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JOURNAL OF SWINE HEALTH AND PRODUCTION

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JSHAP SPOTLIGHT

Dr Russ Daly

South Dakota State University

Dr Russ Daly earned a BS ('88) and MS ('13) from South Dakota State University (SDSU) and a DVM ('90) from Iowa State University. He is currently the Extension Veterinarian at SDSU and is involved with applied research and field investigations that often arise from diagnostic cases in their Animal Disease Research and Diagnostic Lab. In addition, he serves as South Dakota's State Public Health Veterinarian, aiding the health community when public health issues involving animals and zoonoses emerge. Dr Daly feels it is a privilege to serve on the JSHAP Editorial Board and play a part in providing practical information to the profession. The position also provides insight into current swine health research and helps keep his understanding of research methodology sharp.

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Parting thoughts

This is my last President's message and I want to begin by expressing my heart felt appreciation for the opportunity to serve. It truly has been an honor! I want to thank the AASV staff for all their assistance. Their efforts far exceeded expectations as we made the journey through preparing and presenting the first (and hopefully last) virtual AASV Annual Meeting in 2021. I appreciated their patience as I navigated the ins and outs of parliamentary procedure, and we should all be delighted that I did not drive Sue Schulteis into retirement! I look forward to the future. I know the AASV is in excellent hands as Drs Mike Senn, Bill Hollis, and Angela Baysinger assume the role of president in the years to come.

AASV Foundation

Please take a moment to express appreciation to those members, both past and present, involved in the AASV Foundation. The Foundation is a giving organization established in 1989. Their mission is to empower swine veterinarians to achieve a higher level of personal and professional effectiveness by:

- enhancing the image of the swine veterinary profession,
- supporting the development and scholarship of students and veterinarians interested in the swine industry,
- addressing long-range issues of the profession,
- supporting faculty and promoting excellence in the teaching of swine health and production, and
- funding research with direct application to the profession.

The Foundation's role includes the selection of scholarship, grant, and award recipients for the distribution of funds so generously donated by sponsors and other AASV members. The volunteers who help select the recipients have many applications and research proposals to read, and hard decisions to make. It can be a daunting task and we greatly appreciate their time and effort. Please support the AASV Foundation and participate in the auction or contribute to an endowment.

Virtual vs in-person meetings

The 2021 Annual Meeting was virtual out of necessity, and I am delighted that it went as well as it did. It was nice to be able to view more of the presentations offered or rewatch a presentation of interest to gain clarity. Several members have expressed interest in a hybrid meeting that offers both a virtual and in-person component. While a hybrid meeting sounds like a good idea, there are several reasons the AASV has elected to not pursue that option. When we commit to holding our Annual Meeting at a hotel, the meeting rooms are often offered free of charge. The hotel makes their money on room rentals, food, and beverages. Harry Snelson looks at attendance from past meetings and estimates the number of members that will attend and the length of their stay. We then commit to filling a set number of room nights. Likewise, the contract stipulates that AASV will meet a minimum food and beverage expense. If we fail to achieve the contracted number of room nights or the minimum food and beverage expense, AASV is responsible for making up the difference. If we had a hybrid meeting and enough people chose to stay home and enjoy the virtual option, we might not meet our contract obligations thus making AASV liable for thousands of dollars in penalties. Similarly, if we elected to not hold the in-person meeting, AASV would be liable for penalties covering all the room and food and beverage obligations which could amount to hundreds of thousands of dollars ($675,000 in the case of Indianapolis). That's a pretty big risk to take. In addition, offering a virtual experience means that every session would have to be professionally recorded and livestreamed. This adds significant costs to conducting the Annual Meeting. Lastly, running a hybrid meeting basically means managing two meetings at the same time. We simply do not have the staff to make that happen. Things may look very different in the future as hotels come up with innovative ways to satisfy customers and remain profitable, but a hybrid meeting in today's environment would be very costly to our association. Do not misunderstand, the AASV is financially sound thanks to excellent leadership, a wise investment team, and good decisions made by the past and present Board of Directors. Unfortunately, it is a lot like farming. It would only take a couple bad years for all of that to change.

"The past couple years have been filled with one obstacle after the next, yet we have managed to navigate around them or plow right through them."

The past couple years have been filled with one obstacle after the next, yet we have managed to navigate around them or plow right through them. The strength of the AASV lies in its members and I have every confidence that we will do what is best for the pigs in our care, our clients, and this association. Thank you all for your steadfast determination and innovative ideas.

Mary Battrell, DVM
AASV President

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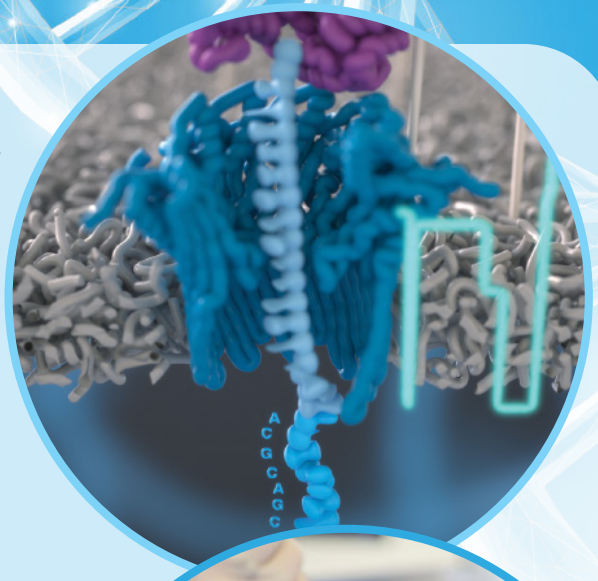

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Defining our future

As the incoming President, I would like to continue to focus on the 2022 Annual Meeting theme, "Defining our Future." As an organization, we have accomplished many successes for our members and the industries that we serve. All these successes are the result of the members who have graciously dedicated their time and talent over many decades. Without these sustaining members, the association cannot fully achieve its mission. Maintaining and growing our membership is critical to our viability for two reasons. First, we need to maintain or grow the pool of talented, engaged members that give their time as committee members, officers, AVMA delegates, and mentors. It is these collective efforts that are the core of the organization achieving its mission. Second, the two largest sources of revenue to support the organization are both driven by membership, membership dues and annual meeting registrations.

The most important aspect of membership is the continued recruitment of new members, with the predominate source being recent graduates, many of which were previously student members. In 2021, the number of new graduate members that joined AASV was 30. This is the first time this number has dropped below 43 members in the past ten years. Similarly, student membership in 2021 was 225 members, the lowest number of student members reported since 2010. While US membership remains relatively steady, we continue to see a decline in international membership, as well as an increasing trend in inactive or retired members. With the decrease in recent graduate and student members and the increase in inactive or retired members, it is imperative that we proactively address membership numbers for the continued success and viability of the organization.

Today, the reasons for the decrease in student and recent graduate members are undefined. It is critical that we work to understand why these trends are occurring and develop strategies to address them. Some thoughts to begin the conversation:

- Are AASV student outreach activities effectively informing a broad range of students about the organization and career opportunities in swine medicine?
- Are there opportunities to improve student outreach and recruitment, such as expanding efforts to reach students earlier in their academic careers prior to acceptance into veterinary school?
- For those who are student members but do not continue to be members after graduation, what are the reasons?
- Is the need for veterinarians focused on swine medicine decreasing?
- Is AASV creating a welcoming, inclusive environment where students and recent graduates want to belong?

"Maintaining and growing our membership is critical to our viability."

The trend in decreased retention of new members in the first five years post graduation is not unique to AASV. In his December 2021 American Association of Bovine Practitioners President's Message, Dr Pat Gorden describes a similar trend among their recent graduates. I would like to recognize the AASV Early Career Committee for creating and planning the successful, first-ever Early Career Swine Veterinarian Conference in conjunction with the 2021 Iowa State University James D. McKean Swine Disease Conference. This is a great example of the continued focus and efforts needed to address current membership issues, well done! I look forward to the continued collaboration with the membership as we move forward in defining the future of AASV. Thank you all for your efforts, the organization would not be successful without each of you and your contributions.

Mike Senn, DVM, MS
AASV President-elect

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The state of change

While the US swine industry is a global enterprise, federal legislation and regulation can obviously impact how the industry functions. Over the years, the AASV, in collaboration with producer organizations, has interacted with legislators and regulators to advocate for policies that enhance swine health and well-being as well as protect public health while ensuring access to domestic and international markets for US pork products. Although no one gets everything they want, we have been reasonably successful maintaining a balance at the national level.

More recently, however, it seems the challenges are often focused at a much more local level. Actions at the state and local levels can have significant impacts on the swine industry and how veterinarians practice. The Proposition 12 legislation in California, various state and sometimes local challenges to the right to farm, and antibiotic use are perfect examples of the impact activist activities at the state and local level can have on the swine industry. Similarly, changes in state practice acts involving things like the veterinarian-client-patient relationship, access to drugs, and continuing education requirements can alter the way food animal practitioners spend their day.

Historically, AASV has not routinely monitored or often commented on local or state activities, but that focus may need to change. The challenge is how do we keep up with all those legislative, regulatory, and practice act changes? We are a small association without adequate staffing or funding to effectively track all these potential challenges. For us to effectively keep you informed and advocate on your behalf and that of the pigs we care for, we need to access a myriad of resources. These resources include working closely with the National Pork Board (NPB), National Pork Producers Council (NPPC), and Swine Health Information Center. In addition, we interact with the American Veterinary Medical Association (AVMA) and other food animal producer and veterinary groups. Membership in the United States Animal Health Association also offers an opportunity to network with state animal health officials who can be a great resource for information and partnership.

The AVMA is a fabulous resource for information on state-level legislative and regulatory activities. There is a department within AVMA focused solely on monitoring veterinary-related activities at the state level. They rely heavily on feedback from the state Veterinary Medical Associations (VMAs) and the VMAs, in turn, benefit from the support the AVMA can provide. That is a definite benefit of membership. Similarly, NPB and NPPC have a network of state pork associations that can help keep them up to date on local and state activities. So, it is important that AASV remains actively engaged in collaborating with and supporting these organizations.

"...no one knows swine veterinary issues better than swine veterinarians."

While these are all valuable resources for local information, no one knows swine veterinary issues better than swine veterinarians. That is why AASV needs all our members to be our eyes and ears on the ground in your local communities. I encourage you to become observant of local legislation, regulation, or practice act changes. If AASV is going to effectively advocate for your interests, we need for you to reach out to us when you hear of something going on that could impact the pigs we care for, the industry we serve, or the practice we cherish.

Harry Snelson, DVM
Executive Director

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Bucket list V2.0

In my 2019 March-April issue I wrote about my bucket list.[1] I spoke about potential items that could (and maybe should) be on my bucket list at the time. I find it interesting to go back and look at that message and my bucket list items given all that has changed over the past two years, and it made me think about what is on my bucket list nowadays?

But first, what was on my bucket list in 2019? I listed some professional and personal goal-related items: contribute to world peace, write a book, travel to Antarctica, complete an Ironman race.[1] All those options seemed worthy of being on a person's bucket list. Big and challenging items. They are all still on my list and could be considered incomplete, but I did do a half Ironman race this past summer so maybe that counts for a little. Nonetheless I am still working on my list. They are life goals vs a list with a specific timeline really, both personal and professional.

My pig veterinarian related bucket list items are still the same as they were in 2019: contribute to feeding the world safe and nutritious animal protein; visit other countries to learn about their swine production systems and animal health strategies (although I did exclude Antarctica); and visit other universities to learn and understand the challenges they face and strategies they use when training new veterinarians.[1]

As veterinarians, we are all familiar with professional development and continuing education. The pandemic has influenced travel significantly, ranging from travel restrictions to various personal comfort levels surrounding travel. I am disappointed to miss attending the AASV Annual Meeting this year in Indianapolis. But I am sure it will be a great Annual Meeting. Regardless of the delivery mode, in-person or virtual, the meeting is always a great time to connect with each other and learn. My professional bucket/goal list remains the same and professional development and continuing education both still rank high on that list. And usually, attending the Annual Meeting helps me fulfill some of my list items and professional development goals. I hope you were able to attend and enjoy the meeting.

"I find it interesting to go back and look at that message and my bucket list items given all that has changed over the past two years, and it made me think about what is on my bucket list nowadays?"

The *Journal of Swine Health and Production* also strives to help fulfill your professional development bucket/goal list and bring peer-reviewed literature to your living room or work office. I hope you enjoy this issue

Terri O'Sullivan, DVM, PhD
Executive Editor

Reference

*1. O'Sullivan T. Bucket list [Editorial]. *J Swine Health Prod*. 2019;28(2):63.

* Non-refereed reference.

ORIGINAL RESEARCH PEER REVIEWED

A descriptive exploration of animal movements within the United States cull sow marketing network

Benjamin W. Blair, DVM; James F. Lowe, DVM, MS

Summary

Objective: Collect and describe data regarding sow movements within the US cull sow marketing network, and what implications those movements may have on disease introduction and dissemination within the United States.

Materials and methods: Premise identification tags (PITs) were collected with the help of the US Department of Agriculture's Animal and Plant Health Inspection Service-Veterinary Services Brucellosis Laboratory. Collection occurred for a total of 6 months. From each PIT the management/sow identification (ID), premises ID, state, facility, and slaughter date were recorded. Participating production systems identified the cull dates of individual sows from their system.

Results: A total of 17,493 PITs were collected. This study collected PITs from 32 states and 1211 unique premises IDs. Facilities received sows from a median (IQR) of 9.5 (12.5) states and 71 (79.25) unique premises each week.

Sows traveled a median (IQR) distance of 472.7 (453.6) km with a maximum of 2812.8 km. A single premises delivered sows to 1, 2, or 3 or more slaughter facilities 59.7%, 33.4%, and 6.9%, respectively. Removal date from the farm of origin was available for 2886 (16.5%) individual sows. Of these, 66.1% were in the market channel for ≤ 3 days, 25% for 4 to 5 days, and 8.9% for > 5 days.

Implications: These results suggest that the cull sow marketing channel provides an independent, but interconnected swine population that can maintain, expand, and transmit pathogens to the US swine herd. Control and elimination plans for novel, transboundary, and foreign animal diseases should include this population.

Keywords: swine, sows, market, disease, movement

Received: December 11, 2020
Accepted: August 31, 2021

Resumen - Exploración descriptiva de los movimientos de animales dentro de la red de mercadeo de cerdas de desecho de los Estados Unidos

Objetivo: Recopilar y describir la información sobre los movimientos de cerdas dentro de la red de mercadeo de cerdas de desecho de EE UU, y qué implicaciones pueden tener esos movimientos en la introducción y diseminación de enfermedades en los Estados Unidos.

Materiales y métodos: La identificación de cada sitio (PITs) se recolectaron con la ayuda del Laboratorio de Brucelosis de los Servicios Veterinarios del Servicio de Inspección de Sanidad Animal y Vegetal del Departamento de Agricultura de EE UU. La recolección de información se llevó a cabo durante un total de 6 meses. De cada PIT se registró la identificación (ID) de manejo/cerda, identificación del sitio, estado, matadero, y fecha de sacrificio. Los sistemas de producción participantes identificaron la fecha individual de desecho de cada hembra de su sistema.

Resultados: Se recolectaron un total de 17,493 PITs. Este estudio recolectó PITs de 32 estados y 1211 ID de sitios únicos. Los mataderos recibieron cerdas de una mediana (RIC) de 9.5 (12.5) estados y 71 (79.25) sitios únicos cada semana.

Las cerdas recorrieron una distancia mediana (RIC) de 472.7 (453.6) km con un máximo de 2812.8 km. Un solo sitio entregó cerdas a 1, 2, o 3 o más mataderos, 59.7%, 33.4%, y 6.9%, respectivamente. La fecha de retiro de la granja de origen estuvo disponible para 2886 (16.5%) cerdas individuales. De estas, el 66.1% estuvo la cadena de mercado durante ≤ 3 días, el 25% durante 4 a 5 días, y el 8.9% por > 5 días.

Implicaciones: Estos resultados sugieren que la cadena de comercialización de cerdas de desecho es una población porcina independiente pero interconectada que puede mantener, aumentar, y transmitir patógenos al hato porcino de EE UU. Los planes de control y eliminación de enfermedades animales nuevas, transfronterizas, y foráneas deben incluir a esta población.

BWB, JFL: University of Illinois College of Veterinary Medicine, Urbana, Illinois.

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Corresponding author: Dr James Lowe, 2001 S. Lincoln Ave, Urbana, IL 61802; Tel: 217-333-6720; Email: **jlowe@illinois.edu**.

Blair BW, Lowe JL. A descriptive exploration of animal movements within the United States cull sow marketing network. *J Swine Health Prod*. 2022;30(2):72-78: **https://doi.org/10.54846/jshap/1245**

Résumé - Une exploration descriptive des mouvements d'animaux au sein du réseau de commercialisation des truies de réforme aux États-Unis

Objectif: Recueillir et décrire des données concernant les mouvements de truies au sein du réseau américain de commercialisation des truies de réforme, et quelles implications ces mouvements peuvent avoir sur l'introduction et la dissémination de maladies aux États-Unis.

Matériels et méthodes: Les étiquettes d'dentification des lieux (PITs) ont été recueillies avec l'aide du Service d'Inspection de la Santé Animale et Végétale du Département de l'Agriculture des États-Unis et du Laboratoire de Brucellose des Services Vétérinaires. La collecte a duré 6 mois au total. À partir de chaque PIT, l'identification de la gestion/de la truie (ID), l'ID des locaux, l'état, l'installation, et la date d'abattage ont été enregistrées. Les systèmes de production participants ont identifié les dates de réforme des truies individuelles à partir de leur système.

Résultats: Un total de 17,493 PITs a été amassé. Cette étude a collecté des PITs de 32 États et 1211 identifiants de locaux uniques. Les installations ont reçu des truies d'une médiane (IQR) de 9.5 (12.5) états et 71 (79.25) locaux uniques chaque semaine. Les truies ont parcouru une distance médiane (IQR) de 472.7 (453.6) km avec un maximum de 2812.8 km. Un seul local a livré des truies à 1, 2, ou 3 abattoirs ou plus à 59.7%, 33.4%, et 6.9%, respectivement. La date de sortie de l'exploitation d'origine était disponible pour 2886 (16.5%) truies individuelles. Parmi celles-ci, 66.1% étaient dans le canal du marché pendant ≤ 3 jours, 25% pendant 4 à 5 jours, et 8.9% pendant > 5 jours.

Implications: Ces résultats suggèrent que le circuit de commercialisation des truies de réforme fournit une population porcine indépendante mais interconnectée qui peut maintenir, étendre, et transmettre des agents pathogènes au troupeau porcin américain. Les plans de contrôle et d'élimination des maladies animales nouvelles, transfrontalières, et exotiques devraient inclure cette population.

The threat of pathogen dissemination posed by the US cull sow market is one of the most significant knowledge gaps within the swine industry today. While the general purpose of the cull sow market is well understood by the industry, transparency (ie, current available data) of the movements that occur within the channel and the resulting risk of disease transmission is limited. With more than 3.2 million cull sows expected to enter the market channel annually,[1] uncontrolled management of this industry segment may lead to negative impacts on the health and production of both breeding and growing herds.[2] With significant concerns about foreign animal disease (FAD) introduction, the swine industry's limited comprehension of the potential for the cull sow marketing channel to both disseminate and serve as a reservoir for pathogens suggests further elucidation of those risks is needed as an essential part of US FAD preparedness.

The US cull sow market is structurally different than the lean hog market. A limited number of centrally located slaughter facilities[3] are fed by a network of local collection points (buying stations) where sows are delivered from the farm. In contrast, the slaughter facilities for the lean hog market, the primary source of pork products in the United States, are predominantly located in pig dense regions resulting in > 95% of lean hogs moving directly from farm of origin to the slaughter facility. The structure of the cull sow marketing network results in the opposite effect where > 90% pass through an intermediary collection point before arriving at slaughter.[2] This structure promotes extensive commingling of sows as they move from the farm through buying stations to the slaughter facility.

Collection points located in sow-dense regions allow farms to cull a small number of sows routinely while minimizing trucking cost. Frequently removing sows from the farm spares the added expense of holding sows until full truck load lots can be created and increased number of sows in inventory on the farm. The collection points serve to add value to these animals. Collection points facilitate the creation of truckload lots of a specific type of cull sow (weight, body condition) to meet the preferences of individual slaughter facilities. While complex, this market structure has benefited all parties involved, but drawbacks exist.

Within the United States, the welfare of cull sows has received little scientific attention, however, concerns regarding the fitness of animals at the time of transport have been raised.[4] The pretransport mixing of cull sows on farm can result in the clinical deterioration of sows in as little as 24 hours.[5] This deterioration is present in animals at the time of arrival at buying stations. Cull sows and boars comprised the majority of swine arriving fatigued, thin, and lame.[6] While there are still significant knowledge gaps regarding fitness during transport, the extended time that some cull sows remain within the marketing channel raises concerns that the current market structure may negatively impact the welfare of cull sows prior to harvest.[2]

The potential for pathogen dissemination through the cull sow marketing network is known but unquantified. The risk for pathogen dissemination originates from three factors: comingling sows from many sources, multiple movements between farm to harvest, and extended time in the market channel. Commingling of sows from many farms allows for uninfected sows from one farm to come in contact with pathogens from other farms in the market channel. The impact of transmission is increased during the movement of sows between multiple, nonterminal points in the marketing channel creating the opportunity for dissemination of disease across broad geographies. It has been estimated that up to 14% of all cull sows make 3 or more stops as they move between different collection points prior to slaughter.[2] The current cull sow marketing channel creates an "off-farm cull sow population" that can both transfer and serve as a reservoir population for pathogens.

While all the sows in the market channel are destined for slaughter, this reservoir population can serve as a source of pathogens for domestic swine herds. During the 2014 US porcine epidemic diarrhea virus (PEDV) outbreak, the lean hog network served as a means of expanding the outbreak when trailers were contaminated at the slaughter facility and returned back to production sites unwashed.[7] The probability of contamination increased with both the temporal proximity of a trailer unloading after a contaminated trailer at the same dock and the viral load present at the slaughter facility.[1] Even with the

implementation of biosecurity practices, compliance failure is common at truck washes or during the loading or unloading of animals creating a route for pathogen introduction into the domestic swine industry.[8,9]

The national scope, structure, and hypothesized complexity of the cull sow market creates a significant opportunity for pathogen transmission, including FADs throughout the US swine industry.[2] This study compiles data from a previously untapped source to generate a dataset capable of describing cull sow movements both spatially and temporally within the United States. By doing so, this study strives to provide a robust descriptive analysis of the US cull sow marketing network to date, serving as a reference to the swine industry in future endeavors.

Animal care and use

Data was obtained from premises identification number tags (PITs) recovered from sows slaughtered in federally inspected facilities under the authority of the USDA Food Safety Inspection Service.

Materials and methods

Data collection

Data collection was in partnership with the USDA Animal and Plant Health Inspection Service-Veterinary Services (APHIS-VS) Brucellosis Laboratory located in Frankfort, Kentucky. The laboratory collected all PITs affiliated with samples submitted for brucellosis surveillance.[10] The samples represent sows randomly sampled from US slaughter facilities as part of the national brucellosis and pseudorabies monitoring program administered by USDA APHIS-VS.

Premises identification number tags serve as the traceability method for sows in the Swine Identification (ID) Plan established by the industry in 2004.[10] The industry compliance with the Swine ID Plan is high as PITs are present in greater than 90% of sows at the time of slaughter.[2] Samples collected by the laboratory originated from 7 US slaughter facilities. To maintain the confidentiality of the slaughter facilities, they are referred to as F1 through F7. Daily slaughter capacities of these slaughter facilities ranged from 20 to over 2800 pigs/day.

Collection of PITs occurred one week per month in May, June, and July of 2018 and February, March, and April of 2019. These dates were selected for ease of collection for the laboratory and to monitor movements in two different calendar quarters. For each PIT the management/sow ID, premises ID, state, facility, and slaughter date were recorded in a database. The geolocation for each unique premises ID was obtained using the premises verification tool from Pork Checkoff[11] which provides the street address of the farm and was visually confirmed and converted to geocoordinates in Google Maps.

For a subset of PITs, the date of removal from the farm of origin was obtained through the participation of 9 privately owned swine production systems and 2 veterinary management companies. These systems have a collective one-time inventory of > 2.4 million sows representing more than 40% of the US swine breeding herd. Premises IDs for each production system were used to match the management ID to the farm removal date in their production record systems.

Data analysis

The Euclidean distance between the farm of origin and the slaughter facility was calculated using the geospatial coordinates for each location. Regional price difference for each sow was also calculated. Regional price difference is defined as the price difference between the sow's origin region versus their slaughter facility region. These regional prices were obtained from the Daily Direct Prior Day Sow and Boar report (LM_HG234)[12] as reported by the USDA Agriculture Marketing Service. A weighted average price for the Iowa/Minnesota, Western Corn Belt, Eastern Corn Belt, and National regions was determined. All premises outside of the Iowa/Minnesota, Western Corn Belt, and Eastern Corn Belt regions were assigned to the National region.

For each slaughter facility, the number of unique premises, the median distance traveled to the slaughter facility, and the number of states animals originated from were determined. For a subset of animals that originated at participating systems, the days in the slaughter market channel was defined as the difference between the farm removal date and the slaughter date. A box and whisker plot of distance traveled was created for each facility. In addition, dot plots of the number of weekly unique premises and states arriving to each facility were generated to elucidate any differences between facilities. All visualizations and statistics for this study were performed using R statistical software.[13]

Results

A total of 17,493 individual PITs were collected, representing approximately 8.4% of the total number of sows slaughtered each week at the 7 slaughter facilities. These 7 facilities are responsible for 33% of the daily national cull sow slaughter. The collected data represents approximately 2.7% of the weekly national cull sow slaughter. The PITs represented 1211 unique premises and 32 states. Farm removal dates of 2886 individuals were recorded, representing 16.5% of all samples collected.

Description of sows

Sow PITs came from 7 different federally inspected slaughter facilities (F1-F7). The largest slaughter facility had a slaughter capacity of 2800 sows/day.[2] The smallest slaughter facility capacity was believed to have been < 20 sows/day, as the surveillance sample submitted represented the entirety of their daily slaughter. In this study the slaughter facilities collected sows from a median (IQR) of 9.5 (12.5) states/day (Figure 1). Sows originated from a median (IQR) of 71 (79.25) premises/week (Figure 2).

The distance from farm of origin to slaughter facility for sows varied between facilities. Across all slaughter facilities, sows traveled a median (IQR) Euclidean distance of 472.7 (453.6) km (Figure 3). Sows entering F2 traveled the furthest with a median (IQR) of 706.2 (614.4) km while sows entering F6 traveled the least with a median (IQR) of 119.5 (173.1) km (Figure 4).

Some sows remained in the market channel for an extended time. Of the subset of 2886 sows from the seven study slaughter facilities, 66.1% remained in the marketing channel for ≤ 3 days, 25% for 4 to 5 days, and 8.9% for > 5 days. The median (IQR) time from removal to slaughter was found to be 3 (3) days with a maximum of 40 days for 2 individuals.

Premises description

Of the 1211 premises in the dataset, 59.7% had cull sows arrive at a single slaughter facility. In comparison, 33.4% of the premises had animals arrive at two slaughter facilities and 6.9% of the farms were represented at three or more slaughter facilities across all tag collection dates.

Figure 1: Number of unique states represented by sows arriving daily at the slaughter facility.

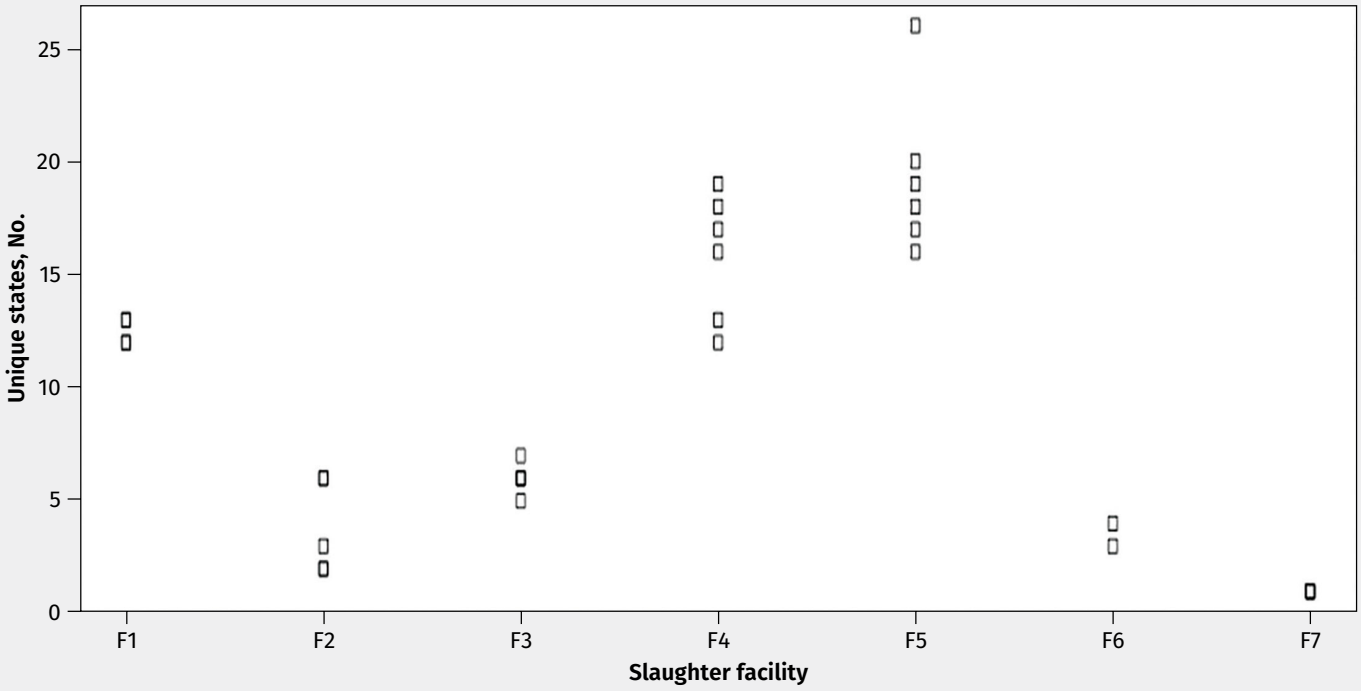


Figure 2: Unique number of premises represented by sows arriving weekly at the slaughter facility.

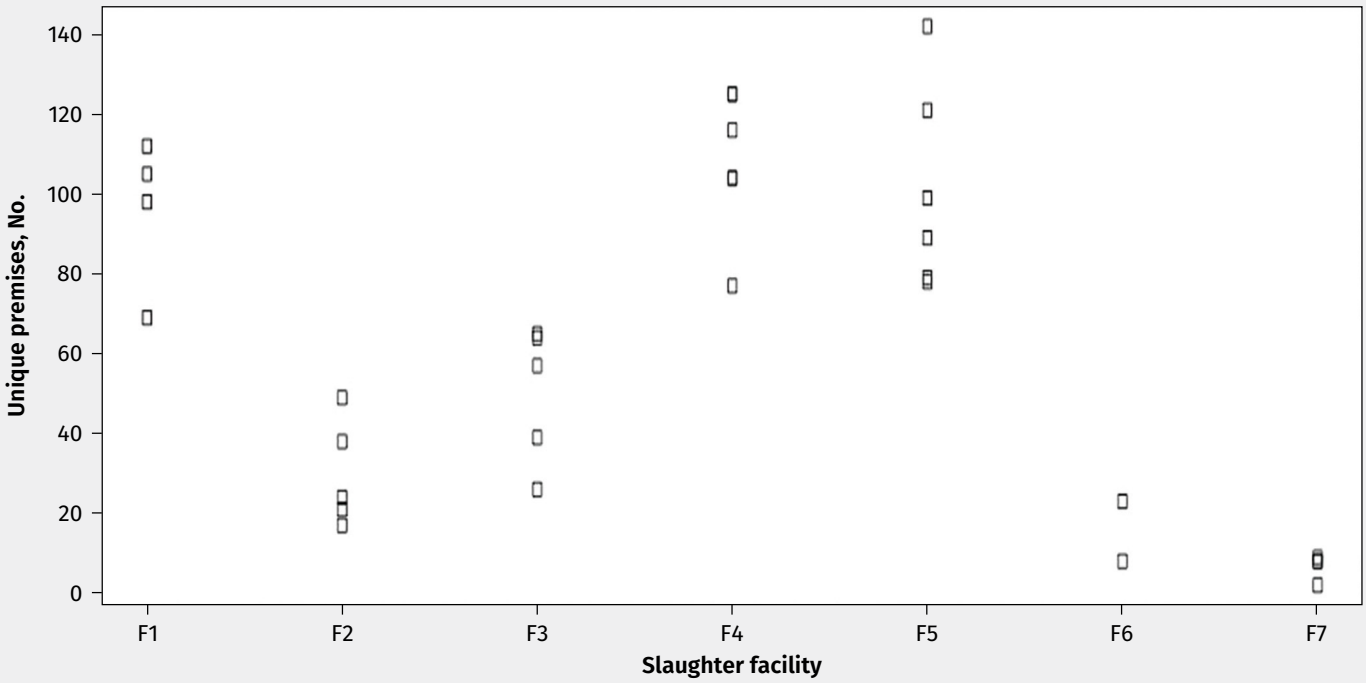


Figure 3: Distribution of the Euclidian distance between the farm of origin and slaughter facility.

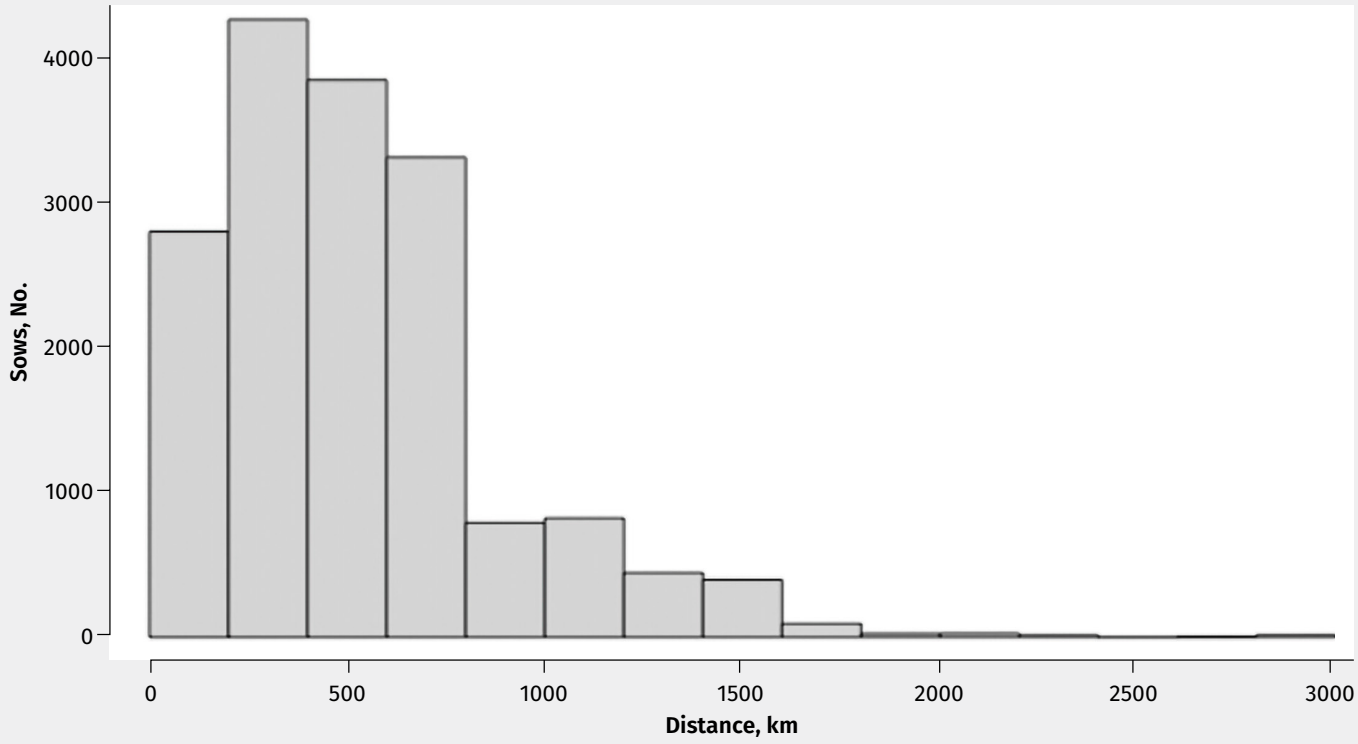
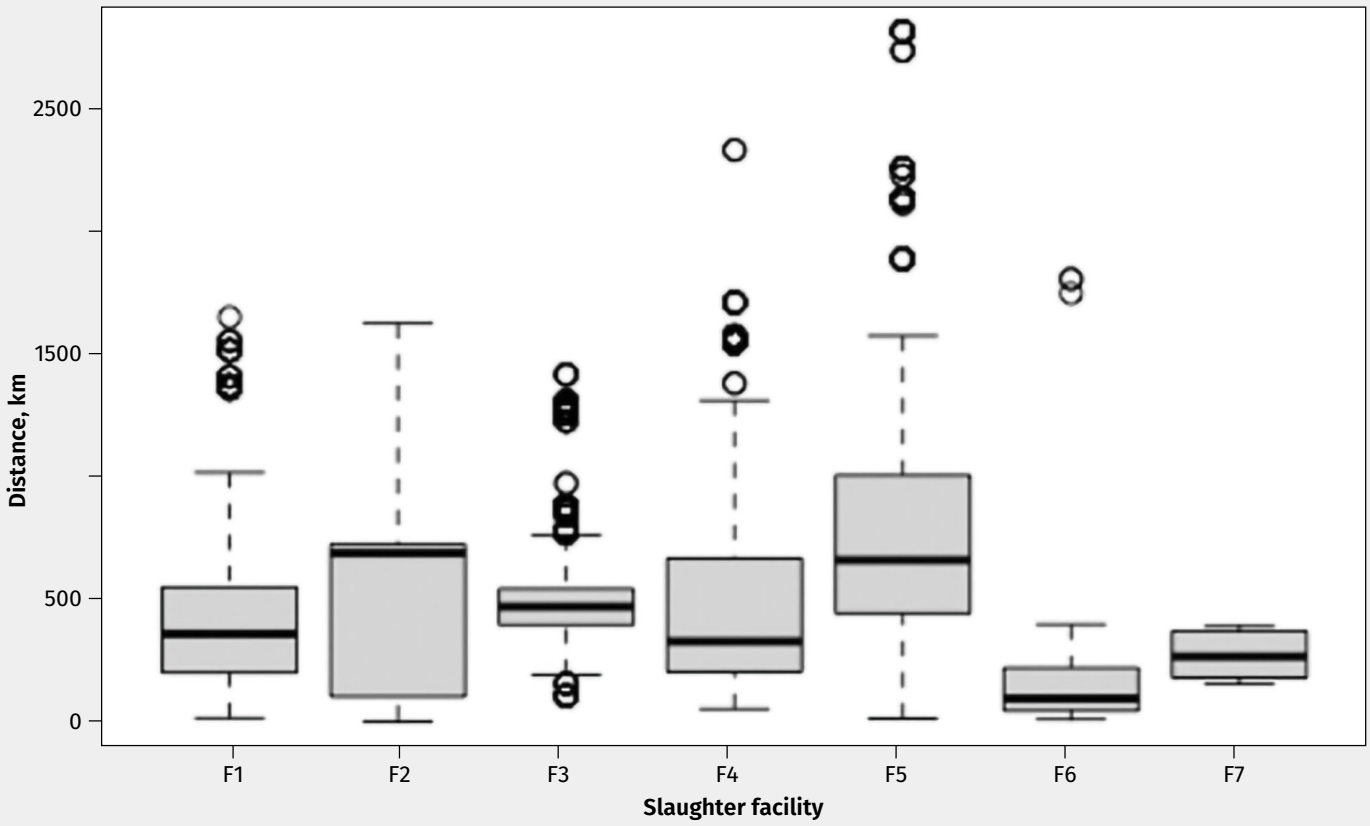


Figure 4: Box plots of the distance traveled by sows to each unique slaughter facility.



Discussion

This study is the first multiple slaughter facility dataset collected describing the US cull sow marketing network. With 17,493 individual PITs collected from sows representing 1211 unique farms, this dataset is nearly seven times as large as the previously published work.[2] The size and temporal component of this dataset allows for exploration into why and how sows are moving within the marketing channel. These data should be used to facilitate improved policy and biosecurity decisions by the industry and regulators.

As previously hypothesized[3] and further supported by this work, the collection area for each slaughter facility is geographically vast and overlapping. The median distance between the farm of origin and terminal processing facility is 472.7 km, with 16% traveling more than 1000 km to reach their destination up to a maximum of 2812.8 km. This documents that sows consistently travel long distances. In addition to the distance traveled by sows, these are the first data to systemically describe the time animals spend within the cull sow marketing network. Some sows remain in the network for an extended amount of time, well beyond the incubation period of many important pathogens including foot-and-mouth disease, African swine fever, and classical swine fever.[14-16] In combination with the routine mixing of sows, this time within the marketing network is poorly defined and untraced resulting in a dynamic population capable of maintaining pathogens independent of the national on-farm herd. The cull sow marketing network can be considered a dynamic, independent herd capable of acting as a reservoir population for pathogens and could facilitate undetected and unmonitored pathogen movement over great distances. The geographic basin of each slaughter facility is, for all practical purposes, nationwide creating connections between farms from disparate regions of the United States as farms from all regions provide animals to the cull sow marketing herd. Similarly, a study of the animal marketing system in the United Kingdom[17] found movements within the UK network increased the number of indirect connections between farms by 50%. Our data, further supported by the UK study, bring to light the potential dangers of this marketing network model.

The cull sow market is both complex and obscure. As previously hypothesized, up to 14% of sows have an extended period from farm removal to slaughter.[2] This study supports that idea, with 8.9% of sows remaining in the marketing channel for greater than 5 days. Current US guidelines prohibit animals from being at a single location in the marketing channel for more than 120 hours.[18] Assuming that market participants are compliant with federal law, sows in the channel for more than 5 days have been at multiple collection points in the network. In the case where animals were in the marketing channel for 40 days, animals would have been in 8 or more collection points prior to slaughter. In addition to significant disease dissemination concerns, there are animal welfare concerns. The extended time sows spend within the marketing channel may result in a reduced quality of life due to various factors.[4,5]

In both this study and prior work,[2] we were unable to locate data that would facilitate tracking the movement of sows between their entry into the marketing network and their arrival at the slaughter facility. Tracing animals from farm to slaughter is important because sows from a single farm may be sent to multiple slaughter facilities. In this limited but representative data set, greater than 40% of premises had animals identified at two or more slaughter facilities. These data are congruent with known market practices, specifically one of the greatest value creation actions of sorting sows at local collection points to meet the specific sow quality preferences of a slaughter facility.

The results of this study suggest that the characteristics of the US cull sow marketing network holds the potential to transmit disease in an undetected manner prior to arrival at a slaughter facility. The mixing and distribution of sows within the dynamic cull sow market population may result in pathogens being maintained and distributed across large geographic regions. Because of the lack of measurement, there is no direct evidence of disease transmission within the network. However, Senecavirus A infections detected in sows at harvest suggest that infections within the network are common and was further supported by an investigation within the North Carolina swine industry.[19] The discordance between farm status and individual sow status at harvest strongly suggests that infection occurred within the marketing channel.

While these data provide a meaningful snapshot of the US cull sow marketing network, they strongly suggest that comprehensive tracking and monitoring of animals in the cull sow marketing network is necessary. To achieve a comprehensive understanding of the network to facilitate the design of systematic mitigation strategies, capturing and maintaining records of individual sow movements within and between collection points is necessary. Ideally these data would be captured and maintained in a manner that would give regulators and the industry quick and easy access in the face of a novel disease outbreak to limit the impact of the cull sow marketing network on US herd health. The current structure of the US cull sow marketing network warrants a robust reevaluation of biosecurity practices by the industry to ensure business continuity if an FAD is introduced or other novel pathogen emerges in the United States.

Implications

Under the conditions of this study:

- Cull sow marketing network attributes serve as a potential means of disease spread.
- The time sows are in the channel creates a potential disease reservoir population.
- Sow movements within the marketing network connect geographically diverse regions.

Acknowledgments

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Conflict of interest

None reported.

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PEER REVIEWED ORIGINAL RESEARCH

Reduced vitamin supplementation with fat-soluble vitamins A, D, and E added at National Research Council requirements may not be adequate for optimal sow and progeny performance

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Summary

Objective: To evaluate performance and physiological vitamin status of sows and progeny fed 2 vitamin supplementation levels, industry vs reduced (all vitamins reduced with fat-soluble vitamins added at National Research Council recommendations).

Materials and methods: Sows (n = 244) were allotted in a randomized complete block design to 1 of 2 vitamin supplementation levels. At weaning, 765 progeny from a subset of sows were allotted to treatments in a 2 × 2 factorial arrangement of two sow and two nursery vitamin supplementation levels with 15 pens/treatment. Performance and vitamin status of sows and progeny were measured from farrowing to nursery exit.

Results: Reduced vitamin supplementation reduced sow lactation feed intake ($P = .01$), hepatic vitamin A ($P = .001$), and serum vitamin D ($P < .001$), but did not affect sow body weight or litter performance. Regardless of vitamin levels fed to the sow, progeny fed reduced levels post weaning had decreased circulating ($P < .001$) and stored ($P = .03$) vitamin levels and a reduction in average daily gain ($P < .001$), average daily feed intake ($P < .001$), gain:feed ratio ($P = .002$), and body weight ($P < .001$) at the end of the nursery period compared to progeny fed industry levels.

Implications: Reduced vitamin supplementation reduced sow feed intake without affecting sow or litter performance, but decreased circulating and stored vitamin levels in sows could impact long-term reproductive performance. Reduced vitamin inclusion levels in nursery diets reduced performance and serum vitamin concentrations compared to industry vitamin levels.

Keywords: swine, sow, vitamin, serum, performance

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Resumen - La reducción de suplementos vitamínicos con vitaminas A, D, y E solubles en grasa agregadas en los requisitos del Consejo Nacional de Investigación puede no ser adecuada para un rendimiento óptimo de la cerda y la progenie

Objetivo: Evaluar el rendimiento y el estado fisiológico vitamínico de cerdas y su progenie alimentadas con 2 niveles de suplementos vitamínicos, la recomendación de la industria frente a la reducida (todas las vitaminas reducidas con vitaminas liposolubles agregadas según las recomendaciones del Consejo Nacional de Investigación).

Materiales y métodos: Las cerdas (n = 244) fueron asignadas en un diseño de bloques completos al azar a 1 de 2 niveles de suplementación vitamínica. Al destete, 765 descendientes de un subconjunto de cerdas se asignaron a tratamientos en una disposición factorial 2 × 2 de dos niveles de suplementación vitamínica, dos de cerdas y dos de destetados con 15 corrales/tratamiento. Se midió el rendimiento y el estado vitamínico de las cerdas y la progenie desde el parto hasta la salida del destete.

Resultados: La reducción de la suplementación con vitaminas redujo la ingesta de alimento durante la lactancia ($P = .01$), la vitamina A hepática ($P = .001$), y la vitamina D en suero ($P < .001$), pero no afectó el peso corporal de la cerda ni el rendimiento de la camada. Independientemente de los niveles de vitamina alimentados a la cerda, la progenie alimentada con niveles reducidos después del destete tuvo niveles de vitamina circulantes ($P < .001$) y almacenados ($P = .03$) disminuidos y una reducción en la ganancia diaria promedio ($P < .001$), promedio diario de consumo de alimento ($P <. 001$),

RBH, KAM, RLM, JAM: United Animal Health, Sheridan, Indiana.

MAA: Pork Veterinary Solutions, New Palestine, Indiana.

RGM: Veterinary Diagnostic Laboratory, College of Veterinary Medicine, Iowa State University, Ames, Iowa.

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proporción ganancia: alimento ($P = .002$), y peso corporal ($P < .001$) al final del período de destete en comparación con los niveles recomendados por la industria para la alimentación de la progenie.

Implicaciones: La reducción de la suplementación con vitaminas redujo la ingesta de alimento de la cerda sin afectar el rendimiento de la cerda o de la camada, sin embargo, la disminución de los niveles de vitaminas circulantes y almacenadas en las cerdas podría afectar el rendimiento reproductivo a largo plazo. Los niveles reducidos de inclusión de vitaminas en las dietas de lechones destetados redujeron el rendimiento y las concentraciones séricas de vitaminas en comparación con los niveles de vitamina recomendados por la industria.

Résumé - Une supplémentation réduite en vitamines avec les vitamines liposolubles A, D, et E ajoutées selon les exigences du National Research Council peut ne pas être suffisante pour des performances optimales des truies et de leur progéniture

Objectif: Évaluer les performances et le statut vitaminique physiologique des truies et de leur descendance nourries avec deux niveaux de supplémentation vitaminique, industrie vs réduite (toutes les vitamines sont réduites avec des vitamines liposolubles ajoutées selon les recommandations du National Research Council).

Matériels et méthodes: Les truies (n = 244) ont été réparties dans un plan en blocs complets randomisés à un des deux niveaux de supplémentation en vitamines. Au sevrage, 765 descendants d'un sous-ensemble de truies ont été affectés aux traitements dans un arrangement factoriel 2 × 2 de deux truies et deux niveaux de supplémentation vitaminique en pouponnière avec 15 enclos/traitement. Les performances et le statut vitaminique des truies et de leur descendance ont été mesurés de la mise bas à la sortie de la pouponnière.

Résultats: Une supplémentation réduite en vitamines a réduit la consommation alimentaire de la truie en lactation ($P = .01$), la vitamine A hépatique ($P = .001$), et la vitamine D sérique ($P < .001$), mais n'a pas affecté le poids corporel de la truie ou les performances de la portée. Indépendamment des niveaux de vitamines donnés à la truie, la descendance nourrie à des niveaux réduits après le sevrage avait une diminution des niveaux de vitamines circulantes ($P < .001$) et stockées ($P = .03$) et une réduction du gain quotidien moyen ($P < .001$), de la moyenne quotidienne de prise alimentaire ($P < .001$), du rapport gain:aliment ($P = .002$), et du poids corporel ($P < .001$) à la fin de la période de pouponnière comparativement à la progéniture nourris avec les niveaux de l'industrie.

Implications: Une supplémentation réduite en vitamines a réduit la consommation alimentaire des truies sans affecter les performances de la truie ou de la portée, mais une diminution des niveaux de vitamines circulantes et stockées chez les truies pourrait avoir un impact sur les performances de reproduction à long terme. Les niveaux réduits de vitamines dans les régimes alimentaires en pouponnières ont réduit les performances et les concentrations de vitamines sériques par rapport aux niveaux de vitamines de l'industrie.

Recommendations from nutritionists, genetic suppliers, and academia offer a range of vitamin inclusion levels for each production phase. The most recently published vitamin requirement estimates from the National Research Council (NRC)[1] are below the current recommendations of genetic companies and standard inclusion levels observed in commercial industry diets.[1-4] Vitamins are included above requirement levels to provide a margin of error against losses in vitamin efficacy during storage and feed manufacturing and provide an insurance factor for ingredient variability and diet mixing imprecision. However, even after accounting for a liberal 15% safety margin,[5] current industry supplementation recommendations for fat-soluble vitamins (A, D, E, and K) are commonly 1.3 to 7.6 times greater than the current sow NRC requirements. The historical approach to vitamin research was to establish requirements based on levels required to alleviate or prevent symptoms of deficiency rather than establish requirements for optimal performance.[6] Therefore, the objective of this research is to evaluate the bodily vitamin concentrations and performance of sow and progeny fed current industry standard vitamin inclusion levels in sow and nursery diets. The hypothesis is commercial industry levels improve sow and progeny performance and vitamin status compared to reduced vitamin supplementation with added fat-soluble vitamins at NRC requirements.

Animal care and use

All experimental procedures were reviewed and approved by the Animal Care and Use Committee of United Animal Health, Inc.

Materials and methods

Animals, housing, and management

A total of 244 sows (PIC 1050, Pig Improvement Company) with mean body weight (BW) of 250.9 kg (range, 166.9-317.1 kg) and mean parity of 2.5 (range, 0-7) were used. The trial was set up as a randomized complete block design (RCBD) with two treatments (industry vs reduced vitamin supplementation level). The industry vitamin supplementation treatment levels were within ranges reported in commercial production surveys.[2,7] The reduced vitamin supplementation treatment contained vitamins A, D, E, and K added at NRC requirements[1] for gestation and water-soluble vitamins supplemented at approximately half the inclusion rate of the industry treatment. Gestating sows from three breeding groups within a batch farrow system were individually housed and received a common diet with industry standard vitamin levels prior to study enrolment. Due to the arrangement of the facility feeding system and pig flow, the two vitamin supplementation levels were fed for the entire lactation period as well as a portion of gestation immediately preceding lactation: group one was fed for 39 days of gestation, group two for 70 days, and group three for 81 days. Sows were sorted by vitamin supplementation level into separate gestation feed rows with equal representation of parity groupings per row to facilitate feeding of the two diets. Upon entry into farrowing, sows (n = 122/treatment) were randomly allotted to trial in replicate blocks based on parity and BW; blocks were contained within farrowing rooms.

Each lactation stall was equipped with a box feeder and individual hopper. When necessary, suckling litter sizes were standardized within 24 hours of birth according to farm standard procedure by transferring piglets among sows on the same treatment; sows that received piglets from a different treatment were removed from the trial. Piglets that were cross fostered were ineligible for serum vitamin analysis.

At weaning, a subsample (765 piglets; PIC 337 × PIC 1050, mean [SD] initial BW: 6.38 [1.09] kg) representative of all 96 litters of group three were allotted to pens (mean [SD]: 12.75 [0.44] pigs/pen) with .26 m^2/pig, round bar flooring, stainless-steel 2-hole feeders, and stainless-steel cup waterers. The trial was set up as a RCBD with blocking factors of sow parity and weaned piglet BW; litters were balanced across pens. There were 15 replicate pens for each of 4 treatments arranged in a 2 × 2 factorial design with two sow vitamin inclusion levels (industry vs reduced) and two nursery vitamin inclusion levels (industry vs reduced supplementation level for all vitamins and vitamins A, D, E, and K added at NRC requirement). The supplemented water-soluble vitamin levels of the reduced treatment were decreased proportionately to the reduction of the vitamin D level in the reduced treatment compared to the industry treatment. Porcine reproductive and respiratory syndrome and *Mycoplasma hyopneumoniae* were endemic in the herd but no clinical symptoms were present during the trial.

Experimental diets and feeding

All experimental diets were formulated to be adequate in all macronutrients according to NRC[1] and utilized up-to-date loading values for commodity grain ingredients. Sows were offered separate gestation and lactation diets (Table 1). In gestation, sows were fed once daily using a drop box set to deliver 1.8 to 2.7 kg feed in meal-form fed to maintain a target body condition score of 3 across all groups and treatments. Sows received experimental gestation diets for at least 6 weeks prior to being transferred to lactation. During lactation, sows were fed experimental lactation diets *ad libitum* and litters were not provided creep feed. At weaning, nursery diets were budgeted by weight until 6 weeks post weaning (Table 2). Within each production phase, diets were formulated to provide the same macronutrient and trace mineral nutrition with only the level of vitamin supplementation differing between treatments. Diets that were formulated to contain reduced levels of vitamins were manufactured and delivered to feeders before diets with industry levels of vitamins.

Performance measurements, sample collection, and analysis

Individual sow weights were recorded as sows were moved to farrowing (entry weight) 5 to 7 days prior to expected farrowing date, and at weaning. Sow weight post farrowing was calculated via a linear regression model (adjusted $r^2 = 0.93$):

Post-farrow sow weight = 29.31485 + (entry weight × 0.89191) + (parity × 1.30677) – (total born × 0.28966) – (native litter weight × 0.79842)

where entry weight is used to represent gravid sow weight at the conclusion of pregnancy and native litter weight indicates combined total weight of piglets born alive, stillborns, and mummified fetuses. Lactation feed intake was recorded. Litter performance was measured by recording native litter weight, standardized litter weight (standardization of litter size completed within first 24 hours post farrowing), number of pigs in standardized litters, piglet count at processing, litter wean weight, number of pigs weaned, and mortality. Litter average daily gain (ADG) was calculated as:

Litter ADG = (litter wean weight + mortality post-standardization weight – standardized litter weight) ÷ (piglet days of live pigs at weaning + piglet days of post-standardization mortality)

Piglet days represents the product of the number of piglets and their days of living for respective subsets ie, pigs alive at weaning, pigs that died post standardization, etc. Litter gain to feed ratio (G:F) was calculated as:

Litter G:F = (litter wean weight + mortality post-standardization weight – standardized litter weight) ÷ sow feed intake

Analysis of fat-soluble vitamin A (ultra-high performance liquid chromatography [UHPLC]), vitamin D (25-hydroxyvitamin D_2 and 25-hydroxyvitamin D_3; liquid chromatography with tandem mass spectrometry [LC/MS/MS]), and vitamin E (UHPLC) in blood serum and liver samples (wet-tissue basis) were performed through the Iowa State University Veterinary Diagnostic Laboratory. Sows from the third group (n = 96) were bled within 24 hours of farrowing (d 0) and 1 day prior to weaning. From the same group of sows, one average-sized pig per litter was tagged and bled on day 5 post farrowing. One day prior to weaning (d 19), pigs bled and tagged on day 5 post farrowing and two additional pigs per litter were bled (total n = 288). Simultaneously, pigs tagged on day 5 were euthanized and liver samples collected. At weaning, all sows from the third group were shipped to a packing plant and liver samples collected.

At 40 days post weaning, 2 pigs/sow of the third sow group from whom blood samples had been collected at weaning were reidentified (n = 192) and bled. One average-sized pig per pen, for a total of 15 pigs/treatment, was euthanized and liver sample collected.

Statistical analysis

Normality of distribution and identification of outliers were determined for all metrics using the UNIVARIATE procedure of SAS Enterprise Guide 7.1 (SAS Institute Inc). An observation more or less than 3 standard deviations from the mean for each metric was deemed an outlier and not included in the dataset. A linear mixed model (MIXED procedure of SAS) was used to analyse sow and litter performance data using sow as the experimental unit, dietary treatment as the fixed effect, and random effects of group and block nested within group. A linear mixed model was also used to analyse nursery performance metrics (experimental unit of pen) as a RCBD with fixed effects of sow diet, nursery diet, and the interaction, and random effect of nursery block. Physiological vitamin concentrations measured in sow progeny were averaged within litter at each timepoint (birth, weaning, nursery exit) and similarly analysed with block included as a random effect. Morbidity, mortality, and other health-related metrics were analysed using (negative) binomial distributions for count data with small means via proc GLIMMIX. The REG procedure of SAS was used to generate the prediction equation for post-farrowing weight. Sow entry weight was used as a covariate for post-farrowing and exit weights; sow entry weight was insignificant ($P \geq .28$) as a covariate for lactation feed intake, number of pigs at weaning, weaning weight, litter ADG, and litter G:F and therefore not included in the model for those metrics. Standardized litter size, birthweight, and nursery start weight were used as

Table 1: Ingredients and calculated nutrient composition of gestation and lactation diets

	Gestation		Lactation	
	Industry	**Reduced**	**Industry**	**Reduced**
Feed component, %				
Ground corn	79.77	80.02	66.07	66.31
Soybean meal	14.73	14.61	26.77	26.66
Choice white grease	1.00	1.00	2.75	2.75
Monocalcium phosphate	1.34	1.34	1.26	1.26
Limestone	1.23	1.23	1.16	1.16
Salt	0.18	0.18	0.21	0.21
L-Lysine HCl	0.21	0.21	0.29	0.29
L-Threonine	0.09	0.09	0.11	0.11
DL-Methionine	0.09	0.09	0.02	0.02
Industry sow VTM premix*	0.60	0.22	0.60	0.22
Reduced sow VTM premix†	0	0.25	0	0.25
Choline chloride, 60%	0.13	0.13	0.13	0.13
Feed additives‡	0.63	0.63	0.63	0.63
Total	**100.00**	**100.00**	**100.00**	**100.00**
Calculated analysis				
ME, kcal/kg	3213	3220	3290	3298
Crude protein, %	13.59	13.61	18.16	18.18
Total Lysine, %	0.79	0.79	1.17	1.17
SID Lysine, %	0.70	0.70	1.05	1.05
SID Methionine, %	0.29	0.29	0.27	0.27
SID Cysteine, %	0.21	0.21	0.26	0.26
SID Threonine, %	0.49	0.49	0.66	0.66
SID Tryptophan, %	0.13	0.13	0.19	0.19
SID Valine, %	0.52	0.52	0.71	0.72
SID Isoleucine, %	0.45	0.45	0.65	0.65
SID Leucine, %	1.11	1.12	1.38	1.38
SID Lysine:ME, g/Mcal	2.45	2.45	3.55	3.55
Calcium, %	0.85	0.81	0.85	0.81
Total Phosphorus, %	0.58	0.58	0.62	0.62
Added vitamin A, IU/kg	11,160	3999	11,160	3999
Added vitamin D, IU/kg	2213	794	2213	794
Added vitamin E, IU/kg	66.3	43.7	66.3	43.7
Added vitamin K, mg/kg	1.4	0.51	1.4	0.51

Table 1: Continued

	Gestation		Lactation	
	Industry	**Reduced**	**Industry**	**Reduced**
Total vitamin content				
Vitamin A, IU/kg	11,332	4173	11,316	4156
Vitamin D, IU/kg	2213	794	2213	794
Vitamin E, IU/kg	75.6	56.2	74.4	51.9
Vitamin K, mg/kg	1.4	0.51	1.4	0.51
Riboflavin, mg/kg	8.0	3.7	8.2	4.0
Niacin, mg/kg	66.0	37.7	65.4	37.1
Pantothenic acid, mg/kg	30.4	15.3	31.4	16.2
Biotin, mg/kg	0.53	0.25	0.56	0.27
Vitamin B_{12}, µg/kg	30.9	11.0	30.9	11.0
Vitamin B_6, mg/kg	6.17	6.01	7.16	7.01
Thiamin, mg/kg	3.43	3.28	3.34	3.19
Folic acid, mg/kg	1.9	0.89	2.1	1.0
Choline, mg/kg	1526	1528	1765	1766

* Industry treatment premix contained phytase (Huvepharma), retinyl propionate, vitamin A acetate (cross-linked beadlet), cholecalciferol (vitamin D_3), dl-alpha tocopheryl acetate (vitamin E), water-soluble vitamin supplements, and inorganic trace minerals.

† Reduced treatment premix was specifically formulated to achieve NRC fat-soluble vitamin levels[1] when included at 0.25% in diets containing 0.22% of a standard industry VTM premix, and using the same vitamin sources as the standard industry VTM premix.

‡ Feed additives included a macromineral supplement (sulfur, magnesium, and potassium; Mosaic Company) and a hydrated sodium-calcium aluminosilicate/yeast cell wall/direct fed microbial bacillus product (United Animal Health).

VTM = vitamin and trace mineral; SID = standardized ileal digestibility; ME = metabolizable energy; NRC = National Research Council.

covariates for the analyses of number of pigs at weaning, litter wean weight, and nursery growth performance metrics, respectively. Results were considered statistically significant at $P \leq .05$; results with P values > .05 and ≤ .10 were considered a trend.

Results

Sow and litter performance

Sow weight at entry into lactation was significantly heavier ($P = .05$) for sows fed the reduced vitamin supplementation treatment than for sows fed the industry vitamin levels treatment. After accounting for entry weight, there was no evidence for difference in sow weights post farrowing ($P = .43$) or at the end of lactation ($P = .26$; Table 3). There was a 5% reduction ($P = .02$) in lactation average daily feed intake (ADFI) of sows fed reduced vitamin supplementation levels compared with sows fed industry vitamin levels. There was no evidence for differences in native litter or standardized litter performance with the exception that sows fed industry levels of vitamins tended to improve ($P = .08$; Table 4) litter G:F.

There was no evidence for differences in sow serum vitamin A concentrations on day 0 ($P = .96$; Figure 1) or day 19 ($P = .98$) of lactation regardless of vitamin supplementation level. However, vitamin A supplementation at NRC requirement for gestation reduced ($P = .001$) vitamin A concentrations in the liver by 15.67% compared with sows fed industry vitamin level. Serum vitamin A in piglets did not differ ($P = .15$) between sow vitamin supplementation levels at day 5, but on day 19 serum vitamin A was 18.81% greater ($P = .003$) in piglets from sows receiving NRC level compared to piglets from sows fed industry level. On day 19, numerically lower ($P = .27$) hepatic vitamin A concentration was observed among offspring of sows receiving NRC level compared to offspring of sows fed industry level.

For sows fed NRC recommended level compared with industry vitamin level, serum vitamin D was decreased ($P < .001$; Figure 2) by 24.52% and 31.24% on days 0 and 19, respectively. In piglets from sows fed NRC recommended level, serum vitamin D was less ($P < .001$) on both day 5 (49.13% less) and day 19 (37.03% less) compared to piglets from sows fed industry vitamin level.

Serum vitamin E on day 0 was reduced ($P = .01$; Figure 3) in sows fed NRC recommended level compared with industry vitamin level, but no evidence of difference ($P = .92$) was observed on day 19. No evidence for a difference ($P = .91$) in sow liver vitamin E concentration was observed between treatments. Maternal vitamin supplementation level did not affect ($P = .29$) piglet serum vitamin E at day 5 but by day 19 serum vitamin E was 16.42% less ($P < .001$) in offspring from sows fed NRC recommended level compared to offspring of sows fed industry level. Moreover, vitamin E liver concentration was reduced ($P < .001$) over 25% in piglets from sows fed NRC recommended level compared to sows fed industry level.

Table 2: Ingredients and calculated nutrient composition of nursery diets fed to weaned pigs for 40 days

Diet: / Feed budget:	Phase 1 0.91 kg/pig		Phase 2 1.81 kg/pig		Phase 3 3.63 kg/pig		Phase 4 until week 6	
	Industry	Reduced	Industry	Reduced	Industry	Reduced	Industry	Reduced
Feed component, %								
Ground corn	28.67	28.57	41.22	41.12	42.54	42.43	50.49	50.47
Soybean meal	14.92	14.92	32.40	32.39	32.98	32.96	33.66	33.66
Basemix*	54.30	54.30	22.55	22.55	10.05	10.05	0.05	0.05
Dried distillers grains & solubles	0	0	0	0	10.00	10.00	10.00	10.00
Choice white grease	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00
Limestone	0.02	0.14	0.50	0.61	0.86	0.99	1.13	1.15
Monocalcium phosphate	0.07	0.07	0.51	0.51	0.55	0.55	0.37	0.37
Salt	0.02	0	0.43	0.43	0.41	0.41	0.61	0.61
L-Lysine HCl	0	0	0.19	0.19	0.33	0.33	0.36	0.36
DL-Methionine	0	0	0.10	0.10	0.15	0.15	0.18	0.18
L-Threonine	0	0	0.06	0.06	0.08	0.08	0.09	0.09
Copper chloride, 54%	0	0	0.02	0.02	0.03	0.03	0.04	0.04
Phytase†	0	0	0.02	0.02	0.02	0.02	0.02	0.02
Industry nursery VTM premix‡	1.00	0	1.00	0	1.00	0	1.00	0
Reduced nursery VTM premix§	0	1.00	0	1.00	0	1.00	0	1.00
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Calculated analysis								
ME, kcal/kg	3332	3329	3221	3220	3198	3197	3237	3237
Crude protein, %	20.45	20.46	22.06	22.06	23.28	23.27	22.44	22.44
Total Lysine, %	1.49	1.49	1.51	1.51	1.54	1.54	1.45	1.45
SID Lysine, %	1.34	1.34	1.35	1.35	1.36	1.36	1.28	1.28
SID Methionine, %	0.58	0.58	0.55	0.55	0.54	0.54	0.50	0.50
SID Cysteine, %	0.27	0.27	0.27	0.27	0.29	0.29	0.29	0.29
SID Threonine, %	0.83	0.83	0.81	0.81	0.82	0.82	0.77	0.77
SID Tryptophan, %	0.24	0.24	0.25	0.25	0.24	0.24	0.23	0.23
SID Valine, %	0.94	0.94	0.88	0.88	0.88	0.88	0.83	0.83
SID Isoleucine, %	0.72	0.72	0.81	0.81	0.83	0.83	0.80	0.80
SID Leucine, %	1.41	1.41	1.49	1.49	1.66	1.66	1.63	1.63
SID Lys:ME, g/Mcal	4.03	4.02	4.19	4.19	4.25	4.25	3.95	3.95
Calcium, %	0.90	0.90	0.80	0.80	0.76	0.77	0.65	0.65
Total Phosphorus, %	0.82	0.82	0.71	0.71	0.65	0.65	0.52	0.52
Zinc, mg/kg	3025	3025	1532	1532	766	766	127	127
Added vitamin A, IU/kg	11,111	2249	11,111	2249	11,111	2249	4012	1742
Added vitamin D, IU/kg	2800	220	2800	220	2800	220	948	198
Added vitamin E, IU/kg	132.3	16.1	132.3	16.1	132.3	16.1	26.7	10.9
Added vitamin K, mg/kg	1.23	0.51	1.23	0.51	1.23	0.51	0.51	0.51

Table 2: Continued

Diet: / Feed budget:	Phase 1 0.91 kg/pig		Phase 2 1.81 kg/pig		Phase 3 3.63 kg/pig		Phase 4 until week 6	
	Industry	Reduced	Industry	Reduced	Industry	Reduced	Industry	Reduced
Total vitamin content								
Vitamin A, IU/kg	11,462	2553	11,222	2313	11,226	2315	4134	1881
Vitamin D, IU/kg	2800	220	2800	220	2800	220	946	201
Vitamin E, IU/kg	135.6	19.3	137.0	20.7	137.1	20.8	32.4	16.7
Vitamin K, mg/kg	1.25	0.50	1.25	0.50	1.25	0.50	0.51	0.50
Riboflavin, mg/kg	8.2	2.0	8.3	2.1	8.2	2.1	6.0	2.5
Niacin, mg/kg	102.4	20.5	107.0	25.0	106.7	24.8	53.4	26.5
Pantothenic acid, mg/kg	61.0	10.3	62.7	12.0	62.5	11.8	26.8	11.8
Biotin, mg/kg	0.08	0.08	0.11	0.11	0.11	0.11	0.11	0.11
Vitamin B_{12}, µg/kg	33.1	2.2	33.1	2.2	33.1	2.2	22.0	4.4
Vitamin B_6, mg/kg	7.3	4.1	10.0	6.8	10.1	6.9	7.1	7.1
Thiamin, mg/kg	5.0	2.8	6.3	4.0	6.2	4.0	4.0	4.0
Folic acid, mg/kg	0.85	0.37	1.04	0.56	1.04	0.56	0.54	0.52
Choline, mg/kg	1286	1287	1427	1427	1392	1392	1316	1316

* Nursery basemix unique to each nursery phase containing one or more of plasma, animal-derived protein products, grain byproducts, direct fed microbial bacillus strains, or specialty ingredients for gut health and conditioning (United Animal Health).

† Natuphos-P E 2500 (BASF Corporation) providing 400 phytase units/kg diet.

‡ Industry treatment premix contained vitamin A acetate (cross-linked beadlet), cholecalciferol (vitamin D_3), dl-alpha tocopheryl acetate (vitamin E), water-soluble vitamin supplements, and inorganic trace minerals.

§ Reduced treatment premix was specifically formulated to achieve NRC A, D, E, and K vitamin levels when included at 1.00% in diets and used the same vitamin sources as the Industry nursery VTM premix.

VTM = vitamin and trace mineral; SID = standardized ileal digestibility; ME = metabolizable energy; NRC = National Research Council.

Nursery performance

Across treatments, nursery mortality, removals, and medication rates were low (Table 5). No interactions ($P \geq .26$) between sow vitamin supplementation and nursery pig supplementation levels were observed for nursery growth performance. Pigs fed industry levels in nursery had increased ADG ($P < .001$), ADFI ($P < .001$), G:F ($P = .002$), and BW ($P < .001$) at the end of the nursery period compared to pigs fed reduced levels in the nursery, regardless of vitamin level fed to the sow (Table 6). Pigs weaned from sows fed industry vitamin levels tended to be heavier ($P = .09$) at 40 days post weaning than pigs weaned from sows fed reduced vitamin levels.

Nursery pig vitamin levels

Downstream impact of maternal supplementation level on piglet serum vitamin levels at 40 days post weaning reduced serum vitamin A ($P = .02$) concentration among offspring whose dams were fed NRC recommended compared to industry levels (Table 5 and Figure 4). An interaction was observed (sow × nursery, $P = .02$) between sow and nursery vitamin supplementation level for serum vitamin E due to the NRC level fed to the sow ($P = .02$) or nursery pig ($P < .001$) reducing nursery pig serum vitamin E, although the reduction observed among nursery pigs fed NRC recommended levels and whose dams were fed industry levels was not as severe as the reduction observed in pigs fed NRC levels and whose dams also were fed NRC levels. Regardless of vitamin levels fed to their dam, hepatic stores of vitamin E were also less ($P = .03$) at 40 days post weaning in pigs fed NRC levels compared to pigs fed industry vitamin levels. Nursery vitamin supplementation at NRC levels compared to industry levels also reduced piglet serum concentrations of vitamin A ($P < .001$) and vitamin D ($P < .001$) after 40 days, regardless of sow vitamin supplementation. An interactive effect (sow × nursery, $P = .01$) of sow and nursery vitamin supplementation on hepatic vitamin A stores at the end of nursery was observed because industry supplementation level in the nursery improved ($P < .001$) stores compared to NRC level supplementation, but the improvement was less pronounced in offspring of sows which had been fed industry vitamin levels compared to offspring of sows which had been fed NRC vitamin levels.

Discussion

When provided in excess, fat-soluble vitamins accumulate within the animal. One limitation of this study is that initial body stores of vitamins were not controlled for, nor was the study designed to measure the impact of the duration of reduced vitamin supplementation during gestation. Since NRC vitamin requirements do not change throughout gestation, further research is needed to understand how stage of gestation might influence vitamin requirements and depletion of maternal reserves.

Table 3: The effect of vitamin inclusion levels in gestation and lactation diets on sow performance*

	Vitamin Level		Pooled	
	Industry	Reduced	SEM	$P^{\dagger}$
Sows completing trial, No.	116	117		
Sow BW at entry, kg	248.05	251.95	7.574	.05
Sow BW post farrowing, kg‡,§	233.40	233.90	1.013	.43
Sow BW at exit, kg§	216.56	218.76	5.353	.26
Sow BW loss from entry, kg	33.45	32.91	6.832	.79
Sow BW loss post farrowing, kg¶	15.93	15.57	5.437	.83
Lactation length, d	19.00	19.03	0.520	.74
Lactation ADFI, kg	5.89	5.57	0.386	.02
G:F, kg:kg**	0.308	0.315	0.040	.70
Sows treated, No.	11	15	NA	.46
Therapeutic medication treatments, No.	24	35	NA	.59

* A total of 244 sows (PIC 1050 genetics) were allotted to dietary treatments supplemented with either standard industry vitamin levels (n = 122; mean parity 2.5) or reduced vitamin levels with fat-soluble vitamins added at 2012 NRC levels[1] for gestation (n = 122; mean parity 2.6). Experimental diets were fed from ≥ 6 weeks before farrowing through weaning.

† Performance data analyzed using linear and generalized linear mixed models and $P \leq .05$ was considered significant.

‡ Post-farrowing sow weight = 29.31485 + (Entry weight, kg × 0.89191) + (parity × 1.30677) – (total born × 0.28966) – (native litter weight, kg × 0.79842)

§ Sow entry weight at time of placement into farrowing room was used as a covariate for post-farrowing and exit weight.

¶ Weight difference post farrowing = exit weight – post-farrowing weight.

** Sow G:F = (sow lactation weight change + litter weight gain) ÷ sow feed intake

BW = body weight; ADFI = average daily feed intake; G:F = body weight gain to feed intake ratio; NA = not applicable; NRC = National Research Council.

Apart from vitamin supplementation level impacting pig physiology and performance in this study, measured physiological concentrations of vitamins A and D were low compared to longstanding reference values[8] used as the basis for veterinary diagnostics (Scott L. Radke, DVM, email communication, September 2019). Serum vitamin A levels measured in both sows and piglets were well below the minimum thresholds of reference ranges (0.25-0.40 mg/kg for sows; 0.40-0.50 mg/kg for neonates) as were piglet liver concentrations (36-57 mg/kg for weaned pigs; 57-114 mg/kg for grow-finish pigs). Serum vitamin D levels measured in NRC-level fed sows of this study were below historic "normal" reference ranges (35-100 ng/mL for sows) and regardless of maternal feeding level, both neonates and especially weaning-age piglets had levels below or well-below the "normal" reference ranges (5-15 ng/mL for neonates; 25-30 ng/mL for weaned piglets; 30-35 ng/mL for grow-finish pigs). Although sow vitamin E concentrations fell just below or aligned with historic reference values for serum and liver depending on sampling timepoint, notably suckling piglet levels were well above historic reference values (1.5-2.5 mg/kg serum; 3.0-5.0 mg/kg liver). However, post weaning piglet serum vitamin E concentrations were lower than "normal" range (2.0-2.5 mg/kg serum).

Serum and tissue levels are not positioned for use as sole diagnostic criterion for establishing deficiencies since immunological and physiological anomalies can impact the dynamic levels measured; clinical or pathological signs of deficiency should be used to support diagnoses of vitamin deficiencies.[8] Expected tissue levels as reported by Puls[8] are based on literature and case studies from 1981-1993 (vitamin A) or dating back even farther to 1969 (vitamin E) and 1964 (vitamin D). While management and rearing conditions from that era would be hardly recognizable today, documented changes in pig physiology include greater reproductive prolificacy, faster growth, more efficient nutrient utilization, later maturation, and altered tissue deposition of chemical components accompanying high lean-gain genotypes.[9-11] These changes not only could be responsible for shifting nutrient requirements and highlight the need for updated vitamin supplementation recommendations, but could also impact vitamin accumulation in tissues. Caution should be exercised in interpreting tissue vitamin levels against traditional "normal" ranges until research validates expected tissue levels in healthy pigs of modern genotypes reared in commercial environments.

The results of the current study suggest there is an industry wide need to re-evaluate vitamin supplementation levels. The vitamin A requirement for optimal reproductive performance is age dependent and likely greater in younger sows.[12] Gilts that received adequate dietary vitamin A through nine months of age completed two reproductive cycles without vitamin A supplementation without developing deficiency symptoms, suggesting adequate vitamin A stores in the liver.[13,14] Moreover, mature sows without vitamin A supplementation required 4 parities before deficiency symptoms became evident.[15] Thus, it is important that females receive adequate

Table 4: The effect of vitamin inclusion levels in gestation and lactation diets on litter performance*

	Vitamin Level		Pooled	
	Industry	Reduced	SEM	*P*†
Litters, No.	116	117		
Total born, No.	15.14	15.39	0.353	.65
Born alive, No.	13.62	13.61	0.306	.98
Stillborn, No.	1.10	1.28	NA	.32
Mummies, No.	0.29	0.23	NA	.30
Native litter weight, kg	21.71	21.11	0.421	.24
Standardized litter size, No.	12.57	12.46	0.131	.41
Standardized litter weight, kg	18.92	18.38	0.315	.13
Pigs weaned, No.‡	11.90	11.69	0.112	.11
Total wean weight, kg‡	70.84	71.28	1.712	.69
Mean wean weight, kg	5.96	6.01	0.116	.57
ADG, kg§	0.23	0.24	0.003	.39
G:F, kg:kg¶	0.50	0.53	0.038	.08
Total mortality, No.	185	219	NA	.16
Mortality post standardization, No.**	74	87	NA	.29
Nutritional mortality, No.††	20	25	NA	.52

* A total of 244 sows (PIC 1050 genetics) were allotted to dietary treatments supplemented with either standard industry vitamin levels (n = 122; mean parity 2.5) or reduced vitamin levels with fat-soluble vitamins added at 2012 NRC levels[1] for gestation (n = 122; mean parity 2.6). Experimental diets were fed from ≥ 6 weeks before farrowing through weaning.

† Performance data analyzed using linear mixed and generalized linear mixed models and $P \leq .05$ was considered significant.

‡ Number of pigs weaned was adjusted for standardized litter size, and weight was adjusted for the birthweight of the standardized litter.

§ Litter ADG = (litter wean weight + mortality post-standardization weight – standardized weight) ÷ (piglet days of live pigs at weaning + piglet days of post-standardization mortality)

¶ Litter G:F = (litter wean weight + mortality post-standardization weight - standardized weight) ÷ sow feed intake

** Pre-wean mortality post standardization (Industry = 4.94%; NRC = 5.77%) = No. of piglet deaths post standardization ÷ No. of piglets standardized.

†† Piglets that died post standardization were classified as a nutritional mortality if they were emaciated, thin, non-eater, etc.

G:F = body weight gain to feed intake ratio; ADG = average daily gain; NA = not applicable; NRC = National Research Council.

vitamin supplementation during gilt development for long-term reproductive success and might explain why vitamin supplementation level in gestation and lactation diets had no direct impact on sow or litter performance over the single reproductive cycle measured in this study. Nonetheless, serum and liver concentrations in this study suggest NRC-level fed sows deplete liver vitamin A stores to sustain circulating levels and offspring serum levels at birth via placental transfer. Since vitamin transfer from sow to offspring is a dynamic process, the serum concentration at birth provides minimal information on how fetal and neonatal hepatic vitamin A stores were established then modulated during lactation and could be responsible for the elevated serum vitamin A observed in offspring of NRC-level fed sows by the time of weaning.

Supplementation of vitamin D at current industry levels compared to NRC levels consistently increased serum vitamin D concentrations in both sows and piglets from birth to weaning. Current NRC requirements for vitamin D may be inadequate not only due to genetic advances in reproductive output, but a majority of vitamin D trials that established requirements were conducted when pigs had access to sunlight thus facilitating endogenous synthesis of vitamin D.[6,11] Placental transfer of vitamin D from sow to progeny is low and since piglets are born with low serum concentrations of 25-hydroxycholecalciferol [25(OH)D_3], a biomarker for vitamin D status, pigs are susceptible to vitamin D deficiency.[16-18] Nonetheless, providing supplemental 25(OH)D_3 to the dam can improve both sow and fetal vitamin D status.[19] Vitamin D supplementation can also improve the vitamin D status of young pigs without influencing growth performance or bone mineralization.[20] In a different study, litter weight gain from sows fed a diet with vitamin D at 2000 IU/kg was greater than that of litters from sows fed a diet with vitamin D at 200 IU/kg.[21] Larger doses of vitamin D (1400 and 2000 IU/kg) decreased the number of stillborn piglets compared with smaller doses in the diet (200 and 800 IU/kg).[17] In the present study, dietary

Figure 1: Impact of sow diet vitamin supplementation on sow and litter vitamin A levels. Sows were allotted to dietary treatments supplemented with either standard industry vitamin levels or reduced vitamin levels with fat-soluble vitamins added at 2012 National Research Council[1] gestation requirement. **A)** Sows (n = 96) were bled within 24 h of farrowing (d 0) and 1 d prior to weaning (d 19). **B)** Liver samples were collected from sows (n = 96) following weaning for liver vitamin analysis. **C)** Three average-sized piglets per sow were tagged (n = 144/treatment) and bled on d 5 and 19 post farrowing. **D)** One average-sized piglet per sow which had been bled on d 5 and 19 was subsequently euthanized for liver vitamin analysis (n = 48 per treatment). Historic physiological reference ranges are provided for context.[8] Data was analyzed using a linear mixed model with $P \leq .05$ considered significant (*). Error bars depict the standard error of the treatment means.

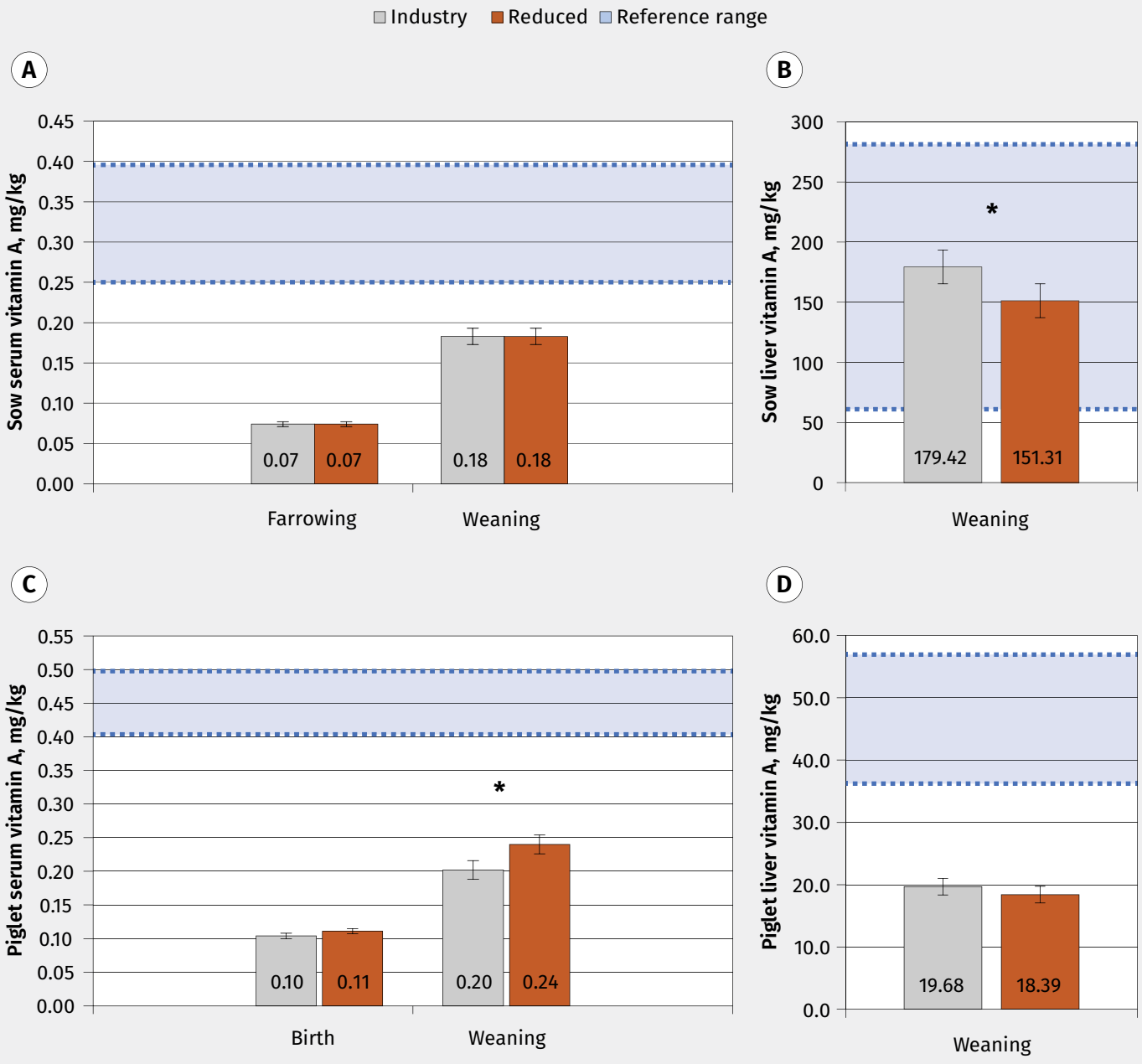
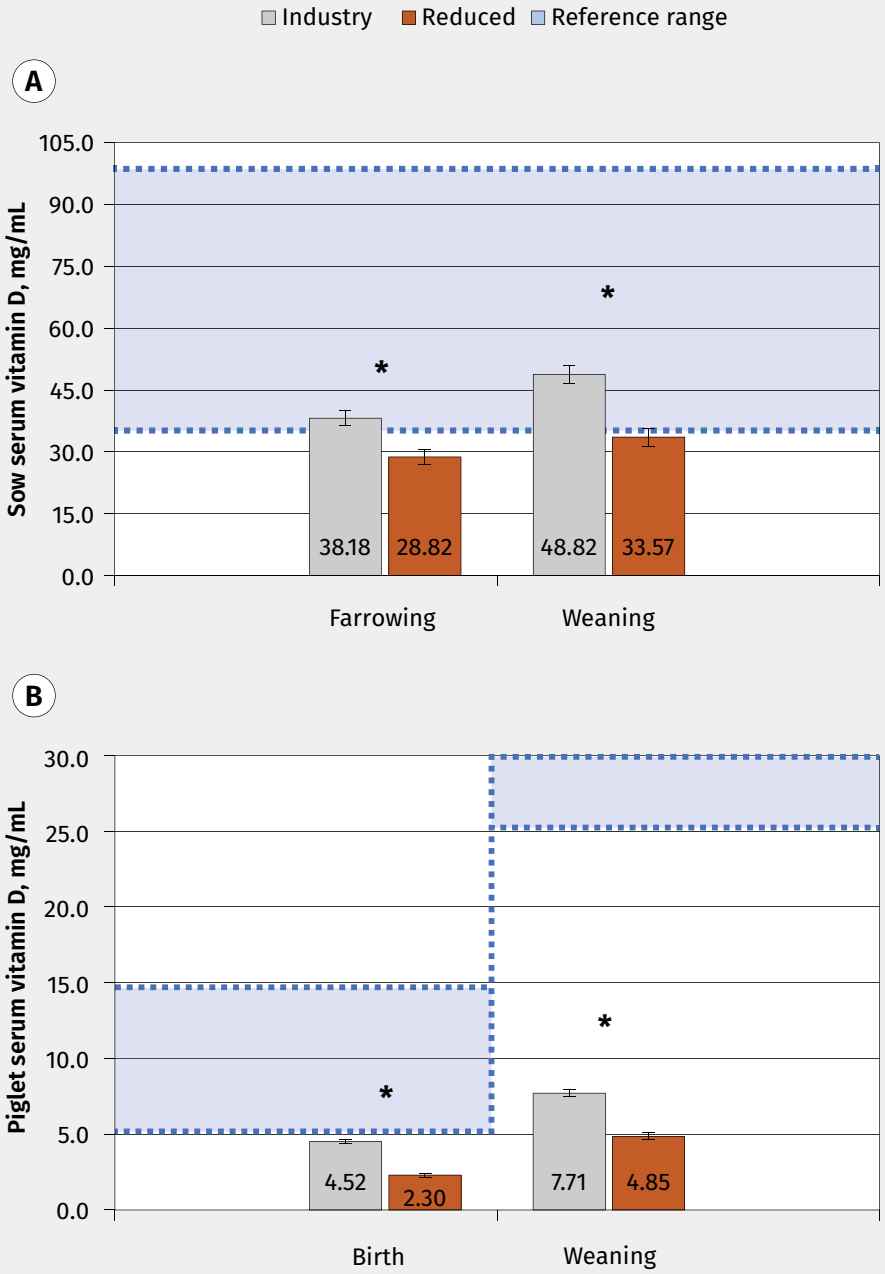


Figure 2: Impact of sow diet vitamin supplementation on sow and litter vitamin D (25-hydroxyvitamin D_2 and 25-hydroxyvitamin D_3) levels. Sows were allotted to dietary treatments supplemented with either standard industry vitamin levels or reduced vitamin levels with fat-soluble vitamins added at 2012 National Research Council[1] gestation requirement. **A)** Sows (n = 96) were bled within 24 h of farrowing (d 0) and 1 d prior to weaning (d 19). **B)** Three average-sized piglets per sow were tagged (n = 144/treatment) and bled on d 5 and 19 post farrowing. Historic physiological reference ranges are provided for context.[8] Data was analyzed using a linear mixed model with $P \leq .05$ considered significant (*). Error bars depict the standard error of the treatment means.



vitamin D level failed to impact stillborn numbers possibly due to insufficient power to detect a statistical difference, or due to differences in farrowing management practices and limited ability to detect response patterns with just two treatment levels (800 and 2000 IU/kg).

It is curious that sow vitamin E serum concentration was less among NRC-level fed sows compared to industry-level fed sows at the beginning of lactation yet sows of both treatments had similar concentrations in both serum and liver by the end of lactation. The inability to control for initial sow hepatic vitamin E concentration between treatments limits fully understanding the effects of vitamin supplementation on maternal vitamin E status. Moreover, since gestational intake of vitamin E was around 126 to 170 IU/day (median NRC and industry treatment intakes, respectively) but lactation mean intake was > 300 IU/day for both treatments (305 IU/day for NRC level, 462 IU/day for industry level) with *ad libitum* feed intake, the higher total vitamin E intake during lactation may have been satisfactory to maintain maternal homeostatic levels while simultaneously deprioritizing lactational transfer to offspring.

Unsurprisingly, no difference in neonate vitamin E concentration between treatments was observed at birth since transfer of vitamin E from dam to offspring occurs primarily postnatally via milk.[22] Yet reductions in circulating and stored vitamin E concentrations of NRC-level fed sows' offspring were apparent by the end of the suckling period despite sow vitamin E status not showing a response to treatment. Piglet vitamin E status is important to combat oxidative stresses, especially those incurred early in life such as iron injection[22] and establish hepatic vitamin E reserves to support performance in subsequent production phases. Improved immune response can be elicited with high doses of supplemental vitamin E; additional vitamin E in sow diets increased serum IgG in sows at farrowing and in pigs on days 1 and 28 post partum.[23] In the same study, vitamin E supplementation increased number of pigs born per litter and improved weaning weights.

In agreement with the present study, gestation vitamin supplementation levels had limited impact on farrowing and litter performance.[24] However, increasing gestation vitamin supplementation from NRC levels to approximately twice

Figure 3: Impact of sow diet vitamin supplementation on sow and litter vitamin E levels. Sows were allotted to dietary treatments supplemented with either standard industry vitamin levels or reduced vitamin levels with fat-soluble vitamins added at 2012 National Research Council[1] gestation requirement. **A)** Sows (n = 96) were bled within 24 h of farrowing (d 0) and 1 d prior to weaning (d 19). **B)** Liver samples were collected from sows (n = 96) following weaning for liver vitamin analysis. **C)** Three average-sized piglets per sow were tagged (n = 144/treatment) and bled on d 5 and 19 post farrowing. **D)** One average-sized piglet per sow which had been bled on d 5 and 19 was subsequently euthanized for liver vitamin analysis (n = 48 per treatment). Historic physiological reference ranges are provided for context.[8] Data was analyzed using a linear mixed model with $P \leq .05$ considered significant (*). Error bars depict the standard error of the treatment means.

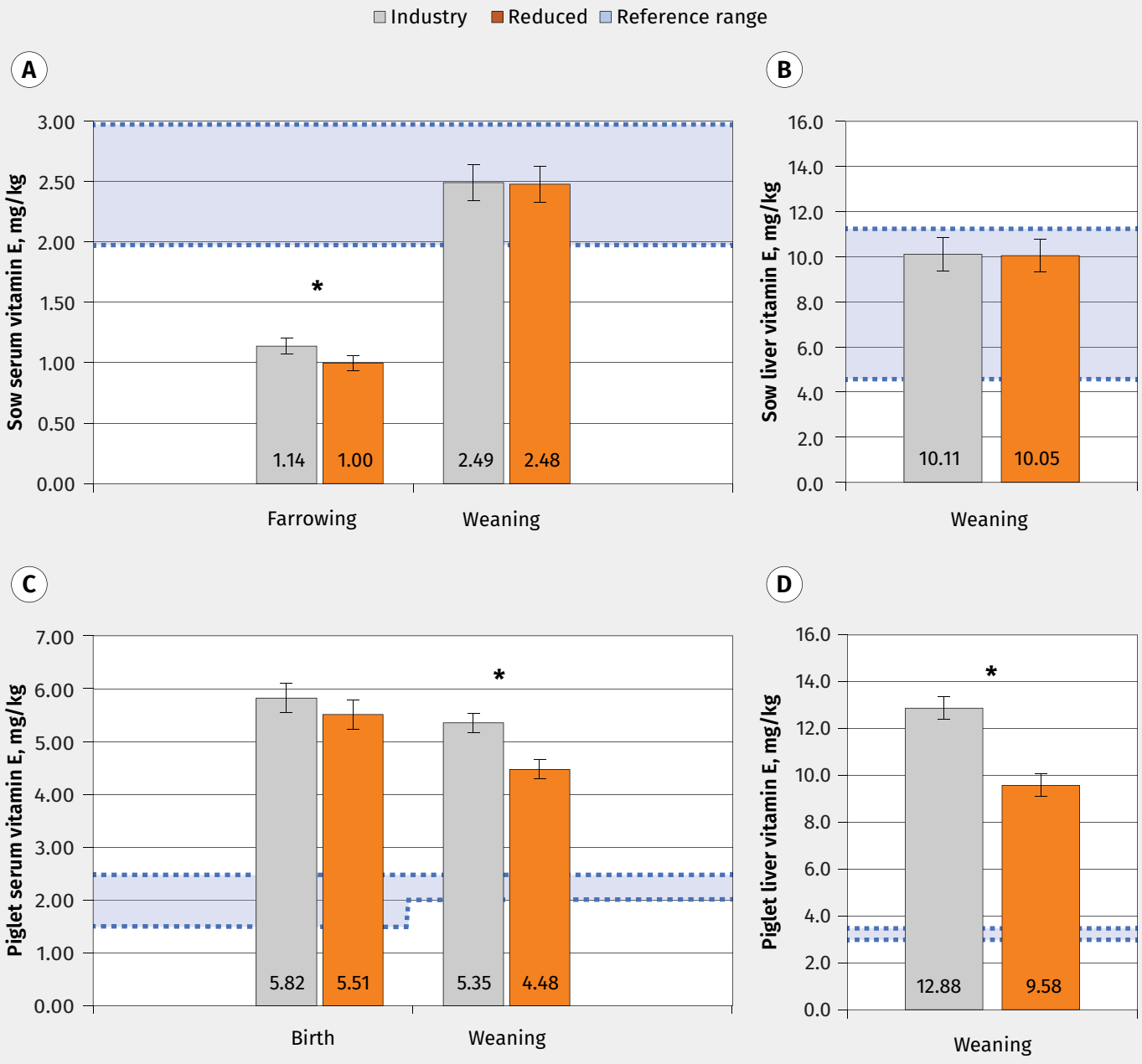
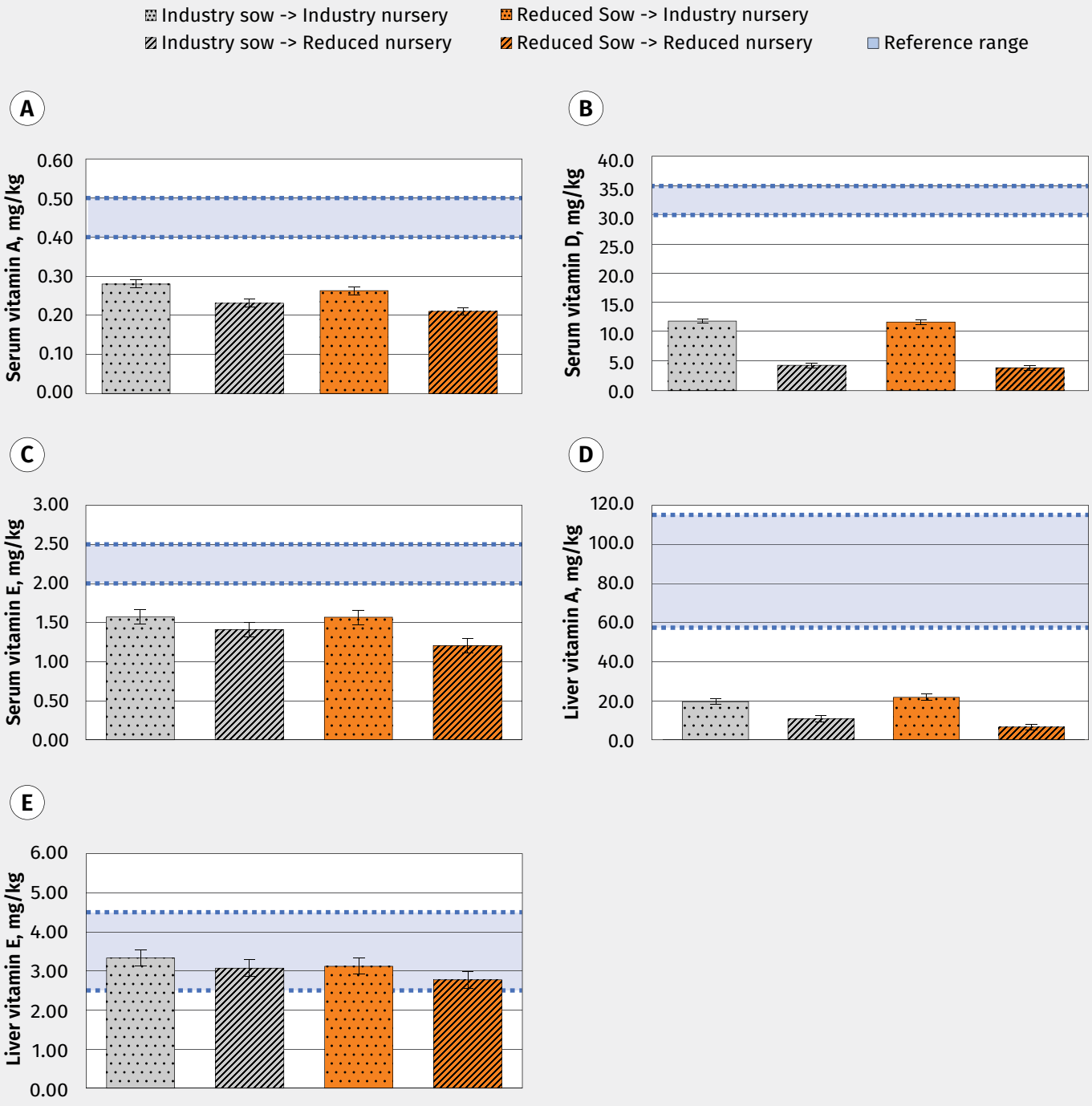


Figure 4: Comparison of vitamin status of nursery pigs receiving different vitamin supplementation strategies to historic physiological reference ranges. Dams were allotted to dietary treatments supplemented with either standard industry vitamin levels or reduced vitamin levels with fat-soluble vitamins added at 2012 National Research Council[1] gestation requirement. Sow offspring (PIC 337 × PIC 1050; n = 765; 15 pens/treatment) were allotted to nursery treatments in a 2 × 2 factorial with nursery diets containing either standard industry vitamin levels or reduced vitamin levels with fat-soluble vitamins added at 2012 NRC levels. Error bars denote the pooled standard error of the means. Offspring bled on d 19 post farrowing were rebled at the end of the nursery period (d 41 post weaning, 2 pigs per sow) for analysis of **A)** vitamin A, **B)** vitamin D (25-hydroxyvitamin D_2 and 25-hydroxyvitamin D_3), and **C)** vitamin E. Liver samples were collected from one representative pig per pen (n = 60) on d 41 post weaning for analysis of **D)** vitamin A and **E)** vitamin E. Samples were collected from 30 littermate pairs, one pig allotted to each nursery treatment and with 15 litters from each sow treatment represented to achieve a balanced sample.



the industry treatment levels of the current study has been shown to increase body condition and suppress lactational feed intake of a common diet fed *ad libitum*. Stressful conditions increase vitamin requirements; moreover, B-vitamin (niacin, thiamine, pantothenic acid, and vitamin B_6) deficiencies can suppress appetite while deficiencies in vitamins A and E lessen immunocompetence and antioxidative capacity which could impact subclinical health status and indirectly affect appetence.[1] The greater lactational feed intake of the industry-level fed sows in the present study tended to reduce litter gain efficiency since the higher caloric intake did not convert to heavier weaning weights. Although the greater feed consumption also did not prevent BW loss, body composition was not measured. Thus, it is possible that body condition of the industry-level fed sows increased with potential benefit to subsequent reproductive performance.

Despite limited growth benefits, the downstream impact of maternal supplementation on weaned pig vitamin status was clearly demonstrated. The feeding of both dam and offspring fat-soluble vitamins at NRC levels compounded to yield even lower serum vitamin E and hepatic vitamin A concentrations than supplementing either production phase alone at NRC levels yielded. Therefore, vitamin supplementation decisions should consider lifecycle supplementation risks and opportunities.

The magnitude of improved growth (10%-12%) observed due to the industry supplementation level is notable considering expected improvement in weight gain due to feed-grade antibiotics is generally only 3% to 9%[25] yet extensive resources are allocated to identifying antibiotic-alternative growth promoters. Similar magnitude improvements in ADG, ADFI, and feed efficiency due to similar vitamin supplementation strategies over NRC levels have been reported by others.[26,27] However, which specific vitamins are responsible for growth improvements has yet to be established. Supplementation of B vitamins at levels similar to the industry concentrations fed in the present study do not always elicit improvements relative to NRC feeding levels,[28] but high-lean growth potential pigs have greater demand for B vitamins to support optimum growth efficiency[29]; indeed, the pigs of the present study had 4% less ADFI yet 6.5% greater ADG than those which failed to respond to B-vitamin supplementation.[28] To identify optimal vitamin supplementation beyond NRC levels, further research is needed to determine the impact of specific vitamins for pigs of varying growth potential and possible interactions between vitamins.

Implications

Under the conditions of this study:

- Reduced vitamins suppress sow ADFI and potentially impact future performance.
- Vitamin supplementation above NRC levels benefits nursery pigs.
- Physiological vitamin levels are "deficient" by historic reference values.

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Conflict of interest

None reported.

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* Non-refereed references.

Table 5: The impact of vitamin level in sow and nursery diets on nursery pig performance and physiology*

Sow Vitamin Level:	Industry		Reduced		Pooled	*P*†		
Nursery Vitamin Level:	Industry	Reduced	Industry	Reduced	SEM	Sow	Nursery	Sow × Nursery
Medications, No.‡	25	25	25	21	NA	.69	.69	.69
Total removals, No.	3	6	3	0	NA	.97	.98	.97
Nutritional removals, No.§	0	5	3	0	NA	> .99	> .99	.98
Mortality, No.	2	1	0	1	NA	.76	.98	.81
Serum vitamin A, mg/kg¶	0.280	0.231	0.263	0.210	0.010	.02	< .001	.75
Serum vitamin D, ng/mL¶	11.847	4.307	11.669	3.883	0.407	.39	< .001	.72
Serum vitamin E, mg/kg¶	1.571	1.411	1.568	1.205	0.093	.02	< .001	.02
Liver vitamin A, mg/kg**	19.55	10.73	21.80	6.53	1.580	.59	< .001	.01
Liver vitamin E, mg/kg**	3.33	3.07	3.12	2.77	0.210	.35	.03	.70

* Sows were allotted to dietary treatments supplemented with either standard industry vitamin levels or reduced vitamin level with fat-soluble vitamins added at 2012 NRC[1] levels. Sow offspring (PIC 337 × PIC 1050; n = 765) were allotted to nursery treatments in a 2 × 2 factorial with nursery diets containing either standard industry vitamin levels or reduced vitamin levels. Performance was monitored from day 0 (weaning) to 40 days post weaning (n = 15 pens/treatment).

† Health, serum, and liver data were analyzed as a 2 × 2 factorial using linear mixed and generalized linear mixed models. Values were considered significant when $P \leq .05$.

‡ Medications are the total number of instances a pig received therapeutic medications regardless of reason.

§ Nutritional removals occur when pigs are removed off trial for reasons which could be attributed to malnutrition ie, emaciation, inability to find feed or water, or low bodyweight.

¶ The same offspring that had been bled on day 19 post farrowing were subsequently bled at the end of the nursery period (d 41 post weaning, 2 pigs/sow) for analysis of vitamins A, D (25-hydroxyvitamin D_2 and 25-hydroxyvitamin D_3), and E.

** One representative pig per pen (n = 60) was selected for liver sample collection on day 41 post weaning. Liver samples were collected from 30 littermate pairs, one pig allotted to each nursery treatment and with 15 litters from each sow treatment to achieve a balanced sample.

NA = not applicable; NRC = National Research Council.

Table 6: The main effects of vitamin supplementation level in sow and in nursery diets on nursery pig performance*

	Sow		Nursery		Pooled SEM	*P*†		
	Industry	Reduced	Industry	Reduced		Sow	Nursery	Sow × Nursery
D 0 BW, kg	6.43	6.33	6.36	6.39	0.288	< .001	.30	.28
D 40 BW, kg	22.20	21.86	23.01	21.04	0.203	.09	< .001	.26
ADG, kg	0.39	0.39	0.41	0.36	0.005	.22	< .001	.34
ADFI, kg	0.56	0.56	0.59	0.53	0.009	.35	< .001	.36
G:F, kg:kg	0.70	0.69	0.70	0.69	0.004	.34	.002	.75

* Sows were allotted to dietary treatments supplemented with either standard industry vitamin levels or reduced vitamin levels with fat-soluble vitamins added at 2012 NRC[1] levels. Sow offspring (PIC 337 × PIC 1050; n = 765) were subsequently allotted to nursery treatments in a 2 × 2 factorial arrangement with nursery diets containing either standard industry vitamin levels or reduced vitamin levels. Performance was monitored from day 0 (weaning) to 40 days post weaning (n = 15 pens/treatment).

† Performance data was analyzed as a randomized complete block experimental design with a 2 × 2 treatment factorial using a linear mixed model. Weight at day 0 was used as a covariate for the analysis of growth performance metrics. Values were considered significant when $P \leq .05$.

BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; G:F = body weight gain to feed intake ratio.

Peer reviewed **Case study**

Placentitis and abortion in domestic pigs (*Sus scrofa domesticus*) associated with *Trueperella abortisuis* on US swine farms

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Summary

We document a case series of abortions and placentitis in domestic pigs from the Midwest United States where aerobic bacterial cultures consistently isolated *Trueperella abortisuis*. Cases were submitted between 2017-2020 to the Kansas State Veterinary Diagnostic Lab. Microscopically, there was suppurative placentitis with necrosis and intralesional, gram-positive coccobacilli. In all cases, molecular diagnostics were negative for major causes of abortion in pigs. This is the first known report of *T abortisuis* isolated from swine abortions or placentitis in the United States.

Keywords: swine, *Trueperella abortisuis,* abortion, bacterial placentitis.

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Resumen - Placentitis y aborto en cerdos domésticos (*Sus scrofa domesticus*) asociados con *Trueperella abortisuis* en granjas porcinas de Estados Unidos

Documentamos una serie de casos de abortos y placentitis en cerdos domésticos del Medio Oeste de los Estados Unidos de donde de los cultivos de bacterias aerobias se aislaron consistentemente a la *Trueperella abortisuis*. Los casos se enviaron entre 2017-2020 al Laboratorio de Diagnóstico Veterinario del Estado de Kansas. Microscópicamente, había placentitis supurativa con necrosis y cocobacilos grampositivos intralesionales. En todos los casos, los diagnósticos moleculares fueron negativos a las principales causas de aborto en cerdos. Este es el primer reporte conocido de *T abortisuis* aislada de abortos porcinos o placentitis en los Estados Unidos.

Résumé - Placentite et avortement chez des porcs domestiques (*Sus scrofa domesticus*) associés à *Trueperella abortisuis* dans des élevages porcins Américains

Nous documentons une série de cas d'avortements et de placentite chez des porcs domestiques du Midwest des États-Unis où des cultures bactériennes aérobies ont systématiquement isolé *Trueperella abortisuis*. Les cas ont été soumis entre 2017-2020 au Laboratoire de Diagnostic Vétérinaire de l'État du Kansas. Au microscope, il y avait une placentite suppurée avec nécrose et des coccobacilles à gram-positif intralésionnels. Dans tous les cas, les diagnostics moléculaires étaient négatifs pour les principales causes d'avortement chez les porcs. Il s'agit du premier signalement connu de *T abortisuis* isolé à partir d'avortements ou de placentites chez des porcs aux États-Unis.

Bacteria in the genus *Trueperella* (formerly *Arcanobacterium*) are aerobic, gram-positive, diphtheroid-type cocci, and incorporate five species capable of causing variable disease among humans and animals: *Trueperella pyogenes*, *Trueperella abortisuis*, *Trueperella bernardiae*, *Trueperella bialowiezensis*, and *Trueperella bonsai*.[1] Of these, *T abortisuis* has been implicated as an emerging abortigenic and causative agent of suppurative placentitis in swine in Japan, Scotland, and Spain and has been isolated from the semen of clinically healthy boars in the United States.[2-6] This bacterium was first isolated in 2006 from a 6-month-old barrow from Japan with necrotizing, hemorrhagic splenitis and multiple organ failure.[7] At discovery, the bacterium was classified as an unpublished *Arcanobacterium* species strain HJ57-14E, with a 99.7% similarity using 16S rDNA gene sequencing.[7] In 2009, the bacterium was isolated from the placenta of a sow following abortion, and the classification *Arcanobacterium abortisuis* was proposed before reclassification of the genus to *Trueperella* in 2011.[3,8] *Trueperella abortisuis* has been isolated from aborted fetal tissues and fetal membranes in Europe and Asia, and isolated from boar semen in Spain and the United States.[2,5,6] Additionally, *T abortisuis* has also been isolated in cases of metritis and vaginitis in cows, and in companion animals including a feline with nephroliths and uroliths, an anal sac abscess in a dog, and a perianal abscess in a cat.[9] However, the

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significance of *T abortisuis* and route of infection is unclear, especially in companion animals and in nonreproductive pathology.

The current report summarizes a case series of abortion in gilts and sows submitted from 3 separate production systems to the Kansas State Veterinary Diagnostic Laboratory (KSVDL) between September 2017 and May 2020 in which *T abortisuis* and other bacteria were isolated from samples of placenta, fetal stomach contents, or uterine fluid from affected sows through aerobic bacterial culture and matrix-assisted laser desorption ionization time-of-flight mass spectrometry (MALDI-TOF MS) analysis. Gross and microscopic lesions in this case series were frequently identified in the placenta and consisted of a necrotizing, suppurative placentitis with variable amounts of gram-positive coccobacilli, frequently arranged in small clusters or pairs, consistent with bacteria as the cause of abortion. The major purposes of this case series are to report the identification of *T abortisuis* in swine farms across the Midwest United States and discuss its role as a potential abortigenic bacteria.

Animal care statement

An animal care protocol was not necessary as only submitted laboratory specimens were used in these cases. Farms associated with case 1 were certified in Pork Quality Assurance Plus.

Case description

Case 1

The first set of cases were submitted to KSVDL from September 2017 through November 2017 from an approximately 5600 gilt-sow farm in Kansas. The farm was experiencing reproductive failure in gilts with a 12% average decrease in conception rate by 30 days of gestation compared to historical data from the farm and cohort farms of similar size, genetics, geographic location, and management practices. The farm had a prior history of Senecavirus A (SVA) infection in the herd. Abortions were reportedly occurring in pregnant gilts and sows between 24 to 70 days of gestation. Affected gilts and sows were not clinically ill but showed clinical signs of reproductive failure including repeating cycles, abortion, and suppurative vaginal discharge with or without expulsion of the fetuses. Multiple sets of formalin-fixed and fresh samples of aborted fetuses, ligated uterine loops and sections of uterine tissue, nasal swabs, feces, kidney, pooled saliva, and serum from numerous sows were submitted within that time frame. Aborted fetuses were not mummified or excessively autolyzed. Testing was performed on samples as requested by the referring veterinarian and variably included necropsy, histopathology, aerobic and anaerobic bacterial cultures, real-time polymerase chain reaction (PCR), serology, and metagenomic next generation sequencing.

In all submissions, aerobic culture was performed on samples of fetal stomach fluid, uterine lavage fluid, uterine swabs, fetal intracavitary swabs, or placental membranes, as available. Aerobic bacterial culture was performed using blood agar (Tryptone Soy Agar with 5% sheep blood); MacConkey agar, or Columbia CNA with 5% sheep's blood at 37°C (± 2°C) with 5% CO_2. Samples were streaked onto half to one-third of agar plates, incubated 15 to 24 hours, and then interpreted following standard laboratory procedures. Isolates were identified using MALDI-TOF MS using MALDI-TOF MS software (Bruker Daltonik), with standard protein extracts. A MALDI-TOF score > 2.0 indicated species identification, a score of 1.7 to 1.9 indicated genus identification, and a score < 1.7 indicated no identification or unreliable identification. *Trueperella abortisuis* was consistently isolated in uterine lavages. Other less consistent aerobic and anaerobic isolates in uterine lavages were identified (Table 1). Semen samples were systematically cultured and yielded no growth of bacterial pathogens.

Formalin-fixed tissues were processed according to standard protocols at the KSVDL. All tissues were stained with hematoxylin and eosin; placental membranes, uterine tissue, or fetal viscera were additionally stained with Twort's Gram stain. Microscopically, uterus from affected sows had moderate to severe fibrinosuppurative endometritis with moderately ectatic endometrial glands containing few neutrophils (Figure 1). The uterine lumen of some sows revealed small numbers of primarily gram-positive coccobacilli, with fewer gram-positive small rods and cocci, and aerobic culture of a fresh sample of this uterus isolated abundant *T pyogenes* (Table 1). Placentas from these sows had multifocal areas of trophoblast necrosis and mild fibrinosuppurative placentitis and variably sized colonies of frequently clustered or paired gram-positive coccobacilli (approximately 0.5-1.0 µm), fewer gram-positive cocci (approximately 0.7 µm) and small (approximately 0.5-1.5 µm in length) bacilli, and similarly sized gram-negative bacilli. Microscopically, lung from one fetus had moderate suppurative pneumonia. No bacteria were identified with special stains on this fetus.

Paired serum samples from multiple sows from this herd were analyzed to determine serum concentrations of immunoglobulin M (IgM) against *Leptospira* serovars Canicola, Pomona, Grippotyphosa, Icterohaemorrhagiae, Hardjo, and Bratislava using a commercially available quantitative sandwich IgM-specific enzyme-linked immunosorbent assay (ELISA) kit according to the manufacture's recommendations. Several sows had elevated titers for *L* Icterohaemorrhagiae and *L* Canicola. The *L* Icterohaemorrhagiae servovar microscopic agglutination test (MAT) had 5 of 19 sows with titers above 1:800 (ranging from 1:1600 to 1:12800). The *L* Canicola serovar MAT had 5 of 19 sows with titers above 1:800 (ranging from 1:1600 to 1:6400). Two weeks following these results, 5 of 18 sows had titers for *L* Icterhaemorrhagiae above 1:800 (ranging from 1:1600 to 1:12800), with only one sample (No. 5195) overlapping from the original sample set, which had maintained a titer of 1:1600 and had reportedly aborted. *Leptospira* PCR with DNA extraction using standard laboratory protocol was negative on samples of pooled tissue and on individual uterine samples from several sows. Porcine circovirus (PCV) type 2 real-time PCR was negative on pooled samples of serum. Virus isolation was not successful. Because of the history of SVA on this farm, PCR testing for this pathogen was performed and was negative on uterine swabs and fetal samples. Porcine parvovirus (PPV) hemagglutination had 2 of 19 sows with titers which were above 1:256 (ranging from 1:1024 to 1:512) suggestive of exposure. Fecal samples were submitted for PCR to detect porcine epidemic diarrhea virus, *Lawsonia intracellularis*, and delta coronavirus and were all negative. Swine influenza virus matrix PCR was negative on samples of pooled oral fluid and nasal swabs. Tetracore real-time PCR for porcine reproductive and respiratory syndrome virus (PRRSV) and *Brucella* buffered acidic plate antigen (BAPA) were negative on samples of pooled serum. Pseudorabies glycoprotein B antibody testing was negative. *Mycoplasma*

Table 1: Bacteria isolates identified from samples submitted by 3 Midwest US swine farms experiencing increased abortions

Case number and date	Submitted tissues	Gross lesions	Microscopic lesions	Bacteriology
Case 1; November 2017	Uterine fluid*	NA	NA	Abundant *Trueperella abortisuis* isolated from uterine fluid, *Trueperella pyogenes*, *Pasteurella multocida*, *Streptococcus dysgalactiae*, *Enterococcus gallinarum*, *Escherichia coli* (non-hemolytic and hemolytic), *Proteus mirabilis*, *Streptococcus suis*, *Streptococcus* species (beta-hemolytic), and *Clostridium perfringens*
Case 1; November 2017	Uterine fluid*	NA	NA	*T abortisuis* isolated from uterine fluid, *Actinobacillus rossii*, *E coli* (non-hemolytic), *Streptococcus hyointestinalis*, *Aerococcus viridans*, gram-negative cocci (unable to identify), *Acinetobacter lwoffii*, *Lactococcus raffinolactis*, *Aeromonas bestiarum*, *Streptococcus parauberis*, *Acinetobacter johnsonii*, and *C perfringens*
Case 2; December 2017	Five aborted fetuses† and five placentas	Mild-moderate placental thickening and hemorrhage; pleural effusion and subcutaneous hemorrhage	Suppurative placentitis and intra-trophoblast gram-positive bacteria; hepatic congestion and renal hemorrhage	Abundant *T abortisuis* isolated from stomach contents, *A rossii*, *E coli* (non-hemolytic), *S hyointestinalis*, *A viridans*, gram-negative cocci (unable to identify), *A lwoffii*, *L raffinolactis*, *A bestiarum*, *S parauberis*, *A johnsonii*, and *C perfringens*
Case 2; December 2017	One aborted fetus‡ and one placenta	Diffuse placental thickening, multifocal tan-brown discolorations and roughening	Suppurative necrotizing placentitis, trophoblast sloughing, gram-positive and negative coccobacilli in airways and placenta	Abundant *T abortisuis* isolated from a fetal swab, *E coli* (non-hemolytic), *Citrobacter gilleni*, *Aeromonas* species, *Lactococcus garvieae*, *Enterococcus faecium*, *A viridans*, *Enterococcus hirae*, gram-negative cocci (unable to identify), *S suis*, *Streptococcus* species (Alpha hemolytic), *Staphylococcus chromogenes*, *Streptococcus alactolyticus*, *S parauberis*, *L raffinolactis*, *Lactobacillus ruminis*, *Enterococcus hirae*, and *C perfringens*
Case 3; May 2020	Three aborted fetuses§ and one placenta	Moderate amount of tan-yellow exudate covering allantois; umbilical cord and allantois hemorrhage	Suppurative gram-negative and gram-positive bacterial placentitis; suppurative, fibrinous omphalitis	Abundant *T abortisuis* isolated from placenta, *E coli* (non-hemolytic), and *A viridans*

* Unknown parity, age, or health status.

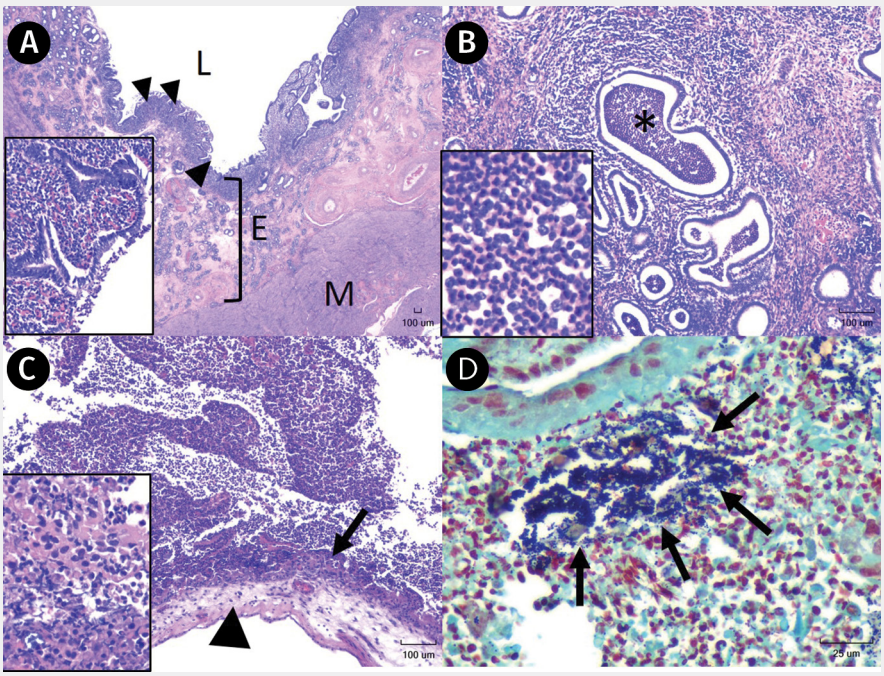
† Crown-rump length of fetuses 150-180 mm (approximately 60-70 days of gestation).

‡ Crown to rump length of fetus 70 mm (approximately 40-50 days of gestation).

§ Crown-rump length of fetuses 50-60 mm (approximately 40 days of gestation).

NA = not available or analyzed.

Figure 1: Representative microscopic lesions from an affected sow's uterus and placental membranes showing suppurative endometritis and placentitis. A) Uterus with numerous inflammatory cells infiltrating the mucosa (arrowheads) of the endometrium (E) with sparing of the myometrium (M) and lumen (L) (hematoxylin and eosin [H&E] stain). Inset: Close up image of the affected mucosa invaded by numerous inflammatory cells (H&E stain). B) The lumen of an affected uterine endometrial gland (asterisk) contains large numbers of neutrophils (H&E stain). Inset: Close up image of numerous neutrophils within the endometrial gland lumen (H&E stain). C) Within the placenta, the amnion (arrowhead) has few inflammatory cell infiltrates, and the chorion (arrow) is infiltrated by numerous neutrophils mixed with prominent necrosis of the chorion (H&E stain). Inset: Degenerating neutrophils and necrosis of the chorion (H&E stain). D) Placenta showing numerous gram-positive coccobacilli (arrows) consistent with *Trueperella abortisuis* (Gram stain).



ELISA was positive or suspect in 17 of 22 (77.3%) submitted cases. The PCV type 2 quantitative indirect fluorescent antibody assay had 11 of 19 sows with titers above 1:320 (with a range of 1:640 to ≥ 1:5120). Trace mineral levels (including selenium) and vitamins A, D, and E were measured in serum of affected sows and were within normal limits for the dams. Metagenomic sequencing on a single uterus sample did not identify *T abortisuis* or viral pathogens within the sample. Bacterial cultures were also done on this sample and did not yield *T abortisuis* or other bacteria.

Case 2

In December 2017, groups of aborted fetuses and placentas from 11 sows were submitted to KSVDL from an 8000 gilt-sow farm in Wyoming with a reported history of worsening abortion rates year-to-year and a fetal loss rate of approximately 6% among pregnant gilts and sows at the time of submission. Submitted fetuses were between 35 and 95 days of gestation and the degree of postmortem autolysis varied from mild to marked between groups. One fetal group was submitted without placental tissues. The 10 groups submitted with placental tissues had at least one sample of fetal membranes or placenta with a chorion or allantois which was multifocally to diffusely thickened, edematous, discolored grey to brown, or hemorrhagic. Microscopically, 6 of 10 groups (60%) with submitted placental tissue had lesions consistent with placental necrosis affecting up to 20% of the tissue. Of those, 3 of 6 (50%) had a fibrinosuppurative placentitis composed of moderate to abundant numbers of gram-positive coccobacilli, diplococci, and short gram-negative rods mixed with exfoliated trophoblasts. One fetus also had mats of moderate to abundant numbers of gram-positive coccobacilli mixed with fewer small, gram-positive rods and rare degenerate neutrophils or foamy macrophages within airways. Fetal swabs or stomach contents from all groups were submitted for bacterial culture, and two of the groups with gross and microscopic suppurative bacterial placentitis and pneumonia had abundant *T abortisuis* isolated. Other aerobic and anaerobic isolates are listed in Table 1. Pooled samples of placenta and lung were submitted from multiple groups for real time PCR for PRRSV and PCV type 2 and type 3, which were all negative. Pooled samples of placenta submitted for PPV PCR were also negative. Metagenomic sequencing was performed on pooled samples of placenta and recovered approximately 46% eukaryotic (host genome), 42% bacteria, 3% virus (bacterial phage), and 6% other. A 550bp partial *T abortisuis* 16S rRNA sequence was extracted from the sample reads and was 98.8% similar to *T abortisuis* strain 15TRD1120-003 (MH040922).

Case 3

In May 2020, a placenta and three pig fetuses from one gilt were submitted for necropsy with additional testing from a 650 gilt-sow farm in Nebraska. History of abortion from other dams or maternal illness on the farm was not disclosed. Submitted fetuses had a gestational age of approximately 40 to 45 days and were randomly assigned identification A, B, or C. The fetuses and placenta were in good to fair postmortem condition. Fetus A was grossly unremarkable. Fetus B was contained within an amniotic sac covered in multifocal to coalescing, tan-yellow, purulent exudate and the allantois had a discrete, locally extensive area of green-brown discoloration. Fetus C was also contained within an amniotic sac and placenta corresponding to the umbilical cord and allantois was transmurally discolored red-black. Microscopically, submitted placenta had a fibrinosuppurative and necrotizing placentitis with few to moderate numbers of gram-positive coccobacilli, fewer cocci, and gram-negative, small-to-medium sized rods adhered to the trophoblast lining or adhered to sloughed, necrotic trophoblasts. Microscopically, fetus C had a suppurative, fibrinous omphalitis with similar intralesional gram-positive coccobacilli and gram-negative small-to-medium rods. A sample of affected amnion from fetus B was submitted for aerobic bacterial culture and isolated

abundant *T abortisuis*, non-hemolytic *Escherichia coli*, and *Aerococcus viridans* (Table 1). Pooled samples of heart, liver, lung, kidney, and spleen were submitted for PCR for PRRSV, PCV type 2 and type 3, and PPV which were all negative.

Discussion

There is a growing body of literature to support the potential role of *T abortisuis* as an emerging abortigenic bacterium of swine. This bacterium has been previously isolated from the placenta, uterus, or fetus from clinically affected sows in Japan and some European countries, and from the semen of clinically healthy boars in the United States.[2-4] To the authors' knowledge, this is the first report of isolation of *T abortisuis* from fetal tissues, placenta, and uterine samples in swine abortions in the United States. In our case series, abortion was not linked with any of the common porcine abortigenic etiologies. Common bacterial causes of abortion, including *Brucella suis* and *Leptospira*, were ruled out by negative ancillary testing as well as lack of typical clinical signs in the dam, which include fever, anorexia, icterus, abortion of fetuses near or full-term, fetal mummification, stillbirth, or birth of weak piglets that die shortly after birth.[10-11] Porcine viral causes of abortion, including PRRSV, PCV type 2 and type 3, and PPV, and other viral etiologies were also ruled out by molecular analysis of fetal tissues and placenta, including metagenomics analysis in some cases. Gross and microscopic lesions consistently observed in placenta, uterus, and, in some cases, fetal lung in our case series were indicative of a bacterial etiology and were consistent with those described in previous reports in which *T abortisuis* was isolated.[3,6]

The role of *T abortisuis* in cases of endometritis and abortions in pigs has not been fully established to date.[12] However, some previous reports have implicated its potential pathogenicity in abortion and reproductive failure in other countries.[4,12] Some authors have reported isolation of *T abortisuis* along with other bacteria in samples from nonclinical pigs suggesting that *T abortisuis* could be a commensal (or opportunistic) pathogen of the urogenital tract of male and female pigs.[2,13] As in the present case series, previous reports mention isolation of *T abortisuis* along with a mixed bacterial population from affected tissues,[2,13] but none of these other bacteria were consistently isolated in these cases. Most of the additional bacteria isolated in this case series have not been implicated as causative agents of abortion in porcine species, and to our knowledge are known skin commensals or contaminants from nonsterile tissue collection, as suggested in previous reports.[12-14] In this present report, *T abortisuis* was consistently isolated from most of the affected tissues in which gram-positive coccobacilli were observed on microscopic examination. This could suggest a potential role of *T abortisuis* in porcine abortion and reproductive failure, whether it is as a primary pathogen or as a cofactor in association with other pathogens. Further research should focus on identifying pathogenic traits of *T abortisuis*, its interaction with other commensal reproductive tract bacteria, and disease reproducibility. Surveillance and diagnostic testing to isolate and confirm the pathogenicity of *T abortisuis* should continue.

Unlike other production animals, abortions and fetal loss in swine are usually due to viral infection, and abortions due to bacteria are often sporadic and of limited herd health significance, with reportedly less than 25% of abortion in swine due to bacteria.[10,15] The route of infection in the cases presented in this report was not determined. In general, the pathogenesis of bacterial-induced abortion includes pre-existing metritis, ascending infection through the cervix, infection of the placenta or fetus following bacteremia of the dam, or maternal illness.[15] In the submitted cases, ascending infection, subclinical metritis, or fetoplacental infection due to subclinical bacteremia are less likely, as dams were reportedly not showing any signs of systemic illness prior to abortion. Other potential sources of bacterial infection include semen, insemination tools or techniques, and fomites in the environment. *Trueperella abortisuis* has been isolated from testes of normal boars suggesting the bacteria could be commensal in the organ and could be a plausible source of infection.[2] In case 1, extensive investigation included systematic aerobic cultures from semen samples and sampling of the facilities and yielded no growth of bacteria. Several management changes were also implemented simultaneously on this farm, as the management team was uncertain if *T abortisuis* was the primary pathogen given the relative lack of literature indicating its role as a primary abortigenic bacteria at the time of the isolation. These changes included transition from post cervical artificial insemination (AI) to traditional AI, emphasis of hygienic AI, increased barn ventilation, decreased barn humidity, and culling of sows/gilts returning to estrus with a purulent vaginal discharge. These protocols resulted in termination of cases of abortion. An inciting cause for immunosuppression which could have predisposed the gilts/sows to bacterial infection was not identified; biosecurity, sanitation, and insemination protocols were not disclosed on the farms from cases 2 and 3. Nutritional status and levels of vitamins and minerals, including selenium and vitamins A, D, and E were within normal limits in all affected animals within one farm in this case series.

In this case series, we also highlight the importance of submitting full sets of tissues, including fetal, placenta, and uterine samples (be it as uterine tissue or swabs from uterus), as fetal gross and microscopic lesions might be absent or nonspecific in abortions. Aerobic and anaerobic bacterial culture results must be interpreted with caution in the absence of microscopic inflammatory lesions, as postmortem overgrowth and fecal or environmental contamination can result in bacterial isolates which may be irrelevant to the cause of abortion. Determining a definitive diagnosis for fetal death or abortion in production animals can be challenging given the numerous infectious and noninfectious potential causes that can contribute to fetal or embryonic loss. Isolation of infectious etiologies of abortion is dependent on appropriate and timely collection of aborted fetuses and placenta, and proper interpretation of diagnostic results. The placenta is often contaminated, and the best sample for bacterial isolation is stomach fluid from the aborted fetus or a swab of the pleural or peritoneal cavity of the fetus, which is not always available in submitted samples.[10] To further complicate reaching a definitive diagnosis, all fetuses in a litter are not usually infected at the time abortion occurs, and fetuses may die or become infected at different points, which was also observed in these cases.[15] Sporadic abortions are expected in large production operations, so many instances of fetal loss are never submitted for diagnostic evaluation. For these reasons, many causes of fetal death and abortion remain idiopathic. Submissions may also fail to include fresh tissue samples or inappropriately sized samples. In pigs, when gross or microscopic evidence of suppurative placentitis or fetal

bronchopneumonia is identified, a bacterial cause for abortion should be included as a potential differential. While typically sporadic, bacterial causes of abortion in swine can contribute to economic losses especially when multiple abortigenic bacteria are isolated. *Trueperella abortisuis* as a sole or contributing cause of abortion in pigs has not yet been fully established but should be considered as a possible cause of bacterial abortion. All or some of the points discussed above could have played a role in the large gap of time of isolation between different cases.

In conclusion, this report brings attention to the isolation of *T abortisuis* within a series of swine abortion cases and underscores the importance of an extensive diagnostic workup in cases of swine abortion to help rule in or out most common infectious causes of abortion.

Implications

- *Trueperella abortisuis* was isolated from swine abortions in the United States.
- No other viral or bacterial etiology was isolated.
- The role of *T abortisuis* in swine abortions remains unknown.

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Conflict of interest

None reported.

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Effectively using ultraviolet-C light for supply decontamination on swine farms

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Summary

The application of ultraviolet-C (UVC) light is not well understood in the swine industry, and best practices for applying UVC technology effectively and safely are lacking. This paper aims to summarize swine industry best practices for using UVC safely and maintenance requirements created as a result of a UVC workshop organized by the Swine Health Information Center. By understanding basic UVC physics, mechanism of action, safety procedures, and general maintenance requirements, the swine industry will be able to use UVC technology safely and effectively for decontamination of surfaces on swine farms.

Keywords: swine, ultraviolet-C light, biosecurity, surface decontamination

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Resumen - Uso efectivo de la luz ultravioleta-C para la descontaminación del suministros en granjas porcinas

La aplicación de la luz ultravioleta-C (UVC) no se comprende bien en la industria porcina, además no se tienen las mejores prácticas para aplicar la tecnología UVC de manera efectiva y segura. Este documento tiene como objetivo resumir las mejores prácticas para el uso seguro de UVC en la industria porcina, y los requisitos de mantenimiento establecidos como resultado de un taller de UVC organizado por el Centro de Información de Salud Porcina. Al entender la física básica de la UVC, el mecanismo de acción, los procedimientos de seguridad y los requisitos generales de mantenimiento, la industria porcina podrá utilizar la tecnología UVC de manera segura y eficaz para la descontaminación de superficies en granjas porcinas.

Résumé - Utilisation efficace de la lumière ultraviolette-C pour la décontamination de l'approvisionnement dans les élevages porcins

L'application de la lumière ultraviolette-C (UVC) n'est pas bien comprise dans l'industrie porcine, et les meilleures pratiques pour appliquer la technologie UVC de manière efficace et sécuritaire font défaut. Ce document vise à résumer les meilleures pratiques de l'industrie porcine pour utiliser les UVC en toute sécurité et les exigences de maintenance créées à la suite d'un atelier UVC organisé par le Swine Health Information Center. En comprenant la physique de base des UVC, le mécanisme d'action, les procédures de sécurité et les exigences générales de maintenance, l'industrie porcine sera en mesure d'utiliser la technologie UVC de manière sûre et efficace pour la décontamination des surfaces dans les fermes porcines.

Ultraviolet-C (UVC) light is widely used for decontamination in many industries, including human medicine and food processing. The practical application of this technology in livestock production is a more recent development. It is increasingly being used on swine farms as producers look for ways to improve biosecurity in response to the threat of African swine fever virus (ASFV). However, many swine producers and veterinarians are unfamiliar with the physics of UVC, the mechanism of action, the doses required to inactivate swine pathogens, and practical conditions under which UVC can operate effectively and practically on swine farms. The swine industry lacks best practices to apply this technology effectively and safely. To address the need for a better understanding of UVC application on swine farms, the Swine Health Information Center (SHIC) organized a one-day workshop with practicing swine veterinarians and academic

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experts in epidemiology, infectious disease, biosecurity, chemistry, and agricultural engineering to outline and define best practices for UVC in the swine industry.

This paper aims to describe swine industry best practices for using UVC safely and effectively developed during the UVC workshop. Development of industry best practices for UVC will allow people in the swine industry to use UVC effectively and safely.

Physics and mechanism of action

Ultraviolet (UV) light is a range of electromagnetic radiation immediately more energetic than the visible light range. The generally accepted range of UV wavelength lies from 100 to 400 nm, which is shorter than the visible light spectrum (400 to 800 nm) seen by humans. The essential physical consequence of the shorter wavelengths is that the photon energy meets or exceeds the energies of chemical bonds, ionization potentials, and band gaps of most materials, although this varies with the exact wavelengths under consideration. There are four UV categories defined based on the wavelength range.[1]

1. vacuum ultraviolet (VUV), 100-200 nm
2. ultraviolet C (UVC), 200-280 nm
3. ultraviolet B (UVB), 280-315 nm
4. ultraviolet A (UVA), 315-400 nm

Ultraviolet-C light has been used for decontamination in a variety of areas, including but not limited to air decontamination, water (and wastewater) treatment, laboratory decontamination such as inside biosecurity cabinets, food and beverage preservation, and medical applications, such as wound care.[2,3] Ultraviolet-C light is readily absorbed by nucleic acids and proteins and induces photochemical reactions of multiple bonds in many organic molecules. Of particular relevance for the mechanism of action is the formation of a cyclobutane ring that covalently joins two previously separate moieties that each contained a C = C double bond. Along with DNA or RNA strands, adjacent thymine or uracil residues are particularly susceptible to such photodimerization. The dimerization along with the DNA or RNA strand causes that particular section of the biopolymer to no longer be recognized correctly, and changes or terminates its biological function. These compounds are essential for cells to function and reproduce.[3] The effect of UVC varies for different materials and microorganisms. Protein has a peak absorption of UV light energy at about 280 nm, while for DNA and RNA, the peak is 260-265 nm,[4,5] where the germicidal effectiveness is at its maximum. The typical 254 nm lamp, which is sold for decontamination purposes, is sufficiently close to this maximum to be effective.

UVC terminology

There are several terms and equations that are important to define and understand when applying UVC technology. Irradiance, also described as light intensity is the UVC light arriving at a surface, at all angles, at a point in time.[3] The unit for irradiance is typically expressed as milliWatts (mW) per unit area, such as square meters (m^2) or square centimeters (cm^2). In idealized conditions, assuming that UVC light comes from a point or line source, light irradiance decreases by the square of the distance from that point or line source, and the relationship is known as the inverse square law, expressed as:

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2}$$

where I_1 = irradiance measured at one point, I_2 = irradiance measured at a second point, d_1 = distance between the light source and one point, d_2 = distance between the light source and the second point.

This relationship demonstrates that with a doubling of the distance from a source (lamp) to a surface to be decontaminated (decontamination surface), the decontamination surface will receive a quarter of the irradiance. Consequently, it is vital to maintain an appropriate distance between the UVC light source when applying UVC to decontaminate objects.

Inactivation of pathogens by UVC is a function of the dose of radiation. The dose is a function of the irradiance on the pathogen-contaminated surface and time. The dose of UVC is measured in millijoules (mJ) per cm^2 for surface decontamination, which is defined by the following equation:

$$D\ (mJ/cm^2) = I\ (mW/cm^2) \times Time\ (s)$$

Because distance, irradiance, and exposure time can all affect the UVC dose, longer exposure times can be used to increase the dose delivered to a pathogen-contaminated surface when the distance from the source lamp is longer to obtain the same desired inactivation of pathogens.[3] A commercially available UVC chamber (Bioshift Series, UVC Germicidal Chamber, ONCE, Inc) delivers a UVC dose of about 150 to 190 mJ/cm^2. The interior of the chamber is approximately 50.80 cm × 50.80 cm × 50.80 cm, with 4 UVC bulbs approximately 45.72 cm long, located at each corner of the chamber. The shelf sits about 2.54 cm from the bottom. It is recommended supplies have a 5-minute exposure time. These are good guidelines to follow when trying to develop a UVC chamber for smaller pass-through items. Ultraviolet-C light has been applied in hospital rooms, and there is thought to whether it could be applied on a larger scale as in supply entry rooms, entry ways, or loadout areas. This concept may not be feasible on swine farms due to the varying levels of permable materials and organic material that may be present.

For the workshop, information about the dose of UVC required to inactivate various bacteria and viruses was assembled from summaries published by companies that manufacture and market equipment for UVC decontamination. Summaries from Once Incorporated, Clordisys Solutions Incorporated,[6] and ECO Scope[7] were used to identify primary references for the UVC dose requirements to inactivate viruses and bacteria. Nearly all the references identified were for microorganisms that were not swine pathogens, but many were in the same genus of swine bacteria or the same family of swine viruses. The summaries included studies applying UVC for physical decontamination of organic and nonorganic surfaces, as well as decontamination of air and water. In addition, a review of the literature for information on doses for swine pathogens was conducted for the UVC workshop.

Only peer-reviewed journal articles discussing the UVC dosage for decontamination of nonorganic surfaces were included since this is the primary purpose for which UVC would be applied as a biosecurity control measure on swine farms. Only studies related to surface decontamination in the United States and Europe were included. The review was conducted for both endemic and foreign viral and bacterial swine pathogens, which were deemed important to pork production in the United States, including those on the SHIC Swine Disease Matrix.[8] For swine bacteria and viruses, such as porcine epidemic diarrhea virus and porcine reproductive

and respiratory syndrome virus,[9] where published studies with information on UVC dose is available, all the doses required for a 3-log reduction (approximately 99.9% kill) are less than the 150 to 190 mJ/cm^2 delivered by a commercially available UVC chamber (ONCE, Inc). For swine bacteria and viruses where published studies with information on UVC dose is not available, but the information is available for bacteria in the same genus or viruses in the same family, the doses required for a 3-log reduction (approximately 99.9% kill) are also less than the 150 to 190 mJ/cm^2 delivered by a commercially available UVC chamber (ONCE, Inc). A significant gap in the literature exists for swine bacteria and viruses where no information is published for them or other bacteria in the same genus or viruses in the same family. Foremost among them is ASFV and classical swine fever virus, two important foreign animal disease pathogens.

Safety and maintenance requirements

Safety best practices

When applying UVC on farms, it is important to remember that UVC is mutagenic and carcinogenic.[10] Exposure to any part of a person's or an animal's body or eyes should be avoided. Exposure to the eyes may result in the development of cataracts, actinic keratosis, or both. Short-term effects of exposure to the skin include sunburn, while long-term cumulative effects of exposure include cancer.

Several general safety practices are recommended:

- Ensure complete enclosure of the UVC chamber without any light leakages.
- Verify with a UVC meter that there is no UVC penetration through the chamber window. Glass windows are safe, quartz windows are not.
- Connect a hard-wired safety shutoff to doors and latches or purchase UVC chambers or lamps with this feature.
- Install warning labels for human safety.
- Properly train all personnel and refresh training annually.
- If exposure to UVC cannot be avoided, consider using personal protective equipment as secondary protection, which may include goggles or face shields (such as American Ultraviolet's Ultra-Spec 100 Safety Goggles and Ultra-Shield Face Shields designed for ultraviolet exposure), and clothing or sunblock.
- Discontinue use and contact the manufacturer if safety controls are malfunctioning.

Following these standard guidelines will help ensure the safety of people working in the swine industry when applying UVC technology.

Maintenance best practices

Proper maintenance of the UVC chamber or lamps used on-farm is important to ensure effective decontamination of surfaces. Ultraviolet-C lamp bulbs should be checked approximately every 3 months. If dirty, the bulbs should be cleaned by applying an alcohol-based disinfectant on soft cotton cloth or gauze. Gloves should be worn, and bulbs should not be touched with bare hands. Oils transferred from the skin surface to the lamp can block UVC light and decrease performance. Regular cleaning of UVC bulbs will also maximize the life of the bulb. Ultraviolet-C chamber walls should be coated with reflective surfaces or panels, such as polished aluminum, to increase UVC efficiency by reflecting and redirecting UVC light and obtain coverage over surfaces not directly under the UVC bulbs.[11] These reflective aluminum panels or surfaces on the inside of the chamber should also be cleaned with nonabrasive cleaners when dirty. The chamber will be less efficient at distributing UVC light when the panels have dull spots.

Temperature and relative humidity (RH) have the potential to decrease UVC performance. The temperature of the UVC bulbs has a significant impact on the decontamination efficiency of UVC chambers. It is recommended that the bulbs be cycled once in the morning to bring the bulb energy level up before the first decontamination cycle. If the RH is high, condensation may form on the bulbs when they cool off. Condensation on the bulbs is a safety concern and should be monitored closely in high humidity environments. Furthermore, RH can affect the overall efficacy of UVC decontamination. Two trends of inactivation related to RH were observed by researchers: 1) inactivation of pathogens decreases as RH increases[12,13] and 2) inactivation of pathogens peaks between 25% to 79% RH and decreases on both ends.[14] Therefore, monitoring humidity in rooms or chambers where UVC technology is being applied is warranted.

It is of utmost importance to monitor the UVC irradiance in the chamber to ensure it is in proper operating condition. The blue light visible when UVC lights are turned on is the result of a phosphor excitation and only serves as a visual safety indicator that the light is on. The blue light intensity does not correlate with UVC irradiance or intensity. Moreover, the illumination with visible light in the chamber can be misleading as to what areas are illuminated by the UVC light, since the reflective and refractive properties of UVC differ from visible light. Ultraviolet-C light may not fully illuminate fomites and tools in the chamber, even if visible light can be seen.

Ultraviolet-C irradiance may be monitored using a calibrated UVC meter such as the UV512C Digital UVC meter (General Tools & Instruments LLC) shown in Figure 1. This UVC meter, along with other meters available on the market displayed in Table 1, has the capability to record the UVC intensity after the allotted exposure time in a UVC chamber. It is recommended to first warm the bulbs by completing one cycle prior to measurements. Always record the same spot in the chamber, with the probe facing up, towards the UVC bulbs. If there are also bulbs located at the bottom of the chamber, then it is recommended to take a second measurement, facing the probe down towards the bulbs. This ensures all bulbs are giving an appropriate irradiance. To calculate the dose, multiply the irradiance (what was measured with the UVC meter) by exposure time in seconds. Ultraviolet-C dosimeters (ONCE Inc) have also been used to monitor UVC bulbs. These are paper coupons that change color according to the UVC dose they were exposed to. They are placed in the chamber for a set amount of time, and the color is immediately compared to a reference color. The color readout has to be done immediately after the light exposure, as the UVC dosimeter color may revert back toward yellow over time.

Ulatraviolet-C bulbs are rated for an expected life and must be changed periodically. Some commercial UVC germicidal chambers (eg, the BioShift series from ONCE Inc) come equipped with a built-in bulb change timer on their models. While bulb ratings are made for an expected life, the number of on-off

Figure 1: A portable, simple UV light meter (UV512C Digital UVC meter, General Tools & Instruments LLC) with a plugged-in sensor that can measure either UVC or UVA, with a data-logging SD card.

cycles is more important and can significantly shorten the life of the bulbs. For example, running 5-minute cycles is estimated to reduce the overall relative lamp life to 4.2% for the rated life. For example, the life of a bulb rated for 8000 hours is reduced to 336 hours (4.2% of 8000 hours) or about 4000, 5-minute cycles. At a minimum, bulbs and ballasts should be changed once a year or every 1000 cycles, whichever occurs earlier. Generally, it is good practice to replace bulbs and the ballast at the same time. Replacing the bulb alone sometimes does not resolve flickering, buzzing, or low output, therefore the ballast needs to be replaced as well. Be sure to check that UVC irradiance is at the desired level after the replacement. If bulbs and ballasts are changed at the same time, the rotation of bulbs is not necessary. Replacement bulbs can be purchased through the manufacturer of commercially available devices.

Practical applications in swine farms

On swine farms, UVC chambers are commonly located as a clean-dirty line between the outside farm entry or hallway, also considered the 'dirty' side, and the office/breakroom considered the 'clean' side of the farm. These chambers are designed as pass-through chambers where items from one side are placed into the chamber and retrieved from the other side of the chamber after being treated. Because of chamber capacity, UVC chambers are mostly used to decontaminate small- or medium-sized items such as lunch boxes, cell phones, small tools, medications, etc, that have surfaces that are nonpermeable and free of organic matter. It is important for the surfaces to be clean because organic material decreases UVC efficacy on surfaces.[15,16] It is important not to stack items in the UVC chambers due to UVC's inability to penetrate most materials, except for quartz glass. Stacking items or placing them too close together will block surfaces from exposure to the UVC light, preventing the surfaces from being decontaminated. Staggering the arrival of personnel or implementing other biosecurity control measures to reduce the frequency of introduction of materials may be necessary to avoid creating a bottleneck in the system and reduce the temptation to stack or place lunch boxes and other supplies too closely together. One advantage of UVC is its inability to penetrate most materials, including plastic. Treatment of semen bags should not affect the viability of the semen, however, more research is needed to know what, if any, impact UVC may have on semen viability. It is known that repeat UVC exposure of certain plastics may result in a change in color and emission of compounds that may cause an odor over long exposure times.

Several studies have shown that the efficacy of UVC may differ with different surface types. For the most part, UVC is more efficacious on nonporous, nonpermeable materials such as plastic, stainless steel, and glassware versus permeable or porous materials such as cardboard, cloth, and wood.[17-19] This could be due to the ability of permeable or porous materials to shield pathogens from direct exposure of UVC. Therefore, exposure of paper, cardboard, or cloth to UVC is unlikely to effectively decontaminate those materials due to the limited capabilities of the UVC light to penetrate them.

Ultraviolet-C chambers are presently installed most frequently in sow farms where biosecurity is considered a priority. It is recommended that farms train employees on the best practices outlined in this paper and provide simple on-site instructions or checklists of

Table 1: Examples of portable and low-cost UV light meters available on the market

Name	Model #	Spectral range	Manufacturer	Price*	Website
UVA-UVC light meter with data logging SD card	UV254SD	240-390 nm	General Tools & Instruments LLC	$688 (Amazon)	**https://www.generaltools.com/uva-uvc-light-meter-with-excel-formatted-data-logging-sd-card-and-k-j-port**
Solarmeter Model 8.0-RP UVC meter with a remote probe	8.0-RP	246-262 nm	Solarlight Inc	$425	**https://solarlight.com/product/solarmeter-model-8-0-uvc-meter-with-remote-probe/**
UVC light meter	UV512C	220-275 nm	General Tools & Instruments LLC	$485 (Home Depot)	**https://www.generaltools.com/uvc-light-meter**
UVA, UVC light meter	HHUV254SD	240-390 nm	Omega Engineering	$874	**https://www.omega.com/en-us/test-inspection/handheld-meters/light-meters/p/HHUV254SD-Meter**

* The price was recorded December 2020.

best practices highlighting how UVC chambers and lamps should be used and maintained. Sources to use for UVC best practices, are available on the SHIC webage (**https://www.swinehealth.org/wp-content/uploads/2020/10/SHIC_UVC_FactSheet10-2020.pdf**) and at the University of Minnesota's Swine Disease Eradication webpage (**z.umn.edu/UVbox**).

Conclusion

Ultraviolet-C technology can be effectively used to decontaminate surfaces in swine farms as long as users sufficiently understand how it works and follow best practices. Ultraviolet C is a technology that requires maintenance. Standardized protocols informing people about proper cleaning of UVC bulbs and chambers, maintaining and changing UVC bulbs and ballasts on a regular basis is important to ensure the industry is appropriately decontaminating incoming supplies and other surfaces on swine farms to prevent disease outbreaks. It is also important to educate people in the swine industry and create standard safety best practices to follow when using UVC due to its risk of damage to human skin and eyes. Overall, UVC can be an economically feasible tool to help prevent disease outbreaks by reducing the likelihood of bringing contaminated supplies into farms. Following best practices for use, safety, and maintenance will ensure it is used effectively and safely.

Implications

- Development of standardized protocols will guide safe and effective use of UVC.
- Need to understand UVC when applying it for surface decontamination.
- Ultraviolet C should only be used on nonporous, relatively clean supplies.

Acknowledgments

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Conflict of interest

At the time the manuscript was drafted, Stephan Aaron and Tina Loesekann were employed by the company that manufactures the Bioshift Chamber mentioned throughout the manuscript.

Disclaimer

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* Non-refereed references.

Conversion tables

Weights and measures conversions

Common (US)	Metric	To convert	Multiply by
1 oz	28.35 g	oz to g	28.35
1 lb (16 oz)	0.45 kg	lb to kg	0.45
2.2 lb	1 kg	kg to lb	2.2
1 in	2.54 cm	in to cm	2.54
0.39 in	1 cm	cm to in	0.39
1 ft (12 in)	0.3 m	ft to m	0.3
3.28 ft	1 m	m to ft	3.28
1 mi	1.6 km	mi to km	1.6
0.62 mi	1 km	km to mi	0.62
1 in^2	6.45 cm^2	in^2 to cm^2	6.45
0.16 in^2	1 cm^2	cm^2 to in^2	0.16
1 ft^2	0.09 m^2	ft^2 to m^2	0.09
10.76 ft^2	1 m^2	m^2 to ft^2	10.8
1 ft^3	0.03 m^3	ft^3 to m^3	0.03
35.3 ft^3	1 m^3	m^3 to ft^3	35.3
1 gal (128 fl oz)	3.8 L	gal to L	3.8
0.26 gal	1 L	L to gal	0.26
1 qt (32 fl oz)	0.95 L	qt to L	0.95
1.06 qt	1 L	L to qt	1.06

Temperature equivalents (approx)

°F	°C
32	0
50	10.0
60	15.5
61	16.1
65	18.3
70	21.1
75	23.8
80	26.6
82	27.7
85	29.4
90	32.2
102	38.8
103	39.4
104	40.0
105	40.5
106	41.1
212	100.0

°F = (°C × 9/5) + 32
°C = (°F - 32) × 5/9

Conversion calculator available at: amamanualofstyle.com/page/si-conversion-calculator

Conversion chart, kg to lb (approx)

Pig size	Lb	Kg
Birth	3.3-4.4	1.5-2.0
Weaning	7.7	3.5
	11	5
	22	10
Nursery	33	15
	44	20
	55	25
	66	30
Grower	99	45
	110	50
	132	60
Finisher	198	90
	220	100
	231	105
	242	110
	253	115
Sow	300	136
	661	300
Boar	794	360
	800	363

1 tonne = 1000 kg
1 ppm = 0.0001% = 1 mg/kg = 1 g/tonne
1 ppm = 1 mg/L

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AgView continues to add new features to benefit producers and veterinarians

The main value proposition of the AgView tool from the Pork Checkoff has not changed. Its primary purpose is to help put users on the path to protection against disruption caused by foreign animal disease (FAD). This is done using the tool's unique ability to do disease traceback and show ongoing pig movement data should a foreign animal disease such as African swine fever reach the United States.

While the overall function of AgView will remain focused on FAD mitigation and business continuity, the National Pork Board will be announcing additional AgView features in 2022. This builds upon a major feature released in late 2021 - the Account Management Partner (AMP) feature, which offers veterinarians quick access to future AgView capabilities such as near real-time lab results.

An early adopter of the AgView AMP feature is Dr Matt Ackerman, DVM, Pork Veterinary Solutions in New Palestine, Indiana. For his clients, he offers related services that include uploading several key pieces of data into AgView, including swine premises, Secure Pork Supply documents, and pig movements. This allows for a custom analysis of this information as well. "Having an AMP portal allows our clients to grant us direct access to their information," says Ackerman. "This provides me the opportunity to manage, analyze, and advocate this information with and for our clients."

According to Ackerman, some unexpected benefits from AgView adoption have also helped both his clinic and clients. "It has forced us to revalidate our premises IDs. It is interesting to see how many barns have changed in our flow over the past couple of years. Getting on AgView allowed us to catch some incorrect premises ID versus map locations."

Plans for future AgView functionality include allowing veterinarians to access client diagnostic data once permission is granted. This will offer a single location to analyze even more data for improved response time. In the interim, the most recent AgView information can be found by going to **porkcheckoff.org/agview**. For additional information, contact Dr Patrick Webb, DVM, at **pwebb@pork.org** or 515-223-3441.

Certified Swine Sampler Collector Training Program is live

The Certified Swine Sampler Collector (CSSC) Training Program has been launched and several state veterinarians across the Hog Belt have already adopted the program. They have begun to launch the CSSC program in their respective states to get more producers trained and prepared should a crisis such as African swine fever reach our shores.

The CSSC program is an industry-wide initiative jointly managed by the National Pork Board, the American Association of Swine Veterinarians, and Iowa State University. The program is designed to help during a foreign animal disease response by relying on the current on-farm labor force as a critical asset for increasing sample collection capacity. The program also assures state and federal animal health officials that producers and caretakers have been trained prior to an outbreak through a standardized process to correctly collect, handle, and submit samples to certified laboratories.

For USDA Category II accredited veterinarians with swine experience who wish to train individuals to become CSSCs, the first step is to contact the State Animal Health Officials in the state(s) where they plan to train or use CSSCs to confirm their eligibility to participate in the program and any additional requirements that exist. For more information and to access the training materials, go to **securepork.org/cssc**. Contact Dr Pam Zaabel, DVM, at **pzaabel@pork.org** or at 515-223-2764.

Alternate Student Delegate selected for AASV Board

The AASV Student Recruitment Committee is pleased to announce the selection of Hunter Everett, a second-year veterinary student at North Carolina State University (NCSU), as the incoming Alternate Student Delegate to the AASV Board of Directors.

Hunter's interest in swine began with a student job on the NCSU 200-sow farrow-to-finish farm where he was employed throughout college. His growing interest in swine led him to hold internships and externships in production and research within multiple different systems. As a member of the Pork Checkoff's Student Social Forces program, he advocated for the pork industry within his animal science network and beyond. Since joining AASV as a first-year veterinary student, he has been selected for two oral presentations in the AASV student seminar (2021, 2022). Because of his experiences in swine production and research, coupled with strong mentorship, Hunter has a firm commitment to pursuing a career in swine medicine.

Hunter is looking forward to connecting with students and members. "I'm so excited to work with and learn more about AASV over the next two years. I can't wait to meet and work with other students, members, and future colleagues at this year's meeting!"

Hunter will assume his duties as Alternate Student Delegate during the 2022 AASV Annual Meeting. The current alternate delegate, Sydney Simmons (NCSU, 2023), will assume the delegate position currently held by Amanda Anderson (Iowa State, 2022), who will rotate off the board. Sydney and Hunter will represent student interests within AASV as nonvoting members of the Board of Directors and the Student Recruitment Committee. Please join us in welcoming Hunter to the AASV Board of Directors and thanking Amanda for her service!

AASV 2022 Annual Meeting proceedings now online

The proceedings of the AASV 2022 Annual Meeting are available for members to download at **aasv.org/annmtg/proceedings**. Current 2022 membership dues-paid status is required to access the files.

As in the past, the papers are available as follows:

- The "big book" of all the regular session papers in a single PDF file with a linked table of contents
- Seminar booklets: A PDF collection of the papers for each seminar
- An individual paper for each presentation is available in the Swine Information Library: **aasv.org/library/swineinfo/**

You will be prompted for your AASV website username and password to access the files. If you have forgotten your password, use the "Reset Password" link in the upper right of the AASV website (**aasv.org**) or contact the AASV office for assistance.

AVMA Committee and Council Positions Open

The AASV designates representatives for several committees of the American Veterinary Medical Association. Current representatives are listed at **aasv.org/members/only/AVMAreps**. Visit **avma.org/membership/volunteering-avma/avma-volunteer-opportunities-vacancies** for more details and descriptions of each committee. Several committees have openings; please contact the AASV office if you are interested in representing AASV.

AASV President challenges AASV members to Give A Ham

During the winter holidays, AASV president Dr Mary Battrell challenged all AASV members to celebrate a season of giving by participating in the National Pork Producer Council's Give A Ham program. Although the winter holidays have passed, you can still participate year-round. Simply go to your local grocery store, purchase pork products, and donate to your favorite charity.

Sandra from Charity Missions Center, Dr Mary Battrell, and her son, Don Banks.

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The #1 iron dextran (III) for baby pigs

1,400

200 mg = 1,109

2 x 200 mg = 427

x (-$2.77) = ?

Opitmal*	≥ 110 g/L	Deficient*	<90 g/L

Q: A truck holds an average of 1,400 baby pigs. If given a single 200 mg dose of iron 1,109 baby pigs will be subject to iron deficiency anemia. If given a second 200 mg dose, only 427 baby pigs will be subject to iron deficiency anemia, which is an increase of 682 optimal-iron baby pigs. If baby pigs subject to iron deficiency anemia bring $2.77 less at market per head,[1,2,3] how much money is a pork producer leaving on the table with every truckload if they don't use a second dose of Uniferon®?

A: $1,889

Change the math by adding a second dose of Uniferon®.

1: Perri A et al. An investigation of iron deficiency and anemia in piglets and the effect of iron status at weaning on post-weaning performance. JSHAP. 2016;24:10–20.

2: Fredericks L et al. Evaluation of the impact of iron dosage on post- weaning weight gain, and mortality. AASV. 2018;315

3: Olsen, C. (2019) The economics of iron deficiency anemia on US swine production: An annual impact of 46-335 million US dollars. American Association of Swine Veterinarians. Orlando. Florida.

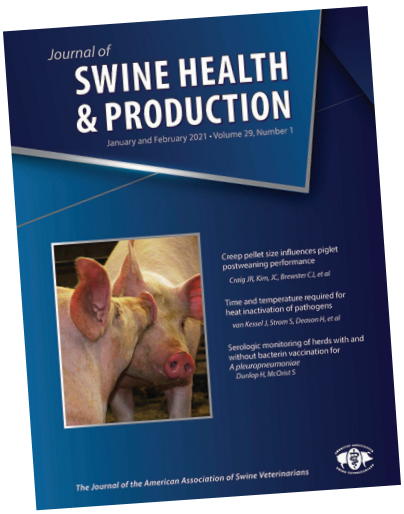
* Industry Standards for Blood Hb Levels (g/L)

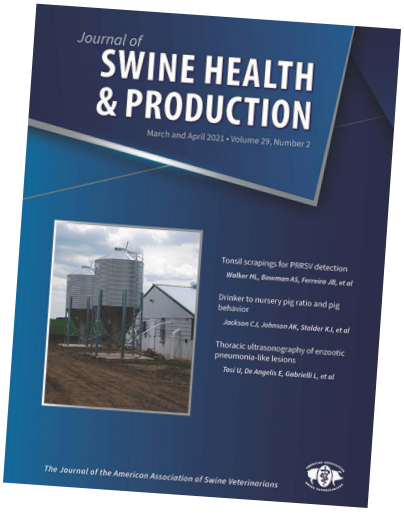
us.uniferon.com

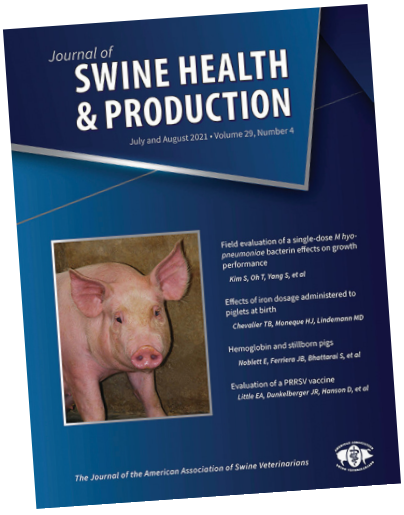
PHARMACOSMOS

PM-060-00

Pigs of #instaham







Share your pig photos for the JSHAP cover

Submissions by readers are welcome!

- Photos must represent healthy pigs and modern production facilities and not include people.
- Photos must be taken using the camera's largest file size and highest resolution.
- Please send the original image(s); do not resize, crop, rotate, or color-correct the image prior to submission.
- Submit photos with your name and affiliation to **tina@aasv.org**.

The American Association of Swine Veterinarians is committed to providing members with resources to promote and enhance well-being - the state of being comfortable, healthy, and happy.

The nine dimensions

Well-being isn't a single measure of health.

It is composed of nine unique dimensions that touch upon every aspect of our lives: occupational, intellectual, spiritual, social, emotional, physical, financial, creative and environmental. These dimensions work together, and collaboratively contribute to our overall well-being.

Intellectual
Learning new things; participating in activities that foster critical thinking and expand your worldviews.

Environmental
Taking an active role in preserving, protecting, and improving the environment.

Social
Surrounding yourself with a network of support built on mutual trust, respect, and compassion.

Emotional
Being able to identify and manage your full range of emotions, and seeking help when necessary.

Physical
Taking care of your body (e.g., getting enough sleep, eating a well-balanced diet, exercising regularly).

Financial
Being aware of your personal finances and adhering to a budget that enables you to meet your financial goals.

Creative
Participating in diverse cultural and artistic experiences.

Occupational
Being engaged in work that gives you personal satisfaction, and aligns with your values, goals, and lifestyle.

Spiritual
Having a sense of inner harmony and balance.

www.aasv.org/resources/wellbeing

Talking about COVID-19 vaccination

Veterinarians are generally regarded as some of the most trusted health professionals and members of a community. Clients value your expertise about animal health, but they might seek your recommendations for other issues, including their own health. These conversations might not always be easy or comfortable. Luckily, resources are available when it comes to COVID-19 and vaccines.[1]

During November 2021, the American Veterinary Medical Association (AVMA) launched a national education and awareness campaign to encourage veterinary teams, their clients, and the general public to get vaccinated against the virus that causes COVID-19.[2] The AVMA developed print, digital, audio, and video tools and resources for veterinary teams to promote vaccination in their communities. Many of the AVMA campaign materials offer multiple versions featuring various animal species, including pigs, so that they are relevant to different audiences.

"Veterinarians are healthcare providers trusted not only by their clients but by the public at large, we understand the power of vaccines, and we have been enlisted as COVID vaccination providers in some areas," said Dr Arce, a practicing veterinarian in San Juan, Puerto Rico, and president of the AVMA. "We recognize that vaccination is a choice and that not everyone may be able to receive one. But we are uniquely qualified to share the importance of preventing and controlling disease in both animals and people. Protecting public health is part of a veterinarian's responsibility and appropriate preventive care, including vaccinations, goes a long way towards protecting public health."

As members of the veterinary medical profession, we vow to protect animal and public health.[3] Most people are trying to make the best choices for their families based on the information they have.

As a veterinarian, you can

- Encourage clients to always talk to their family healthcare provider.
- Share facts about infectious disease risks and vaccine safety and efficacy, within the boundaries of your degree, ethics, and knowledge.
- Encourage clients to scrutinize their sources.
- Provide resources for clients to make informed decisions.

The AVMA understands that not every veterinarian will be comfortable discussing COVID-19 or human vaccines. The resource materials are intended to make conversations easier for those who do want to take the opportunity to discuss it with their colleagues and clients.

Visit **avma.org/VaccinationTools** to view and download materials for your use in your clinics or communities.

"Protecting public health is part of a veterinarian's responsibility and appropriate preventive care, including vaccinations, goes a long way towards protecting public health."
- Dr José Arce

References

*1. Talking about COVID-19 vaccination. AVMA. Accessed January 14, 2022. **https://www.avma.org/resources-tools/animal-health-and-welfare/covid-19/talking-about-covid-19-vaccination**

*2. AVMA launches national awareness campaign to encourage COVID-19 vaccinations. News release. AVMA; November 22, 2021. Accessed January 14, 2022. **https://www.avma.org/news/press-releases/avma-launches-national-awareness-campaign-encourage-covid-19-vaccinations**

*3. Veterinarian's Oath. AVMA. Accessed January 14, 2022. **https://www.avma.org/resources-tools/avma-policies/veterinarians-oath**

* Non-refereed references.

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Director of Public Health and Communications

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UPCOMING MEETINGS

American Association of Swine Veterinarians 53rd Annual Meeting

February 26 - March 1, 2022 (Sat-Tue)
JW Marriott Indianapolis
Indianapolis, Indiana

For more information:
American Association of Swine Veterinarians
830 26th Street
Perry, Iowa 50220 USA
Tel: 515-465-5255
Email: **aasv@aasv.org**
Web: **aasv.org/annmtg**

Animal Agriculture Alliance Stakeholders Summit

May 11 - 12, 2022 (Wed-Thu)
Kansas City, Missouri

For more information:
Animal Agriculture Alliance
2101 Wilson Blvd, Suite 810-B
Arlington, VA 22201
Web: **animalagalliance.org/initiatives/stakeholders-summit**

World Pork Expo

June 8 - 10, 2022 (Wed-Fri)
Iowa State Fairgrounds
Des Moines, Iowa

For more information:
National Pork Producers Council
10676 Justin Drive
Urbandale, Iowa 50322
Web: **worldpork.org**

7th International Symposium on Animal Mortality Management

June 13 - 16, 2022 (Mon-Thu)
Raleigh, North Carolina
Web: **animalmortmgmt.org**

26th International Pig Veterinary Society Congress

June 21 - 24, 2022 (Tue-Fri)
A hybrid conference
Riocentro Convention and Event Center
Rio de Janeiro, Brazil

For more information:
Rua Guaicuí 26, 10º andar
Coração de Jesus
Belo Horizonte, MG 30380.380
BRAZIL
Tel: +55 31 3360 3663
Email: **ipvs2022@ipvs2022.com**
Web: **ipvs2022.com**

ZeroZincSummit 2022

June 22 - 23, 2022 (Wed-Thu)
Copenhagen, Denmark

For more information:
SEGES Danish Pig Research Centre
Axelborg, Axeltorv 3
1609 Copenhagen V
DENMARK
Web: **tilmeld.dk/zerozincsummit2022**

2022 Annual Therio Conference

July 20 - 23, 2022 (Wed-Sat)
Bellevue, Washington

Hosted by the Society for Theriogenology and the American College of Theriogenologists

For more information:
Web: **theriogenology.org**

For additional information on upcoming meetings: aasv.org/meetings

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