

REVIEW PAPER

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Optimizing sow nutrition and physiological condition to enhance reproductive performance, piglet development, and productivity: Current advances and future perspectives

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ABSTRACT

Modern swine production has undergone remarkable genetic improvement, resulting in increased litter sizes and enhanced production efficiency. However, these advances have also imposed greater nutritional and physiological demands on breeding sows, making maternal nutritional management increasingly important for sustaining reproductive performance, piglet survival, and sow longevity. This review synthesizes current evidence on the relationships among sow physiological condition, nutritional management during gestation and lactation, and subsequent reproductive and productive outcomes. Particular emphasis is placed on body condition score (BCS) and backfat thickness as practical indicators of maternal energy reserves that influence fetal development, mammary gland function, milk production, reproductive recovery, and piglet growth. Nutritional strategies, including stage-specific feeding during gestation, increased feed allowance during late pregnancy, optimized lactation feeding programs, and precision feeding approaches, are discussed in relation to their effects on sow metabolism, reproductive efficiency, piglet birth weight, weaning performance, and overall production sustainability. Emerging advances in precision livestock farming, including automated feeding systems, sensor technologies, and real-time physiological monitoring, are also examined as promising tools for individualized nutritional management and improved production efficiency. Although considerable progress has been achieved, inconsistencies remain regarding the optimal nutritional management of sows across different parities, genetic lines, and production systems. Future research should integrate precision nutrition, physiological biomarkers, and smart farming technologies to develop adaptive feeding strategies that improve reproductive efficiency, enhance piglet lifetime performance, and promote sustainable swine production. Collectively, the available evidence highlights that maintaining optimal maternal physiological condition through targeted nutritional management is fundamental to maximizing sow productivity, improving piglets weaned per sow per year, and supporting the long-term sustainability of modern pork production.

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INTRODUCTION

Swine production is one of the most important sectors of global livestock agriculture, providing a major source of high-quality animal protein for a growing human population. Pork accounts for approximately one-third of global meat consumption and continues to play a critical role in ensuring food security, particularly in Asia and Europe (Kim *et al.*, 2024; OECD, 2023). Continued population growth, urbanization, and rising household incomes are expected to further increase pork demand over the coming decades, placing additional pressure on the swine industry to improve production efficiency while maintaining high standards of animal health, welfare, and environmental sustainability. Consequently, enhancing reproductive efficiency has become a major priority because increasing the number of healthy piglets weaned per sow per year (PSY) remains one of the most effective approaches for improving productivity and economic returns without proportionally increasing herd size (Bell *et al.*, 2015; Guan *et al.*, 2022).

Recent genetic selection has substantially increased litter size and lean growth potential in commercial sow populations. While these improvements have enhanced production capacity, they have also increased the metabolic demands associated with pregnancy and lactation. Modern hyperprolific sows frequently experience negative energy balance during late gestation and lactation as nutrient requirements for fetal growth, mammary development, and milk synthesis exceed voluntary feed intake (Kim *et al.*, 2015). Consequently, excessive mobilization of maternal body reserves can impair reproductive performance by reducing milk production, delaying the return to estrus, compromising subsequent fertility, and shortening productive lifespan (Clowes *et al.*, 2003; Maes *et al.*, 2004). Therefore, maintaining optimal physiological condition throughout the reproductive cycle has become increasingly important for supporting both maternal productivity and offspring performance.

Among the practical indicators of sow physiological status, body condition score (BCS) and backfat thickness are widely used to evaluate maternal energy

reserves and guide nutritional management. Numerous studies have demonstrated that both inadequate and excessive body condition negatively influence reproductive outcomes, piglet birth weight, farrowing performance, and lactational productivity (Lavery *et al.*, 2019; Mun *et al.*, 2023; Roongsitthichai and Tummaruk, 2014). Likewise, nutritional management throughout gestation and lactation—including feed allowance, feeding frequency, dietary nutrient composition, and precision feeding strategies—plays a central role in regulating fetal development, colostrum production, milk yield, piglet growth, and sow welfare (Ampode *et al.*, 2023; Gonçalves *et al.*, 2016; Pouloupoulou *et al.*, 2018; Wu *et al.*, 2020). As precision livestock farming technologies continue to advance, opportunities are emerging to develop individualized nutritional programs that improve productivity while supporting animal welfare and resource-use efficiency.

Hence, this review aims to synthesize current knowledge regarding the interactions between maternal nutrition, physiological condition, and reproductive performance in modern sows. Specifically, it examines the roles of body condition score and backfat thickness as indicators of maternal physiological status, evaluates nutritional strategies during gestation and lactation, discusses their implications for piglet development and lifetime productivity, and explores the application of precision feeding and smart farming technologies in reproductive management. Finally, current knowledge gaps and future research priorities are identified to support the development of sustainable, evidence-based nutritional strategies for modern swine production.

LITERATURE SEARCH STRATEGY

This review was conducted as a narrative synthesis of published scientific literature focusing on the relationships among sow nutrition, physiological condition, reproductive performance, piglet development, and emerging precision feeding technologies. Relevant peer-reviewed articles were identified through comprehensive searches of

electronic databases, including Web of Science, Scopus, PubMed, ScienceDirect, and Google Scholar. Searches included studies published primarily between 2000 and 2025, while seminal earlier publications were incorporated when they provided foundational knowledge regarding sow physiology, nutritional management, or reproductive biology.

The literature search employed combinations of the following keywords: sow nutrition, gestation feeding, lactation feeding, body condition score, backfat thickness, reproductive performance, piglets weaned per sow per year, piglet birth weight, milk production, precision feeding, precision livestock farming, smart farming, animal welfare, and swine reproduction.

Additional references were identified through manual screening of the bibliographies of relevant review articles and original research papers to ensure comprehensive coverage of the topic.

Priority was given to peer-reviewed experimental studies, systematic reviews, meta-analyses, and authoritative review articles published in international journals. Studies were selected based on their relevance to maternal nutritional management, physiological indicators, reproductive performance, piglet growth, and technological innovations in swine production. Where appropriate, findings from multiple studies were critically compared and synthesized to identify areas of consensus, inconsistencies among experimental results, and remaining knowledge gaps. Emphasis was placed on integrating physiological mechanisms with practical nutritional management strategies to provide a comprehensive overview of current advances and future perspectives in sow nutrition and reproductive efficiency.

PHYSIOLOGICAL CONDITION OF SOWS

The physiological condition of breeding sows is a major determinant of reproductive efficiency, lifetime productivity, and piglet performance (Table 1).

Table 1. Physiological condition of sows and their effects on reproductive performance

Physiological indicator	Optimal condition	Deficient condition	Excessive condition	Major reproductive consequences	Key references
Body condition score (BCS)	Supports fetal growth, mammary development, and reproductive recovery	Poor follicular development, prolonged WEL, reduced fertility	Increased farrowing difficulty, reduced feed intake, and excessive postpartum weight loss	Reduced reproductive efficiency and sow longevity	Filha <i>et al.</i> , 2010; Lavery <i>et al.</i> , 2019; Kim <i>et al.</i> , 2015
Backfat thickness	Adequate energy reserves for gestation and lactation	Greater body reserve mobilization, reduced milk yield, and poorer piglet growth	Dystocia, lower lactation feed intake, metabolic stress	Lower reproductive performance and piglet survival	Roongsitthichai and Tummaruk, 2014; Mun <i>et al.</i> , 2023
Maternal Energy balance	Maintains reproductive hormones and milk production	Negative energy balance delays estrus and conception	—	Reduced fertility and shortened productive lifespan	Clowes <i>et al.</i> , 2003; Maes <i>et al.</i> , 2004

Modern hyperprolific sows have greater metabolic demands because of increased litter sizes and milk production, making the maintenance of optimal body condition throughout gestation and lactation essential for supporting fetal development, lactation, and reproductive recovery. Inadequate nutrient intake or excessive mobilization of maternal body reserves during these stages can impair reproductive performance and prolong recovery before the next breeding cycle (Kim *et al.*, 2015; Mun *et al.*, 2023).

Body condition score (BCS) and backfat thickness are widely used to estimate maternal energy reserves and guide nutritional management. Maintaining optimal

body condition supports fetal growth, mammary development, and subsequent fertility, whereas both insufficient and excessive body reserves negatively affect reproductive performance, feed intake, and sow longevity (Filha *et al.*, 2010; Kim *et al.*, 2015; Lavery *et al.*, 2019; Oliviero *et al.*, 2010; Roongsitthichai and Tummaruk, 2014). During late gestation and lactation, excessive depletion of body fat and protein reserves may reduce milk production, delay estrus, and compromise fertility (Clowes *et al.*, 2003; Maes *et al.*, 2004; Serenius *et al.*, 2006).

Maternal physiological condition also directly influences piglet performance. Adequate energy

reserves enhance fetal growth, colostrum and milk production, and litter uniformity, contributing to higher piglet birth weights and improved pre-weaning survival (Mun *et al.*, 2023; Thongkhuy *et al.*, 2020). The major physiological indicators and their effects on reproductive performance are summarized in Table 1.

IMPORTANCE OF BACKFAT THICKNESS

Backfat thickness is one of the most reliable indicators of maternal energy reserves and has

become an essential management tool for evaluating sow nutritional status and reproductive potential (Fig. 1). Composed primarily of lipid tissue, collagen, and water, backfat serves as a reservoir of energy that supports fetal growth, mammary gland development, lactation, and the restoration of reproductive function after weaning (Cerisuelo *et al.*, 2008; Roongsittichai and Tummaruk, 2014). Because energy requirements increase markedly during late gestation and early lactation, maintaining appropriate backfat reserves is fundamental to sustaining reproductive performance.

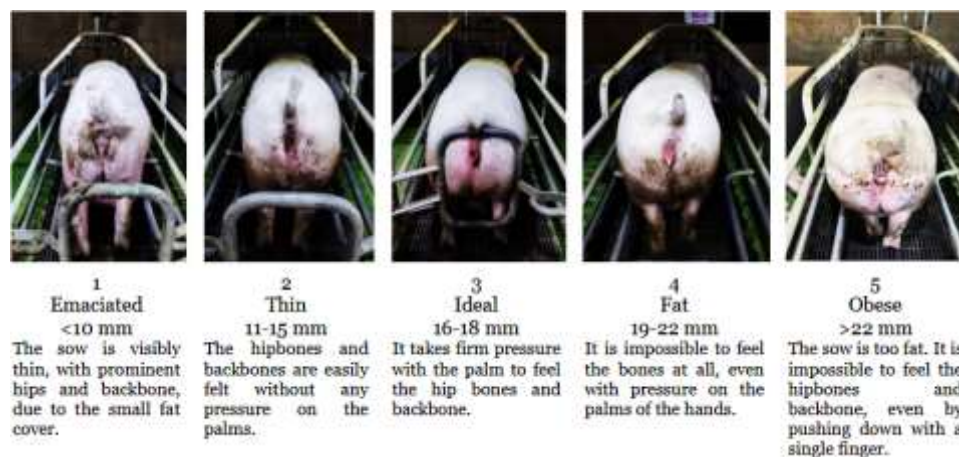


Fig. 1. Body condition scores of sows; images by Ampode, KMB

Numerous studies have reported significant associations between backfat thickness and reproductive outcomes. Sows with inadequate backfat reserves often experience greater mobilization of body tissues during lactation, resulting in prolonged WEI, reduced pregnancy rates, impaired ovarian activity, and lower lifetime productivity (Clowes *et al.*, 2003; Maes *et al.*, 2004; Mun *et al.*, 2023). Moreover, reduced backfat thickness has been linked to lower milk yield, poorer piglet growth, and increased pre-weaning mortality because insufficient maternal energy reserves limit nutrient transfer to offspring (Thongkhuy *et al.*, 2020).

Conversely, excessive backfat accumulation is not necessarily advantageous. Over-conditioned sows frequently exhibit lower feed intake during lactation, greater postpartum body weight loss, and increased susceptibility to dystocia and other farrowing complications (Kim *et al.*, 2015; Oliviero *et al.*, 2010; Peltoniemi *et al.*, 2016). These findings indicate that

reproductive performance is optimized by maintaining an intermediate rather than maximal level of body fat. Appropriate backfat thickness supports both metabolic adaptation and reproductive recovery while minimizing the negative consequences associated with either excessive fat deposition or severe tissue depletion.

Backfat thickness also has considerable practical value in commercial swine production because it can be measured rapidly using ultrasonography and incorporated into precision feeding programs. Monitoring maternal body reserves throughout gestation allows producers to adjust nutrient supply according to physiological requirements, thereby improving reproductive efficiency while reducing unnecessary feed costs. Consequently, backfat thickness should be considered not only as a predictor of reproductive performance but also as a management tool for developing individualized nutritional strategies that maximize sow longevity and piglet productivity.

NUTRITIONAL MANAGEMENT DURING GESTATION

Gestation represents one of the most critical periods in the reproductive cycle because maternal nutrition directly influences embryo survival, placental development, fetal growth, mammary gland development, and the subsequent productivity of both sows and piglets. Nutrient requirements vary considerably throughout pregnancy; therefore, nutritional management should be adapted to the physiological priorities of each gestational stage rather than relying on a uniform feeding strategy (Boyd *et al.*, 2002; Johnston, 2010; Moehn *et al.*, 2009).

Early gestation

During early gestation, nutritional management primarily aims to restore maternal body reserves following lactation while supporting embryo implantation and survival. Excessive nutrient restriction during this period may impair embryonic development and increase embryonic mortality, whereas excessive energy intake may adversely influence embryo survival through alterations in the endocrine environment (Boyd *et al.*, 2002; Johnston, 2010). Consequently, maintaining an appropriate body condition during the first month of pregnancy is essential for maximizing litter size and reproductive success.

Mid gestation

The nutritional emphasis during mid gestation shifts toward maternal growth in young females and replenishment of body reserves depleted during previous lactation in multiparous sows. Adequate nutrient intake during this period supports placental development while preparing the sow for the substantial metabolic demands of late gestation and lactation (Boyd *et al.*, 2002; Moehn *et al.*, 2009). Failure to restore maternal reserves during mid gestation may increase tissue mobilization during lactation and compromise subsequent reproductive performance.

Late gestation

The final third of gestation is characterized by rapid fetal growth and accelerated mammary gland development, accounting for the greatest increase in

nutrient requirements throughout pregnancy. During this stage, nutritional strategies focus on improving piglet birth weight, litter uniformity, and mammary development while ensuring adequate maternal energy reserves for lactation (Goodband *et al.*, 2013; Johnston, 2010). Studies have demonstrated that increasing feed allowance during late gestation, commonly referred to as *bump feeding*, enhances piglet birth weight, milk production, and reproductive performance by providing sufficient nutrients during the period of greatest fetal demand (Ampode *et al.*, 2023; Choi *et al.*, 2019; Gonçalves *et al.*, 2016).

Beyond increasing feed allowance, strategic nutrient supplementation has also shown considerable promise. Functional amino acids such as L-carnitine and L-arginine have been reported to improve litter uniformity, neonatal thermoregulation, and fetal development through enhanced nutrient utilization and placental function (Moreira *et al.*, 2020; Ramanau *et al.*, 2008). Similarly, optimizing dietary lysine and energy concentrations during late gestation has been associated with improved piglet birth weight and enhanced sow reproductive performance under commercial production conditions (Gonçalves *et al.*, 2016).

Collectively, current evidence indicates that successful gestational nutrition depends not only on the quantity of feed provided but also on matching nutrient supply with physiological requirements throughout pregnancy. Stage-specific feeding strategies that maintain optimal maternal body condition while supporting fetal growth and mammary development are fundamental to improving reproductive efficiency, piglet viability, and overall production sustainability.

FEEDING STRATEGIES DURING LACTATION

Lactation is the most nutritionally demanding stage of the reproductive cycle because nutrient requirements for milk production, maintenance, and recovery of maternal body reserves often exceed voluntary feed intake. Consequently, modern hyperprolific sows commonly experience negative energy balance,

resulting in excessive mobilization of body fat and protein reserves that can reduce milk production, delay the weaning-to-estrus interval (WEI), impair subsequent fertility, and shorten productive lifespan (Kim *et al.*, 2015; Clowes *et al.*, 2003; Maes *et al.*, 2004). Therefore, nutritional management during lactation should aim to maximize nutrient intake while minimizing body reserve depletion to support both sow productivity and welfare.

Several nutritional and feeding management strategies have been developed to improve lactational performance (Table 2). Increasing voluntary feed intake, optimizing feeding frequency, implementing

ad libitum feeding when appropriately managed, and adopting precision feeding technologies have all been shown to improve nutrient utilization, reduce excessive body reserve mobilization, enhance milk production, and promote reproductive recovery (Cools *et al.*, 2014; Pouloupoulou *et al.*, 2018; Sulabo *et al.*, 2010; Thingnes *et al.*, 2012; Wu *et al.*, 2020; Gorr *et al.*, 2024). However, unrestricted feeding immediately after farrowing should be carefully managed because excessive feed intake during the early postpartum period may increase the risk of periparturient dysgalactia syndrome (PDS), adversely affecting sow health and piglet survival (Papadopoulos *et al.*, 2010).

Table 2. Feeding strategies during lactation and their effects

Feeding strategy	Physiological effect	Benefits to sow	Benefits to piglets	References
Increased voluntary feed intake	Reduces negative energy balance	Less body reserve mobilization; improved reproductive recovery	Higher milk production and weaning weight	Cools <i>et al.</i> , 2014; Strathe <i>et al.</i> , 2017
Increased feeding frequency	Improves nutrient utilization	Better BCS and shorter WEI	Improved growth performance	Pouloupoulou <i>et al.</i> , 2018; Wu <i>et al.</i> , 2020
<i>Ad libitum</i> feeding	Maximizes nutrient intake	Improved welfare and milk production	Increased piglet growth	Sulabo <i>et al.</i> , 2010; Thingnes <i>et al.</i> , 2012
Precision feeding	Individualized nutrient supply	Improved feed efficiency and productivity	Better litter performance	Gorr <i>et al.</i> , 2024

Recent advances in precision livestock farming have further improved lactation management through automated feeding systems and real-time monitoring of sow performance. These technologies enable individualized nutrient delivery according to parity, body condition, litter size, and environmental conditions, improving feed efficiency while supporting reproductive performance and animal welfare

MATERNAL NUTRITION AND PIGLET DEVELOPMENT

Maternal nutrition during gestation and lactation plays a fundamental role in determining piglet viability, growth performance, and lifetime productivity. The nutritional status of the sow influences fetal development, placental function, mammary gland development, colostrum production, and milk yield, all of which directly affect neonatal survival and postnatal growth. Consequently, optimizing maternal nutrient intake throughout the

reproductive cycle has become a central strategy for improving production efficiency in modern swine systems. Current evidence suggests that nutritional interventions targeting the physiological requirements of the sow not only enhance reproductive performance but also provide long-term benefits for offspring through improved prenatal and postnatal development (Boyd *et al.*, 2002; Johnston, 2010; Thongkhuy *et al.*, 2020).

MATERNAL NUTRITION AND FETAL GROWTH

Fetal development is highly dependent on adequate maternal nutrient supply, particularly during late gestation when approximately two-thirds of fetal growth occurs. During this period, rapid placental expansion, muscle fiber formation, and organ development substantially increase the nutritional demands of the sow. Insufficient energy or amino acid intake during late gestation restricts nutrient transfer across the placenta, resulting in reduced fetal growth,

lower birth weights, and increased within-litter variation (Gonçalves *et al.*, 2016; Shelton *et al.*, 2009; Soto *et al.*, 2011). Conversely, strategic increases in nutrient supply through late-gestation feeding programs have been associated with improved fetal development, increased piglet birth weight, and enhanced litter uniformity, indicating that nutritional management during this critical period has lasting consequences for piglet performance (Ampode *et al.*, 2023; Gonçalves *et al.*, 2016).

The physiological condition of the sow also influences nutrient partitioning between maternal tissues and developing fetuses. Adequate body reserves provide an additional energy source when nutrient intake is insufficient, whereas excessive mobilization of body tissues may compromise both maternal health and fetal development (Kim *et al.*, 2015; Mun *et al.*, 2023). These observations emphasize that successful gestational nutrition depends not only on dietary formulation but also on maintaining an appropriate body condition throughout pregnancy.

Birth weight as a determinant of piglet survival

Piglet birth weight is widely recognized as one of the strongest predictors of neonatal survival, pre-weaning growth, and subsequent production performance. Piglets born with low birth weight have reduced energy reserves, diminished thermoregulatory capacity, and weaker competitive ability for colostrum intake, increasing their susceptibility to hypothermia, starvation, and mortality during the neonatal period (Ferrari *et al.*, 2014; Muns *et al.*, 2016; Oliviero *et al.*, 2010). Restricted colostrum consumption further compromises passive immunity, thereby increasing the risk of infectious diseases and reducing survival during the first weeks of life (Ferrari *et al.*, 2014).

Beyond the neonatal stage, birth weight continues to influence growth performance throughout the production cycle. Low-birth-weight piglets generally exhibit lower weaning weights, slower average daily gain, delayed market age, and reduced carcass weight compared with heavier littermates (Alvarenga *et al.*,

2013; Fix *et al.*, 2010; Magnabosco *et al.*, 2016; Quiniou *et al.*, 2002). Whittemore (1993) reported that each 0.2 kg increase in birth weight may increase average daily gain by approximately 24 g from birth to slaughter, corresponding to an increase of nearly 3 kg in final carcass weight (Fix *et al.*, 2010). Collectively, these findings highlight the economic importance of maternal nutritional strategies that improve fetal growth and increase birth weight.

Lactational nutrition and piglet growth

Following parturition, milk production becomes the primary determinant of piglet growth and survival. Milk yield depends largely on maternal feed intake, body reserve mobilization, mammary gland development, and endocrine regulation during lactation. Because modern sows frequently nurse larger litters, inadequate nutrient intake during lactation may reduce milk production, thereby limit piglet growth and increasing variation within litters (Kim *et al.*, 2015; Strathe *et al.*, 2017).

Several studies have demonstrated that improving feed intake during lactation increases milk production, enhances weaning weight, and reduces body reserve losses in sows (Cools *et al.*, 2014; Sulabo *et al.*, 2010; Thingnes *et al.*, 2012). Feeding management practices such as increasing feeding frequency or implementing controlled feeding systems have also been shown to improve nutrient utilization while supporting sow welfare and reproductive recovery (Poulopoulou *et al.*, 2018; Wu *et al.*, 2020). These improvements ultimately translate into higher piglet growth rates, improved litter performance, and greater production efficiency.

Long-term consequences for piglet productivity

The effects of maternal nutrition extend beyond the pre-weaning period through a phenomenon commonly referred to as developmental or fetal programming. Nutritional conditions experienced during prenatal and early postnatal life influence muscle fiber development, metabolic function, immune competence, and growth potential, thereby affecting lifetime productivity (Fix *et*

al., 2010; Quiniou *et al.*, 2002). Piglets with greater birth and weaning weights generally exhibit improved feed efficiency, faster growth, and higher carcass yields during finishing, whereas pigs experiencing early nutritional restriction often fail to achieve compensatory growth despite improved post-weaning nutrition (Magnabosco *et al.*, 2016). From a production perspective, improving piglet performance through maternal nutritional management provides substantial economic benefits by increasing survival, reducing variation within litters, shortening the time required to reach market weight, and enhancing overall production efficiency. Therefore, maternal nutrition should be regarded not only as a reproductive management strategy but also as an investment in the long-term productivity of offspring.

CURRENT PERSPECTIVES

Current evidence consistently demonstrates that maternal nutrition is a major determinant of piglet development from fetal life through market age. Nevertheless, considerable variation exists among studies regarding the optimal feeding strategies required to maximize offspring performance because responses are influenced by parity, genotype, litter size, environmental conditions, and dietary composition (Ampode *et al.*, 2023; Gonçalves *et al.*, 2016; Thongkhuy *et al.*, 2020).

Future research should move beyond evaluating individual nutritional interventions and instead adopt integrated approaches that combine maternal physiological monitoring, precision nutrition, and reproductive management to optimize both sow productivity and piglet lifetime performance. Such strategies are expected to play an increasingly important role in improving the sustainability and efficiency of modern swine production systems.

PRECISION FEEDING AND SMART FARMING

Recent advances in precision livestock farming (PLF) have created new opportunities to improve nutritional management and reproductive efficiency in modern swine production. Unlike conventional feeding systems

that provide uniform diets to all animals, precision feeding aims to match nutrient supply with the individual physiological requirements of each sow according to factors such as parity, body condition, reproductive stage, litter size, and environmental conditions. This individualized approach has the potential to improve feed utilization, reduce nutrient wastage, minimize excessive body reserve mobilization, and enhance reproductive performance while supporting animal welfare.

The integration of automated feeding systems with sensor-based technologies has further advanced nutritional management in commercial swine operations. Electronic sow feeders, automated body weight scales, ultrasonic backfat measurement, and real-time monitoring of feed intake enable continuous assessment of the physiological status of individual sows. These technologies allow producers to adjust feeding programs dynamically throughout gestation and lactation, thereby maintaining optimal body condition and improving productivity. Recent studies have demonstrated that automated feeding systems capable of delivering smaller quantities of feed at multiple intervals throughout the day can increase voluntary feed intake, improve sow comfort, reduce feed wastage, and support better reproductive performance compared with conventional feeding schedules (Gorr *et al.*, 2024; Pouloupoulou *et al.*, 2018; Wu *et al.*, 2020).

The application of smart farming technologies extends beyond feeding management. Artificial intelligence (AI), machine learning, and Internet of Things (IoT)-based monitoring systems are increasingly being explored for predicting reproductive events, detecting health disorders, and optimizing environmental conditions in real time. Continuous monitoring of behavioral activity, feed intake patterns, body weight, and thermal responses provides valuable information for early intervention and precision management. Although these technologies remain under development in many commercial production systems, their integration with precision nutrition offers considerable potential to improve reproductive

efficiency, reduce production costs, and enhance animal welfare. Future implementation will depend on improvements in sensor accuracy, cost-effectiveness, and the development of decision-support systems capable of translating large datasets into practical nutritional recommendations.

KNOWLEDGE GAPS AND FUTURE PERSPECTIVES

Despite considerable advances in sow nutritional management, several important knowledge gaps remain regarding the optimization of reproductive performance under modern production systems. Although body condition score and backfat thickness are widely recognized as useful indicators of maternal physiological status, there is still no universal consensus regarding their optimal ranges across different genetic lines, parity groups, housing systems, and environmental conditions. Variability among published studies suggests that nutritional recommendations should increasingly account for individual animal characteristics rather than relying on generalized feeding guidelines.

Another important research priority involves improving the understanding of maternal metabolic adaptation during gestation and lactation. While nutritional interventions such as bump feeding, increased feeding frequency, and ad libitum feeding have demonstrated beneficial effects under many production conditions, responses remain inconsistent because of differences in genetics, litter size, environmental temperature, and management practices. Additional research is therefore needed to identify physiological biomarkers that accurately reflect nutrient requirements throughout the reproductive cycle and facilitate the development of individualized feeding programs.

Emerging disciplines such as nutrigenomics, metabolomics, and microbiome research also offer promising opportunities for advancing sow nutrition. Improved understanding of the interactions among dietary nutrients, intestinal microbiota, endocrine regulation, and reproductive physiology may facilitate

the development of functional nutritional strategies that enhance maternal health and offspring performance. Furthermore, integrating precision livestock farming technologies with automated feeding systems, artificial intelligence, and real-time physiological monitoring has the potential to transform nutritional management by enabling dynamic, data-driven decision-making at the individual animal level. Future research should therefore move beyond evaluating isolated nutritional interventions and instead adopt multidisciplinary approaches that integrate physiology, nutrition, genetics, digital technologies, and animal welfare. Such strategies will contribute to improving reproductive efficiency, increasing piglets weaned per sow per year, extending sow longevity, and promoting more sustainable and resilient swine production systems.

CONCLUSION

Optimizing sow nutrition and maintaining appropriate physiological condition throughout gestation and lactation are essential for improving reproductive performance, piglet development, and long-term herd productivity. Practical indicators such as body condition score and backfat thickness provide valuable guidance for nutritional management, while stage-specific feeding strategies help support fetal growth, milk production, and reproductive recovery. Emerging precision feeding systems and smart farming technologies offer promising opportunities to individualize nutritional programs, improve feed efficiency, and enhance animal welfare. Future research should integrate precision nutrition, physiological biomarkers, and digital technologies to develop adaptive feeding strategies that maximize sow longevity, piglet lifetime performance, and the sustainability of modern swine production.

GENERATIVE AI AND AI-ASSISTED TECHNOLOGY STATEMENT

The author declares that AI-assisted tools (ChatGPT and Grammarly) were used solely to improve English language quality and grammar. All outputs were reviewed by the author, and no AI tools were used for data analysis or interpretation.

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