

International Journal of Agriculture Extension and Social Development

Volume 9; SP-Issue 7; July 2026; Page No. 103-106

Received: 19-04-2026
Accepted: 23-05-2026

Indexed Journal
Peer Reviewed Journal

Modern nutritional paradigms in swine production: A comprehensive review of global concepts and their relevance to the Indian Industry

¹Prajwal M and ²Madhusudhan HS

¹Ph.D. Scholar, Department of Animal Nutrition, Veterinary College, Hebbal, Bengaluru, Karnataka, India

²Associate Professor, Department of Animal Nutrition, Veterinary College, Hebbal, Bengaluru, Karnataka, India

DOI: <https://doi.org/10.33545/26180723.2026.v9.i7Sb.3922>

Corresponding Author: Prajwal M

Abstract

The global swine industry has transitioned to high-productivity genotypes, necessitating a shift toward modern nutritional paradigms. Precision pig feeding is a cornerstone of this evolution, utilizing sensors (RFID, 3D cameras) and mathematical models to provide individualized daily diets. This approach reduces feed costs by >4.6% and nitrogen/phosphorus excretion by >38%, which is crucial for India, where feed accounts for 65–75% of production costs and nitrate pollution is an environmental concern. For hyper-prolific sows, research indicates that multiparous genotypes require 16.0 to 16.7 g/d of SID Lysine in late gestation to optimize nitrogen utilization and maximize backfat gain. Low-protein diets supplemented with crystalline amino acids further enhance sustainability by reducing the feed's climate footprint. The weaning transition remains the most critical period, as villus height can decrease by 75% within 24 hours. Functional additives like protein hydrolysates and probiotics are essential to restore intestinal balance and mitigate "weaning anorexia". Simultaneously, feed processing—specifically optimizing particle size (485–600 µm) and thermal treatments like pelleting—maximizes nutrient bioavailability and improves feed conversion by 4–12%. Finally, micronutrients like vitamins are recognized as "unknown heroes" of swine health. In India, precision vitamin nutrition is vital to mitigate heat stress, which increases the requirement for antioxidant vitamins (A, C, and E). Transitioning from traditional standards (e.g., BIS 1986) to these modern concepts is an imperative for the Indian swine sector's global competitiveness and environmental sustainability.

Keywords: Precision feeding, feed processing, weaning transition, micronutrients

1. Introduction

The global swine industry has undergone a dramatic transformation over the past few decades, transitioning from the production of slow-growing, fat animals to lean, efficient genotypes bred for maximum meat output and high prolificacy. While this genetic progress has significantly increased productivity, it has simultaneously created complex metabolic demands that traditional "one-size-fits-all" group-feeding strategies can no longer satisfy. In modern production systems, it is now common for hyper-prolific sows to give birth to more than 20 piglets, placing extreme metabolic strain on the sow, particularly during the last third of gestation when fetal growth and mammary development accelerate (Feyera *et al.*, 2021; Johannsen *et al.*, 2024a) [2, 5]. Past nutritional standards and studies conducted on sows with lower reproductive performance are increasingly viewed as inapplicable to these modern high-performance herds (Johannsen *et al.*, 2024a) [5]. At the center of this nutritional evolution is the concept of precision pig feeding, which represents a paradigm shift toward providing the accurate amount of feed with a tailored composition at the exact time required by each individual animal (Gaillard *et al.*, 2020; Pomar and Remus, 2019; Koley *et al.*, 2023) [3, 9, 6]. This approach is identified as a breakthrough for sustainability, capable of reducing feeding costs by more than 4.6% and decreasing nitrogen (N) and

phosphorus (P) excretion by over 38% (Pomar *et al.*, 2009; Koley *et al.*, 2023) [10, 6]. Such efficiency is particularly critical for emerging markets like India, where feed costs represent the maximum input expense (65–75%) and where the industry faces growing environmental challenges, including nitrate pollution of aquifers from pig manure (Pomar and Remus, 2019; Koley *et al.*, 2023) [9, 6]. Integrating precision feeding is essential for the Indian swine sector to augment its competitiveness and sustainability while transitioning away from traditional standards, such as the Bureau of Indian Standards (BIS, 1986) [1], which may not adequately reflect the requirements of modern genotypes (Koley *et al.*, 2023) [6]. Beyond precision delivery, modern nutritional paradigms emphasize the specialized management of critical life stages and gastrointestinal health. For hyper-prolific sows, research indicates that a standardized ileal digestible (SID) lysine intake of 16.0 to 16.7 g/d is required in late gestation to optimize N utilization and maximize backfat gain without the metabolic cost of excessive protein oxidation (Johannsen *et al.*, 2024) [5]. Simultaneously, the weaning transition remains the most critical period in pig management, characterized by "weaning anorexia" and profound morphological changes in the small intestine, such as a 75% reduction in villus height within 24 hours (Hampson, 1986; Zheng *et al.*, 2021) [4, 13]. To combat these challenges,

functional feed additives—including protein hydrolysates, probiotics, and exogenous enzymes—are being utilized to restore intestinal balance and enhance nutrient absorption (Zheng *et al.*, 2021) ^[13].

Furthermore, advanced feed processing technologies, such as particle size optimization (aiming for 485 to 600 µm) and thermal treatments like pelleting or extrusion, are vital for maximizing nutrient bioavailability and managing costs (Rojas and Stein, 2015) ^[11]. Finally, the role of micronutrients has been re-evaluated; vitamins are now recognized as the "unknown heroes" of swine health, requiring precision supplementation to support immune function and productivity under modern environmental pressures like heat stress, which is prevalent in the Indian climate. This review aims to synthesize these modern nutritional concepts—precision feeding, functional gut health management, advanced sow requirements, and feed processing—while specifically examining their relevance to the Indian swine industry. By bridging global scientific advancements with local production challenges, this article provides a comprehensive roadmap for enhancing both the economic profitability and environmental sustainability of pork production in the region.

Precision Pig Feeding – Individualized Real-Time Nutrition

Precision pig feeding represents a paradigm shift from traditional group-based nutritional standards to an individualized, data-driven approach (Koley *et al.*, 2023; Pomar and Remus, 2019) ^[6, 9]. Historically, feeding programs relied on factorial methods, such as those from the National Research Council or the Bureau of Indian Standards (BIS, 1986) ^[1], which estimate nutrient requirements for large groups of animals over long production phases (Koley *et al.*, 2023; Pomar and Remus, 2019) ^[6, 9]. However, these "one-size-fits-all" strategies often lead to nutrient excesses or deficiencies, as individual animals within a herd vary significantly in their behavioral and physiological responses (Koley *et al.*, 2023) ^[6]. The modern concept of precision feeding aims to provide the accurate amount of feed with the exact composition required by each individual pig daily (Pomar and Remus, 2019) ^[9]. Implementation of this system in commercial farms requires the integration of three core actions: automatic data collection, real-time data processing, and automated control systems (Koley *et al.*, 2023; Pomar and Remus, 2019) ^[6, 9]. Data collection is achieved through an array of sensors, including RFID tags for movement monitoring and non-invasive 3D video cameras equipped with depth sensors to track body weight gain (Koley *et al.*, 2023) ^[6]. These data are then processed through mathematical models like InraPorc, which predict real-time requirements by combining empirical elements with mechanistic factorial equations (Koley *et al.*, 2023; Pomar and Remus, 2019) ^[6, 9]. Finally, automated feeders mix high-nutrient-dense and low-nutrient-dense diets in real-time to match the pig's calculated daily demand (Koley *et al.*, 2023; Pomar and Remus, 2019) ^[6, 9]. The economic and environmental impacts are profound; precision feeding can reduce feeding costs by more than 4.6% while decreasing nitrogen (N) and phosphorus (P) excretion by more than 38% (Koley *et al.*, 2023; Pomar and Remus, 2019) ^[6, 9]. Advanced biological

models suggest that excretion reductions could eventually exceed 60% (Pomar and Remus, 2019) ^[9]. This is achieved by supplying individual pigs with daily customized diets that require less crude protein (CP) than traditionally fed pigs (Koley *et al.*, 2023) ^[6]. By controlling individual animal variations, producers can drastically reduce the industry's environmental footprint, particularly concerning nitrate pollution of aquifers (Koley *et al.*, 2023; Pomar and Remus, 2019) ^[6, 9].

Nutritional Management of Hyper-Prolific Sows

Modern swine production is defined by the rise of hyper-prolific sows, which frequently give birth to litters exceeding 20 piglets (Johannsen *et al.*, 2024; Zheng *et al.*, 2021) ^[5, 13]. This prolificacy places extreme metabolic strain on the sow, especially during the last third of gestation (day 84 to 108), when fetal growth and mammary development accelerate (Johannsen *et al.*, 2024) ^[5]. During this phase, it is estimated that sow body weight (BW) increases by 16 kg due to the growth of the conceptus and mammary glands (Johannsen *et al.*, 2024) ^[5]. If the sow is fed below her nutrient requirements during this window, she must mobilize body protein to support the litter (Johannsen *et al.*, 2024) ^[5]. Excessive mobilization is associated with an increased weaning-to-estrus interval and reduced litter size in subsequent cycles (Johannsen *et al.*, 2024) ^[5]. Recent research indicates that multiparous hyper-prolific sows require 16.0 to 16.7 g/d of SID Lysine (Lys) in late gestation to optimize nitrogen utilization and maximize backfat (BF) gain (Johannsen *et al.*, 2024) ^[5]. While sow BW gain plateaus at 5.63 g/kg of SID Lys, BF gain reaches its peak at a lower concentration of 4.85 g/kg (Johannsen *et al.*, 2024) ^[5]. Feeding protein in excess of these requirements leads to amino acid oxidation and energy-costly urea excretion, which reduces the energy available for fat retention (Johannsen *et al.*, 2024) ^[5]. A highly effective strategy is the use of low-protein diets supplemented with crystalline amino acids (CAA) (Johannsen *et al.*, 2024) ^[5]. By providing essential amino acids like Lys, Met, Thr, Trp, and Val while reducing overall CP, producers can meet the sow's requirements without the metabolic cost of deaminating excess protein (Johannsen *et al.*, 2024) ^[5]. Research has shown that sows fed high-CAA diets gain more body protein and have significantly reduced urea excretion compared to those on traditional high-protein diets (Johannsen *et al.*, 2024) ^[5]. This strategy also significantly reduces the climate footprint of the feed by lowering reliance on soybean meal (Johannsen *et al.*, 2024) ^[5].

Enhancing Intestinal Health and the Weaning Transition

The weaning transition is a critical period characterized by "weaning anorexia" and severe gastrointestinal challenges (Zheng *et al.*, 2021) ^[13]. Upon weaning, pigs move from liquid sow milk to solid cereal-based feeds, which often results in depressed growth and diarrhea (Zheng *et al.*, 2021) ^[13]. Morphological changes to the small intestine are profound; within 24 hours of weaning, villus height can reduce by 75%, leading to a loss of absorptive surface area (Zheng *et al.*, 2021) ^[13]. Furthermore, weaning compromises the paracellular barrier function by decreasing the expression of tight junction proteins, allowing the entry of

toxins and pathogens into circulation (Zheng *et al.*, 2021)^[13]. To mitigate these effects, modern nutrition emphasizes functional feed additives (Zheng *et al.*, 2021)^[13]. Protein hydrolysates, such as spray-dried porcine plasma, are highly digestible and enhance barrier function while reducing immune system activation (Zheng *et al.*, 2021)^[13]. Prebiotics and probiotics modulate the intestinal microbiota to suppress pathogens like *E. coli* while stimulating beneficial *Lactobacilli* (Zheng *et al.*, 2021)^[13]. Probiotics improve host health by maintaining epithelial integrity, while prebiotics provide the necessary substrate for beneficial microbial growth (Zheng *et al.*, 2021)^[13]. Other critical interventions include organic acids and exogenous enzymes (Zheng *et al.*, 2021)^[13]. Organic acids are used to decrease gastric pH, which is essential because the optimum pH for vegetable protein digestion is 2.0–3.5, whereas newly weaned pigs often range between 2.6 and 5.0 (Zheng *et al.*, 2021)^[13]. Feed enzymes like xylanases and proteases break down non-starch polysaccharides and allergenic proteins (such as glycinin in soy), which reduces digesta viscosity and gut inflammation (Zheng *et al.*, 2021)^[13]. These interventions are vital for preventing the morbidity associated with early weaning stress (Zheng *et al.*, 2021)^[13].

Advanced Feed Processing Technologies

Feed processing is a critical lever for maximizing nutrient bioavailability, particularly when using high-fiber alternative ingredients (Rojas and Stein, 2015)^[11]. Particle size optimization is the first step; reducing the mean particle size of cereal grains increases the surface area for enzyme action, improving the digestibility of energy and starch (Rojas and Stein, 2015)^[11]. Research suggests that a particle size range of 485 to 600 µm provides the best balance for nutrient utilization (Rojas and Stein, 2015)^[11]. However, grinding grains too finely (< 400 µm) or pelleting finely ground diets can increase the risk of esophagogastric ulcers due to increased mixing in the stomach and faster gastric emptying (Rojas and Stein, 2015)^[11]. Thermal treatments such as pelleting, extrusion, and expansion offer further benefits (Rojas and Stein, 2015)^[11]. Pelleting uses steam and pressure to create durable feed forms, which can increase feed conversion by 4% to 12% (Rojas and Stein, 2015)^[11]. These improvements are largely due to the gelatinization of starch during the heating process, making it more accessible to digestive enzymes (Rojas and Stein, 2015)^[11]. Extrusion results in more severe physico-chemical changes and is particularly beneficial for ingredients with high fiber concentrations (Rojas and Stein, 2015)^[11]. Chemical treatments are also gaining traction for high-fiber co-products (Rojas and Stein, 2015)^[11]. Treating cereal co-products with Sodium Hydroxide (NaOH) or ammonia can solubilize hemicellulose and lignin fractions, increasing the energy contribution from fiber (Rojas and Stein, 2015)^[11]. While these technologies require careful management to avoid palatability issues, they represent a significant opportunity to improve the digestibility of alternative feed ingredients, thereby reducing reliance on traditional corn-soybean meal diets (Rojas and Stein, 2015)^[11].

Micronutrients

While swine nutrition has traditionally focused on

macronutrients like protein and energy, the extreme metabolic demands of modern, high-productivity genotypes necessitate a reevaluation of vitamin supplementation levels (NRC, 2012)^[8]. Modern hyper-prolific sows frequently give birth to more than 20 piglets, placing extreme strain on maternal reserves during late gestation when fetal growth and mammary development accelerate (Feyera *et al.*, 2021; Johannsen *et al.*, 2024a)^[2, 5]. Deficiencies in these essential micronutrients are associated with poor growth performance and increased vulnerability to disease challenges (NRC, 2012)^[8]. Specific vitamins play critical roles in supporting health: Vitamin A supports vision and immune function, while Vitamin D3 is essential for bone development and overall skeletal health (NRC, 2012)^[8]. Vitamin E acts as a powerful antioxidant, protecting cells from oxidative damage and enhancing the overall immune response (NRC, 2012)^[8]. B-complex vitamins, including Niacin, Biotin, and B12, are critical for supporting energy metabolism and enzyme function in rapid-growth animals (NRC, 2012)^[8]. Furthermore, ascorbic acid (Vitamin C) is utilized for stress reduction and immune support, as it has been shown to reduce direct and indirect oxidative stress in porcine intestinal cell models (Vergauwen *et al.*, 2015; Zheng *et al.*, 2021)^[12, 13]. Current advancements in precision nutrition aim to provide updated recommendations based on real-world field pressures rather than traditional static standards (Pomar and Remus, 2019)^[9]. Modern challenges such as environmental heat stress increase the animal's metabolic requirements for antioxidant vitamins, necessitating adjustments in supplementation to maintain efficiency (NRC, 2012; Koley *et al.*, 2023)^[8, 6]. Additionally, feed processing technologies must be carefully managed to ensure vitamin retention and stability against heat and oxidation during pelleting (Lewis *et al.*, 2015a; Rojas and Stein, 2015)^[7, 11]. Ultimately, precision delivery allows producers to fine-tune vitamin intake to meet the specific requirements of individual animals, reducing environmental waste while maximizing herd productivity (Pomar and Remus, 2019; Koley *et al.*, 2023)^[9, 6].

Relevance to the Indian Swine Sector

The Indian swine industry is transitioning toward high-performance production systems while facing unique local challenges (Koley *et al.*, 2023)^[6]. Feed costs constitute 65–75% of total input costs in India, making the adoption of modern nutritional concepts an economic imperative (Koley *et al.*, 2023)^[6]. One of the most significant hurdles is the continued reliance on traditional standards like BIS (1986), which may not adequately reflect the metabolic needs of the modern, hyper-prolific genotypes now being introduced into the country (Koley *et al.*, 2023)^[6]. Integrating precision pig feeding is identified as an essential means to augment competitiveness and sustainability in India (Koley *et al.*, 2023)^[6]. By supplying daily customized diets to individual animals, Indian farmers can notably decrease the environmental load and reduce feed costs (Koley *et al.*, 2023; Pomar and Remus, 2019)^[6, 9]. This is particularly relevant given India's concerns regarding nitrate pollution of aquifers and surface water eutrophication from pig manure (Koley *et al.*, 2023; Pomar and Remus, 2019)^[6, 9].

Furthermore, the move toward low-protein, amino-acid-supplemented diets offers a path to reducing nitrogen excretion (Koley *et al.*, 2023; Johannsen *et al.*, 2024) ^[6, 5]. India's tropical climate also necessitates a specialized focus on mitigating heat stress (DSM-Firmenich, 2025). Seasonal temperature spikes increase oxidative stress, making the integration of precision vitamin nutrition—specifically higher levels of Vitamins A, C, and E—essential for maintaining productivity. Additionally, given the high cost of energy, adopting advanced feed processing technologies and exogenous enzymesis critical for maximizing nutrient bioavailability from locally available feedstuffs (Rojas and Stein, 2015; Zheng *et al.*, 2021) ^[11, 13]. By bridging global modern concepts with the local production context, the Indian swine industry can ensure a future that is both economically profitable and environmentally responsible (Koley *et al.*, 2023) ^[6].

Conclusion

The evolution of swine nutrition toward modern, data-driven paradigms is essential to meet the complex metabolic demands of today's high-productivity genotypes. Precision pig feeding represents a breakthrough for sustainability, providing a system that delivers individualized nutrition to reduce feed costs and decrease nitrogen and phosphorus excretion by over 38%. For India, where feed represents the primary production cost (65–75%), adopting these strategies alongside low-protein, crystalline amino-acid-supplemented diets is an economic and environmental imperative to mitigate nitrate pollution and enhance industry competitiveness. Simultaneously, the specialized management of hyper-prolific sows and the mitigation of weaning-associated intestinal disorders through functional additives are critical for maintaining animal welfare and productivity. By integrating advanced feed processing technologies to optimize particle size and precision vitamin nutrition to combat environmental stressors like heat stress, the industry can further maximize nutrient bioavailability. Ultimately, transitioning from traditional standards, such as BIS (1986), toward these global concepts will provide the Indian swine sector with a comprehensive roadmap for a sustainable, efficient, and profitable future.

References

1. Bureau of Indian Standards. Nutrient requirements of livestock and poultry. New Delhi: Bureau of Indian Standards; 1986.
2. Feyera T, Højgaard CK, Vinther J, Bruun TS, Theil PK. Dietary lysine requirements of modern hyper-prolific sows during late gestation. *Journal of Animal Science*. 2021;99(4):skab077.
3. Gaillard C, Gauthier R, Khamis M, Weary DM, *et al.* Precision livestock farming technologies for swine production: A review. *Animal Frontiers*. 2020;10(2):6-15.
4. Hampson DJ. Alterations in piglet small intestinal structure at weaning. *Research in Veterinary Science*. 1986;40:32-40.
5. Johannsen M, Feyera T, Bruun TS, Theil PK. Standardized ileal digestible lysine requirement of modern hyper-prolific sows during late gestation. *Journal of Animal Science*. 2024;102:skae019.
6. Koley D, Singh AK, Roy B, Bhatt RS. Precision pig feeding: Current status, opportunities and challenges in India. *Indian Journal of Animal Nutrition*. 2023;40(3):235-247.
7. Lewis AJ, Southern LL, Baker DH. Vitamin nutrition and stability during feed processing. In: Lewis AJ, Southern LL, editors. *Swine nutrition*. 2nd ed. Boca Raton (FL): CRC Press; 2015.
8. National Research Council. Nutrient requirements of swine. 11th rev. ed. Washington (DC): National Academies Press; 2012.
9. Pomar C, Remus A. Precision pig feeding: A breakthrough toward sustainability. *Animal Frontiers*. 2019;9(2):52-59.
10. Pomar C, Pomar J, Dubeau F, Joannopoulos E, Dussault JP. The impact of precision feeding on nitrogen and phosphorus excretion in growing pigs. *Animal*. 2009;3:145-153.
11. Rojas OJ, Stein HH. Processing of ingredients and diets and effects on nutritional value for pigs. *Journal of Animal Science and Biotechnology*. 2015;6:48.
12. Vergauwen H, Degroote J, Van Ginneken C, Michiels J. Effects of vitamin C on oxidative stress and intestinal epithelial function in pigs. *Veterinary Research*. 2015;46:50.
13. Zheng L, Duarte ME, Loftus AS, Kim SW, *et al.* Nutritional strategies to improve intestinal health during the weaning transition in pigs. *Animals (Basel)*. 2021;11:2836.