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Midwest Swine Nutrition Conference

Schedule of Presentations

- 8:15 Registration and check-in
- 9:00 Welcome. *Dennis Liptrap, Chairman of Planning Committee*
- 9:05 Policy outlook for animal agriculture and animal science: opportunities and challenges. *Lowell Randel, Texas Tech University*
- 9:50 The functional role of colostrum to the metabolic transition of neonates to the external environment. *Theresa Casey, Purdue University*
- 10:25 Break
- 11:00 Translating fiber nutrition into practical strategies for U.S. sow diets. *Amy Petry, University of Missouri*
- 11:30 Impacts of heat stress on energy balance in sows and their progeny: consequences for growth and developmental outcomes. *Jay Johnson, University of Missouri*
- 12:00 Lunch
- 1:10 European experience for a holistic approach to feeding nursery pig diets without therapeutic zinc. *Neil Jaworski, Trouw Nutrition, The Netherlands*
- 1:55 Impacts of non-nutritive sweeteners on performance and gastrointestinal development in weaned pigs. *Kwangwook Kim, Michigan State University*
- 2:25 Break
- 2:40 Nutritional management of health compromised pigs: implications and approaches. *Nicholas Gabler, Iowa State University*
- 3:20 From papers to profit: bridging research and real world application in production swine nutrition. *Trey Kellner, AMVC Group*
- 4:00 Wrap-up and adjourn

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Policy Outlook for Animal Agriculture and Animal Science: Opportunities and Challenges

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Summary

The convergence of government reforms, budget reconciliation, Farm Bill and appropriations pose unique opportunities and challenges for animal agriculture and animal science. President Trump's plans to reform and restructure the federal government are impacting animal scientists inside the government and across academia and industry. This includes proposed major reductions to USDA research funding in the President's Budget, although Congress appears to be avoiding large spending cuts. At the same time, the recently completed budget reconciliation provides significant funding and opportunities to address critical needs for animal agriculture and animal science. Animal scientists and producers should stay informed of policy developments and be nimble and creative to adapt to change.

Government Reforms

Since taking office in January 2025, President Donald Trump has signed hundreds of Executive Orders (EOs) relating to a wide variety of policy areas, many of which are intended to reform the structure and operation of the federal government. Among the actions were EOs that froze funding to enable a review of pending expenditures to ensure that they reflect the priorities of the administration. The Biden administration prioritized programs that focused on climate change and incorporated diversity, equity and inclusion (DEI). Through EOs and memos to agency heads, the Trump administration has directed that all pending expenditures, including research grants, be reviewed to ensure that they do not focus on climate change or DEI (Executive Order No. 14151, 2025). That freeze-and-review process is still underway within the United States Department of Agriculture's (USDA) research agencies and has led to a halt in most external funding streams (The White House, 2025a). As of August 1, 2025, it was unclear when the review process would conclude. This poses questions about how remaining funds for fiscal year 2025 will be allocated.

In addition to pausing the granting process, the Trump administration has also taken action to revise indirect cost recovery rates (IDC) for research grants citing the current levels allowed by agencies such as the National Institutes of Health as too high. In February 2025, NIH set a standard IDC rate of 15 percent for all grants, a change from negotiated IDC rates that averaged above 50 percent and were much higher for some institutions (NOT-OD-25-068, n.d.). Indirect rates for grants administered by the USDA's National Institute of Food and Agriculture (NIFA) are set by statute, in the Farm Bill, at 30 percent and would require Congressional action to change (Agriculture Improvement Act, 2018).

The Trump administration is also moving to reduce the size of the federal government. This began with an immediate hiring freeze, which has been extended until at least October 15, 2025 (The White House, 2025b). Agencies have also offered an aggressive set of incentives to reduce the size of the federal workforce including deferred resignations and voluntary early retirements. According to USDA, over 15,000 USDA employees had accepted deferred resignations as of July 24, 2025. Details on the number of USDA research agency employees who are leaving have not been released.

On July 24th, Secretary of Agriculture Brooke Rollins released Secretary Memorandum: SM 1078-015 (The Secretary of Agriculture, 2025) which outlines the Department of Agriculture’s Reorganization Plan. The plan includes four pillars:

- Principle 1: Ensure the Size of USDA's Workforce Aligns with Financial Resources and Priorities - USDA will continue to utilize voluntary programs such as the Deferred Resignation Program (DRP), Voluntary Early Retirement Authority (VERA) and Voluntary Separation Incentive Payments (VSIPs). The Department will also use directed and voluntary reassignments to ensure the workforce is aligned with mission priorities. Focused and limited Reductions in Force will be implemented only if needed and only after approval by USDA's Deputy Secretary.
- Principle 2: Bring USDA Closer to Its Customers by Relocating Resources Outside of the National Capital Region – The reorganization calls for the establishment of five hubs that will house USDA programs and personnel. The announced locations are Raleigh, North Carolina; Kansas City, Missouri; Indianapolis, Indiana; Fort Collins, Colorado; and Salt Lake City, Utah. Given that NIFA and the Economic Research Service headquarters were relocated to Kansas City during the first Trump administration, this hub will likely house the majority of USDA research agency staff.
- Principle 3: Eliminating Management Layers and Bureaucracy – USDA plans to reduce or eliminate stand-alone regional offices and other similar management layers and focus co-location at the five hub locations. The Agriculture Research Service (ARS) will eliminate its Area Offices with functions transferred to the Office of National Programs. The National Agricultural Statistics Service (NASS) will consolidate its 12 existing regions into the five USDA hubs over a multi-year period. In the national capital region, multiple USDA facilities will be vacated as a part of the process. This includes the USDA South Building and the ARS Beltsville Agricultural Research Center.
- Principle 4: Consolidate Support Functions – The plan states that department and agency support functions will be consolidated to reduce duplication and provide consistency across USDA. Mission area and agency resources will be realigned to the consolidated functions.

The reorganization plan is expected to take several years for completion. During the transition period it will be important for animal scientists to stay informed of staffing and organizational changes.

Budget and Appropriations

On May 30th, the Trump Administration released the full details of its proposed budget for FY 2026 (United States Department of Agriculture, 2026). The President’s Budget proposes major cuts to USDA supported research, education and economics programs. Under the President’s Budget, overall funding for USDA’s Research, Education and Economics Mission Area agencies would go from \$4 billion in FY 2025 to \$3.2 billion in FY 2026. This would include the elimination of funding for the Hatch Act capacity program and major reductions to Smith-Lever and 1890’s capacity programs. The Agriculture and Food Research Initiative (AFRI) would be funded at \$405 million, a \$40 million reduction from FY 2025. ERS would be cut by \$10 million and NASS by \$2.5 million.

The House and Senate Appropriations Committees have advanced their respective versions of the FY 2026 Agricultural Appropriations Bill and given clear indications that they are not supportive of deep cuts to USDA’s research agencies (Harris, 2025 and Hoeven, 2025). In both the House and Senate versions, funding for capacity programs (Hatch, Smith-Lever, etc..) and the AFRI program would be funded at FY 2025 levels. ARS salaries and expenses would receive a \$5 million increase in the House and a \$38 million increase in the Senate. Funding levels for selected USDA research accounts are provided in Table 1 that compare FY 2025 final appropriations, FY 2026 President’s Budget, FY 2026 House and FY 2026 Senate.

Table 1: Appropriations for Selected USDA Research Accounts – FY 2025-2026

ACCOUNT	FY25 FINAL	FY 26 PRESIDENT	FY26 HOUSE	FY26 SENATE
Hatch	\$265 million	\$0	\$265 million	\$265 million
Smith Lever	\$325 million	\$175 million	\$325 million	\$325 million
AFRI	\$445 million	\$405 million	\$445 million	\$445 million
AGARDA	\$1 million	\$0	\$1 million	\$1 million
Ag Genome to Phenome	\$2 million	\$0	\$2.5 million	\$2 million
Research Facilities Act	\$1 million	\$1 million	\$1 million	\$1 million
ARS Salaries	\$1.788 billion	\$1.756 million	\$1.793 billion	\$1.826 billion
ARS Facilities	\$57.1 million	\$0	\$21 million	\$42.6 million
ERS	\$90.6 million	\$80 million	\$85 million	\$90.6 million
NASS	\$187.5 million	\$185 million	\$187.5 million	\$187.5 million

Budget Reconciliation

On July 4th, President Trump signed the “One Big Beautiful Bill” budget reconciliation package into law. The package represents Trump’s top legislative priority for 2025. The package is a combination of tax provisions as well as spending cuts to pay for the tax policies and targeted increases for areas such as immigration and border security (One Big Beautiful Bill Act, 2025). In addition, the final package includes mandatory funding for a wide array of agriculture programs traditionally found in Farm Bill legislation ranging from commodity programs to conservation and nutrition. The legislation also includes funding for several agricultural research programs. Most notably it provides \$125 million per year to fund the Research Facilities Act to help address research infrastructure needs. The Association of Land Grant and Public Universities (APLU) had made infrastructure a top priority for the next Farm Bill, responding to the \$11.5 billion need to address deferred maintenance and infrastructure needs identified in a study published in 2021 (Reeves et al., 2021).

While the budget reconciliation package does not fully fund the backlog of infrastructure needs, the new funding represents the largest ever investment in agricultural research infrastructure. This program will be administered by NIFA under its authorities provided by the Research Facilities Act. It is expected that there will be a competitive process announced in the coming months for the program. Other research programs included in the legislation include \$60 million in one-time funding for 1890s Scholarships, \$80 million in 2025 for the Specialty Crops Research Initiative and \$175 million in subsequent years, \$8 million one-time funding for the Assistive Technology Program and \$2 million per year for Urban/Indoor Ag Research.

The budget reconciliation also provides critical funding for animal disease prevention and management programs, originally established in the 2018 Farm Bill. The “three-legged stool” of programs includes the National Animal Health Laboratory Network (NAHLN), National Animal Disease Preparedness and Response Program (NADPRP) and the National Animal Vaccine Bank (NAVB). Overall funding for the suite of programs will be \$233 million per year. For each fiscal year between 2026-2030, \$10 million is provided for the NAHLN, \$70 million is provided for NADPRP, and \$153 million is provided for NAVB. Starting in fiscal year 2031, \$75 million will be provided, of which not less than \$45 million for each of those fiscal years shall go to fund NADPRP.

“Skinny” Farm Bill

The Farm Bill is normally reauthorized every five years, with the last one signed into law in 2018. The 2018 Farm Bill has been extended twice, with the latest extension scheduled to expire on September 30, 2025 (United States Congress, 2024). While budget reconciliation provided funding for most of the mandatory programs normally included in the Farm Bill, there is still a need to address numerous authorities that will expire without Congressional action. Most provisions within the Research Title of the Farm Bill are discretionary programs not included in budget reconciliation. As a result, dozens of programs will be without authority if Congress does not pass a new Farm Bill or further extend the 2018 Farm Bill. House Agriculture Committee Chairman G.T. Thompson (R-PA) has indicated his desire to move a so-called “skinny” Farm Bill in the fall of 2025 to reauthorize programs not included in budget reconciliation. Because most mandatory funding issues have been resolved through reconciliation, the price of a “skinny” Farm Bill is currently estimated to be \$8 billion (Brasher, 2025).

In addition to providing needed reauthorizations, a “skinny” Farm Bill also provides an opportunity to address emerging policy issues. One such policy issue is California’s Prop 12, which dictates livestock production methods for producers marketing their products in the state of California (California Department of Food and Agriculture, 2018). The policy covers pork, egg and veal production and places restrictions on the types of housing systems allowed for product intended for sale in California. The largest impact of Prop 12 has been on the pork industry and the National Pork Producers Council is actively working to change the policy at the federal level (National Pork Producers Council, n.d.). A lawsuit was brought challenging the validity of Prop 12 and its impact on producers outside of California. In 2023, the Supreme Court ruled that Prop 12 is constitutional, allowing the policy to stay in place (Gorsuch, 2023). Legislation has been introduced in the House and Senate to prohibit states and local jurisdictions from dictating production methods for producers outside their borders (Hinson, 2025 and “Food Security and Farm Protection Act,” 2025). Chairman Thompson has stated his desire to include such language in the next Farm Bill.

Despite the much lower price tag and the fact that controversial nutrition provisions were addressed in budget reconciliation, the prospects for completing the Farm Bill are unclear. The House expected to act first on moving a “skinny” Farm Bill, with committee action likely in early fall 2025. Should Congress not be able to complete a new bill by the end of calendar year 2025, a further extension of the 2018 Farm Bill would be needed.

Summary

The current policy outlook for animal science and animal agriculture is complicated by government reform efforts, budget reconciliation and the Farm Bill, and the annual appropriations process. Changes to the federal workforce and USDA's science agencies have the potential to cause disruption to intramural and extramural research programs. While the President's Budget proposes deep cuts to USDA research, Congress appears poised to provide level funding for most major programs. At the same time, the budget reconciliation process has yielded significant new resources for research infrastructure and animal health programs and the House and Senate Agriculture Committees are working to reauthorize other Farm Bill programs before the end of the year. Given the dynamic environment surrounding agricultural policy, it is important for animal scientists to stay informed of developments and adapted to evolving challenges and opportunities.

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Translating Fiber Nutrition into Practical Strategies for U.S. Sow Diets

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Summary

The role of dietary fiber in sow nutrition has evolved beyond bulk and gut fill to include measurable benefits on satiety, gut health, energy balance, and sow longevity. European systems have long embraced fiber as a tool to manage sow behavior and welfare under restrictive feeding programs. In the U.S., recent research has begun to demonstrate how targeted fiber inclusion can improve sow retention, reduce farrowing complications, support colostrum production, and enhance performance across parities. However, widespread adoption of fiber strategies in U.S. systems remains limited due to variability in ingredient composition, lack of analytical tools, and commercial formulation constraints. Fiber - The Next Frontier collaboration between the University of Missouri and Iowa State University was formed to address these challenges. The goal of this partnership is to provide practical, research-supported guidance for fiber use across gilt development, gestation, and the transition period. This document summarizes key findings from recent research effort and offers a framework for considering functional fiber in formulation.

Introduction: Dietary Fiber in Sow Diets- Balancing Benefits and Challenges

In recent decades, the metabolic and physiological demands on the modern sow have increased substantially as genetic selection has intensified expectations for pigs per sow per year. As a result, the sow's nutrient and energy requirements have also increased. Today's gestating sow experiences greater metabolic and behavioral stress, increasing susceptibility to health and management challenges. This coincides with rising sow mortality, lower birth weights and milk intake per pig, and increased annual culling rates—costing the U.S. pork industry more than \$1 billion per year in actual and opportunity losses (National Pork Board, 2023). Nutritional strategies must evolve to meet the physiological and behavioral needs of the modern prolific sow to ensure sustainable pork production.

Dietary fiber (DF) supplementation is a promising strategy to support the physiological demands of hyperprolific sows. In the gastrointestinal tract, DF can form viscous gels, increase bulk density, improve hydration, facilitate cation exchange, and undergo fermentation. These properties influence passage rate, energy uptake, insulin sensitivity, satiety, laxation, and gut health. Gestating sow diets outside the U.S. often include 40 to 120% more DF to promote satiety,

gut fill, and weight control (Jo and Kim, 2023). The EU mandates a minimum of 200 grams of crude fiber (CF) per sow per day during gestation, and higher DF intake is associated with improved sow longevity (EEC, 2001). Recent literature suggests DF supports homeorhetic energy metabolism, enhances insulin sensitivity, reduces constipation, improves farrowing kinetics, and increases milk production, all key physiological processes for large litters (Fig. 1; Theil et al., 2022; Jo and Kim, 2023). Our U.S. based research with commercial integrators shows DF supplementation reduces mortality in pen housed gestating sows, decreases stillborn rates by 17% when fed during the transition period, alleviates pre farrow constipation, and minimizes body weight (BW) loss during lactation (Cardona et al., 2024).

However, including DF into U.S. sow diets presents several practical challenges, notably the logistics of managing higher bulk density feeds, ingredient availability and consistency, and the limited adoption of advanced DF characterization tools. One of the primary logistical barriers is the physical nature of fibrous ingredients. Feedstuffs such as soyhulls, wheat midds, or beet pulp generally have lower energy density and greater bulk density, which complicates handling, storage, transport, and incorporation into existing feeding methods. Furthermore, ingredient availability and

consistency limit diet formulation and consistency across operations. We recently characterized 80 soyhull samples from 22 processing locations across 10 U.S. states (Lima et al. 2025). This analysis revealed substantial DF variability, with neutral detergent fiber (NDF) ranging from 51.3% to 68.2%. Compounding this challenge is the limited adoption of advanced fiber analytics, such as total dietary fiber (TDF) or physicochemical profiling, which are important to design diets that elicit predictable outcomes such as enhancing sow satiety and farrowing ease.

To address these challenges, Dr. Petry and Dr. Rosero have formed a strategic partnership through the *Fiber – The Next Frontier* collaboration, leveraging their complementary expertise to advance fiber nutrition in sows. This proceeding highlights both collaborative and individual studies from their respective labs, integrating applied and basic research to better understand the role of fiber in sow health and performance. Together, our partnership aims to provide science-based and practical strategies to support the physiological needs of prolific sows in modern production systems.

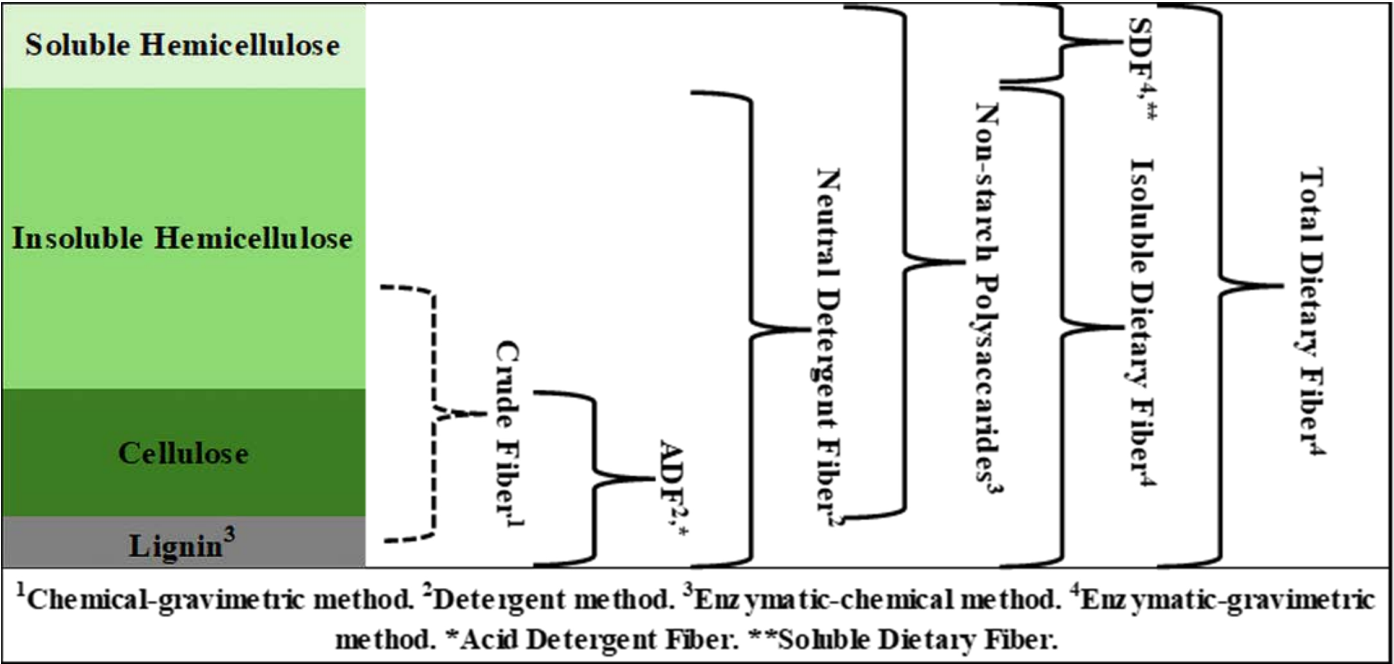
Dialing in Fiber Nutrient Loadings for Formulation

In the context of swine nutrition, DF is defined by Codex Alimentarius, “as carbohydrate polymers with 10 or more monomeric units, which are not hydrolyzed by the endogenous enzymes in the small intestine, this includes naturally occurring and synthetic polymers” (Jones et al., 2014). Dietary fiber is methodologically separated into distinct fractions based on solubility and structural characteristics. Using enzymatic–chemical and gravimetric techniques, DF

can be divided into soluble non-cellulosic polysaccharides (water-soluble NSP), insoluble non-cellulosic polysaccharides (insoluble NSP), cellulose, and lignin (Bach Knudsen, 2001). Soluble and insoluble hemicelluloses represent the non-cellulosic polysaccharides that contribute to the fiber’s water-holding and fermentability properties. Cellulose, a structural polysaccharide, and lignin, a non-carbohydrate component, add rigidity and resistance to microbial degradation. Figure 1 illustrates this hierarchical separation of fiber fractions and the corresponding analytical approach for each component. This systematic breakdown helps nutritionists more accurately estimate both DF content and its functional effects in animal diets.

Crude fiber (CF) quantifies the portion of plant material that remains after sequential acid and alkaline digestion and serves as the legal standard for DF analysis in regulatory contexts. However, the CF method dissolves portions of lignin and hemicelluloses during digestion, resulting in a 30 to 60% underestimation of total DF content in feed ingredients (Fahey et al., 2019). This methodology results in inaccurate estimates of indigestible bulk and fermentable DF fractions and should be phased out by the feed industry.

AOAC Official Method 2002.04 describes the determination of amylase-treated neutral detergent fiber (aNDF) in feeds (AOAC, 2002). The method uses a neutral detergent solution, sodium sulfate, and heat stable α-amylase to solubilize proteins, sugars, starches, and pectins, isolating a fibrous residue composed largely of cellulose, hemicellulose, lignin, and residual indigestible nitrogen. This analysis provides a reasonable estimate of the insoluble fiber fraction in feedstuffs, which is generally inversely related to



Adapted from: Fiber in swine nutrition. In: L. I. Chiba, editor. Sustainable swine nutrition. 2nd ed. <https://doi.org/10.1002/9781119583998.ch14>

Figure 1. Schematic overview of dietary fiber analysis implemented in swine nutrition.

digestibility and feed intake (Latimer, 2023). However, detergent procedures are subject to variation between laboratories and technicians (Fahey et al., 2019). Additionally, NDF methods exclude most soluble fiber components, whereas TDF methods capture both soluble and insoluble fiber fractions.

Total dietary fiber methodology characterizes all nondigestible carbohydrates and lignin that are intrinsic and intact in plants, as well as isolated or synthetic nondigestible carbohydrates. It also provides insight into fiber solubility by quantifying insoluble dietary fiber (**IDF**), soluble dietary fiber (**SDF**), and, in some methods, nondigestible oligosaccharides (**NDO**). Eight recognized TDF methods exist, with AOAC 2022.01 being the most comprehensive and current. This method captures resistant starch and NDOs often missed by simpler approaches, while AOAC 991.43 remains the most widely used for feed ingredients due to its efficiency and cost effectiveness in separating SDF and IDF. All TDF procedures follow a core methodology in which feed samples are first treated with α -amylase and amyloglucosidase to remove digestible starch, followed by protease to eliminate protein. IDF is filtered and weighed, while SDF is either precipitated with alcohol or quantified in the filtrate using liquid chromatography. This approach provides a comprehensive fiber measurement that captures both soluble and insoluble fractions, offering a more complete understanding of fiber's nutritional role in swine diets.

Beyond solubility, the hydration and physicochemical properties of DF play a key functional role in the digestive process of pigs. According to Lindberg (2014), these properties can be described by swelling capacity, solubility, water holding capacity (**WHC**), and water binding capacity (**WBC**). They influence how fiber interacts with water in the gastrointestinal tract, affecting digesta viscosity, transit time, nutrient absorption, and fermentation. For example, fibers with high WHC and WBC can retain more water in the gut, supporting digestion and potentially enhancing gut health and satiety. Measuring these hydration properties can also offer valuable insight for selecting and formulating fiber-rich ingredients in monogastric diets.

However, DF composition and functional properties vary widely among ingredients commonly used in sow diets, influencing gut fill, fermentability, and energy contribution. As shown in Table 1, soy hulls (**SH**) and sugar beet pulp contain high TDF (47% and 52%, respectively), moderate SDF, and favorable WHC and water swelling capacity (**WSC**) values, supporting fermentation and fecal hydration. In contrast, distiller's dried grains with solubles (**DDGS**) and

Table 1. Fiber composition and physicochemical properties of common fiber sources, as-is basis¹

Fiber Source	TDF, %	IDF, %	SDF, %	WHC ml/g	WBC ml/g	WSC ml/g
Rice bran	25	20	5	2	3	3
Wheat Midds	26	23	3	4	3	3
DDGS	34	33	1	2	2	3
Soy hulls	47	38	9	7	5	7
Sugar Beet Pulp	52	44	8	5	4	8
Lignocellulose	55	53	2	12	2	11
Pea Hulls	80	72	8	7	4	6

¹Represents average of 5 samples per assay conducted at the MU Monogastric Nutrition Lab.

wheat midds are dominated by IDF with low SDF, WHC, and WSC, contributing mainly to bulk. Pea hulls and lignocellulose have the highest TDF (80% and 55%), primarily as IDF, though lignocellulose exhibits the highest WHC and WSC among ingredients evaluated. These differences highlight the importance of characterizing fiber beyond CF values to achieve targeted effects on satiety, motility, and fermentation discussed later.

To advance our understanding of fiber characterization in feed ingredients, our partnership evaluated the fiber composition (NDF, ADF, IDF, SDF, TDF) and physicochemical properties (WHC, WBC, WSC) of soybean meal (**SBM**) and SH. A subset of 80 SBM samples, primarily sourced from Iowa, Minnesota, Indiana, Nebraska, and Missouri, was selected from an initial pool of 225. On a dry matter (**DM**) basis, fiber concentrations in SBM varied by analytical method: NDF averaged 9.8% (CV = 31%), IDF 18.8% (CV = 7.8%), SDF 5.2% (CV = 17%), and TDF 24.0% (CV = 6.2%) (Figure 2). Physicochemical analysis revealed moderate WBC (3.05 ± 0.17 g/g), WHC (4.61 ± 0.46 g/g), and WSC (3.02 ± 0.36 g/g). These findings suggest that TDF provides a more consistent and comprehensive estimate of fiber content in SBM than NDF, which underestimates total fiber and exhibits greater variability.

The 80 selected SH samples, derived from 135 initially collected and primarily sourced from Missouri, Iowa, Minnesota, and Illinois, exhibited a consistently high-fiber profile across all methods (Figure 2). On a DM basis, NDF averaged 62.6% (CV = 5.1%), while enzymatic methods showed IDF at 69.1% (CV = 6.3%), SDF at 7.6% (CV = 23%), and TDF at 76.6% (CV = 6.7%). SH also demonstrated elevated water-related physicochemical properties, with WBC at 4.9 ± 0.39 g/g, WHC at 6.6 ± 0.91 g/g, and WSC at 8.22 ± 1.94 g/g. These findings highlight the importance of using TDF analysis to more accurately characterize fiber content in feedstuffs, due to its lower analytical variability and greater consistency across ingredients. This is especially important for ingredients with higher soluble fiber content, such as SBM and SH. In addition, accurate fiber and physicochemical

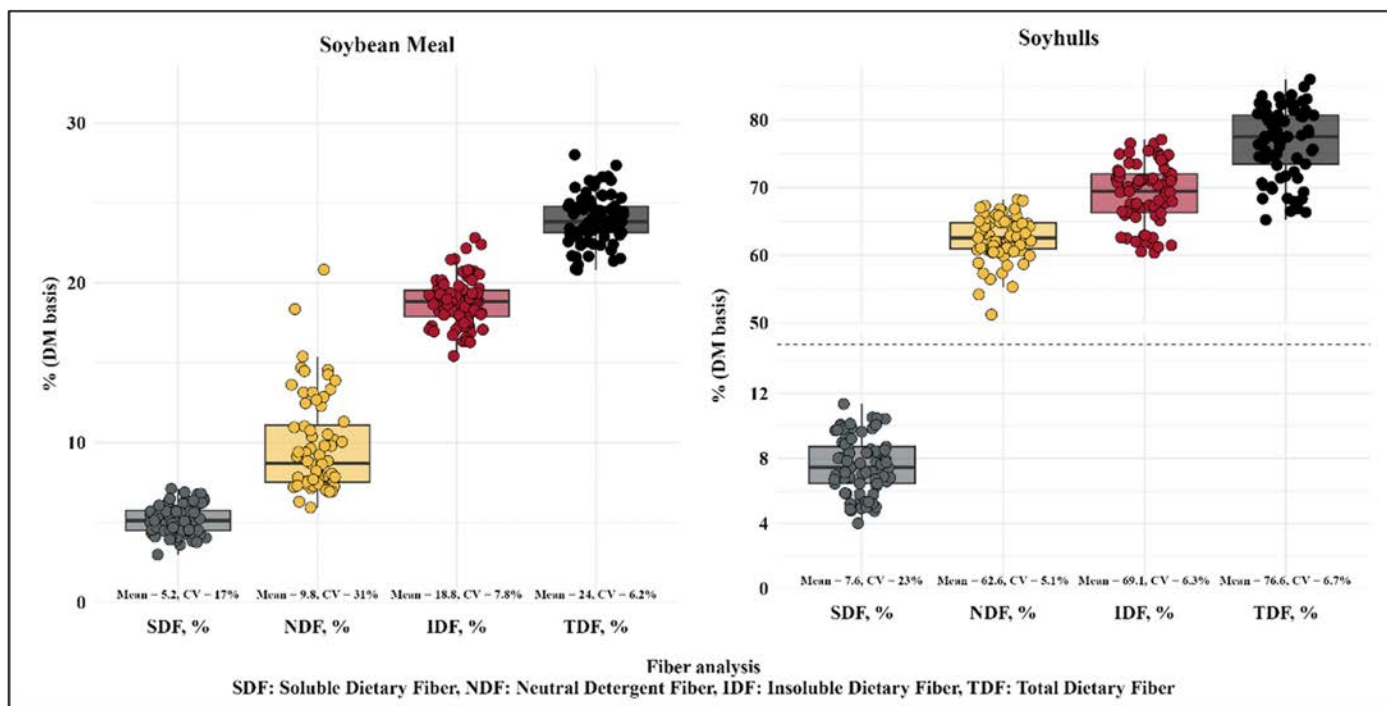


Figure 2. Fiber composition of soybean meal and soyhulls (n = 80 each) collected in 2024 from U.S. soy processors.

properties characterization is essential for understanding fiber feeding strategies to improve gut development, increase satiety, improve gut motility and health, and optimize gilt and sow performance.

Role of Dietary Fiber in Gilt Development

Inclusion of DF in gilt development feeding programs has demonstrated multiple benefits, including increased gastrointestinal capacity (Priester et al., 2020), improved lactation feed intake (Winkel et al., 2018), and enhanced embryo survivability and oocyte maturation (Ferguson et al., 2006). Managing growth in gilts under *ad libitum* conditions often involves combining fibrous ingredients with reduced dietary protein and energy content. Controlling the growth rate during development is critical to achieving the target BW of 135 to 150 kg at breeding (Patterson and Foxcroft, 2019). Gilts bred below 135 kg BW produce fewer total piglets across three parities (Williams et al., 2005), whereas heavier gilts are at increased risk for locomotion issues and early culling (Filha et al., 2010). A study by Gregory et al. (2023) demonstrated that gilts fed a high fiber diet containing 2.5 times more NDF and reduced Net energy (NE) by 20% and crude protein (CP) by 13% from 49 kg BW until breeding were 9.5 kg lighter at breeding (145.7 vs. 155.2 kg) compared to those fed a standard commercial diet, without any adverse effects during their first gestation or lactation. While such strategies are effective for managing growth rate, limited data exist on their long-term impacts on sow lifetime productivity and retention.

To address this gap, a study was conducted at The Hanor Company under commercial conditions to evaluate the effects of nutritional interventions including increased TDF content, reduced standardized ileal digestibility (SID) Lys, and reduced metabolizable energy (ME) on growth performance during gilt development and subsequent reproductive performance and survivability through four parities.

A total of 810 PIC Camborough L42 gilts of 9 to 11 weeks of age with initial BW of 27 ± 0.8 kg were assigned to a randomized complete block design. Gilts were allotted to one of two treatments balanced by average pen weight and week of birth with a total of 24 pens per treatment. Dietary treatments included a Control and Slow-Growth diet fed in three diet phases; 27 to 54 kg, 54 to 82 kg, and 82 to 113 kg BW. Control diets were corn and SBM based with wheat middlings formulated to meet or exceed PIC 2020 recommendations for SID Lys and contained 10, 10, and 11% TDF in phases 1, 2, and 3 respectively. Slow-Growth diets had a reduction of 6, 11, and 11% in SID Lys, dietary ME was reduced by 2.7, 4.6, and 4.7%, and TDF was increased to 15, 18, and 20% for phases 1, 2, 3, respectively. The higher level of TDF in Slow-Growth diets was achieved by increasing wheat middlings inclusion and adding corn germ. At 24 weeks of age, gilts were selected, heat checked, distributed to 8 commercial sow farms (balanced by treatment), fed a common diet, and bred at their next estrus. Once in the sow farms, gilt reproductive performance and survivability was tracked through four parities.

Gilts fed Slow-Growth diets had lower average daily gain (ADG) than Control in phase 1 (838 g/d vs. 929 g/d; $P < 0.001$), phase 2 (860 g/d vs. 936 g/d; $P < 0.001$), and phase

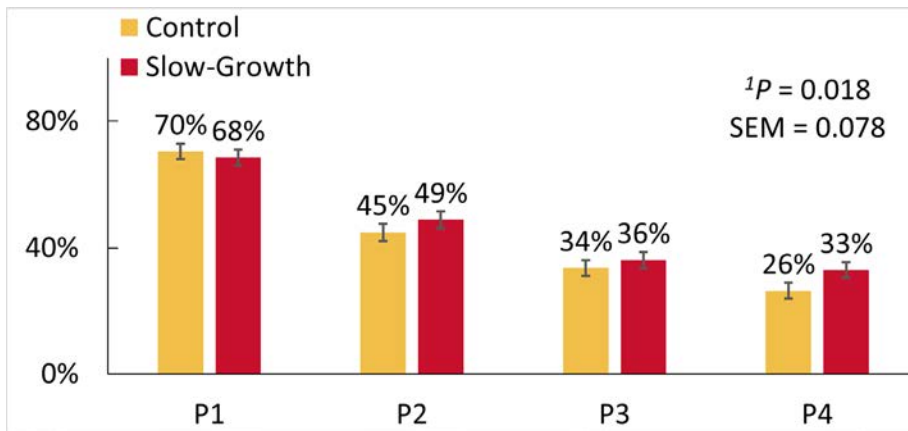


Figure 3. Effect of a Slow-Growth feeding program during gilt development on sow survivability through 4 parities.
¹ P-Values for the comparison between the probability of success of the events, being success the event "1" and failure the event "0" in a binomial distribution.

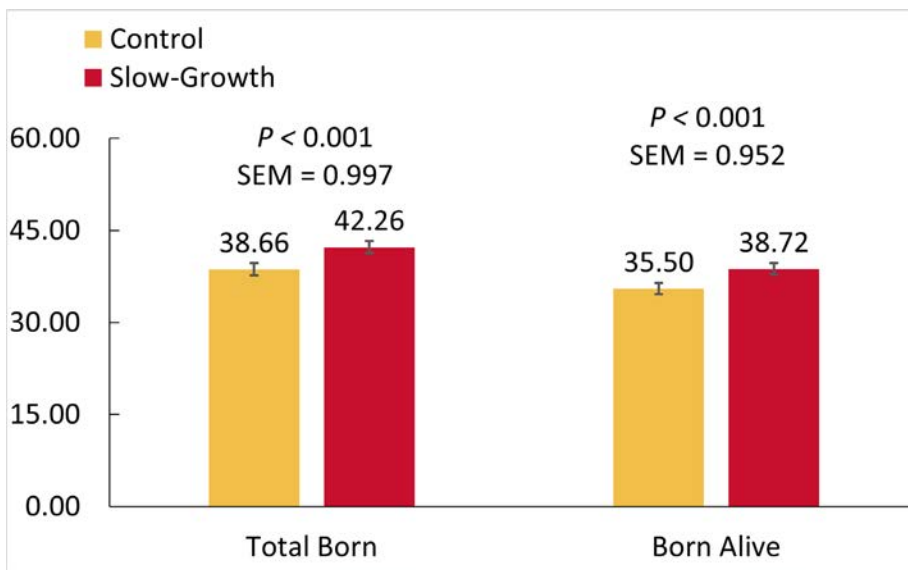


Figure 4. Effect of a Slow-Growth feeding program during gilt development on sow productive performance through 4 parities.

3 (881 g/d vs 928 g/d; $P < 0.001$). Slow-growth gilts had a higher average daily feed intake (ADFI) than Control during phase 2 (2.4 kg/d vs. 2.2 kg/d; $P = 0.002$), and phase 3 (2.7 vs 2.4 kg; $P < 0.001$). At the end of phase 3 of development, Slow-Growth gilts were 4.8 kg lighter (112 vs. 116.8 kg; $P = 0.04$) than Control. As a result of lower ADG and higher ADFI, gilts from the Slow-Growth treatment had reduced feed efficiency in all 3 development phases ($P < 0.05$). No effect of treatment was observed for age at first heat no service, age at first service, or gilt selection and breeding rates ($P > 0.310$). Sows from the Slow-Growth group had a 7% higher retention rate (33 vs. 26%, $P = 0.018$; Figure 3) through parity 4 than Control. Although mortality was similar, Control sows had a greater cull rate than Slow Growth (60 vs. 52.7%; $P = 0.014$), driven by reproductive removals. No differences in litter size per parity were observed, but Slow Growth sows had 3.6 more total born and 3.22 more

born alive piglets overall, driven by improved retention to parity 4 (Figure 4).

In summary, Slow Growth diets with high TDF (> 15%) and reduced energy and SID Lys effectively controlled gilt growth during development, though with lower feed efficiency. These diets improved survivability through parity four by reducing reproductive removals, potentially enhancing productivity through increased sow retention. Further research is needed to clarify the underlying mechanisms.

Role of Dietary Fiber in Gestation Diets

Gestating sows are often feed restricted to manage weight and reproductive soundness. Feed restriction can cause inadequate satiety, interfere with natural satiation behaviors, and increase food-seeking stereotypies (De Leeuw et al., 2008). In modern pen-gestation housing, these stereotypies can heighten pen aggression, feeder competition, and lameness incidences, and in turn, compromise production efficiencies and sow longevity and welfare. European studies show feeding fiber-enriched diets to gestating sows can reduce pen aggression and lameness by augmenting post-prandial satiation (Hoorweg et al., 2017).

Indeed, recent studies from our collaboration with The Hanor Company investigated the impact of DF inclusion in sow gestation diets. In a commercial group-housing system, gestation sows were fed either a Low Fiber (TDF = 14%) or a High Fiber diet (TDF = 32%). Though reproductive performance (litter size, birth weight, pre-weaning mortality) was not significantly impacted, notable differences were observed in sow survivability. Specifically, sows fed the High Fiber diet had a lower overall mortality rate (4.36%) compared to those fed the Low Fiber diet (7.05%). Mortality reduction was mainly due to lameness, as mortality for this reason decreased from 2.56% to 0.67% for sows fed the Low Fiber and High Fiber diets, respectively (Figure 5). We hypothesize that this is through improved satiation reducing aggression and activity.

Satiety refers to the neurobiological mechanisms that regulate eating, prompt satiation, and prolong the feeling of fullness between meals. There are three main mechanisms for how DF can increase satiety:

1. The physicochemical properties of DF stimulate gastrointestinal mechanoreceptors by increasing gastric distension, thus delaying gastric emptying and rate of passage (Mercado-Perez et al., 2022)
2. Short chain fatty acids (SCFA) produced from DF fermentation stimulate the release of satiety-related peptides (GLP-1, CCK, PYY, and GIP) initiating a neuro-endocrine signaling cascade that delays gastric emptying (Akhlaghi, 2024)
3. DF delays and stabilizes postprandial glucose and insulin levels initiating glucagon suppression and hypothalamic-endocrine mediation of metabolic satiety

However, not all DF types or sources can initiate these mechanisms, and there are currently no analytical feed procedures that will determine if a DF source increases satiety. Practical implementation of DF strategies must also consider the characteristics and composition of the fiber source to achieve targeted physiological outcomes in gestating sows. For example, in group-housed systems, selecting fiber sources that delay gastric emptying and enhance satiety may contribute to lower sow aggression. Highly fermentable fibers have been associated with improved satiety, glycemic control, and reduced behavioral stress, whereas poorly fermentable sources like DDGS may lack these functional benefits. However, the translation of these effects to commercial sow farms remains to be validated. Our collaborative research teams are currently investigating these knowledge gaps under U.S. commercial conditions, and to develop diet formulation tools that link feed analysis to fiber's satiety effects.

Role of Dietary Fiber in the Transition Sow

During the peripartum period, defined as the 7 to 10 days before parturition through 3 to 5 days after, sows undergo significant physiological and metabolic changes that impact farrowing success and piglet survival. In late gestation, rapid uterine and fetal growth reduces gastrointestinal motility and defecation frequency, increasing the risk of constipation. Pre-farrow constipation can lead to partial birth canal obstruction, prolonged farrowing, increased

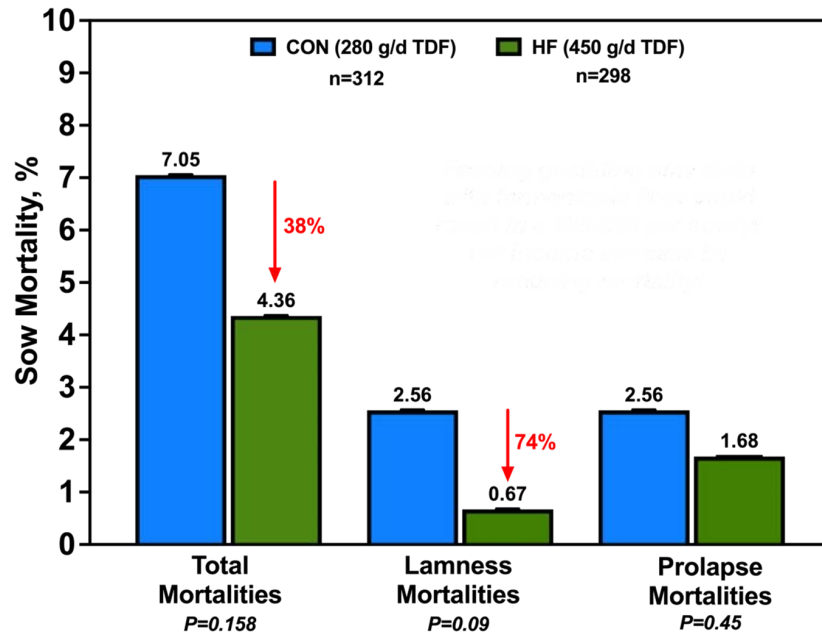


Figure 5. Supplementation of DF in pen housed gestating sows reduces lameness related mortalities CON= Control with 280 g/d TDF; HF = 450 g/d TDF from soyhulls and wheat midds list abbreviation-CON and HF

stillbirth rates, and reduced postpartum feed intake (Oliviero et al., 2010). At the same time, energy demands rise due to nest building behavior and the metabolic shift required to support fetal development and placental maintenance. If not met, these demands may push the sow into a catabolic state during farrowing. Dietary fiber can address both challenges by improving gut motility and contributing to sustained energy availability through microbial fermentation.

Fermentable fibers, such as those in SH or beet pulp, chemically bind water and increase microbial mass, enhancing fecal bulk and hydration. Unfermentable fibers, like corn DDGS, physically trap water within cell walls and increase fecal output. Prior research outside the United States has shown that fiber sources with high WHC can reduce constipation by up to 60% and lower stillborn rates (Feyera et al., 2017; Lu et al., 2023). Indeed, a commercial study we conducted with Iowa Select Farms demonstrated a similar response, whereas supplementing 170 g/d of additional TDF from a combination of SH, wheat midds, and sugar beet pulp to nulliparous sows for at least 3 days prior to farrowing reduced constipation scores by 21%, improved fecal hydration, and lowered stillborn rates (Figure 6). These constipation alleviating effects of fiber supplementation were consistent across three additional studies involving more than 1,700 sows.

To further explore the impact of DF during the transition period, we conducted a study with Seaboard Farms evaluating a fiber top dress composed of both SH and wheat midds, with or without a stimbiotic additive. In this 2 × 2 factorial design, sows received an additional 160 g/day of TDF

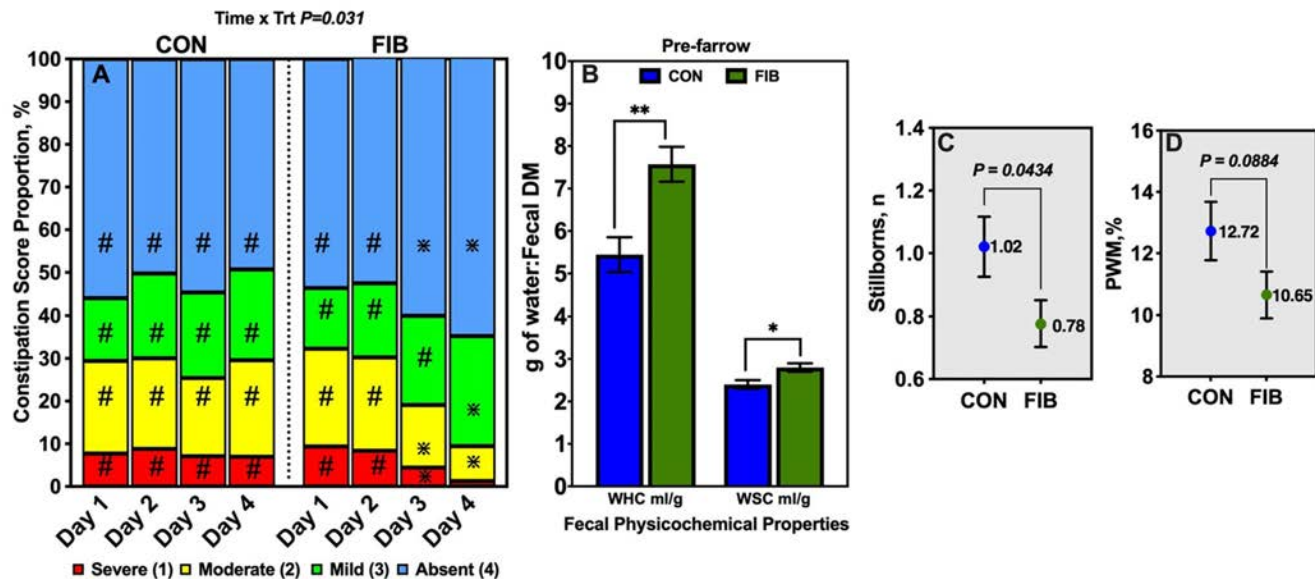


Figure 6. Providing an additional 170 g of TDF (FIB) pre-farrow reduced constipation compared to control (CON) (A), altered fecal physicochemical properties of water hold and swelling capacity (B), reduced stillborns (C), and pre-weaning mortality (D).

from loading into farrowing crates through lactation. Fiber supplementation alone reduced pre-farrow constipation by 27% compared to control ($P < 0.01$). Fecal physicochemical traits improved, with WBC and WHC increasing by 7.5% and 5.6%, and fecal DM decreasing by 3.1% ($P < 0.05$). Sows fed the fiber top dress had 0.29 fewer stillborn piglets per litter ($P < 0.05$). Stimbiotic supplementation enhanced fermentation capacity, increasing total SCFA concentrations, including a 36.8% increase in butyrate and elevated acetate levels five days post-supplementation ($P < 0.01$). These metabolites serve as key substrates for sustained energy production during reduced intake. As energy demands rise prior to farrowing, due to nest-building and the metabolic shift supporting placental function, DF fermentation can provide continuous energy through SCFA production. Acetate and butyrate act as ketogenic substrates, while propionate supports hepatic gluconeogenesis, sparing glucose for the mammary gland. Together, these mechanisms improve energy plasticity and may reduce energy imbalance during farrowing, supporting improved colostrum composition and reduced stillbirths. These results highlight the functional benefits of DF during the transition period. Improved gastrointestinal motility and fermentation-driven energy availability contribute to reduced constipation and stillbirth rates.

Conclusion

Dietary fiber is a valuable tool for improving sow productivity, welfare, and longevity when strategically implemented across reproductive stages. Research presented in this document demonstrates that specific fiber sources can reduce constipation, lower stillbirth rates, support energy

balance during farrowing, and improve sow retention. These benefits depend on fiber composition and functional properties, emphasizing the need for precise characterization beyond crude fiber or NDF values. Adopting fiber-based strategies in U.S. systems requires bridging the gap between controlled research and commercial application. *Fiber - The Next Frontier* collaboration between the University of Missouri and Iowa State University is addressing this need by generating applied data and developing practical tools to support fiber integration into sow diets. Through continued partnership, we aim to advance fiber nutrition in ways that are both biologically sound and commercially feasible.

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Impacts of Heat Stress on Energy Balance in Sows and Their Progeny: Consequences for Growth and Developmental Outcomes

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Summary

Heat stress alters gestating and lactating sow energy use, often causing excess fat gain, impaired mammary development, and lower milk output, even when feed intake remains stable. These effects carry over to piglets, who grow slower, convert feed less efficiently, and yield poorer carcasses if their dam experienced heat stress during gestation. Conventional feeding models and farrowing room temperatures often fail to reflect the physiological impact of heat stress on today's sows. Furthermore, our research demonstrates that cooler farrowing rooms with piglet heating pads enhance sow comfort, intake, and litter growth. To remain productive and profitable, producers must modernize feeding and facility strategies to reflect these physiological shifts. This integrated approach improves sow performance, piglet outcomes, and long-term herd sustainability.

Introduction

Heat stress is a critical environmental challenge that significantly impairs the health, productivity, and welfare of gestating and lactating sows. Under heat stress conditions, sows actively balance heat gain and heat loss to maintain thermal equilibrium, primarily by reducing internal metabolic heat production and prioritizing thermoregulation over productive processes (Fig. 1). While this adaptive response helps maintain homeostasis and prioritize survival of the pig, it negatively impacts long-term productive outcomes such as lean tissue accretion, reproductive success, lactogenesis, and overall growth efficiency. Interestingly, despite impaired reproductive efficiency (i.e., smaller less viable litters) under heat stress (Tompkins et al., 1967), gestating sows can paradoxically exhibit a more positive energy balance, characterized by increased growth rates and enhanced back fat deposition under heat stress conditions (Byrd et al., 2022, 2025; Cecil et al., 2025). This bioenergetic shift during gestational heat stress has important implications, particularly for offspring, who experience long-term detrimental effects on growth, metabolic efficiency, and overall productivity due to altered prenatal development.

Additionally, gestational heat stress may disrupt mammary gland development, mediated by bioenergetic adaptations as sows transition from heat stress to thermoneutral environments, potentially compromising lactogenesis.

Traditionally, reductions in lactogenesis and milk production observed in heat stress exposed lactating sows have been largely attributed to decreased feed intake, which limits nutrient availability necessary for sustaining high milk yields. Milk production in sows is energetically demanding, and research indicates a close association between total metabolic heat production and milk yield, with reductions in total metabolic heat production correlating to diminished milk output. Studies from our laboratory (Johnson et al., 2022) and others (de Braganca et al., 1998) demonstrate that heat stress impairs milk production in sows independent of feed intake, mirroring observations in dairy cattle (Johnson et al., 1965; Rhoads et al., 2009). For instance, maintaining lactating sows at a similar nutritional plane directly reduces indirect biomarkers of milk production (e.g., total metabolic heat production) and litter growth rates under heat stress when compared to thermoneutral conditions (de Braganca et al., 1998; Johnson et al., 2022). These

data emphasize that heat stress intrinsically disrupts metabolic pathways critical for lactation. Thus, recognizing and addressing the direct physiological effects of heat stress beyond feed intake reductions is essential for enhancing lactation performance and ensuring optimal piglet growth.

Effective management practices play a crucial role in mitigating heat stress-induced declines in milk production and subsequent poor litter performance. Our research underscores the importance of carefully controlling farrowing room and piglet microenvironment temperatures. Maintaining sow farrowing environments above thermoneutral thresholds for lactating sows (20.49°C; Cecil et al., 2024) to accommodate piglet thermal requirements exacerbates heat stress in lactating sows, leading to reduced feed consumption, diminished milk yield, and impaired litter growth. Optimizing macroenvironment conditions and employing targeted supplemental heating strategies for piglets, such as heated pads, can effectively alleviate these negative impacts. Ultimately, adopting a holistic management approach that comprehensively addresses environmental conditions and bioenergetic demands is vital to sustain sow productivity, maintain optimal body condition for future reproductive success, and enhance overall welfare outcomes for both sows and their offspring across all physiological and production stages.

Gestational Heat Stress and Bioenergetic Dynamics in Limit-Fed Sows

Under thermoneutral conditions, swine dietary energy formulations are designed to meet well-defined maintenance and production requirements (NRC, 2012). However, heat stress significantly alters these energy dynamics. Traditionally, it was assumed that maintenance energy requirements increase during heat stress due to the elevated energetic demands of thermoregulatory processes such as evaporative cooling and panting (Kleiber, 1971). Reports in livestock have supported this view, attributing increased energy needs to homeostatic maintenance as ambient temperatures rose above the upper critical limit (Kleiber, 1971). However, more recent research suggests a more nuanced and adaptive physiological response in pigs. Under prolonged heat stress, pigs exhibit reductions in visceral mass, feed intake, and reductions in circulating thyroid hormones (Johnson et al., 2015a,b). These changes reflect a shift in en-

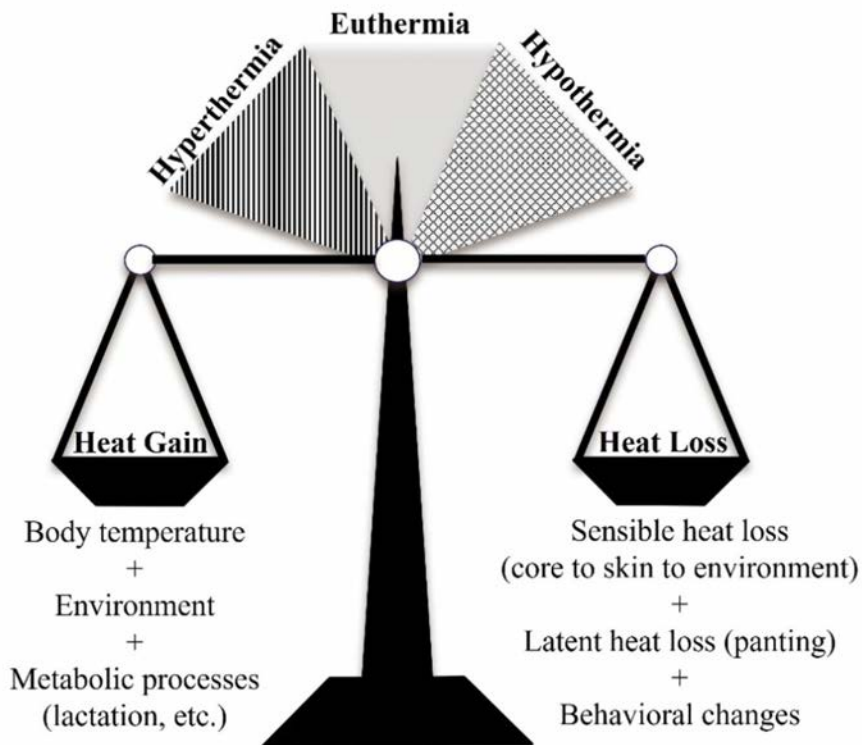


Figure 1. Schematic describing heat gain versus heat loss balance in swine.

ergy metabolism wherein pigs downregulate internal heat production to minimize thermal load (Fig. 1). While these adaptations may be protective against overheating, they introduce challenges in accurately estimating energy requirements and formulating appropriate diets under heat stress conditions.

This complexity is particularly relevant for gestating sows, which are routinely limit-fed to manage maternal body condition (NRC, 2012). Unlike pigs fed *ad libitum*, limit-fed gestating sows do not alter their total daily feed intake during heat stress (Byrd et al., 2022, 2025; Cecil et al., 2025). Instead, they tend to consume their daily allotments during cooler periods of the day, such as nighttime or early morning, resulting in a similar nutritional plane across thermal environments. However, despite these similarities, heat stress-exposed gestating gilts and sows exhibit greater body weight gain (Fig. 2A), improved feed efficiency (Fig. 2B), and increased backfat (Fig. 3) when compared to their thermoneutral counterparts (Byrd et al., 2022, 2025; Cecil et al., 2025). These observations could suggest that energy typically allocated to thermogenesis under thermoneutral conditions is instead redirected toward tissue accretion when maintenance costs are reduced under heat stress (Johnson et al., 2015a). This interpretation is supported by studies in grow-finish pigs and rodents demonstrating greater weight gain during heat stress when compared to pair-fed counterparts housed under thermoneutral conditions (Pearce et al., 2013; Johnson et al., 2015c). When considering the composition of this excess weight gain, energy models demon-

strate increased energy retention as lipid relative to current NRC (2012) estimates, as opposed to improvements in litter growth (Byrd et al., 2022, 2025; Cecil et al., 2025). These data imply that current NRC maintenance energy models may overestimate thermogenic demands under heat stress, leading to excessive energy supply and adiposity. Given that over conditioning can impair reproductive success and decrease sow longevity, refining maintenance energy estimates under heat stress is essential.

Despite the greater weight gain observed in gilts and sows exposed to gestational heat stress, upon returning to thermoneutral conditions during late gestation, heat stress-exposed gilts lose weight despite remaining on the same nutritional plane (Fig. 4; Byrd et al., 2025). Notably, this late gestation weight loss coincides with impaired mammary gland development in heat stress-exposed gilts characterized by a decrease in mammary epithelial cell proliferation and altered lumen to alveolar ratios (Musa et al., 2023). This suggests that energy reallocation and increased metabolic demand upon return to thermoneutral conditions may have downstream effects on future lactation capacity. This reversal suggests a metabolic rebound effect, potentially due to compensatory thermogenesis (Curcio et al., 1999). As such, we've hypothesized that gestational heat stress conditions may induce a transient decrease in maintenance energy requirements, and that resuming thermoneutral conditions reactivates thermogenic processes, increasing maintenance energy needs and resulting in negative energy balance that have adverse downstream impacts on the sow.

Long-Term Effects of Gestational Heat Stress on Offspring Bioenergetics and Productivity

Piglets exposed to *in utero* heat stress experience long-lasting physiological impairments that reduce postnatal growth performance, metabolic efficiency, and carcass quality (Table 1; Johnson et al., 2020). These animals frequently exhibit decreased reproductive potential, impaired thermoregulation, altered immune function, and poorer welfare outcomes compared to those gestated under thermoneutral conditions (Table 1; Johnson et al., 2020). *In utero* heat stress is associated with intrauterine growth restriction, likely due to heat-induced reductions in uterine blood flow and placental insufficiency, which stunts fetal development and results in lower birth weights (Johnson et al., 2020). Although this reduction in birthweight is inconsistently observed in swine, potentially due to controlled, limit-fed gestation diets in heat stress studies or the timing of gestational heat stress, data from multiple species support the association between *in utero* heat stress and *in utero* growth restriction driven growth deficits (Johnson et al., 2020).

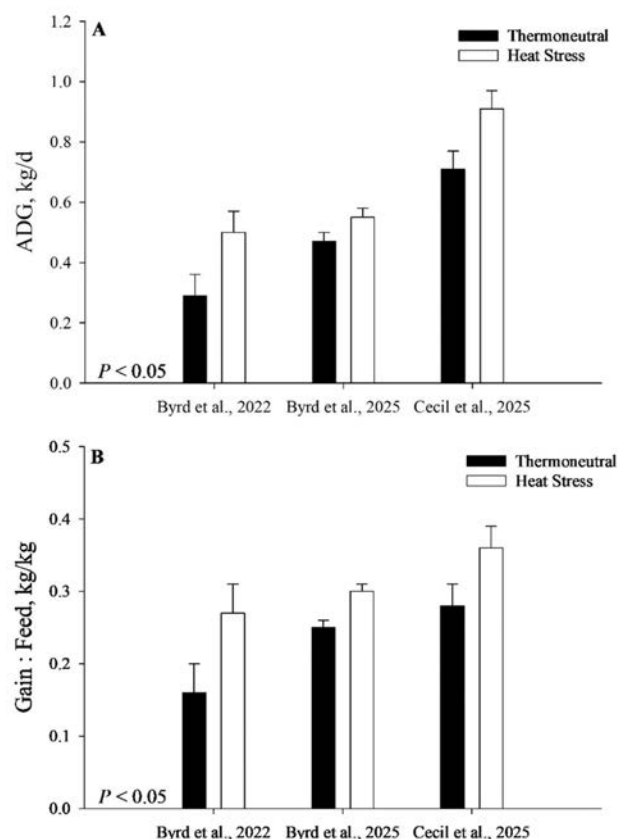


Figure 2. (A) Average daily gain (ADG) and (B) feed efficiency (Gain : Feed) of sows (Cecil et al., 2025) and gilts (Byrd et al., 2022, 2025) exposed to thermoneutral or heat stress conditions from d 0 to 60 of gestation.

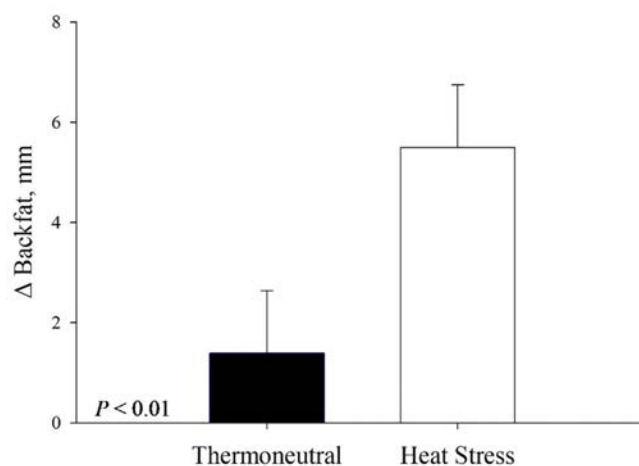


Figure 3. Change in backfat (mm) of sows (Cecil et al., 2025) exposed to thermoneutral or heat stress conditions from d 0 to 60 of gestation.

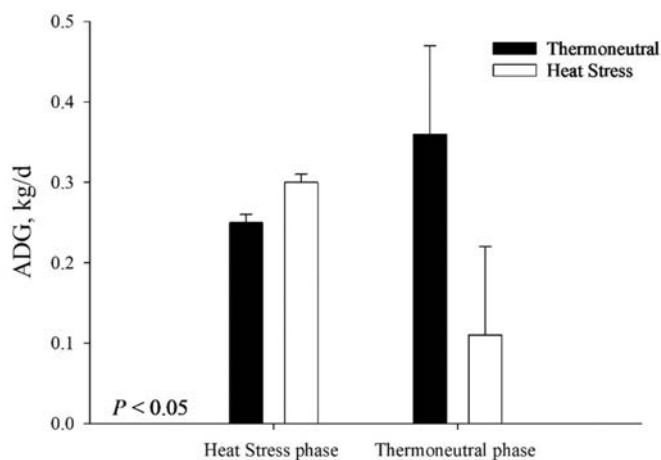


Figure 4. Average daily gain (ADG) of sows exposed to thermoneutral or heat stress conditions from d 0 to 70 of gestation (Heat Stress phase) and then exposed to thermoneutral conditions (Thermoneutral phase) from d 70 of gestation to farrowing.

Beyond birthweight, *in utero* heat stress has profound effects on postnatal growth trajectories and bioenergetics. Offspring from heat stress-exposed dams show altered nutrient partitioning, characterized by greater feed intake and disappearance without corresponding increases in growth, ultimately reducing feed efficiency (Johnson et al., 2020). These inefficiencies may stem from persistent alterations in metabolic regulation, including increased maintenance energy requirements (Chapel et al., 2017) and elevated body temperature set-points (Johnson et al., 2015b). Hyperinsulinemia has been described in *in utero* heat-stressed pigs, particularly those exposed during early gestation, and is associated with reduced non-esterified fatty acid mobi-

lization, suggesting impaired lipid metabolism and a compromised ability to meet energy demands during fasting or feed restriction (Maskal et al., 2020). This may be especially problematic for *in utero* heat-stressed gilts that become pregnant and are limit-fed during gestation, placing them at greater risk for maternal undernutrition and further *in utero* growth restriction in their own litters (Johnson et al., 2020).

Moreover, *in utero* heat stress influences postnatal body composition and carcass traits. Studies have reported increased subcutaneous fat deposition, reduced muscle mass, and lower carcass lean percentages in *in utero* heat-stressed pigs (Johnson et al., 2015b; Johnson et al., 2020). These animals exhibit a tendency to repartition energy away from lean tissue accretion and toward adiposity, further compromising growth efficiency and meat quality (Tuell et al., 2021). Such outcomes align with the thrifty phenotype hypothesis, which suggests that fetal adaptations to nutrient-restricted environments, such as those caused by placental insufficiency or maternal undernutrition during heat stress, favor energy conservation and fat storage at the expense of lean tissue development (Johnson et al., 2020). Collectively, the long-term consequences of *in utero* heat stress not only impair individual animal performance and carcass value but also pose significant economic and sustainability challenges for swine production systems, reinforcing the critical importance of managing thermal stress during gestation.

Heat Stress-Induced Alterations in Bioenergetics and Milk Production in Lactating Sows

Lactating sows are uniquely vulnerable to heat stress due to the substantial increase in metabolic heat production associated with milk synthesis and the demands of support-

Table 1. Consequences of *in utero* heat stress in pigs¹.

Production phase	Phenotype	Production consequence
Gestation and Farrowing	- Reduced birthweight - Teratogenic defects (e.g., micrencephaly) - Altered placental efficiency - Impaired organ development - Reduced testicular size and sperm count	- Higher early mortality - Increased need for veterinary support - Poorer viability - Reduced fertility and reproductive success
Lactation	- Reduced milk lactose content - Increased feed intake without improved weaning weight - Greater maintenance costs	- Reduced piglet survival and weaning weights - Greater feed costs for lactating sows
Nursery	- Reduced IgG levels - Increased intestinal permeability - Increased cortisol and ACTH - Greater stress behaviors post-weaning	- Increased disease susceptibility - Impaired growth - Higher mortality and treatment costs - Higher feed costs
Grow-Finish	- Increased core body temperature set-point - Reduced feed efficiency - Increased maintenance costs - Altered stress responses	- Reduced growth rate and feed efficiency - Increased thermal sensitivity - Greater production losses - Higher feed costs
Market	- Increased adiposity - Reduced lean mass - Decreased carcass quality	- Lower carcass value - Greater variability in end-product quality - Higher feed costs

¹Adapted from Johnson et al., 2020

ing large litters (Cabezón et al., 2017). While reductions in feed intake under heat stress conditions have long been considered a primary factor contributing to decreased milk output, recent evidence reveals that heat stress also imposes direct physiological effects on lactogenesis in sows (Johnson et al., 2022). Studies employing pair-feeding models have demonstrated that even when caloric intake is held constant, litter growth rates are reduced under heat stress conditions (de Braganca et al., 1998), suggesting that thermal stress directly impairs lactational performance. Since direct measurement of milk yield in sows is not feasible, litter growth is often used as a proxy indicator of milk output, as piglets rely entirely on the sow's milk supply for nutrition (de Braganca et al., 1998). Complementary studies comparing cooled versus non-cooled sows under HS conditions have demonstrated that total metabolic heat production is reduced by approximately 20% in non-cooled sows, and their litters grow 25% slower, despite both sow groups being maintained on similar nutritional planes (Johnson et al., 2021). These findings corroborate earlier reports by Black (1993), who estimated that a 20% reduction in total metabolic heat production is associated with a 25% reduction in milk production in sows (Black, 1993).

While the specific mechanisms in sows remain to be fully elucidated, several biological pathways have been implicated in the observed reductions in lactation performance under heat stress. Notably, heat stress alters the endocrine profile of the sow by reducing circulating concentrations of prolactin, growth hormone, and thyroid hormones, factors critical for initiating and sustaining milk synthesis (Li et al., 2010; Johnson et al., 2015a). These hormonal disruptions may reduce the mammary gland's functional capacity and responsiveness to lactation demands. Additionally, heat stress impairs mammary gland perfusion and nutrient partitioning, both of which are essential for the delivery of energy and substrates needed for milk production (Zeng et al., 2024). Together, these alterations likely contribute to the impaired mammary function observed under heat stress conditions, even in the absence of changes in feed intake.

In addition to climate-induced environmental heat stress, management practices have the potential to exacerbate heat stress in lactating sows, particularly when macroenvironment temperatures are elevated to meet the thermal requirements of neonatal piglets. Common farrowing room temperatures (23–25°C) often exceed the thermoneutral zone for lactating sows, which is further reduced due to metabolic heat production associated with lactation (Johnson et al., 2022). When housed in these conditions, sows exhibit reduced feed intake, increased respiration

Table 2. Macroenvironment temperature thresholds to improve sow and piglet welfare and production outcomes¹.

Characteristic	Macroenvironment Threshold	Response
Sow daily feed intake, kg	17.20°C	Increased
Piglet growth rate, kg/d	17.00°C	Increased
Sow body temperature, °C	20.49°C	Increased
Piglet body temperature, °C	18.90°C	Reduced

¹Adapted from Cecil et al., 2025

rates, higher skin and core temperatures, and altered behavior, all indicative of thermal stress (Cecil et al., 2024). Importantly, these responses are accompanied by lower feed intake and impaired piglet growth that is likely associated with reduced milk production (Cecil et al., 2024).

Studies evaluating sow and litter performance under varying farrowing room temperatures have demonstrated that cooler room temperatures, when combined with supplemental heating pads for piglets, improve sow feed intake, thermal comfort, and nursing behavior (Table 2; Cecil et al., 2024). Under these conditions, piglets maintain euthermic body temperatures through behavioral thermoregulation and exhibit greater average daily gain without increased preweaning mortality (Cecil et al., 2024). These observations support the idea that thermal environments for sows and piglets should be managed independently, allowing each to occupy their optimal thermal zone.

From a production standpoint, heat stress induced declines in milk yield reduce piglet weaning weights, compromise early-life health, and increase mortality risk. Additionally, HS during late gestation can impair mammary gland development, further limiting milk output postpartum. This combination of direct and indirect effects on lactation underscores the importance of integrated management strategies that address both nutritional and environmental challenges. By optimizing farrowing room conditions and supporting mammary development during gestation, producers can mitigate heat stress effects, enhance sow and piglet welfare, and improve overall production efficiency.

Conclusion

Collectively, the evidence presented highlights the substantial and multifaceted impacts of heat stress on gestating and lactating sows, as well as their offspring. Gestational heat stress alters maternal energy metabolism, shifts nutrient partitioning, and disrupts mammary development, which not only impairs reproductive performance and lactation but also compromises the long-term bioenergetics and growth potential of offspring. These disruptions are amplified when sows transition between thermal environments, revealing vulnerabilities in current feeding models and energy requirement estimates that may not account for

heat-induced metabolic adaptations. In the postnatal period, lactating sows face compounded heat challenges due to increased metabolic load and environmental temperatures managed for piglet needs. Without appropriate intervention, these conditions lead to decreased feed intake, reduced milk production, and poorer piglet outcomes.

To address these challenges, swine production systems must implement more refined strategies that integrate accurate nutritional modeling with adaptive thermal management. Feeding programs should be adjusted to reflect dynamic maintenance energy requirements under heat stress, avoiding over-conditioning or undernutrition during gestation. Simultaneously, farrowing environments should be designed to decouple sow and piglet thermal needs, employing targeted technologies such as heating pads for piglets and environmental cooling for sows. Embracing a holistic, evidence-based approach to heat stress mitigation will be essential to improving sow productivity, offspring viability, and the overall sustainability of swine production in an increasingly variable climate.

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European Experience for a Holistic Approach to Feeding Nursery Pigs Diets without Therapeutic Zinc

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Summary

Therapeutic levels of zinc (Zn; ~2,500 ppm zinc from zinc oxide) have been used for decades in nursery pig diets due to the positive benefits observed on growth performance, immune function, gut health, and mortality. However, in 2017, the European Union (EU) ruled that the environmental risks associated with feeding diets containing therapeutic levels of zinc are greater than the above-mentioned benefits to piglets. Since that ruling, many studies have been conducted to replace therapeutic zinc from piglet diets and maintain the positive benefits. Research found that lactose concentration, protein and fiber digestion kinetics, and the use of hydroxy zinc are key feeding strategies to help replace pharmacological doses of zinc oxide. Furthermore, a holistic approach to feed, farm, and health was in the end necessary to achieve this goal. Since June 2022, feeding diets containing levels greater than 150 mg/kg zinc is not allowed in the EU. The feed, farm, and health approach has been able to maintain pig performance similar to diets containing therapeutic levels of zinc with minimal impact on the cost of production.

Introduction

Since the famous finding of Poulsen (1989), many studies have confirmed what became common practice in feeding nursery pigs: supplementing diets with 3,000 ppm of Zn from zinc oxide for the first 14 days post-weaning reduced scours and increased weight gain of piglets. Several other reports have demonstrated benefits of nursery diets containing pharmacological levels of Zn on immune function, gut health, and mortality since that initial finding. In 2017, the EU Committee for Medicinal Products for Veterinary Use concluded that the benefits of pharmacological doses of Zn in piglets do not outweigh the environmental risks. Subsequently, the European Commission decided to ban medicinal Zn, implementing a phase-out, and as of June 2022, feeding nursery pig diets with a high-dose of Zn is prohibited in the EU, and the limit is 150 mg/kg total Zn in feed. The objective, therefore, is to present research on 3 key feeding strategies and to provide a European feed, farm, health approach now that the EU is 3 years without pharmacological doses of zinc oxide in nursery diets.

Feed Management Strategies

Raw material assessments, feed safety programs to control molds, mycotoxins, shelf life, and salmonella are several strategies that are needed as part of the holistic approach to replacing therapeutic levels of Zn. Furthermore, our research has identified 3 key feed management strategies necessary to maintain pig performance and health without a pharmacological dose of zinc oxide. The first strategy is the appropriate stimulation of the microflora using dietary lactose levels, 2) Precise utilization of protein digestion kinetics and fiber fermentation kinetics to steer feed ingredient selection and inclusion in nursery diets, and 3) strategic selection of zinc source.

1). Appropriate stimulation of the microflora using dietary lactose levels

A dose of 3,000 ppm Zn from zinc oxide included in a diet fed to nursery pigs reduced ($P < 0.05$) *lactobacilli* and increased ($P < 0.05$) *lachnospira* in feces on d 14 post-wean compared with pigs fed 150 ppm zinc from zinc oxide (Figure 1; Trouw Nutrition R&D study V00101-19). This study

indicated that a high dose of zinc oxide was responsible for helping the nursery pig's gastrointestinal tract (GIT) cope with the abrupt change from sow milk (greater lactose and lactobacilli) towards solid feed (greater starch and dietary fiber and *Lachnospira*) in the first 14 days post-wean. This result led to the hypothesis that an optimal level of lactose in post-wean diets would help the nursery pigs GIT cope with the weaning transition and, thus, reduce piglet scours and improve performance similar to a high dose of zinc oxide. A meta-analysis was conducted and indicated that piglet performance from d 0–14 post-wean was quadratically increased ($P = 0.20$) as lactose level in the diet increased from 0 to 35% whereas dietary lactose level did not impact piglet performance when growth promoters were used in feed (Zhao et al., 2021). These results are based on the numerical comparison of slopes of the 2 quadratic models and further interpretation and use of the results are cautioned due to the fact that the slopes of all models were not different ($P > 0.10$) from 0. The observations for no significant responses of dietary lactose levels on pig ADFI and ADG is most probably due to an insufficient number of data points (i. e.

references containing anti-biotic growth promoters versus references without). The models indicated that the level of dietary lactose to optimize average daily gain of weanling pigs from d 0–7 and 7–14 post-wean was 20% and 15% for piglets with an average initial body weight of 6.56 kg and weaned at 22 day of age.

2). Precise utilization of protein digestion kinetics and fiber fermentation kinetics to steer feed ingredient selection and inclusion in nursery diets

It was also hypothesized that less protein and more dietary fiber reaching the hind-gut of the post-weaned pig would help reduce *lactobacilli* and increase *Lachnospira* in feces and that this would result in less scours and greater performance similar to pigs fed the high-dose of zinc oxide. A study was conducted to test this hypothesis by feeding post-weaned pigs a negative control diet containing 150 ppm Zn from zinc oxide, a positive control diet containing 2,500 ppm Zn from zinc oxide, and a negative control diet with a greater amount of fast digestible protein and resistant fiber. Fast protein is quantified in a feed ingredient as the protein that is digested in the stomach

and by the end of the duodenum as simulated in vitro. Resistant dietary fiber is quantified in feed ingredients as acid detergent lignin plus unfermentable fraction of insoluble non-starch polysaccharides. Results indicated that pigs fed the positive control diet had less ($P < 0.05$) scours and greater ($P < 0.05$) performance compared with those fed the negative control diet. Further, the performance and scours of pigs fed the negative control diet was ameliorated to the level of the positive control when the diet was formulated with greater fast protein and resistant fiber (Jaworski et al., 2019). This study concluded that a minimum of 11% fast protein and 4.5% resistant fiber should be included in post-wean diets to maintain performance and reduce scours similar to a pharmacological dose of zinc oxide. The performance benefit did not stop at 14 d post-wean as there was a carry-over effect improving ($P < 0.05$) pig feed conversion ratio that lasted until market which resulted in an additional \$0.30-0.40/market pig.

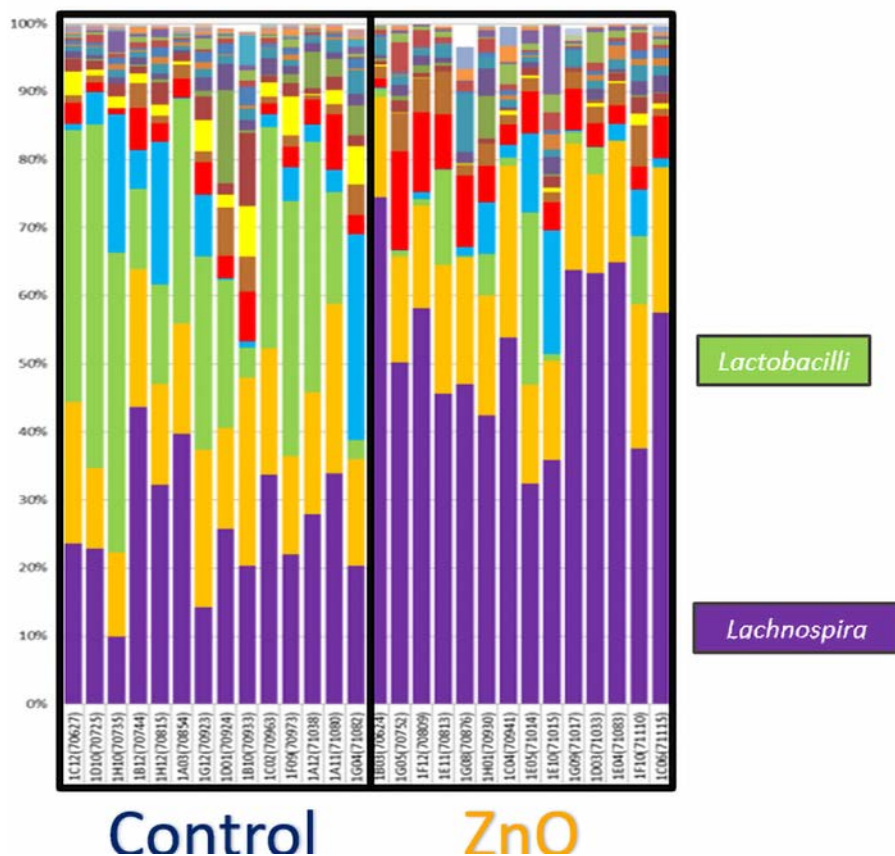


Figure 1. Microbial composition of feces collected from pigs 14 d post-wean fed either a control phase 1 diet with 150 ppm Zn from ZnO or a positive control diet with 3,000 ppm Zn from ZnO.

Concentration of ZnO changes the composition of the intestinal microbiome. (14 pigs each treatment) as shown by a reduction ($P < 0.05$) in lactobacilli and an increase in lachnospira (butyrate producing bacteria) and also an overall increase ($P < 0.05$) in microbial diversity 2 weeks after weaning.

3). *Strategic selection of zinc source*

Zinc plays a critical role in the immune system of the pig and the immune system is highly sensitive at weaning due to the large transition that is required by the piglet at this time. Therefore, ensuring that the Zn requirement of the post-weaning pig is met without the use of a pharmacological dose of zinc oxide is important. Zinc oxide is an inorganic, insoluble in neutral & acidic conditions and the most concentrated (72%) source of Zn with a relatively low and unpredictable bioavailability (when assessed as described by Hahn and Baker, 1993 and Davin, 2014) by the post-weaned pig. There are alternatives that are more soluble and bioavailable, but less concentrated. Hydroxychloride sources of Zn (IntelliBond Z; Nutreco, Amersfoort, Netherlands) have higher availability due to their distinct solubility characteristics. This acidic solubility of zinc hydroxychloride helps prevent the binding of Zn with phytate, thus, increasing the bioavailability of Zn. Research was conducted to compare a nutritional level of 100 ppm Zn from zinc oxide, zinc sulfate or IntelliBond Z included in diets fed to post-weaning pigs under a lipopolysaccharide (LPS) challenge. Results indicated that pigs fed IntelliBond Z had a lower ($P < 0.05$) TNF- α response indicating an improved immune response which resulted in improved ($P < 0.05$) feed efficiency compared with pigs fed 100 ppm zinc from zinc oxide or zinc sulfate (Harshman et al., 2022). In conclusion, it is recommended to supplement a minimum of 80 to 100 ppm Zn from zinc hydroxychloride in post-weaning diets in order to support performance and immune status of pigs (i.e. Zn requirements).

Farm Management Strategies

A pharmacological dose of zinc oxide always reduces scours and enhances performance in poor environmental and post-wean piglet health conditions. Therefore, it is critical to increase the environmental and piglet health conditions through management strategies in order to maintain low levels of scours and performance when a pharmacological dose of zinc oxide is not used. Thus, enhanced biosecurity, cleaning and disinfection, housing and climate, animal management, and people management and training are important to up-scale in this scenario. The supply of water has been proven to be the most critical farm management strategy when replacing a pharmacological dose of zinc oxide. European experience has found that it is recommended to have a maximum of 10 piglets per nipple, a flow rate of 500 ml per minute, and good access in the pens. Further, the use of Selko-pH (Nutreco, Amersfoort, Netherlands) is warranted to ensure a low pH in drinking water that minimizes bacterial growth, while promoting stomach health. Selko-pH is a synergistic blend of free and buffered organic acids that acidify drinking water and, upon ingestion, have the potential to lower the pH in the stomach, thereby en-

hancing protein digestion and supporting microbial balance. A study indicated that the addition of Selko-pH to water lines of pigs fed 150 ppm Zn from zinc oxide had a 32% increase in water intake and a 30 g increase in average daily gain over day 0-21 post-wean (Trouw Nutrition R&D study V00104-25).

Health Management Strategies

The approach, again, to replacing a pharmacological dose of zinc oxide is to tackle the health challenges that medicinal levels of zinc oxide seem to mask in the first weeks post-weaning. Infection chain and prevention chain, transition periods, diagnosis and monitoring, medication, and vaccination programs are several health management items that need to be improved in order to replace a pharmacological dose of zinc oxide.

European best practice has found that stabilizing the microflora in the small intestine and binding of pathogenic bacteria also helps to replace a pharmacological dose of ZnO. This can be addressed through the use of 2 additional feed additives that help reduce scours and maintain performance similar to a pharmacological dose of zinc oxide. Presan-FX (Nutreco, Amersfoort, Netherlands) is used to stabilize the microflora in the small intestine while Fysal Solute (Nutreco, Amersfoort, Netherlands) is used to bind bacteria and support intestinal mucosal immunity.

Conclusions to an EU approach to Feed, Farm, Health

An independent evaluation was conducted at SEGES in Denmark that made use of Trouw Nutrition's feed, farm, health approach outlined above to replace a pharmacological dose of zinc oxide. Three other feeding concepts for weaned pigs in the period 7-30 kg were compared with the Trouw Nutrition approach and also against feed including pharmacological dose of zinc oxide the first 14 days post-weaning and with feed with nutritional levels of zinc from zinc oxide. Results indicated that piglet morbidity and mortality was reduced ($P < 0.05$) compared with a pharmacological dose of zinc oxide. Further, there were 10% fewer ($P < 0.05$) medical interventions compared with a pharmacological dose of zinc oxide. Nursery pig ADFI, ADG, and FCR of pigs fed the Trouw Nutrition approach was similar ($P > 0.05$) to a pharmacological dose of zinc oxide and this was greater ($P < 0.05$) than all other treatments. This still resulted in an additional \$1.24 per pig compared with a pharmacological dose of zinc oxide. There is no magic bullet to replace a pharmacological dose of zinc oxide in terms of cost of production. A holistic approach has been taken by Trouw Nutrition and the entire EU over the past 3 years and each production system is different and for this reason some solutions are more important than others and this is what has been used to keep the cost of production neutral in the replacement of the pharmacological use of zinc oxide.

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Impacts of Non-nutritive Sweeteners on Performance and Gastrointestinal Development in Weaned Pigs

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Summary

This study investigated the potential of non-nutritive sweeteners (NNS) to support piglet health and performance during the early post-weaning period, a critical phase characterized by reduced feed intake, intestinal disruption, and heightened disease susceptibility. The findings indicate that NNS can enhance early growth, reduce diarrhea incidence, and promote intestinal barrier function and local immune regulation. Notably, the two sweeteners evaluated showed distinct physiological effects, suggesting different modes of action. These results highlight the potential of NNS as functional feed additives to improve weaning outcomes and reduce the need for in-feed antibiotics in swine production systems.

Introduction

Early weaning at 2 to 4 weeks of age is commonly practiced in commercial swine production to improve productivity (Moeser et al., 2017; Kim et al., 2022). However, this practice disrupts normal physiological processes, resulting in reduced feed intake, impaired growth, compromised intestinal integrity, and weakened immune responses (Campbell et al., 2013; Tang et al., 2022). These challenges often result in increased susceptibility to organisms that can cause diarrhea and elevated post-weaning mortality rates (Kim et al., 2022). Historically, in-feed antibiotics have been used to mitigate these effects, but growing concerns over antimicrobial resistance and regulatory restrictions have driven the search for alternative approaches.

Non-nutritive sweeteners (NNS), which provide intense sweetness with negligible caloric value, have gained interest as potential feed additives in swine diets. Previous research suggests that NNS may improve feed palatability (Glaser et al., 2000; Clouard and Val-Laillet, 2014; Chen et al., 2020), enhance nutrient intake (Sterk et al., 2008; Wang et al., 2014; Zhu et al., 2016; Lee et al., 2019), and modulate gut health (Moran et al., 2010; Zhang et al., 2020; Daly et al., 2021; Xiong et al., 2022), particularly under stress conditions like

weaning. The potential benefits of NNS are thought to stem not only from increased feed attractiveness but also from their influence on gut-brain signaling, hormonal regulation, and microbial composition (Liu et al., 2022).

Sucralose, a chlorinated derivative of sucrose, and neotame, a derivative of aspartame, are two FDA-approved NNS with markedly higher sweetness intensities than sucrose (Chen et al., 2020). Their use in swine nutrition has been limited, but emerging evidence suggests they may help mitigate post-weaning growth lag and intestinal dysfunction. Specifically, these sweeteners could help improve nutrient absorption and reduce inflammation by enhancing feed intake and maintaining intestinal morphology (Zhu et al., 2016; Lee et al., 2019; Zhang et al., 2020; Daly et al., 2021).

Despite growing interest, limited data exist regarding the effects of specific NNS such as sucralose and neotame in early-weaned pigs. Therefore, this study aimed to investigate the impact of sucralose and neotame supplementation on growth performance, diarrhea incidence, systemic immunity, and intestinal development in weaned piglets. The hypothesis was that NNS supplementation would support piglet health and growth during the critical weaning transition.

Experimental Procedures

Animals and Housing

A total of 288 weaned pigs (PIC 800 x Yorkshire; 21 ± 1 days old; initial body weight: 6.21 ± 0.45 kg) were randomly assigned to one of four dietary treatments in a randomized complete block design, with pens blocked by initial body weight (heavy to light). Each treatment had 12 replicate pens with 6 pigs per pen (3 barrows and 3 gilts). The four dietary treatments were: 1) a basal diet with no additives (**CON**); 2) basal diet supplemented with 150 mg/kg sucralose (**SCL**); 3) basal diet supplemented with 30 mg/kg neotame (**NEO**); and 4) basal diet supplemented with 50 mg/kg carbadox (**CBX**). A two-phase feeding program was employed with Phase 1 spanning the first two weeks and Phase 2 covering the final two weeks of the study. Diets did not include spray-dried plasma or zinc oxide at levels exceeding standard industry recommendations (Table 1).

Pigs were housed in environmentally controlled nursery rooms with ad libitum access to feed and water throughout the 28-day experimental period. Body weight and feed intake were recorded on days 0, 7, 14, and 28 to calculate average daily gain (**ADG**), average daily feed intake (**ADFI**), and gain-to-feed ratio (**G:F**). Diarrhea incidence was scored daily using a scale of 1 to 5 (1 = normal feces, 2 = moist feces, 3 = mild diarrhea, 4 = severe diarrhea, 5 = watery diarrhea). The frequency of diarrhea was calculated as the percentage of pen days with a diarrhea score of 3 or greater.

On days 0, 3, 7, 14, and 28, blood samples were collected from 12 pigs per treatment for serum analysis of tumor necrosis factor- α (**TNF- α**), C-reactive protein (**CRP**), and haptoglobin. On days 14 and 28, 12 pigs per treatment were randomly selected for intestinal tissue collection. Segments of the small intestine were harvested for morphological evaluation. Jejunal and ileal mucosal samples were also collected for gene expression analysis. In the jejunum, expression of **TNF α** , mucin 2 (**MUC2**), claudin 1 (**CLDN1**), occludin (**OCN**), tight

Table 1. Ingredient compositions of experimental diets¹

Ingredient, %	Control, phase I	Control, phase II
Corn	44.41	57.27
Dried whey	15.00	10.00
Soybean meal	18.00	22.00
Fish meal	10.00	7.00
Lactose	6.00	-
Soy protein concentrate	3.00	-
Soybean oil	2.00	2.00
Limestone	0.56	0.70
L-Lysine-HCl	0.21	0.23
DL-Methionine	0.08	0.05
L-Threonine	0.04	0.05
Salt	0.40	0.40
Vit-mineral, Sow 6 ²	0.30	0.30
Total:	100.00	100.00
Calculated energy and nutrient content		
Metabolizable energy, kcal/kg	3,463	3,429
Net energy, kcal/kg	2,601	2,575
Crude protein, %	22.27	20.80
Arg, ³ %	1.23	1.15
His, ³ %	0.49	0.47
Ile, ³ %	0.83	0.76
Leu, ³ %	1.62	1.55
Lys, ³ %	1.35	1.23
Met, ³ %	0.45	0.39
Thr, ³ %	0.79	0.73
Trp, ³ %	0.23	0.21
Val, ³ %	0.91	0.84
Met + Cys, ³ %	0.74	0.68
Phe + Tyr, ³ %	1.45	1.38
Ca, %	0.80	0.70
Total P, %	0.68	0.59
Digestible P, %	0.47	0.37

¹In each phase, three additional diets will be formulated by adding 150 mg/kg sucralose, 30 mg/kg of neotame, or 50 mg/kg or carbadox to the control diet, respectively.

²Provided the following quantities of vitamins and micro minerals per kg of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine HCl, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

³Amino acids are indicated as standardized ileal digestible (SID) AA.

junction protein-1 (**TJPI**), sodium glucose cotransporter-1 (**SLC5A1**), and glucagon-like peptide 2 receptor (**GLP2R**) was analyzed. In the ileum, genes assessed included **TNF α** , interleukin-1 α (**IL1 α**), interleukin-1 β (**IL1 β**), interleukin-6 (**IL6**), interleukin-7 (**IL7**), and interleukin-10 (**IL10**).

Table 2. Growth performance of weaned pigs fed diets supplemented with non-nutritive sweeteners or antibiotic

Item ¹	CON ²	SCL ³	NEO ⁴	CBX ⁵	SEM	P-value
BW, kg						
d 0	6.21	6.19	6.20	6.20	0.19	0.795
d 7	6.53 ^b	6.59 ^{ab}	6.62 ^{ab}	6.63 ^a	0.21	0.183
d 14	7.96 ^b	8.08 ^{ab}	8.17 ^{ab}	8.23 ^a	0.25	0.125
d 21	11.04	11.17	11.37	11.15	0.44	0.555
d 28	14.93	15.00	15.47	15.03	0.55	0.380
ADG, g/d						
d 0 to 7	45 ^b	57 ^{ab}	61 ^a	63 ^a	5.25	0.060
d 7 to 14	205	213	222	229	10.44	0.295
Phase 1 ⁶	125 ^b	135 ^{ab}	141 ^{ab}	146 ^a	6.73	0.071
d 14 to 21	431	439	455	417	38.41	0.378
d 21 to 28	554	548	583	554	23.58	0.569
Phase 2 ⁷	493	493	520	486	26.33	0.276
Overall ⁸	311	315	331	316	15.53	0.370
ADFI, g/d						
d 0 to 7	121 ^b	134 ^a	136 ^a	135 ^a	6.13	<0.01
d 7 to 14	262 ^b	277 ^a	265 ^b	268 ^{ab}	8.55	0.030
Phase 1	192 ^b	207 ^a	200 ^a	201 ^a	7.02	<0.01
d 14 to 21	579 ^b	604 ^a	579 ^b	548 ^c	26.59	<0.01
d 21 to 28	863 ^a	821 ^b	860 ^a	795 ^b	23.22	<0.01
Phase 2	758 ^a	744 ^a	757 ^a	706 ^b	30.37	<0.01
Overall	449 ^a	443 ^{ab}	453 ^a	431 ^b	16.76	0.017
Gain:Feed						
d 0 to 7	0.37	0.41	0.45	0.46	0.04	0.285
d 7 to 14	0.78	0.77	0.84	0.85	0.03	0.279
Phase 1	0.65	0.66	0.71	0.72	0.03	0.216
d 14 to 21	0.74	0.72	0.77	0.75	0.04	0.454
d 21 to 28	0.64	0.68	0.68	0.70	0.03	0.261
Phase 2	0.65	0.67	0.69	0.69	0.02	0.354
Overall	0.69	0.72	0.73	0.73	0.02	0.328

^{a,b}Within a row, means without a common superscript differ ($P < 0.05$).

¹BW = body weight, ADG = average daily gain, and ADFI = average daily feed intake.

²CON = the complex nursery basal diet

³SCL = CON + 150 mg/kg sucralose

⁴NEO = CON + 30 mg/kg neotame

⁵CBX = CON + 50 mg/kg carbadox

⁶Phase 1 = weaning day (d 0) to d 14 of experiment

⁷Phase 2 = d 14 to d 28 of experiment

⁸Overall = weaning day (d 0) to d 28 of experiment

Sample Analysis

Serum concentrations of TNF- α (R&D Systems Inc., Minneapolis, MN), CRP, and haptoglobin (Aviva Systems Biology Corp., San Diego, CA) were analyzed using porcine-specific ELISA kits. Absorbance was measured at 450 nm with a correction wavelength of 540 nm using a BioTek 800TS plate reader (BioTek Instruments, Inc., Winooski, VT), and concentrations were calculated using standard curves.

Fixed intestinal segments from the duodenum, jejunum, and ileum were trimmed, placed in plastic cassettes, dehydrated, embedded in paraffin, and sectioned at 5 μ m. Sections were stained with hematoxylin and eosin at the Michigan State University Histology Laboratory (East Lansing, MI), scanned at 20x using an Aperio VERSA system (Leica Biosystems, Deer Park, IL), and morphometric measurements (villus height, width, area, and crypt depth) were

obtained using ImageScope software (Leica Biosystems, Deer Park, IL).

For gene expression, total RNA was extracted from jejunal and ileal mucosa using TRIzol (Invitrogen, Waltham, MA) and homogenized with the TissueLyser II (QIAGEN, Hilden, Germany). After quality verification using a NanoDrop spectrophotometer (Thermo Fisher Scientific Waltham, MA), RNA was reverse-transcribed to cDNA with the High-Capacity cDNA Reverse Transcription Kit (Applied Biosystems, Waltham, MA). Quantitative PCR was performed using TaqMan reagents and the QuantStudio 6 Pro system (Thermo Fisher Scientific Waltham, MA). Ct values were normalized to ribosomal protein S18 (*RPS18*) and ribosomal protein L4 (*RPL4*), and gene expression was calculated using the $2^{-\Delta\Delta C_t}$ method (Livak and Schmittgen, 2001).

Statistical Analysis

Data normality was assessed, and outliers were identified using the UNIVARIATE procedure in SAS (SAS Institute, Inc., Cary, NC). All data were analyzed using ANOVA with the PROC MIXED procedure in SAS, following a randomized complete block design. Pen was considered the experimental unit. The statistical model included dietary treatment as a fixed effect and block (based on initial body

weight) as a random effect. Least squares means were separated using the LSMEANS statement with the PDIF option in PROC MIXED. The frequency of diarrhea was analyzed using the chi-square test. Statistical significance was declared at $P < 0.05$, and trends were noted when $0.05 < P \leq 0.10$. Differences with $P < 0.05$ are indicated in tables, while tendencies ($0.05 < P \leq 0.10$) are reported only in the text.

Results and Discussion

Growth performance and diarrhea incidence

Pigs supplemented with SCL or NEO tended to have greater ($P < 0.10$) body weight at days 7 and 14 compared to CON, while CBX-fed pigs were significantly heavier ($P < 0.05$) on both days (Table 2). NEO supplementation increased ADG and ADFI from day 0 to 7 ($P < 0.05$) and during Phase 1 ($P < 0.10$), and tended to improve ($P < 0.10$) ADG

from day 21 to 28, compared to CON. Similarly, SCL-fed pigs tended to have greater ($P < 0.10$) ADG from day 0 to 7 and had significantly higher ($P < 0.05$) ADFI throughout Phase 1, including days 0 to 7, 7 to 14, 14 to 21. CBX supplementation improved ($P < 0.05$) ADG and ADFI from day 0 to 7, tended to improve ($P < 0.10$) ADG from day 7 to 14, and enhanced both ($P < 0.05$) ADG and ADFI during Phase 1 compared to CON. NEO supplementation significantly reduced ($P < 0.05$) diarrhea frequency during both Phase 1 and the entire study period compared to CON (Table 3). SCL and CBX also tended to reduce ($P < 0.10$) diarrhea frequency over the same periods. The enhanced early growth performance observed with both NNS was most evident during Phase 1, the most critical period post-weaning. The positive effects on ADG and ADFI may reflect enhanced feed palatability and acceptance, which is consistent with previous studies (Sterk et al., 2008; Lee et al., 2019; Zhang et al., 2020). The reduction in diarrhea incidence, particularly in the NEO group, is indicative of improved gut health and better nutrient assimilation. This is likely attributed to enhanced mucosal integrity and immune regulation, which are critical during the early post-weaning period which is marked by inflammation and barrier dysfunction.

Systemic immunity

Serum inflammatory markers showed minimal treatment effects (Table 4). On day 7, pigs supplemented with SCL or NEO tended to have lower ($P < 0.10$) serum haptoglobin compared to CON pigs, suggesting potential early anti-inflammatory effects. However, NEO-supplemented pigs showed elevated ($P < 0.05$) TNF- α on day 28, an unexpected finding that warrants further investigation into the long-term immune modulation by NNS.

Intestinal morphology

On day 14, SCL increased ($P < 0.10$) ileal villus height, villus height-to-crypt depth ratio (VH:CD; $P < 0.05$), and reduced ($P < 0.05$) crypt depth, suggesting a potential to improve nutrient absorption (Table 5). CBX supplementation increased ($P < 0.05$) VH:CD, while also reducing ($P < 0.05$)

Table 3. Frequency of diarrhea of weaned pigs fed diets supplemented with non-nutritive sweeteners or antibiotic

Item ¹	CON ²	SCL ³	NEO ⁴	CBX ⁵
Frequency of diarrhea, > 3				
Phase 1 ⁶	45.51 ^a	38.46 ^{ab}	33.97 ^b	36.54 ^{ab}
Phase 2 ⁷	7.74	5.36	4.17	5.95
Overall ⁸	25.93 ^a	21.3 ^{ab}	18.52 ^b	20.68 ^{ab}

^{a,b}Within a row, means without a common superscript differ ($P < 0.05$).

¹Frequency = number of pen days with fecal score ≥ 3

²CON = the complex nursery basal diet

³SCL = CON + 150 mg/kg sucralose

⁴NEO = CON + 30 mg/kg neotame

⁵CBX = CON + 50 mg/kg carbadox

⁶Phase 1 = weaning day (d 0) to d 14 of experiment

⁷Phase 2 = d 14 to d 28 of experiment

⁸Overall = d 0 to d 28 of experiment

Table 4. Serum tumor necrosis factor-alpha and acute-phase proteins of weaned pigs fed diets supplemented with non-nutritive sweeteners or antibiotic

Item	CON ¹	SCL ²	NEO ³	CBX ⁴	SEM	P-value
d 0						
TNF- α , pg/mL	76.11	67.31	83.06	79.10	5.51	0.26
C-reactive protein ng/mL	21.87	14.57	13.75	11.43	5.69	0.64
Haptoglobin, ng/mL	8.44	9.79	7.64	9.04	4.55	0.99
d 3						
TNF- α , pg/mL	78.39	106.51	119.55	92.91	19.41	0.27
CRP, ng/mL	21.52	11.34	20.02	25.10	6.73	0.42
Haptoglobin, ng/mL	14.61	17.61	12.91	14.55	8.95	0.98
d 7						
TNF- α , pg/mL	112.75	131.22	111.12	108.47	12.53	0.56
CRP, ng/mL	54.13	54.13	86.57	79.45	18.24	0.41
Haptoglobin, ng/mL	95.92	38.22	38.09	66.16	35.23	0.46
d 14						
TNF- α , pg/mL	116.75	127.58	115.96	106.61	13.59	0.56
CRP, ng/mL	62.32	54.63	51.75	68.01	12.85	0.81
Haptoglobin, ng/mL	79.76	96.58	97.05	87.34	32.00	0.98
d 28						
TNF- α , pg/mL	96.90 ^b	109.44 ^b	178.31 ^a	124.36 ^b	24.19	0.02
CRP, ng/mL	126.95	108.11	160.38	98.35	26.41	0.29
Haptoglobin, ng/mL	41.51	38.56	22.89	20.56	15.46	0.58

^{a,b}Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = the complex nursery basal diet

²SCL = CON + 150 mg/kg sucralose

³NEO = CON + 30 mg/kg neotame

⁴CBX = CON + 50 mg/kg carbadox

crypt depth compared to CON. On day 28, pigs fed SCL increased ($P < 0.10$) jejunal villus width but reduced ($P < 0.05$) VH:CD. CBX continued to enhance ($P < 0.05$) jejunal villus width. Morphological improvements observed in SCL-fed pigs indicate that SCL may support epithelial renewal and enhance nutrient absorption during the early post-weaning phase. Specifically, increased villus height and VH:CD in the ileum suggest improved nutrient absorptive and immunological capacity. However, the subsequent reduction in VH:CD observed at day 28 suggests a potential temporal limitation in SCL's efficacy, possibly due to mucosal adaptation or feedback regulation over time. This shift highlights the need for further investigation into optimal dosing strategies and supplementation duration to sustain beneficial morphological effects. In contrast, NEO supplementation

Table 5. Intestinal morphology of weaned pigs fed diets supplemented with non-nutritive sweeteners or antibiotic

Item	CON ¹	SCL ²	NEO ³	CBX ⁴	SEM	P-value
d 14						
Duodenum						
Villi height, μm	376	376	375	375	15.27	1.00
Crypt depth, μm	426	438	414	409	13.89	0.47
Villi height:Crypt depth	0.88	0.83	0.92	0.93	0.04	0.27
Villi width, μm	152	149	155	146	5.88	0.59
Villi area, mm^2	0.052	0.053	0.055	0.052	0.004	0.96
Jejunum						
Villi height, μm	336	357	356	358	16.42	0.74
Crypt depth, μm	325	323	317	305	10.58	0.51
Villi height:Crypt depth	1.05	1.12	1.10	1.18	0.05	0.39
Villi width, μm	122 ^{ab}	120 ^{ab}	118 ^b	127 ^a	4.32	0.12
Villi area, mm^2	0.039	0.040	0.040	0.040	0.002	0.93
Ileum						
Villi height, μm	281 ^b	304 ^{ab}	285 ^b	330 ^a	14.01	0.10
Crypt depth, μm	302 ^a	267 ^b	283 ^{ab}	269 ^b	10.70	0.10
Villi height:Crypt depth	0.90 ^c	1.15 ^{ab}	1.02 ^{bc}	1.25 ^a	0.06	< 0.01
Villi width, μm	121	122	123	127	4.34	0.72
Villi area, mm^2	0.033	0.034	0.033	0.039	0.002	0.26
d 28						
Duodenum						
Villi height, μm	477	477	489	478	20.94	0.88
Crypt depth, μm	503	507	512	491	19.93	0.72
Villi height:Crypt depth	0.98	0.97	0.97	1.00	0.07	0.89
Villi width, μm	184	182	179	184	3.97	0.74
Villi area, mm^2	0.089	0.082	0.082	0.084	0.005	0.58
Jejunum						
Villi height, μm	437	409	425	443	16.25	0.40
Crypt depth, μm	352	383	379	358	14.10	0.26
Villi height:Crypt depth	1.27 ^a	1.07 ^b	1.14 ^{ab}	1.19 ^{ab}	0.07	0.18
Villi width, μm	138 ^b	148 ^{ab}	140 ^b	155 ^a	4.70	< 0.01
Villi area, mm^2	0.056	0.061	0.056	0.063	0.003	0.27
Ileum						
Villi height, μm	406	401	416	389	17.15	0.64
Crypt depth, μm	327	341	339	326	13.79	0.73
Villi height:Crypt depth	1.25	1.20	1.25	1.24	0.08	0.93
Villi width, μm	148	144	147	139	3.35	0.27
Villi area, mm^2	0.057	0.056	0.058	0.051	0.003	0.33

^{a,b}Within a row, means without a common superscript differ ($P < 0.05$).

¹CON = the complex nursery basal diet; Control

²SCL = CON + 150 mg/kg sucralose

³NEO = CON + 30 mg/kg neotame

⁴CBX = CON + 50 mg/kg carbadox

did not elicit significant changes in intestinal morphology, suggesting a distinct mode of action or different target sites compared to SCL.

Intestinal barrier and innate immunity

On day 14, pigs fed SCL or NEO tended to show increased ($P < 0.10$) mRNA expression of *TJP1* in the jejunal mucosa, while CBX supplementation significantly increased ($P < 0.05$) *TJP1* expression on compared to CON (Figure 1). However, by day 28, SCL supplementation significantly reduced ($P < 0.05$) *TJP1* expression relative to CBX. Both SCL and CBX also increased ($P < 0.05$) *CLDN* expression in the jejunal mucosa on day 28 compared to CON. In the ileal mucosa, SCL and NEO tended to increase ($P < 0.10$) *IL-10* expression, while CBX significantly upregulated ($P < 0.05$) *IL-10* expression on day 14 compared to CON (Figure 2). Both NNS treatments influenced the expression of tight

junction proteins, particularly *TJP1* and *CLDN1*, which are essential for maintaining intestinal barrier integrity. These findings indicate a short-term enhancement in tight junction dynamics, which may explain the reduced diarrhea during Phase 1. Additionally, the trend toward increased *IL-10* expression in the ileum by both SCL and NEO supports the hypothesis that these compounds promote a local anti-inflammatory environment, potentially mitigating immune-driven epithelial disruption post-weaning. Interestingly, NEO-fed pigs exhibited elevated *TNF α* concentrations in serum on day 28, which contrasts with the local anti-inflammatory trends. This systemic elevation may reflect a mild immunostimulatory effect or metabolic cost associated with NEO metabolism. Further work is needed to determine whether this systemic pro-inflammatory marker has biological relevance or reflects transient immune activation not detrimental to overall performance.

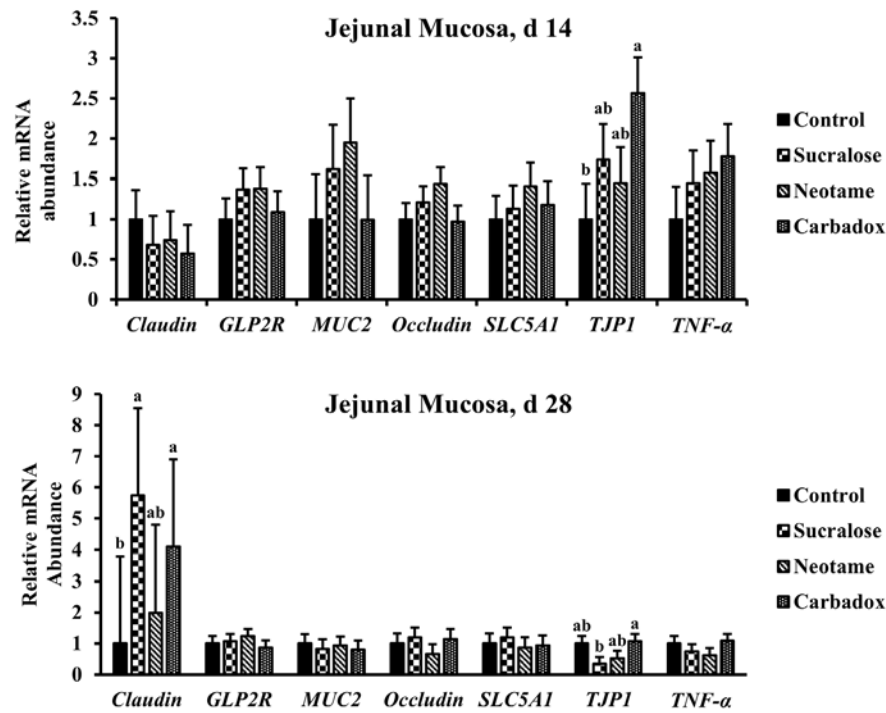


Figure 1. Gene expression profiles in jejunal mucosa of weaned pigs fed diets supplemented with non-nutritive sweeteners. ^{a,b}Means without a common subscript differ ($P < 0.05$). Each least squares mean represents 6 observations. *GLP2R* = Glucagon-like Peptide 2 Receptor; *MUC2* = Mucin-2; *SLC5A1* = Sodium/Glucose Cotransporter 1; *TJP1* = Tight Junction Protein 1; *TNF-α* = Tumor Necrosis Factor-alpha.

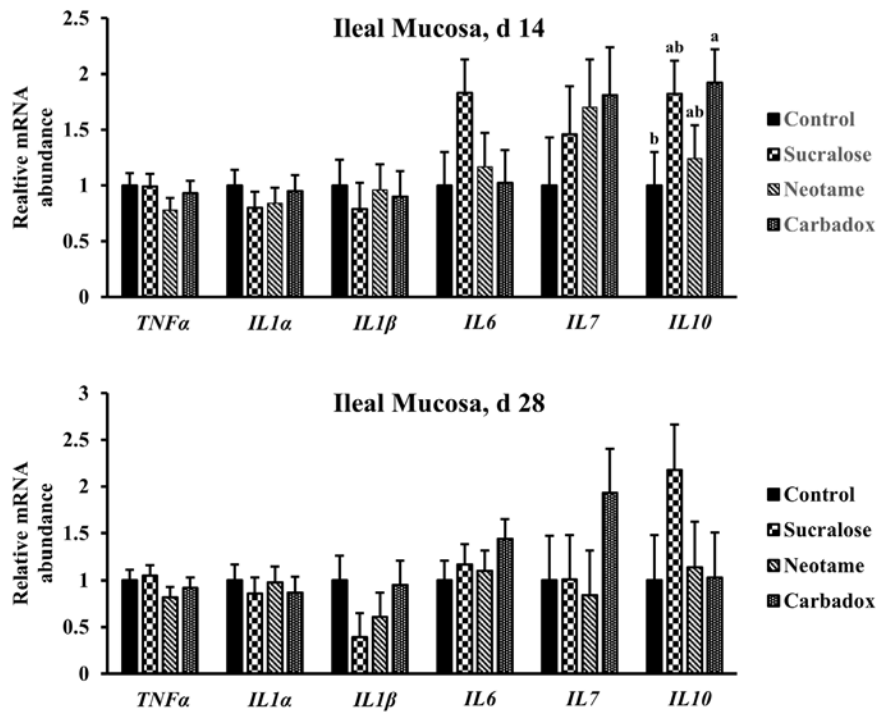


Figure 2. Gene expression profiles in ileal mucosa of weaned pigs fed diets supplemented with non-nutritive sweeteners. ^{a,b}Means without a common subscript differ ($P < 0.05$). Each least squares mean represents 6 observations. *TNF-α* = Tumor Necrosis Factor – Alpha; *IL1α* = Interleukin-1alpha; *IL1β* = Interleukin-1beta; *IL6* = Interleukin-6; *IL7* = Interleukin-7; *IL10* = Interleukin-10.

Conclusion

This study contributes novel insights into the functional benefits of SCL and NEO in weaned pigs. Both sweeteners enhanced early growth performance and feed intake, with neotame notably reducing diarrhea incidence. SCL improved intestinal morphology and barrier integrity during the early post-weaning phase; however, some effects diminished by day 28, suggesting temporal adaptation. Gene expression analyses showed that both sweeteners modulated tight junction proteins and promoted anti-inflammatory responses, supporting intestinal function. While CBX remained an effective positive control, the comparable outcomes observed with SCL and NEO highlight their potential as alternatives in early nursery diets. Notably, SCL appeared to target epithelial structure, whereas NEO influenced immune and gut function more broadly. These distinct physiological effects underscore the importance of selecting non-nutritive sweeteners based on production goals. Overall, these results support the use of NNS as effective nutritional tools to enhance piglet health and performance while contributing to reduced antibiotic use in swine production. Future studies should explore the underlying mechanisms of these effects through integrative approaches such as metabolomics and gut microbial profiling, which could provide deeper insights into host–microbe–diet interactions and help refine sweetener selection and application strategies in nursery nutrition.

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Nutritional Management of Health Compromised Pigs: Implications and Approaches

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Summary

Health-compromised pigs, those facing immune challenges, disease pressure, weaning stress, or exposure to suboptimal environments, exhibit altered nutrient and energy metabolism, reduced feed intake, impaired gut function, and growth. Depending on the stage of production, the stress type, severity, and duration, of these conditions may require specialized nutritional strategies to mitigate production losses and support recovery. Altogether, these impact pig production efficiency and increase the risk of mortality. Dietary crude protein levels, acids, reducing anti-nutritional factors, energy to lysine ratios, antioxidants, acidifiers, probiotics, therapeutic minerals, functional amino acids and functional fiber are all nutritional strategies and approaches to manage health-compromised pigs. These nutritional strategies for health-compromised pigs may go beyond supporting growth. However, they need to be targeted to specific pathogens, pathogenesis, and the age of the pig.

Introduction

Despite significant advancements in pig housing, sanitation, and biosecurity, subclinical and clinical disease-associated production losses remain one of the greatest challenges facing the global pork industry. Pigs experiencing pathogenic challenges often exhibit reduced growth, feed intake, and feed efficiency, leading to diminished profitability for producers. Both clinical and subclinical diseases caused by enteric and respiratory pathogens negatively impact swine health across all stages of production. The economic consequences are significant depending on the production phase and the pathogen(s) involved. Beyond financial losses, poor health status raises concerns related to animal welfare and antimicrobial usage, which are increasingly important to both producers and consumers. Improving disease prevention and treatment strategies requires a deeper understanding of the physiological, cellular, and molecular responses elicited by specific pathogens.

In the U.S., common swine pathogens include both bacterial and viral agents, often acting in combination. Notable bacterial threats include *Mycoplasma hyopneumoniae*, *Salmonella typhimurium*, hemolytic Enterotoxigenic *Escherichia coli* (ETEC), *Streptococcus suis*, *Clostridium spp.*, and *Actinobacillus pleuropneumoniae*. Viral infections of concern include Porcine Circovirus, Swine Influenza Vi-

rus, Porcine Reproductive and Respiratory Syndrome Virus (PRRSV), and Porcine Epidemic Diarrhea virus. Alone or in combination, these bacterial and viral pathogens can trigger acute or chronic immune responses, either locally or systemically. In nursery-to-finisher systems, co-infections and multifactorial etiologies are common, complicating the identification of primary causative agents and the development of targeted interventions.

Enteric Health

A key physiological system affected by both pathogenic and non-pathogenic insults is the gastrointestinal tract, particularly its function and integrity. Over the past decade, the concept of “gut health” has gained increasing attention in swine production. Gut health broadly encompasses intestinal barrier permeability, nutrient digestion and absorption, host metabolism and energy generation, mucus layer integrity, microbiome stability, and mucosal immune responses. Among these, intestinal barrier function, commonly referred to as “leaky gut,” has received particular focus in health-compromised pigs. Although a somewhat vague term, “leaky gut” generally refers to increased intestinal permeability and has been reported under stressors such as weaning (Moeser et al., 2007), heat stress (Pearce et al., 2013), and pathogenic infection (Schweer et al., 2016).

However, a critical gap remains in our understanding of what constitutes optimal barrier integrity and how it is altered *in vivo* by various pathogen challenges. This gap stems, in part, from the complexity of the intestinal barrier system, which involves intricate interactions among structural, immune, and secretory elements, as well as functional redundancies that help preserve barrier integrity. Consequently, no single assay or biomarker can be considered the definitive measure of epithelial barrier function. Moreover, because pathogens employ diverse mechanisms to disrupt host physiology, the impact on barrier function likely varies by pathogen.

Nutritional Management of Disease

In parallel with biosecurity and therapeutic approaches, nutritional management offers a practical and effective strategy to mitigate the impact of disease on pig health and performance. During immune activation, nutrient partitioning shifts away from growth and toward maintenance and immune function. This altered metabolic state, compounded by reduced voluntary feed intake, increases the risk of nutrient deficiencies precisely when metabolic demands are elevated. Therefore, nutritional strategies should aim to support immune resilience, maintain gut barrier integrity, and sustain energy and protein metabolism during disease.

Tailoring diets to the specific challenge (e.g., respiratory vs. enteric; viral vs. bacterial) may offer further benefits, though such precision nutrition requires a deeper understanding of pathogen-specific nutrient demands and responses. Nutritional strategies must also consider the timing and duration of intervention, as preemptive dietary fortification during high-risk periods (e.g., post-weaning, seasonal transitions) may offer better outcomes than reactive approaches. Ultimately, integrating targeted nutritional support into disease management frameworks offers a promising avenue to improve pig robustness and reduce reliance on antimicrobials.

Specific dietary interventions to improve enteric health have included the use of highly digestible protein sources or formulating diets low in crude protein. However, the latter is typically achieved via reducing standardized ileal digestible (SID) lysine levels below the requirement. The premise for these diets is to reduce fermentable protein, bioamine production and to minimize substrates for pathogenic bacteria (Pearce et al., 2024). Pigs fed **low SID lysine diets or diets lower in fermentable protein during the nursery** period, to alleviate enteric health stress and reduce mortality rates, may experience **compromised growth performance during grow-to-finish**, compared to those fed higher lysine levels (Miller et al., 2024). Therefore, implementing low-SID Lys diets as a strategy to support enteric health may carry a performance penalty lasting until marketing.

Supplementation of pig diets with functional feed additives has been extensively reviewed (Schweer et al., 2019). However, pig health and performance outcomes have been highly variable. Pig age and stress-dependent benefits have been shown with the use of dietary organic acids, medium-chain fatty acids, probiotics and yeast-derived products, phytogenics or phytobiotics, and essential trace minerals such as zinc. Functional amino acids such as threonine, tryptophan, and methionine have also been shown to support mucosal repair and immune cell function (Rodrigues et al., 2022).

Feed Intake Disruption in Pigs

Feed intake and gut integrity in pigs are tightly linked, especially during the weaning period, when pigs experience abrupt dietary, social, and environmental stress (Moeser et al., 2007). Reduced feed intake during this time is not just a symptom of stress; it can cause or exacerbate gut barrier dysfunction, leading to increased disease susceptibility, reduced nutrient absorption, and poorer growth (McLamb et al., 2013). Disease-induced hypophagia in pigs is a well-documented phenomenon with major implications for gut health, barrier integrity, and post-weaning performance (Helm et al., 2020). Helm et al. (2020) investigated how disease-induced hypophagia (reduced feed intake) impacts intestinal function and barrier integrity in nursery pigs during PRRSV infection. Pigs were either infected with PRRSV and fed *ad libitum*, non-infected but pair-fed to match intake (hypophagia), or non-infected and fed *ad libitum*. Both PRRSV-infected and pair-fed pigs showed reduced transepithelial resistance, indicating impaired barrier function. Only PRRSV-infected pigs had reduced brush-border enzyme activity, suggesting additional virus-specific impacts on nutrient digestion. Tight junction protein gene expression was altered in PRRSV pigs, but localization remained unaffected. Helm et al. (2020) concluded that reduced feed intake alone impairs gut barrier function, and PRRSV further compromises digestion. Strategies to improve or maintain adequate feed intake during disease are needed to support pig health and performance. This could include the use of flavoring agents or olfactory and palatability enhancers in diet formulation.

Anecdotal field observations suggest that PRRSV and its associated reduction in feed intake may contribute to increased incidence of gastric ulcers in pigs. Supporting this, our group has demonstrated that restricting feed intake to levels mimicking disease-associated hypophagia (Helm et al., 2020) significantly increases the incidence of gastric ulcers in healthy grower pigs fed finely ground corn diets (Gabler et al., 2022). Pelleted diets, particularly those formulated with finely ground ingredients, further elevate ulcer risk. Thus, irregular or reduced feed intake, whether induced by disease, stress, or management, creates conditions

in the upper stomach that favor acid pooling and prolonged mucosal exposure, predisposing pigs to gastric ulcerations. Effective nutritional management strategies include formulating diets with coarser particle sizes, increasing the inclusion of coarse cereal grains, enhancing dietary fiber levels, and improving pellet quality by reducing fines. Additionally, maintaining consistent feed availability with minimal disruptions is critical to mitigating ulcer risk.

Pre- and Post-weaning Challenges

Pre- and post-weaning scouring, reduced milk or feed intake, and suboptimal growth rates are commonly observed in commercial production and are strongly associated with increased disease risk, poor downstream pig performance, higher medication use, and elevated mortality. Despite this, the swine industry often treats sow farm and nursery health as independent systems. However, mounting evidence suggests that enteric health and performance in the early nursery period are primarily established on the sow farm.

Pathogens such as ETEC, *Clostridium perfringens*, *Salmonella* spp., rotavirus, coronaviruses, and *Cystoisospora suis* (coccidia) are under active investigation as potential contributors. However, it is increasingly clear that non-infectious factors, particularly low early caloric intake from milk or feed, may play a key role in predisposing piglets to gastroenteritis. Our recent field and diagnostic work have

revealed signs of gastroenteritis in pigs as young as seven days of age, underscoring the early onset and severity of this issue.

Contributing to poor weaning transitions and subpar early nursery pig health is a growing incidence of pre-weaning and early nursery gastroenteritis (**Figure 1**). Gastroenteritis, defined as inflammation of the stomach, small intestine, and/or large intestine, disrupts nutrient digestion and absorption, and can result in diarrhea, dehydration, malnutrition, and mortality if not managed effectively. In swine, this condition is frequently multifactorial, caused by infectious agents such as enteric viruses, coccidia, and bacterial pathogens, and compounded by non-infectious factors including inadequate milk or feed intake. These multifactorial enteric health challenges are becoming increasingly prevalent in commercial sow farms and nurseries across Iowa. To address this, a more integrated approach that links sow farm management, early caloric intake, weaning transition, and nursery nutrition is essential for improving health, performance, and survivability in young pigs.

Enteric Disease and Fiber

The functional value of dietary fiber in improving intestinal health and immune function of nursery pigs has gained industry attention as a potential to reduce ETEC and post-weaning diarrhea through characteristics such as solubility, viscosity, and fermentability. Oats are commonly

used to improve nursery pig fecal consistency and enteric health (Molist et al., 2014). Wheat bran has been shown to mitigate the negative effects associated with K88 ETEC in nursery pigs due to their nutritional value and physiochemical properties (Molist et al., 2010). Unfortunately, dietary fiber manipulation may not provide the same protection in the case of other swine diseases. As manipulating these components acts largely to induce changes in large intestinal microbial populations and fermentation, it is likely that pathogens that primarily affect the small intestine would be less affected by alterations to dietary fiber. In nursery pigs, inclusion of soluble fibers only provided marginal growth benefits to pigs facing an F18 ETEC challenge, while addition of insoluble fibers increased pathogen shedding, but did not alter growth compared with challenged pigs fed a lower fiber diet (Li et al., 2020).

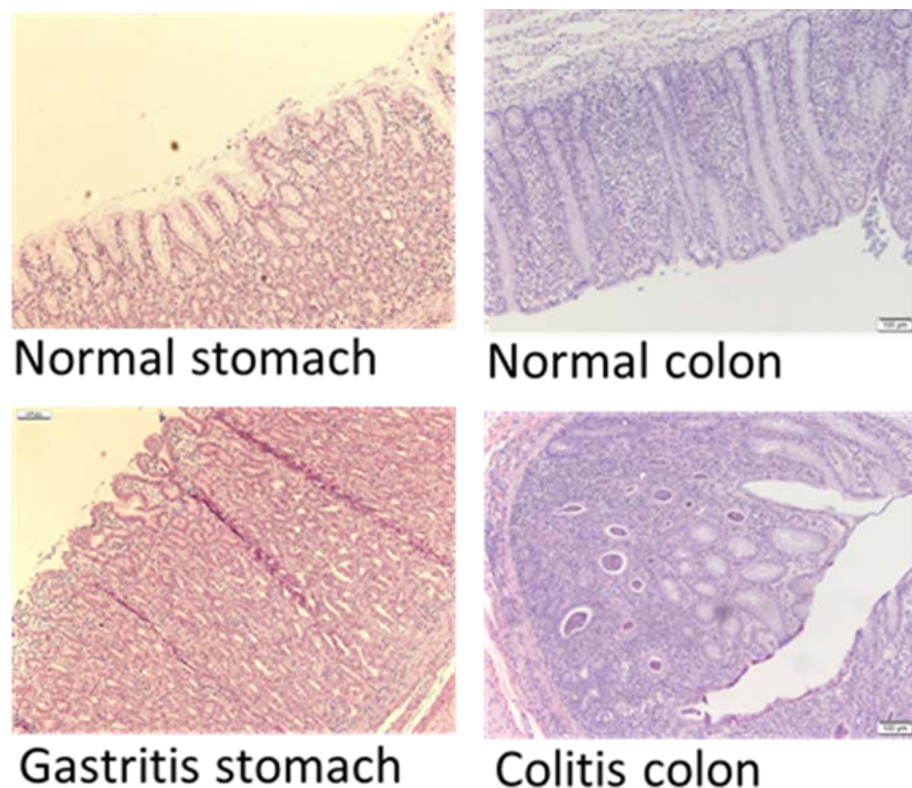


Figure 1. Histologic examples of normal and inflamed stomach and colon sections from pigs around weaning age. Note the thickening of the mucosa in the gastritis and colitis sections and the exudation of neutrophils in the colonic crypts.

Since 2008, there has been an increase in the detection of cases of swine dysentery at the Iowa State University Veterinary Diagnostic Laboratory, from which either *Brachyspira hyodysenteriae* or *Brachyspira hampsonii* were isolated by culture. Although conflicting results have been published (Pluske et al., 1996; Pluske et al., 1998), generally diets increasing in insoluble fiber increase swine dysentery disease. However, when diets are formulated with more fermentable fiber, positive health benefits have been observed in the face of swine dysentery (Hansen et al., 2011). In the case of Midwest U.S. swine producers, most diets are based on ground corn and soybean meal, and may also contain fibrous ingredients like corn distiller's dried grains with solubles (DDGS). It has been demonstrated that replacing lowly fermentable fiber, such as corn DDGS, with highly fermentable fiber in pig diets can mitigate the severity of swine dysentery (Helm et al., 2021). Pigs on high fermentable fiber diets had improved growth performance and reduced clinical signs of the disease, highlighting the role of diet in disease management. However, the soluble fiber utilized in these studies, beet pulp and resistant potato starch, are cost-prohibitive for Midwest pork producers, and other more common fermentable carbohydrate sources need evaluation.

In the case of *Lawsonia intracellularis*, Whitney et al., (2006a) found that inclusion of 10% DDGS reduced ileal lesion severity of pigs following experimental challenge, although growth performance was not improved. Further, these authors were unable to replicate this protective effect in two follow-up studies (Whitney et al., 2006b). Therefore, it appears unlikely that insoluble fiber plays a large role in ileitis. However, further research is needed to investigate the efficacy of highly fermentable fibrous feedstuff in modulating ileitis in pigs.

Respiratory Health and Nutrition

Nutritional management of PRRSV in pigs is problematic due to rapid viral mutations, antigenic diversity, limited cross-protection between strains, and disease severity. As mentioned earlier, PRRSV-induced hypophagia is common, and feed intakes can be reduced by 15-50% from healthy expected levels. Based on this, we have conducted several studies that increased the ratio of SID lysine to metabolizable energy (SID Lys:ME) in order to mitigate the PRRSV effect on pig growth, by better aligning amino acid supply with reduced energy intake during infection. Schweer et al. (2017) and Jasper et al. (2020) reported that increasing SID Lys:ME ratios beyond recommendations significantly improved average daily gain and gain-to-feed in PRRSV-challenged pigs. In these studies, health-compromised pigs responded linearly to elevated SID Lys:ME ratios, with optimal performance observed at ~10–20% above standard requirement estimates. Importantly, this improvement was

observed whether the dietary lysine content was increased or the dietary energy density was diluted to achieve the target ratio. This work also highlighted that sick pigs eat to meet their energy needs.

More recently, our group also evaluated targeted increases in SID Lys:ME starting at peak PRRSV infection (3 weeks post-PRRSV challenge) and reported that these diets were not beneficial to pig performance (Miller et al., 2022). This indicated that this diet strategy needs to be in place near the time of PRRSV onset and underscoring the timing and practical benefit of dietary adjustments in response to the disease state. Further work with PRRSV and diet has shown that soybean meal and dietary soy isoflavone supplementation (~1.6 g/kg feed) can reduce pig mortality and aid immune protection to PRRSV (Smith et al., 2020). These findings further highlight a practical nutritional strategy to improve disease resilience during viral challenge in swine.

Conclusion

Disease remains a major barrier to swine performance, with both enteric and respiratory infections. Biosecurity, good management practices, and therapeutics set the foundation for optimal pig health and production. However, diet remains a flexible tool for pig producers. Nutritional strategies that support feed intake, gut health, and immune resilience are critical during these challenges. Depending on the pathogen or stressor and pig age, adjusting amino acid density, managing fiber type, and improving feed form and composition can all help mitigate losses. Soybean meal, while sometimes negative depending on anti-nutritional factors and crude protein levels in complete feed, may enhance immune responses and reduce pig mortality. Ultimately, precision nutrition delivered early and tailored to the pathogen and production phase offers a powerful, daily tool to reduce antimicrobial reliance and preserve pig livability and performance.

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From Papers to Profit: Bridging Research and Real-World Application in Production Swine Nutrition

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Introduction

In today's rapidly evolving pork industry, the role of the swine nutritionist is more critical than ever. As scientific advancements in nutrition and physiology accelerate, bridging the gap between academic research and practical implementation becomes both a challenge and an opportunity. The swine nutritionist stands at this intersection, translating complex data generated in controlled research environments into actionable strategies that deliver consistent results on commercial farms.

Developing an effective feed program requires more than just understanding nutrient requirements; it demands the ability to evaluate trial data, weigh economic realities, assess ingredient variability, and account for real-world constraints such as facility design, labor, and animal health. The process involves integrating peer-reviewed research, supplier data, and field observations to formulate diets that optimize performance, enhance animal well-being, and support profitability.

This presentation will take a deeper look into how a production swine nutritionist turns academic insights into feeding strategies. Moreover, this presentation will provide suggestions on how future research approaches can lead to easier application by pork producers and production nutritionists. Bridging the gap between academic research and commercial pork production requires more than traditional small-scale "feed and weigh" studies. Today's swine nutritionists and integrated pork production systems demand clear, quantifiable modes of action that define how nutritional interventions influence biological systems and production outcomes. Without this mechanistic understanding, the application of novel feed additives, ingredient strategies, or precision nutrition technologies remains speculative and inconsistent across commercial environments. To confidently incorporate innovations into large-

scale feed programs, the industry needs scalable data that is biologically relevant, economically validated, and operationally executable. This presentation emphasizes the need for research frameworks that prioritize clarity, repeatability, and commercial translatability, enabling nutritionists to move beyond empirical testing toward data-driven, system-wide decision-making. The objective of this presentation is to ensure that innovation does not just stay in the lab but rather feeds the pigs in commercial production.

Example of how to take papers to profit

In 2015, Theil et al. demonstrated that reducing the interval between the sow's final meal and the onset of farrowing significantly decreased stillbirth rates in controlled research environments. The proposed mechanism involves improved energy availability during parturition, thereby reducing farrowing duration and hypoxia-related losses.

To evaluate the commercial relevance of this finding, AMVC implemented a field study (Miller and Kellner, 2020). The objective was to assess whether adjusting the timing of the sow's last meal prior to farrowing could reduce stillbirth rates under commercial conditions, while maintaining operational feasibility.

The study was conducted across multiple commercial farrowing sites. Feeding schedules were modified to reduce the fasting period prior to farrowing by ensuring a late-day meal was provided to sows approaching term. Farrowing outcomes, including total born, stillborn, and farrowing duration, were recorded and analyzed.

Results indicated that sows receiving feed closer to the onset of labor had a lower incidence of stillbirths compared to standard feeding protocols. The intervention proved both biologically effective and operationally practical within the constraints of commercial production systems.

These findings validate the physiological hypothesis proposed by Theil et al. (2015) and demonstrate that modifying peripartum feeding schedules is a low-cost, high-return strategy to improve piglet survivability. This work underscores the value of bridging academic research with applied field trials to enhance sow productivity and animal welfare in commercial settings.

Conclusion

As the pork industry continues to evolve, the role of the swine nutritionist must evolve with it, serving not just as a diet formulator, but as a translator of science into practice. This presentation highlights the critical importance of turning peer-reviewed insights into practical, scalable strategies that drive productivity, profitability, and animal welfare in real-world settings. The example of reducing stillbirths

through refined feeding schedules illustrates how academic innovation, when tested and tailored for commercial conditions, can yield tangible on-farm results. To advance this progress, future research must prioritize mechanisms of action, commercial relevance, and operational feasibility. When science meets execution, innovation does not sit on a shelf - it feeds pigs, improves outcomes, and moves our industry forward.

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20	BASF Corporation	6	Azomite Mineral Products Pharmgate Animal Health
19	Hubbard Feeds Provimi North America (previously Akey) Ralco Nutrition	5	Feedworks USA Hanley International King Techina Group Newsham Choice Genetics Nutriad Phileo Lesaffre Animal Care Topigs Norsvin
18	ADM Animal Nutrition Darling Ingredients (previously Griffin Industries) Distributors Processing Evonik-Degussa Corporation Kemin Animal Nutrition and Health Novonesis (previously Chr. Hansen Animal Health and Nutrition)	4	CSA Animal Nutrition
17	Ajinomoto Animal Nutrition (previously Ajinomoto Heartland) Kent Nutrition Group	3	Green Plains Fortiva (previously PMI) Pancosma
16	Fats and Proteins Research Foundation National Pork Board	2	Ani-Tek Group Arm & Hammer Animal Nutrition Boehringer Ingelheim Animal Health CHS Murphy-Brown Mycogen Seeds Pfizer The Sunswine Group U.S. Soy
15	IFF/Danisco Animal Nutrition (previously Dupont) The Maschhoffs Zoetis (previously Pfizer Animal Health, Alpharma)	1	Biomatrix ChemGen EW Nutrition Gladwin A. Read Co. KWS Cereals USA Norel Animal Nutrition NRCS Conservation Innovation Grant Nutraferma Pharmacosmos Prairie Systems Standard Nutrition Services Vetagro Vi-Cor Animal Health and Nutrition
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13	AB Vista Feed Ingredients Selko USA (previously Micronutrients)		
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