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Economic Impact and Management Strategies for Post-Weaning Diarrhea in Piglets: A Comprehensive Review

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Abstract: Contemporary swine production systems impose a critical developmental challenge through abrupt weaning at 21-35 days postpartum, triggering multidimensional stress axes that converge on gastrointestinal dysbiosis and neuroendocrine disruption. This ontogenic shock manifests as enterocyte apoptosis, tight junction protein degradation and pancreatic zymogen deletion, elevating preharvest mortality while inflating antimicrobial expenditures. Economic imperatives are driving innovation in microbial ecosystem engineering, with advanced interventions targeting hologenome optimization through two-phase nutritional. Strategies such as cross-breeding, energy supplements and liquid/dry creep feeding aim to promote intestinal maturation, immune and microbiota resilience. While feed additives such as probiotics, organic acids show promise, their variable efficacy and upfront costs necessitate tailored, context-specific combinations. For instance, hybrid breeding programs may reduce long-term health expenditures, whereas precision-formulated additives improved feed efficiency, lowering production costs per unit gain. Balancing immediate investment with long-term profitability remains critical, particularly as market demands for antibiotic-free pork incentivize sustainable, economically viable solutions.

1. Introduction

The strategic implementation of early weaning protocols (2.5-4 weeks postpartum) in modern intensive swine operation has emerged as a pivotal approach for optimizing annual farrowing cycles and mitigating vertical pathogen transmission. This biosecurity-oriented paradigm enhances sow throughput through accelerate productive turnover [1,2], while simultaneously enabling real-time growth surveillance and precision nutrient supplementation via automated monitoring systems [3]. Nevertheless, the abrupt termination of lactation induces a multisystem stress syndrome characterized by neuroendocrine dysregulation and gut barrier compromise. Clinically manifested through transient anorexia, growth check phenomena, and enteric disturbances [4], this transitional crisis imposes

substantial economic burdens: post-weaning diarrhea elevates neonatal mortality rates within critical adaptation phases [5,6], and extended finishing period (7-14 days) amplify feed-to-gain ratios and therapeutic expenditures [7].

The historical reliance on prophylactic chemotherapeutics in swine production has created dual challenges of antimicrobial residues and resistance gene reservoirs, posing transnational threats to food safety ecosystems. Global pharmacovigilance milestones-including the Europe's 2006 ban on antimicrobial growth promoters [8], China's 2020 total feed antibiotic prohibition, and the 2022, Europe restriction on high-dose zine oxide in post-weaning diets [9] - have catalyzed paradigm shifts toward precision gut health management. Contemporary solutions bifurcate into bioactive and husbandry innovations.

2. Risks of weaning stress

2.1. Damage to the morphological structure of the gut

The gastrointestinal tract serves as the principal interface for nutrient assimilation and xenobiotic exclusion, maintaining selective permeability through intricate structural and functional homeostasis [10]. Morphometric indices including villous architecture and crypt-to-villus proportionality directly correlate with enteric absorptive efficiency and barrier competency. Contemporary gastroenterological research confirms that abrupt weaning induces pathomorphological alterations, characterized by villous atrophy, crypt hyperplasia, and compromised mucosal integrity, that collectively impair nutrient partitioning and immunological surveillance. Empirical evidence demonstrates that premature dietary transition precipitates multifactorial intestinal compromise in swine, manifesting as crypt-villus axis dysregulation, relative decrease in intestinal mass, and impaired mucin biosynthesis [11]. Such structural derangements disrupt enteroendocrine signaling pathways while facilitating paracellular leakage of luminal antigens. Consequently, strategic mitigation of weaning-induced enteropathy requires targeted preservation of intestinal ultrastructure, particularly through interventions stabilizing crypt progenitor cell kinetics and preserving brush border enzyme functionality, to optimize swine production outcomes.

2.2. Inhibition of intestinal digestive enzyme secretion

The enzymatic machinery governing nutrient hydrolysis constitutes a pivotal determinant of xenobiotic metabolism and growth regulation in swine, with luminal hydrolase activity directly modulating feed conversion efficiency through substrate-specific catalytic cascades [12]. Intestinal absorptive epithelia, differentiated through crypt-villus axis morphogenesis, synthesize a spectrum of brush border enzymes (disaccharidases, oligopeptides, alkaline phosphatases) essential for macromolecular degradation. Neonatal porcine development features dynamic upregulation of these enzymatic systems, where lactase and aminopeptidase-N activity peak during the third postnatal week under optimal nursing conditions. Abrupt dietary transition disrupts this developmental trajectory: comparative enzymology studies reveal the reductions in maltase-glucoamylase complex activity and pancreatic lipase secretion within 72 hours post-weaning [13]. The resultant luminal carbohydrate maldigestion precipitates osmotic diarrheal cascades through colonic accumulation of undegraded disaccharides, while parallel deficits in proteolytic processing exacerbate intestinal inflammation via oligopeptide-mediated TLR4 activation. Such pathophysiological intersections underscore the criticality of preserving enteroendocrine enzyme homeostasis during dietary transitions, particularly through nutritional strategies stabilizing brush border enzyme gene expression and enterochromaffin cell signaling networks.

2.3. Disruption of the integrity of the intestinal barrier function

The enteric barrier system, a dynamic interface mediating nutrient assimilation and xenobiotic exclusion, operates through coordinated structural and functional synergy among mucosal epithelia, glycocalyx matrices, immunocompetent cells, and microbial consortia with their metabolic byproducts [14]. This multilayered defense architecture, comprising mechanical, biochemical, immunological, and ecological components, maintains intestinal homeostasis via regulated paracellular permeability and pathogen surveillance [10]. Weaning stress induces pathophysiological disintegration of these barrier systems: paracellular junctional complexes (ZO-1, occludin) undergo proteasomal degradation [15]. Changes in mucin sulfation patterns may compromise glycocalyx integrity, thereby elevating translocation risks for endotoxins and enteropathogens [16]. The resultant microbial dysbiosis manifests as ecological succession failure, in which indigestible nutrients promote the proliferation of *Enterobacteriaceae* bacteria [17]. Such multi-layered barrier dysfunction precipitates a gut leaky syndrome, which is marked by crypt hyperplasia, goblet cell metaplasia and microbial translocation ultimately driving enteropathy-associated growth faltering.

3. Strategies to improve weaning stress diarrhea

3.1. Management strategies

Progressive weaning methodologies have evolved to address abrupt separation stressors. Sow-controlled housing systems permit matrilineal separation dynamics, where dams voluntarily reduce nursing contact through access to communal sow areas while piglets remain confined. This replicates natural weaning behaviors, with sows progressively decreasing farrowing pen occupancy during late lactation. Complementary nutritional transition strategies incorporate intermittent suckling regimens coupled with supplemental feeding systems, including dry creep feeds and liquid milk replacers, to stimulate dietary exploration while maintaining standard weaning timelines.

3.2. Nutritional strategies

Dietary components and their bioactive metabolites exert profound modulatory effects on gut microbial ecology and intestinal barrier function through both direct and indirect mechanisms. Extensive research has explored diverse nutritional interventions, which include adjustments in feed composition or its levels such as protein levels and sources, soluble/insoluble fiber and fat composition, incorporation of feed additives such as probiotics, prebiotics, enzymes, antimicrobial peptides, organic acids, plant extracts, and amino acids, and variations in feed form such as liquids, dry, roughage, fines, pellets, and meal. Other less researched but promising strategies include vaccines, phage treatment (phage therapy) and antibodies [18].

3.2.1. Establishment of a strong gut microbiota

For weaned piglets, gut flora is one of the key regulators for maintaining healthy growth and development. Prior to weaning, the maternal and environmental microbiota shape the gut flora of the piglet in a gradual process. Diarrhetic and non-diarrhetic piglets at weaning have different composition, homogeneity and diversity of fecal microbiota prior to weaning [19], suggesting that the composition of the microbiota prior to weaning influences susceptibility to weaning stress. Therefore, the emerging paradigm of microbial ecosystem engineering offers revolutionary strategies to mitigate post-weaning diarrheal syndromes through targeted manipulation of the hologenome—the interdependent genetic landscape encompassing host and microbiota. One approach involves supplementing sow diets with microbiota-modulating compounds, which vertically transfer to

offspring through both the birth canal and postnatal environment [20]. Alternatively, direct supplementation of weaned piglet diets with microbial regulators—including probiotics, prebiotics, and synbiotics—has demonstrated efficacy in mitigating intestinal inflammation and enhancing growth performance. Current commercial swine probiotics primarily consist of bacterial genera such as *Bacillus*, *Bifidobacterium*, *Clostridium* and *Lactobacillus*, along with fungal species like *Saccharomyces cerevisiae* [21,22].

3.2.2. Accelerating intestinal maturation

The dietary transition from milk to solid feed represents one of the most significant physiological challenges during weaning, often coinciding with periods of reduced feed consumption. To facilitate this shift, creep feeding, typically utilizing dry formulations, is employed both to acclimate piglets to solid feed and to supplement nutritional intake for those with limited nursing access. Critical modifications in post-weaning diets involve precise adjustments to protein and energy content. Reduced protein levels demonstrate a dual effect: while potentially limiting growth metrics, they decrease production of enterotoxic metabolites like ammonia, thereby supporting intestinal health [23,24]. It has been found that a reduction in feed protein level from 23% to 17%-19% may affect growth performance of piglets, but the piglets' intestines may remain healthy due to lower production of toxic metabolites such as ammonia. The addition of arginine to low protein diets is beneficial in promoting intestinal development in piglets. Moreover, it was found that the adjustment of energy level in feed also has an effect on the growth performance and nutrient digestibility of piglets, and the antinutritional factors in soya bean meal may affect the digestion, absorption and utilization of the piglets' intestines, but fresh fermented soya bean meal may promote intestinal morphology development of weaned piglets, and improve intestinal function and thus reduce the rate of diarrhea [25].

3.2.3. Improvement of immune function

A major determinant of weaning stress diarrhea risk is the host's immune competence. Post-weaning anorexia-induced nutritional stress has been identified as a primary contributor to localized intestinal inflammation, largely due to its effects on gut morphology [26]. Notably, most interventions influence host immunity either directly or indirectly. For instance, rosemary extract supplementation in weaned piglets has been shown to elevate serum immunoglobulin levels, suppress inflammatory pathways triggered by weaning, and enhance immune activity [27]. Amino acids play a vital role in intestinal immunity and barrier function. Glutamine, threonine, arginine, methionine, and cysteine may alleviate weaning stress by enhancing intestinal immune responses, antioxidant capacity, and anti-inflammatory activity. Tryptophan further contributes to immune regulation beyond its role in appetite control [28]. Thus, one or more additives/strategies can exert their role through multiple modes of operation, depending on the gut ecosystem present throughout the individual hosts at the time of administration.

4. Conclusion

Over recent decades, the multifactorial etiology of post-weaning diarrhea in piglets have been continuously explored, with primary causative factors encompassing environmental stressors, psychological disturbances, nutritional imbalance. The growing recognition of the detrimental consequences associated with weaning stress-induced diarrhea has spurred the development of diverse mitigation strategies in swine production systems. Historically, efforts concentrated on antibiotic reduction protocols; however, contemporary research has shifted toward sustainable alternatives, including dietary modifications such as protein and energy optimization and functional

additives including phytogenic compounds and probiotic supplementation, which demonstrate measurable efficacy in enhancing gastrointestinal health. From an economic and operational management perspective, the selection and integrations must be tailored to farm-specific conditions to maximize cost-benefit rations and production efficiency. Strategic implementation requires rigorous cost-effectiveness analyses. Future innovation should prioritize the development of novel, evidence-based additives and management frameworks that concurrently address animal welfare, economic viability, and environmental sustainability, thereby aligning with global agendas for one health and circular bioeconomy principles.

References

[1] Han, X.; Hu, X.; Jin, W.; Liu, G. Dietary nutrition, intestinal microbiota dysbiosis and post-weaning diarrhea in piglets. Anim Nutr, 2024, 17, 188-207, doi:10.1016/j.aninu.2023.12.010.

[2] Leal, D.F.; de Paula, Y.H.; de Sousa Faria, C.B.; GAM, E.C.; Tavares, I.C.; de Souza Cantarelli, V. The effect of different weaning strategies on piglet growth, feed intake and gut health. Trop Anim Health Prod, 2024, 56, 279, doi:10.1007/s11250-024-04118-4.

[3] Fardisi, M.; Thelen, K.; Groenendal, A.; Rajput, M.; Sebastian, K.; Contreras, G.A.; Moeser, A.J. Early weaning and biological sex shape long-term immune and metabolic responses in pigs. Sci Rep, 2023, 13, 15907, doi:10.1038/s41598-023-42553-9.

[4] Zhang, Y.; Wang, S.; Hei, M.Y. Maternal separation as early-life stress: Mechanisms of neuropsychiatric disorders and inspiration for neonatal care. Brain Res Bull, 2024, 217, doi:10.1016/j.brainresbull.2024.111058.

[5] Tang, Q.; Lan, T.; Zhou, C.; Gao, J.; Wu, L.; Wei, H.; Li, W.; Tang, Z.; Tang, W.; Diao, H., et al. Nutrition strategies to control post-weaning diarrhea of piglets: From the perspective of feeds. Anim Nutr, 2024, 17, 297-311, doi:10.1016/j.aninu.2024.03.006.

[6] Renzhammer, R.; Vetter, S.; Dolezal, M.; Schwarz, L.; Kasbohrer, A.; Ladinig, A. Correction: Risk factors associated with post-weaning diarrhoea in Austrian piglet-producing farms. Porcine Health Manag, 2023, 9, 27, doi:10.1186/s40813-023-00322-0.

[7] Vangroenweghe, F.; Poulsen, K.; Thas, O. Supplementation of a beta-mannanase enzyme reduces post-weaning diarrhea and antibiotic use in piglets on an alternative diet with additional soybean meal. Porcine Health Manag, 2021, 7, 8, doi:10.1186/s40813-021-00191-5.

[8] Vondruskova, H.; Slamova, R.; Trckova, M.; Zraly, Z.; Pavlik, I. Alternatives to antibiotic growth promoters in prevention of diarrhoea in weaned piglets: a review. Vet Med-Czech, 2010, 55, 199-224, doi:10.17221/2998-Vetmed.

[9] Long, L.N.; Chen, J.S.; Zhang, Y.G.; Liang, X.; Ni, H.J.; Zhang, B.; Yin, Y.L. Comparison of porous and nano zinc oxide for replacing high-dose dietary regular zinc oxide in weaning piglets. Plos One, 2017, 12, doi:ARTN e0182550 10.1371/journal.pone.0182550.

[10] Chelakkot, C.; Ghim, J.; Ryu, S.H. Mechanisms regulating intestinal barrier integrity and its pathological implications. Exp Mol Med, 2018, 50, 1-9, doi:10.1038/s12276-018-0126-x.

[11] Bomba, L.; Minuti, A.; Moisa, S.J.; Trevisi, E.; Eufemi, E.; Lizier, M.; Chegdani, F.; Lucchini, F.; Rzepus, M.; Prandini, A., et al. Gut response induced by weaning in piglet features marked changes in immune and inflammatory response. Funct Integr Genomics, 2014, 14, 657-671, doi:10.1007/s10142-014-0396-x.

[12] Xiong, X.; Tan, B.; Song, M.; Ji, P.; Kim, K.; Yin, Y.; Liu, Y. Nutritional Intervention for the Intestinal Development and Health of Weaned Pigs. Front Vet Sci, 2019, 6, 46, doi:10.3389/fvets.2019.00046.

[13] Siracusa, F.; Schaltenberg, N.; Kumar, Y.; Lesker, T.R.; Steglich, B.; Liwinski, T.; Cortesi, F.; Frommann, L.; Diercks, B.P.; Bönisch, F., et al. Short-term dietary changes can result in mucosal and systemic immune depression. Nat Immunol, 2023, 24, 1473-+, doi:10.1038/s41590-023-01587-x.

[14] Thoo, L.; Noti, M.; Krebs, P. Keep calm: the intestinal barrier at the interface of peace and war. Cell Death Dis, 2019, 10, doi:ARTN 849 10.1038/s41419-019-2086-z.

[15] Xu, Q.; Jian, H.; Zhao, W.; Li, J.; Zou, X.; Dong, X. Early Weaning Stress Induces Intestinal Microbiota Disturbance, Mucosal Barrier Dysfunction and Inflammation Response Activation in Pigeon Squabs. Front Microbiol, 2022, 13, 877866, doi:10.3389/fmicb.2022.877866.

[16] Birchenough, G.M.; Johansson, M.E.; Gustafsson, J.K.; Bergstrom, J.H.; Hansson, G.C. New developments in goblet cell mucus secretion and function. Mucosal Immunol, 2015, 8, 712-719, doi:10.1038/mi.2015.32.

[17] Uddin, M.K.; Mahmud, M.R.; Hasan, S.; Peltoniemi, O.; Oliviero, C. Dietary micro-fibrillated cellulose improves growth, reduces diarrhea, modulates gut microbiota, and increases butyrate production in post-weaning piglets. Sci Rep, 2023, 13, 6194, doi:10.1038/s41598-023-33291-z.

[18] Ghosh, S.; Whitley, C.S.; Haribabu, B.; Jala, V.R. Regulation of Intestinal Barrier Function by Microbial

Metabolites. Cell Mol Gastroenterol Hepatol, 2021, 11, 1463-1482, doi:10.1016/j.jcmgh.2021.02.007.
[19] Garcias, B.; Migura-Garcia, L.; Giler, N.; Mart ń, M.; Darwich, L. Differences in enteric pathogens and intestinal microbiota between diarrheic weaned piglets and healthy penmates. Vet Microbiol, 2024, 295, doi:10.1016/j. vetmic. 2024. 110162.
[20] Poulsen, A.R.; Jonge, N.; Nielsen, J.L.; Hojberg, O.; Lauridsen, C.; Cutting, S.M.; Canibe, N. Impact of Bacillus spp. spores and gentamicin on the gastrointestinal microbiota of suckling and newly weaned piglets. Plos One, 2018, 13, e0207382, doi:10.1371/journal.pone.0207382.
[21] Bekebrede, A.F.; Keijer, J.; Gerrits, W.J.J.; Boer, V.C.J. The Molecular and Physiological Effects of Protein-Derived Polyamines in the Intestine. Nutrients, 2020, 12, doi:10.3390/nu12010197.
[22] Wang, J.; Ji, H. Influence of Probiotics on Dietary Protein Digestion and Utilization in the Gastrointestinal Tract. Curr Protein Pept Sci, 2019, 20, 125-131, doi:10.2174/1389203719666180517100339.
[23] Chen, X.; Song, P.; Fan, P.; He, T.; Jacobs, D.; Levesque, C.L.; Johnston, L.J.; Ji, L.; Ma, N.; Chen, Y., et al. Moderate Dietary Protein Restriction Optimized Gut Microbiota and Mucosal Barrier in Growing Pig Model. Front Cell Infect Microbiol, 2018, 8, 246, doi:10.3389/fcimb.2018.00246.
[24] Ren, Z.; Fan, H.; Deng, H.; Yao, S.; Jia, G.; Zuo, Z.; Hu, Y.; Shen, L.; Ma, X.; Zhong, Z., et al. Effects of dietary protein level on small intestinal morphology, occludin protein, and bacterial diversity in weaned piglets. Food Sci Nutr, 2022, 10, 2168-2201, doi:10.1002/fsn3.2828.
[25] Muniyappan, M.; Shanmugam, S.; Park, J.H.; Han, K.; Kim, I.H. Effects of fermented soybean meal supplementation on the growth performance and apparent total tract digestibility by modulating the gut microbiome of weaned piglets. Sci Rep, 2023, 13, 3691, doi:10.1038/s41598-023-30698-6.
[26] Cao, S.; Hou, L.; Sun, L.; Gao, J.; Gao, K.; Yang, X.; Jiang, Z.; Wang, L. Intestinal morphology and immune profiles are altered in piglets by early-weaning. Int Immunopharmacol, 2022, 105, 108520, doi:10.1016/j.intimp.2022.108520.
[27] Yang, M.; Yin, Y.; Wang, F.; Bao, X.; Long, L.; Tan, B.; Yin, Y.; Chen, J. Effects of dietary rosemary extract supplementation on growth performance, nutrient digestibility, antioxidant capacity, intestinal morphology, and microbiota of weaning pigs. J Anim Sci, 2021, 99, doi:10.1093/jas/skab237.
[28] Li, Q.; Tan, D.; Xiong, S.; Yu, K.; Su, Y.; Zhu, W. Time-restricted feeding promotes glucagon-like peptide-1 secretion and regulates appetite via tryptophan metabolism of gut Lactobacillus in pigs. Gut Microbes, 2025, 17, 2467185, doi:10. 1080/19490976.2025.2467185.