0	99.0	150.0
K (mg/kg)	13	3.5	3.5	7.0	1.0	1.8	2.6	3.7	4.4	4.8
Other vitamins										
Biotin (mg/kg)	13	0.31	0.33	1.6	0.15	0.22	0.22	0.29	0.40	0.64
Choline (mg/kg)	10	637.6	715.7	0.6	507.8	259.8	480.7	584.1	786.1	2079
Folic acid (mg/kg)	13	1.8	1.8	1.4	0.70	1.1	1.3	1.7	2.3	3.5
Niacin (mg/kg)	13	41.4	44.9	4.5	6.6	33.0	41.4	45.1	49.5	55.0
Pantothenic acid (mg/kg)	13	27.7	27.7	2.3	4.2	22.0	25.3	27.5	28.8	37.0
Riboflavin (mg/kg)	13	7.7	8.1	2.2	1.5	5.5	7.5	8.4	9.5	9.9
Thiamin (mg/kg)	5	2.1	2.0	2.0	1.2	0.09	1.1	2.2	2.8	3.3
Vitamin B6 (mg/kg)	10	3.7	3.3	3.2	1.6	0.13	2.2	3.3	4.6	5.1
Vitamin B12 (μg/kg)	13	39.2	46.4	3.1	34.8	27.3	33.0	37.2	44.0	160.8
Trace minerals										
Copper (mg/kg)	13	16.6	19.8	4.0	10.6	11.2	13.7	15.1	23.9	46.5
Iodine (mg/kg)	13	0.62	0.61	4.4	0.31	0.22	0.36	0.52	0.71	1.3
Iron (mg/kg)	13	109.6	109.0	1.4	26.9	61.1	90.1	105.8	122.5	165.0
Manganese (mg/kg)	13	35.3	45.1	2.3	22.9	21.2	28.1	38.5	64.9	96.8
Selenium (mg/kg)	13	0.31	0.31	1.0	0.03	0.30	0.30	0.30	0.30	0.42
Zinc (mg/kg)	13	122.3	142.5	2.8	50.5	83.8	112.8	129.8	170.0	279.3
Conditionally essential nutrients										
Carnitine (mg/kg)	1	60.0	60.0	NA	ND	60.0	ND	60.0	ND	60.0
Chromium (mg/kg)	7	0.21	0.21	NA	0.08	0.20	0.20	0.20	0.20	0.24
Cobalt (mg/kg)	1	0.39	0.39	NA	ND	0.39	ND	0.39	ND	0.39
Vitamin C (mg/kg)	1	250.0	250.0	NA	ND	250.0	ND	250.0	ND	250.0

* Thirteen producers' nutritionists provided information for boar diets, totaling approximately 1,921,100 sows (33.4% of the US sow herd). All reported values are on a complete-feed basis.
† N indicates the number of producers adding concentrations of a nutrient.
‡ Weighted averages were calculated using the sumproduct function of Excel in which the producer supplementation rate was multiplied by the size of the producer (sow herd size). After summing those products they were divided by the total number of sows for all participating producers.
§ Values represent average supplementation rates as a proportion to total dietary vitamin and trace-mineral requirements from the NRC 2012.[1]
NA = not applicable; NRC[1] does not list a requirement for conditionally essential nutrients.
ND = not done; standard deviation (SD) is not meaningful for N of 1, or for the 25th and 75th percentiles for N = 1 or N = 2.

the participating production systems. Thus, to standardize the information, the last diet fed before gilts entered the breeding herd was used. Since the NRC does not provide specific requirements for gilt development, the gilt-development diets were compared to NRC[1] growing-pig (25 to 50 kg) and gestation requirements. We used these two categories because most recommended vitamin and trace-mineral feeding strategies for developing gilts are similar to those for feeding growing pigs in the early-finisher or gestation diet supplementation rates.

In conclusion, adding a margin of safety for vitamin and trace-mineral supplementation rates over those requirement estimates of NRC[1] appear to be standard practice in many US swine diet formulations. However, the degree or range of supplementation varies considerably. We believe this wide variation represents differing opinions on vitamin and trace-mineral requirements and highlights the need for research to examine vitamin and trace-mineral requirements of today's modern genotypes.

Table 12: Percentage of participating producers using alternative vitamin and trace-mineral sources*

	Nursery phase†			Finishing‡				Breeding herd			
	1	2	3	Early	Mid	Late	Ract	Gilt dev	Gestation	Lactation	Boar
Participating producers (n)	**13**	**17**	**18**	**18**	**18**	**18**	**7**	**17**	**17**	**17**	**13**
Vitamins											
AD (%)§	92	76	67	67	67	67	86	65	65	65	54
E (%)¶	38	62	56	56	33	33	29	41	41	41	38
Trace minerals**											
Copper (%)	15	18	6	0	0	0	0	29	29	29	46
Manganese (%)	15	18	6	0	0	0	0	29	29	29	46
Selenium (%)	69	47	33	6	6	6	0	76	76	76	77
Zinc (%)	15	18	6	0	0	0	0	29	29	29	46

* A total of 18 swine producers' nutritionists representing approximately 2,268,900 sows (39.4% of the US sow herd) were surveyed on their supplementation rates of vitamins and trace minerals.
† Nursery diets consisting of phase 1 (weaning to 7 kg), phase 2 (7 to 11 kg), and phase 3 (11 to 23 kg).
‡ Finishing diets consisting of early-finishing (23 to 55 kg), mid-finishing (55 to 100 kg), late-finishing (100 kg to market), and late-finishing with ractopamine HCl (Ract;100 kg to market). Ractopamine is fed in late-finishing diets at a rate of 5 to 10 g/tonne for improved feed efficiency and gain.
§ Values represent the percentage of producers supplying at least 25% of vitamin D from a vitamin AD3 cross-linked beadlet.
¶ Values represent the percentage of producers that specify natural (d-alpha-tocopherol) vitamin E as a potential source of vitamin E.
** Values represent the percentage of producers that supplement partial or complete trace-mineral concentrations from chelated sources.
Gilt dev = gilt development.

Implications

- There is variation in vitamin and trace-mineral supplementation rates across the population of respondents within this survey.
- Although supplementation rates are variable, on the basis of this survey, inclusion of margins of safety for vitamin and trace-mineral supplementation rates appears to be standard practice in US swine diets.
- This survey provides a baseline for characterization of standard practice for trace-mineral supplementation rates.
- The variation in vitamin and trace-mineral supplementation observed in this survey will be useful in identifying research needed to determine vitamin and trace-requirements for various phases of production.

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Conflict of interest

None reported

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