Review Article

Advantages, disadvantages, and factors influencing the reproductive performance of gilts and sows raised in gestational group housing and free-farrowing systems

Natchanon Dumniem[1*] Thomas D. Parsons[2] Padet Tummaruk[1,3]

Abstract

In the modern global pig industry, there is a growing interest in animal-friendly agriculture, encouraging farmers to prioritize humane practices and meet the welfare needs of their animals. In developed countries, consumers are increasingly concerned about animal welfare, particularly regarding pigs as social animals, advocating for their housing in groups that reflect their natural behaviors in the wild. There is significant societal pressure to eliminate the use of crate systems, which cause discomfort to animals in commercial farming. In these systems, breeding females are often restricted in movement throughout the reproductive cycle. As a result, alternative husbandry and housing systems have been developed to improve animal welfare and allow the expression of natural behaviors under semi-natural conditions. One such approach is the adoption of group housing systems for pregnant pigs and loose housing systems during farrowing and lactation. These systems provide breeding females with greater freedom of movement by enabling group rearing and increasing the space allocated per animal. Thailand has emerged as a significant pork producer in tropical Southeast Asia, but the use of gestation stalls and farrowing crates remains common across commercial swine herds. Over the past decade, there has been a growing interest among the Thai public and society in farm animal welfare. Consequently, there is a need for a comprehensive understanding of management practices for alternative systems to facilitate the transition from crate systems to loose housing systems. This presents a significant opportunity for novel research aimed at investigating the effects of alternative housing systems on health, reproduction, and productivity in female breeders under tropical conditions. This review aims to update the existing knowledge on the advantages, disadvantages, and factors influencing the reproductive performance of gilts and sows raised in gestational group housing and free-farrowing systems within the modern swine industry under tropical conditions.

Keywords: animal welfare, housing system, pig, reproduction, tropics

[1]*Department of Obstetrics, Gynaecology and Reproduction, Faculty of Veterinary Science, Chulalongkorn University, Bangkok 10330, Thailand*

[2]*Swine Teaching and Research Unit – New Bolton Center, School of Veterinary Medicine, University of Pennsylvania, Kennett Square, PA 19348, USA*

[3]*Centre of Excellence in Swine Reproduction, Chulalongkorn University, Bangkok 10330, Thailand*

***Correspondence**: natchanon.d@chula.ac.th* (N. Dumniem)

Received October 22, 2024

Accepted March 19, 2025

https://doi.org/10.56808/2985-1130.3785

Introduction

In the modern global pig industry, advancements in agricultural science have led to increasingly intensive livestock production practices, primarily aimed at boosting yield and productivity per unit. However, there is also a growing interest in animal-friendly agriculture, which encourages farmers to raise animals more humanely and address their welfare needs. In developed countries, consumers are becoming increasingly concerned about animal welfare, particularly regarding pigs as social animals, and are advocating for housing them in groups that reflect their natural behavior in the wild (Ryan *et al*., 2015; Schütz *et al*., 2023). In Europe, public opinion is increasingly unfavorable toward housing systems that compromise pig welfare, even if this results in greater pork-product prices (Einarsson *et al*., 2014; Schütz *et al*., 2023). Additionally, there is strong societal pressure to eliminate the use of crate systems due to the discomfort they cause animals in commercial farming, where breeding females are often movement-restricted throughout the reproductive cycle (Ryan *et al*., 2015; Vandresen and Hotzel, 2021). As a result, alternative husbandry and housing systems have been developed to improve animal welfare and enable the expression of natural behaviors under semi-natural conditions. One such approach is the adoption of group housing systems for pregnant pigs and loose housing systems during farrowing and lactation, with some countries even making these systems mandatory (Vandresen and Hotzel, 2021; Dumniem *et al*., 2023). These systems provide breeding females with greater freedom of movement by allowing group rearing and increasing individual space allocation.

Thailand has emerged as a significant pork producer in tropical Southeast Asia. However, gestation stalls and farrowing crates are still widely used in commercial swine herds (Tummaruk *et al*., 2023). Over the past decade, there has been growing interest among the Thai public in food hygiene, antimicrobial drug residues, hormone use, and the welfare of farm animals (Visetnoi and Nelles, 2023). Thai consumers are increasingly concerned about the source, quality, food safety, and sustainability of pork products. They are also more willing to pay higher prices for products from organic farms that prioritize animal welfare and social well-being (Visetnoi and Nelles, 2023). As a consequence, major swine producers in Thailand are actively seeking opportunities to capitalize on this market by enhancing public engagement and adopting new marketing strategies. These efforts include offering premium-quality meat, organic and hormone-free products, and implementing housing systems that allow breeding female pigs more freedom of movement. However, several challenges arise with these housing systems, including larger litter sizes, heat stress in tropical environments, disease prevention concerns, and farmers' unfamiliarity with the new systems. These challenges collectively impact pig health and reproduction while requiring farmers to maintain productivity. Achieving a balance between sustainable agriculture and the socioeconomic aspects of pig farming in Thailand requires input from all stakeholders, including pork producers, the public, consumers, government agencies, and academic institutions, before implementing any policies (Visetnoi and Nelles, 2014). Therefore, there is a need for a comprehensive understanding of management practices in alternative systems to facilitate the transition from crate systems to loose housing systems (Dumniem *et al*., 2023). This highlights the significant opportunity for novel research to evaluate the effects of alternative housing systems on health, reproduction, and productivity in female breeders under tropical conditions. This review aims to update existing knowledge on the advantages, disadvantages, and factors influencing the reproductive performance of gilts and sows raised in gestational group housing and free-farrowing systems within the modern swine industry under tropical conditions.

Disadvantages of the conventional crate housing systems

In Thailand's swine industry, most breeding females are typically housed in restrictive systems, i.e., gestation stalls and farrowing crates, for much of their production cycle (Tummaruk *et al*., 2023). While these systems offer several benefits, including individualized care, ease of hygiene maintenance, efficient space utilization, safe and simple working conditions for stockpersons, and increased farm productivity (Koketsu and Iida, 2017; Bumpenkul and Imboonta, 2021), they also severely limit the natural behavioral expression of the pigs. In the wild, pigs generally live in relatively small groups during pregnancy and are usually isolated for a few weeks for farrowing and lactation (Rhodes *et al*., 2005; Einarsson *et al*., 2014). Pigs are naturally inclined to engage in affiliative behaviors such as socializing, nest building, sniffing, gentle rooting, and grooming (Rhodes *et al*., 2005). The restrictive environment can negatively impact animal welfare and health. For example, sows are unable to engage in normal exploratory behaviors such as rooting, walking, or interacting socially with other animals. The lack of space also prevents them from performing natural postural movements such as turning around, particularly in the case of older sows where the stalls are often smaller than their body size. Additionally, the inability to interact with other sows often results in social isolation (Chapinal *et al*., 2010b). These limitations can result in stereotypical behaviors such as bar biting, a repetitive behavior caused by frustration and boredom (Chapinal *et al*., 2010b). These conditions predispose sows to stress, altering physiology, compromising immune systems, and increasing susceptibility to diseases, thereby affecting overall animal well-being (Maes *et al*., 2016; Tripipat *et al*., 2021). Although pigs are social animals, confrontations often occur when they group together to establish social hierarchies (dominant and subordinate) for resource access (Arey and Edwards, 1998; Chapinal *et al*., 2010b; Verdon *et al*., 2016). While such behavior is observed in nature, strong and prolonged aggression is rare in free-range or extensive farming systems (D'Eath and Turner, 2009). Conversely, in high-density swine herds, harsh social dynamics often result in health complications, chronic stress, and compromised welfare for subordinate sows (D'Eath and Turner, 2009; Maes *et al*., 2016). These challenges underscore the need to consider factors of the housing system, particularly during the production stages associated with intense stress.

The global trend in animal welfare perspectives

From an animal welfare perspective, many regions have enacted legislation or codes of conduct aimed at gradually eliminating the use of confined stalls and crates for indoor breeding herds (Plush *et al*., 2023). However, the specifics and timelines for banning confined crates vary by country. As of 2024, these regulations have been implemented in the European Union (EU), certain states in the USA (i.e., Arizona, California, Colorado, Florida, Maine, Massachusetts, Michigan, New Jersey, Ohio, Oregon, and Rhode Island), the United Kingdom, Norway, Switzerland, Australia, and New Zealand (Plush *et al*., 2023). Canada and Brazil have also proposed bans on gestation stalls by 2029 and 2045, respectively (de Castro Lippi *et al*., 2022; Plush *et al*., 2023). However, among Asian countries, only South Korea is transitioning to enforce group housing systems for sows, with full implementation expected by 2030 (Min *et al*., 2020).

In Europe, according to Council Directive 2008/120/EC, EU member states are prohibited from keeping pregnant pigs in stalls from 4 weeks after insemination until 1 week before farrowing. While farrowing crates are still commonly used worldwide during the lactation period, they have been abolished or severely restricted in Switzerland, Norway, Sweden, Austria, and Germany (Einarsson *et al*., 2014; Baxter *et al*., 2022; de Castro Lippi *et al*., 2022; Plush *et al*., 2023). Additionally, California is the only state in the USA that introduce regulations on farrowing crate use in 2024 (Plush *et al*., 2023), while New Zealand has proposed a change in 2025, with a minimum pen space allowance of 6.5 m^2 (Baxter *et al*., 2022). However, major barriers to farmers transitioning to more animal-friendly housing systems are the high production cost and concerns regarding herd health and productivity (Tuyttens *et al*., 2011).

Advantage of group housing system during gestation

The group housing system involves keeping sows together during pregnancy, mimicking pigs' natural social structure. In this system, pregnant sows have more space to move and interact with other pigs. The pens are designed to accommodate the social dynamics of group living, allowing pigs to establish hierarchies and interact socially. Implementing a group housing system for pregnant pigs aims to improve animal welfare by enabling sows to express natural behaviors, such as nesting and socializing while providing a more comfortable and enriching environment (Spoolder *et al*., 2009). However, managing sows in a group housing system differs significantly from the conventional crate system, both in terms of individual care and herd management (Peltoniemi *et al*., 2016; Koketsu and Iida, 2017). Currently, there is no universal consensus on the best designs and management practices for breeding females in group housing systems under tropical conditions. Therefore, several factors must be carefully considered before implementing this housing system to ensure a balance between sow productivity and welfare in tropical environments. Key considerations include the feeding system, group size, and the timing of group mixing.

Feeding system: The feeding system plays a crucial role in determining the amount of feed intake per animal, with sows needing to maintain a positive energy balance throughout gestation (Ferreira *et al*., 2021). Traditionally, breeding females are subjected to feed restriction to maintain body weight and condition during gestation. However, this approach may not meet the nutritional demands of modern hyperprolific sows, which require higher levels of specialized nutrition due to genetic modifications (Bortolozzo *et al*., 2023). In commercial settings, feed intake is often restricted in sows to prevent progesterone clearance by the liver during early pregnancy. However, restricting feed intake beyond the first three days of gestation in group housing systems has been shown to negatively affect corpus luteal development and embryo survival rates. This results in increased returns to estrus and non-productive days (Spoolder et al., 2009; Langendijk, 2021). Additionally, sows on restricted feed may exhibit more negative behaviors related to hunger and stereotypies, particularly in group housing systems where space allows them to express these behaviors, potentially compromising their welfare (Verdon *et al*., 2015). It is important to recognize that in group housing systems, sows may experience feed restrictions, especially during early pregnancy, due to disturbances in social hierarchy and unfamiliarity with feeding systems. These factors highlight the importance of careful management practices to ensure adequate nutrition and welfare for breeding females in group housing systems, especially during early pregnancy.

Feeding management for group-housed sows should prioritize adequate nutrition, considering daily maintenance energy requirements for pregnancy, sow body weight, fetal growth, and the elevated energy expenditure associated with increased activity compared to the crate system. Inappropriate feeding management may hinder sow health and reproductive performance by both underfeeding and overfeeding (Ferreira *et al*., 2021). This is a challenge in tropical conditions, where heat stress often reduces feed intake. In group-housed systems, where feed is restricted, sows often compete for access, leading to increased stress, injuries, and pregnancy disruption (Verdon *et al*., 2015). Melchior *et al*. (2012) found a negative correlation between metabolizable energy and salivary cortisol concentration. A restricted diet during pregnancy could contribute to stereotyped behavior and elevated cortisol levels, as such diets do not provide sufficient satiation for the animals (Melchior *et al*., 2012). To mitigate sow hunger, providing dietary fiber can enhance sow satiety and regulate the hunger hormone, potentially reducing aggression and stereotypic behaviors (Jensen *et al*., 2015; Verdon *et al*., 2015). In tropical environments, increasing feeding levels in primiparous sows in a group-housed system during early pregnancy can effectively restore their body condition without any detrimental effects on subsequent litters (Dumniem *et al*., 2025). Increasing feed intake during the first 35 days of gestation from 1.9 to 2.9 kg/sow/day significantly improved backfat thickness gain, while fertility and litter traits remained unchanged (Dumniem *et al*., 2025). Interestingly, the proportion of piglets with birthweights <1000 g was significantly reduced in sows with an average daily feed intake of 2.8 to 2.9 kg/day compared to sows with an intake of 2.4 kg/day (Dumniem *et al*., 2025).

Feeding systems in group-housed sows are typically classified into competitive and non-competitive designs. Competitive systems allow sows to compete for feed, whereas non-competitive systems ensure each sow has exclusive access to her allotment without competition (Koketsu and Iida, 2017). The basic feeding systems used in group housing for gestating sows include *i)* Floor feeding, where feed is distributed simultaneously to all sows in the pen, potentially leading to competition for access, *ii)* Drop feeding, which delivers the entire meal into the feeding trough at once, allowing sows to consume feed independently, and *iii)* Trickle feeding, which dispenses feed slowly in small amounts to encourage sows to focus on eating and reduce aggression (Hulbert and McGlone, 2006). Drop and trickle feeding systems in non-competitive designs typically include stanchions (shoulder-level partitioners) to separate and protect sows during feeding. In competitive systems, dominant sows may occupy feeders, preventing submissive sows from accessing feed. Additionally, individual feed adjustments are often impractical. To address this issue in competitive systems, free access stalls with lockable rear gates allow only one sow to feed at a time. The electronic sow feeder (ESF) provides an automated solution for individualized feeding in group housing systems (Fig. 1A). When a sow enters the feeder, a radio-frequency identification reader identifies her and dispenses feed according to pre-programmed settings tailored to animals' needs. This system offers flexibility in pen configurations and is suitable for both small and large group sizes. However, its implementation requires costly installation, trained animals, and experienced staff to manage the feeders. In the ESF system, sows often queue to access the feed (Fig. 1B), leading to aggression and potential injuries (Chapinal *et al*., 2010b; Olsson *et al*., 2011). Olsson *et al*. (2011) observed that the duration of feeding settings significantly impacts queuing behavior and the incidence of vulva biting. Longer feeding times also lead to overcrowding, reducing overall feeder capacity. These findings underscore the competitive and frustrating dynamics of sow interactions for feed within the ESF system. Proper management of feed settings, feeder numbers, design, location, and feeding levels is essential to mitigate queuing issues in group housing systems using ESF.

Figure 1 The electronic sow feeders (ESF) used in the group housing system: (A) an individual sow accessing the feeder and (B) overcrowded sows queuing at the entrance when the feeding time resets.

Group size: While pigs in nature typically live in small groups of two to five adults and their offspring, commercial herds manage breeding females in both static and dynamic groups (D'Eath and Turner, 2009; Einarsson *et al*., 2014). Static groups, which are generally smaller, involve mixing inseminated sows at a single time, with the group composition remaining unchanged throughout gestation. Conversely, dynamic groups are typically larger and allow for the introduction or removal of sows on multiple occasions during gestation, leading to a continuously changing social environment. Recent reviews have found no significant differences in aggression levels between small and large groups (Spoolder *et al*., 2009; Verdon *et al*., 2015). Hemsworth *et al*. (2013) reported comparable levels of aggression around feeding and farrowing rates among sows in groups ranging from 10 to 80 per pen. Large groups may offer advantages, such as providing submissive sows with more space to escape or hide from aggressors, thereby reducing the likelihood of direct confrontation (Séguin *et al*., 2005; Verdon *et al*., 2015). However, interpreting the effects of group size is complicated, as they are influenced by factors including space allowance, feeding systems, and social hierarchy (Lagoda *et al*., 2022). Anil *et al*. (2006) suggested that large dynamic group sizes experience higher levels of aggression due to frequent disruptions in the social hierarchy caused by newly introduced sows. Similar findings were also found in the semi-static large groups, where sows are grouped at 5 to 7 days post-insemination, while submissive sows are at a greater risk of long-term injuries. These sows are increased in body lesions at 26 and 84 days of gestation compared to dominant sows (Brajon *et al*., 2021). In ESF systems, group sizes are typically large due to the capacity of one feeder serving 40 to 60 sows, which may result in increased injuries and vulva-biting lesions due to the inability to feed simultaneously from ESF systems (Olsson *et al*., 2011). The animal-to-feeder ratio is another factor to consider in large dynamic groups. Sows with a ratio of four animals per feeder have higher skin injuries compared to those with a one-to-one ratio (Angermann *et al*., 2021). These findings highlight the importance of feeder availability in mitigating sow aggression during feeding as group size increases. Therefore, large group sizes with inappropriate feeding management pose a potential risk factor for the development of chronic stress in group housing systems.

In Thailand, sows in group housing systems are typically placed in dynamic groups of 220 to 280 sows per pen (Dumniem *et al*., 2025). These gestational pens measure 22 × 22 meters with a fully concrete floor, providing roughly 2.2 square meters per sow (Fig. 2). The pens usually do not include enrichment or bedding. On average, each gestational pen is equipped with six ESFs and 24 nipples for *ad libitum* access to drinking water. Each feeding station measures 2.0 × 0.6 meters and is positioned adjacent to the pen. Sows usually remain in the group-housed system from 35 to 109 days of gestation before being transferred to the free-farrowing house approximately seven days prior to farrowing (Dumniem *et al*., 2025). In smaller herds, sows and gilts are sometimes housed in a static group system during gestation (Adi *et al*., 2024). In this setup, each group typically consists of around 40 to 45 sows, with the gestational pen measuring 9 × 11 meters. Generally, in static group housing, sows are placed in the group within three days after the last insemination and remain there until 108 days of gestation before being moved to the farrowing house (Adi *et al*., 2024).

Figure 2 The environment within a large dynamic group housing system (22 × 22 meters) with a fully concrete floor, where 220 to 280 sows are housed per pen under tropical conditions.

Mixing time: Mixing inseminated sows into group housing systems presents significant challenges for sow health and pregnancy establishment. Following mixing, aggressive encounters occur as unfamiliar sows establish dominance hierarchies, typically lasting for a few days (Greenwood *et al*., 2016). However, improper management of this process can disrupt pregnancy physiology. Alterations in luteinizing hormone, which is essential for corpus luteum formation and function during the early luteal phase, may occur in group-housed sows due to stress from inter-sow aggression and insufficient feed intake (Razdan *et al*., 2004). This disruption affects progesterone synthesis and uterine modifications, thereby hindering embryo implantation (Peltoniemi *et al*., 2016; Salak-Johnson, 2017). The timing of mixing influences stress levels among sows, as evidenced by lower cortisol levels and reduced aggressiveness in sows that are mixed later (Stevens *et al*., 2015). Repeated mixing events of sows leads to more aggression and expression of displacement behaviors toward pen mates (Schalk *et al*., 2018). By the end of the mixing period, sows exhibit reductions in cytotoxic T cells, antigen-experienced T helper cells, and natural killer cells due to acute stress-induced immunosuppression (Schalk *et al*., 2018). However, this stressful period typically resolves within a few days, suggesting that sows can adapt to their environment over time. This is supported by findings that the number of skin injuries and the neutrophil-to-lymphocyte ratio at late gestation, an indicator of chronic stress, are not affected by the timing of mixing (Stevens *et al*., 2015). Furthermore, Lagoda *et al*. (2021) found no association between skin lesions three weeks after mixing and hair cortisol concentrations.

Aggression among sows can also lead to physical injuries, particularly lameness. Lameness is considered the main reason for culling sows in group housing systems (Jensen *et al*., 2010). Lame animals have reduced activity levels, making it difficult for them to access feed and water, which leads to poor body condition and compromised reproductive performance (Prasomsri, 2022). The stress and anxiety triggered by aggressive interactions also result in behavioral changes, such as changing activity, reduced exploration, and increased aggression (Greenwood *et al*., 2016). Additionally, sows may exhibit stereotypic behaviors due to hunger and reduced feed intake, followed by aggressive encounters. These behavioral changes not only indicate compromised welfare but also have implications for reproduction. Restricted feed intake during early pregnancy can disrupt the sow's energy balance, leading to health problems and decreased reproductive performance (Langendijk, 2021). The timing of mixing varies among herds depending on management practices. However, mixing should not occur during the period of maternal recognition, which is between days 11 and 13 of gestation, as this can negatively impact pregnancy establishment (Peltoniemi *et al*., 2016). Additionally, mixing sows into small groups after weaning to allow hierarchy formation may help to prevent early pregnancy disruption and reduce aggression among pregnant sows (Verdon *et al*., 2015; Peltoniemi *et al*., 2016).

In tropical environments, primiparous sows that are housed in dynamic group systems from 1 to 109 days of gestation have a farrowing rate that ranges between 75.0% and 92.9%, with a total of 13.4 to 15.0 piglets born per litter (Dumniem *et al*., 2025). In static group housing systems, where gilts and sows are mixed from 3 days until 108 days of gestation, the average total number of piglets born per litter is 13.1 (Adi *et al*., 2024). These findings suggest that group housing systems can be successfully implemented in the swine industry under tropical climates with acceptable reproductive performance. However, variation among batches and herds is still observed and requires further investigation.

Reproductive performances of sows in group housing systems during gestation

In comparison to the crate system during gestation, group-housed sows are at risk of negative impacts on fertility and productivity. Aggression among sows is a major risk factor in group housing, especially after mixing, as it can heighten stress responses and increase injury risk. Elevated cortisol levels resulting from stress can disrupt reproductive hormones and hinder embryo development (Spoolder *et al*., 2009; Salak-Johnson, 2017). Although some levels of aggression are unavoidable in group housing as sows establish social hierarchies, prolonged and persistent aggression due to inappropriate environments and management can lead to chronic stress and welfare concerns. Typically, sows establish a hierarchy within a few days after mixing, resulting in fewer subsequent confrontations across the herd (Greenwood *et al*., 2016). Adequate feed intake during early pregnancy is essential, as nutrition directly influences pregnancy establishment and maintenance (Langendijk, 2021). Poor selection of feeding systems and strategies may exacerbate the effects of aggression. Previous reviews have reported reproductive challenges in group housing, such as lower pregnancy rates and higher remating rates compared to gestation crates (McGlone, 2013; Koketsu and Iida, 2017; Salak-Johnson, 2017), potentially resulting in lower farrowing rates when inseminated sows are grouped during the early pregnancy period. In contrast, litter size generally appears to be similar between these two systems (Koketsu and Iida, 2017; Salak-Johnson, 2017). However, the introduction of hyperprolific sow genetics into the modern swine industry worldwide has led to a significant increase in litter size (Bortolozzo *et al*., 2023; Tummaruk *et al*., 2023). Additionally, advancements in husbandry management and the adoption of precision livestock farming technologies have the potential to enhance the overall fertility and productivity of female pigs.

Table 1 presents a comparison of reproductive traits between the crate system and the group housing system for gestating pigs based on articles published between 2010 and 2021. Fertility traits generally remain a challenge in group housing systems. Johnston and Li (2013) reported a 5% lower farrowing rate in sows kept in small-group housing systems compared to the crated system. Knox *et al*. (2014) found a similar effect when sows were mixed soon after insemination (3 to 7 days after insemination). However, mixing after pregnancy confirmation (35 days after insemination) resulted in farrowing rates comparable to those in crates. Potential benefits for farrowing rate and litter size have been observed in group-housed hyperprolific sows when mixed after pregnancy confirmation (38 to 42 days of gestation) compared to the crate system (Perini *et al*., 2021). Effective management of sows during early pregnancy requires adequate space and feeding strategies to promote satiety and reduce the intensity of social restructuring after mixing.

In tropical conditions, exposure to heatwaves, i.e., ≥25 °C and temperature-humidity index (THI) >74, is common, and it is a key factor contributing to reduced farrowing rates and increased abortion rates (Brito *et al*., 2022). In Thailand, sows that are kept in group housing systems have a conception rate of around 90% (Adi *et al*., 2024; Dumniem *et al*., 2025). Furthermore, these sows produce an average of 13.5 total piglets per litter, with 11.5 piglets born alive, 0.8 stillborn, and 0.8 mummified fetuses (Adi *et al*., 2024). This litter size is comparable to that of conventional crate systems under tropical conditions (Tummaruk *et al*., 2010; Thiengpimol *et al*., 2024). However, under certain conditions, the farrowing rate of sows in group housing systems can reach as high as 92.9%, with up to 14.6 piglets born alive per litter (Dumniem *et al*., 2025). Additionally, the current farrowing rate and litter size of group-housed sows in Thailand are relatively higher than a report from a group-housing system on the tropical island of Guadeloupe (Gourdine *et al*., 2006), which is attributed to the different in group size and significant improvements in genetic sow lines over recent decades. These findings suggest that further investigation into the management of sows in group housing systems under tropical conditions is necessary to achieve optimal reproductive performance.

Free-farrowing system

The free-farrowing system provides sows with ample space to move around during the 5 to 7 days before farrowing and throughout lactation, allowing them to express natural behaviors related to parturition and nursing. In contrast, farrowing crate systems confine the sows, limiting their interaction with the environment from the time they enter the farrowing house until weaning, often resulting in negative behaviors. The farrowing pens encourage sows to increase their movement and interaction with their surroundings (Kinane *et al*., 2022). Additionally, sows confined before parturition exhibit more frequent and prolonged negative stereotypic behaviors compared to those allowed to move freely before farrowing (Yun *et al*., 2015). Confinement induces acute stress, evidenced by elevated cortisol levels for up to 24 h after transition from group housing to farrowing crates (Cronin *et al*., 1991). However, cortisol concentrations from days 1 to 21 of lactation do not differ between farrowing systems (Cronin *et al*., 1991). Cortisol profiles throughout the lactation vary between sows in farrowing crates and those in free-farrowing pens. A previous study demonstrated that crated gilts had higher cortisol concentrations than penned gilts during the prepartum period (overall mean 41.5 vs. 30.7 ng/mL) (Jarvis *et al*., 1997). On the other hand, Oliviero *et al*. (2008) found no significant differences in cortisol levels between sows in crates and pens (19.9 vs. 13.2 ng/mL, respectively), although penned sows exhibited lower cortisol levels from 5 days prepartum to 1 day postpartum. Interestingly, Kinane *et al*. (2022) reported higher salivary cortisol concentrations in sows within free-farrowing systems compared to those in farrowing crates, suggesting cortisol levels may respond to both positive and negative stimuli, possibly linked to increased activity within the pen. Confinement during farrowing has negative impacts on sow behavior, leading to higher levels of stereotypies, reduced nest building, altered responsiveness toward piglets, and disrupted nursing and lying behaviors (Sánchez-Salcedo and Yáñez-Pizaña, 2024). These effects can compromise maternal postpartum health and increase piglet mortality.

Table 1 Summary of some studies (From 2010 to 2021) comparing reproductive parameters of sows in the crate system and group housing system during gestation.

Study	Gestational housing	Feeding system	Group size	Mixing time (d)	Space allowance (m^2/sow)	Farrowing rate (%)	TB	BA	SB	Country
Estienne and Harper (2010)	Crate	-	-	-	1.3	-	12.9	12.1*	0.7	USA
	Group	Floor feeding	5 to 6	0	2.6 to 3.2	-	11.6	9.1*	1.7	
	Group	Floor feeding	5 to 6	30	2.6 to 3.2	-	12.9	11.3*	0.6	
Chapinal *et al.* (2010a)	Crate	Through	-	-	1.3	-	n/a	n/a	1.2*	Spain
	Group	Unprotected ESF	10	-	2.3	-	n/a	n/a	0.5*	
	Group	Trickle feeding	10	-	2.3	-	n/a	n/a	1.0*	
Zhao *et al.* (2013)	Crate	-	-	-	1.2	87.5	13.4	11.1	1.9	USA
	Group	-	3	35	2.5	86.5	12.4	10.4	1.7	
Johnston and Li (2013)	Crate	Through	-	-	1.2	97.6*	13.1	12.3	0.9	USA
	Group	Floor feeding	26	35	1.5	92.2*	13.2	12.5	0.7	
	Group	Floor feeding	6	35	1.5	94.8*	13.1	12.2	0.9	
Knox *et al.* (2014)	Crate	-	-	-	1.3	92.8*	12.4	11.8	0.6	USA
	Group	ESF	58	3 to 7	1.7	82.8*	11.9	11.3	0.5	
	Group	ESF	58	13 to 17	1.7	87.8*	12.4	11.6	0.7	
	Group	ESF	58	35	1.7	90.5*	12.2	11.5	0.6	
Li *et al.* (2014)	Crate	-	-	-	1.3	-	12.3	11.5	0.7	USA
	Group	ESF	50	7	2.2	-	11.9	11.0	0.8	
Zhou *et al.* (2014)	Crate	-	-	-	1.2	-	-	10.2^	0.7	China
	Group	-	4	-	2.5	-	-	8.9^	0.6	
Jang *et al.* (2015)	Crate	-	-	-	1.3	97.6*	11.4	10.6	0.7	South Korea
	Group	ESF	42	35	3.8	95.2*	11.5	10.8	0.6	
Kim *et al.* (2016)	Crate	-	-	-	1.4	-	11.5	10.0	-	South Korea
	Group	-	16	80	3.5	-	11.5	10.2	-	
Ren *et al.* (2018)	Crate	-	-	-	1.3	-	14.9	13.0	1.2	USA
	Group	ESF	55	35	2.2	-	14.9	13.4	1.1	
Choe *et al.* (2018)	Crate	-	-	-	1.2	-	11.9	11.4	0.5^	USA
	Group	ESF	28	-	1.3	-	11.9	10.6	0.9^	
Cunha *et al.* (2018)	Crate	Dropped feeding	-	-	1.3	89.7*	14.8	12.1	1.5*	Brazil
	Group	ESF	55	70	2.2	83.2*	14.8	12.6	1.2*	
	Group	ESF	55	30	2.2	84.9*	14.6	12.4	1.4*	
Min *et al.* (2020)	Crate	-	-	-	1.5	-	12.0	10.9	1.0	South Korea
	Group	Unprotected ESF	10	56	2.4	-	10.8	10.1	0.4	
	Group	FAS	10	56	2.5	-	11.3	9.8	1.3	
	Group	ESF	10	56	2.8	-	13.1	11.0	1.4	
Jeong *et al.* (2020)	Crate	Through	-	30	1.5	-	12.1	11.0	1.1	South Korea
	Group	FAS	25	30	2.4	-	12.3	11.2	1.2	
Schwarz *et al.* (2021)	Crate	-	-	-	2.2	82.0*	11.6*	11.4*	0.3*	Poland
	Group	-	7 to 8	At wean	3.0 to 3.4	85.3*	12.2	11.6*	0.5*	
Capoferri *et al.* (2021)	Crate	-	-	-	-	88.0*	12.0	11.0	-	Italy
	Group	ESF	60	1	2.2	78.0*	12.0	11.0	-	
Perini *et al.* (2021)	Crate	-	-	-	1.3	91.7*	14.2*	11.7*	0.3*	Brazil
	Group	ESF	80	3 to 5	2.2	n/a	15.0*	12.6	0.3*	
	Group	ESF	80	38 to 42	2.2	92.6*	14.9*	12.5*	0.3*	

^ indicated $P < 0.10$, * indicated $P < 0.05$.
'-' indicated no available data, and 'n/a' indicated data was mentioned, but no actual number was provided.
TB = the total number of piglets born per litter, BA = the number of piglets born alive per litter, SB = the number of stillborn piglets per litter, ESF = electronic sow feeder, FAS = free access stalls.

Nest-building behavior typically begins around 24 h before farrowing (Illmann *et al*., 2016). However, intensive swine farms often restrict space and nesting materials, limiting the expression of these behaviors. Performing nest-building behavior is associated with increased secretion of oxytocin and prolactin during the pre-partum (Yun *et al*., 2014) and peri-partum (Yun *et al*., 2013; Maria *et al*., 2023) in sows. Oxytocin is crucial for stimulating uterine contractions during farrowing, and plasma oxytocin concentrations during the peripartum period have been positively correlated with prepartum levels (Yun *et al*., 2015). This results in shorter piglet expulsion intervals and reduced farrowing durations in penned sows compared to crated sows (Oliviero *et al*., 2008), suggesting that a constrained farrowing environment negatively affects the farrowing process. Prolonged farrowing may also be linked to increased endogenous opioids triggered by poor farrowing conditions, which inhibit oxytocin secretion (Yun *et al*., 2013; Zeng and Zhang, 2023). Furthermore, sows with limited access to nesting materials may exhibit increased stereotypies and stress during farrowing (Damm *et al*., 2003). Therefore, providing pre-partum sows with adequate space and nesting materials before parturition, as in the free-farrowing system, enhances farrowing performance and improves sow welfare.

Farrowing duration is a critical factor influencing both sow health and the viability of newborn piglets (Kirkwood *et al*., 2021). In tropical climates, sows housed in free-farrowing systems have an average farrowing duration ranging from 213.2 to 216.0 min (Adi *et al*., 2022; Dumniem *et al*., 2023; Dumniem *et al*., 2024). The increasing use of hyperprolific sow genetics in tropical regions has contributed to larger litter sizes, which significantly extends farrowing duration (Bortolozzo *et al*., 2023; Tummaruk *et al*., 2023). This effect is further compounded by environmental conditions, as extreme heat and humidity impose additional physiological stress on sows during parturition. Adi *et al*. (2022) reported that in tropical conditions, farrowing duration in free-farrowing systems increases as maximum temperature and THI rise before parturition. Similarly, Akkhaphan *et al*. (2025) found that in a temporarily confined system, every 1 °C rise in the average temperature during the 7 days before parturition resulted in a 4.3-min increase in farrowing length. These findings underscore the significant impact of heat stress on farrowing efficiency in tropical swine production. One approach to alleviate prolonged farrowing is dietary modification during the transition period. For example, supplementing the diet with 75 g/day of dietary fiber has been shown to reduce constipation symptoms, resulting in a 43.6-minute reduction in farrowing duration compared to control sows (Dumniem *et al*., 2024).

The free-farrowing system provides post-partum sows with more space, but this increased space can lead to more frequent postural changes, raising the risk of piglet crushing (Dumniem *et al*., 2023). During the lactation, sows must lie laterally to nurse their piglets, exposing their udders for suckling. This position makes it easier for piglets to access the sow's teats, ensuring they receive sufficient colostrum and milk. However, the frequency and suddenness of postural changes, such as lying down and rolling, can directly impact piglet mortality (Damm *et al*., 2005). Crushing incidents predominantly occur within the first three days of piglet life (Dumniem *et al*., 2023), with crushed piglets often being lighter at birth and less viable than those that survive (Sporri-Vontobel *et al*., 2023). Proper space allocation and pen design adjustments can help mitigate sow postural changes. For example, providing support walls for the sow to lean against before lying down enhances maternal responsiveness and reduces the risk of piglet crushing (Damm *et al*., 2005; Zeng and Zhang, 2023). Therefore, management practices that minimize sudden overlaying by sows and ensure adequate colostrum intake for newborn piglets are essential in free-farrowing systems (Dumniem *et al*., 2024).

Piglets preweaning mortality

In intensive pork production systems, the preweaning mortality rate for sows kept in conventional crate systems typically ranges between 10% and 20% (Muns *et al*., 2016). A key factor contributing to this mortality is the inadequate colostrum intake by low-viability piglets, which leads to insufficient energy and passive immunity transfer (Muns Vila and Tummaruk, 2016; Kirkwood *et al*., 2021). Juthamanee and Tummaruk (2021) demonstrated that piglets with birthweight over 1300 g have a higher average colostrum intake compared to those weighing less than 800 g, 800–999 g, and 1000–1299 g. Additionally, when colostrum intake increased from less than 100 g to 300 g or more, piglet mortality decreased from 88.8% to 6.3% (Juthamanee and Tummaruk, 2021). Dumniem *et al*. (2023) observed that free-farrowing systems tend to improve sow colostrum production, resulting in increased piglet colostrum intake compared to conventional crate systems under tropical conditions. However, despite the higher colostrum intake, overall preweaning mortality in the free-farrowing system remains as high as 26.8%, with approximately 50% of total piglet deaths attributed to crushing by sows (Dumniem *et al*., 2023). Moreover, piglet serum immunoglobulin G concentration decreases when litter size increases, emphasizing the impact of piglet individual colostrum intake and subsequent mortality rates (Muns Vila and Tummaruk, 2016). Additionally, prolonged farrowing duration and increased competition for colostrum among later-born piglets in larger litters also contribute to higher preweaning mortality rates (Laothong *et al*., 2024). These findings clearly indicate a strong relationship between litter size, piglet birthweight, colostrum consumption, and preweaning mortality in hyperprolific sows under tropical conditions.

In the free-farrowing system, where sows have more freedom of movement compared to farrowing crates, preweaning mortality rates among piglets tend to be higher due to an increased risk of accidental crushing by the sow (Goumon *et al*., 2022; Dumniem *et al*., 2023). A recent meta-analysis found that piglet mortality in farrowing pens was 14% higher than in farrowing crates (Glencorse *et al*., 2019). Kielland *et al*. (2018) necropsied the dead piglets in loose housing systems and found that 29.1% of piglet deaths were due to trauma. These piglets are likely to be overlain by the sow, with most deaths occurring within the first day of life. Pathological findings in crushed piglets have included bruising, liver rupture, internal bleeding in the thorax and/or abdomen, and protruding tongues (Chidgey *et al*., 2022). A significantly higher proportion of piglets are crushed by sows in free-farrowing systems compared to conventional crate systems, as reported in both temperate and tropical studies (Dumniem *et al*., 2023). In China, 25.5% of piglets are crushed in free-farrowing systems, while 10.8% are crushed in farrowing crates (Gu *et al*., 2011). In Thailand, crushed piglets accounted for 13.1% vs. 5.8% in free-farrowing pens and farrowing crates, respectively (Dumniem *et al*., 2023).

In the free-farrowing system, the use of protection bars can reduce piglet-crushing incidents to levels comparable to those in farrowing crates (9.3% vs. 10.8%, respectively) (Gu *et al*., 2011). Moreover, the amount of space available also significantly affects preweaning mortality. Sows housed in free-farrowing systems with a space of 5.6 m^2 do not have a significant difference in preweaning mortality compared to those in farrowing crates with less space (1.1 m^2), with rates of 5.1% and 4.7%, respectively (Loftus *et al*., 2020). However, excessively large space allowances (9.7 m^2) have been associated with higher preweaning mortality rates compared to smaller pens (7.9 m^2) (Baxter *et al*., 2015). This may be due to the larger space allowing piglets to wander further, increasing the risk of chilling away from heat sources (Baxter *et al*., 2015). To address this issue, temporarily crating lactating sows for a short period after farrowing is suggested (Goumon *et al*., 2022). Ceballos *et al*. (2021) demonstrated that confining post-partum sows for seven days reduced piglet preweaning mortality rates during the first week of lactation to levels similar to those observed in crated systems (4.8% vs. 5.6%, respectively). Furthermore, piglets in free-farrowing systems have more frequent access to the sow's udder, lower incidences of tail and ear biting, and better growth rates throughout production stages, highlighting the welfare benefits of these systems. (Kinane *et al*., 2021). These findings suggest that appropriate management and housing designs can mitigate the risk of crushing while maintaining the welfare of both sows and piglets.

In conclusion, adopting group housing and free-farrowing systems in the swine industry enhances the freedom of movement for gilts and sows. As Thailand leads the pig industry in Southeast Asia, there is increasing interest in improving farm animal welfare. This underscores the need for a thorough understanding of management practices in alternative housing systems under tropical conditions to support the transition from crate systems to loose housing. This presents a significant opportunity for innovation and research focus on addressing the impacts of alternative housing systems on health, reproduction, and productivity in female breeders under tropical conditions.

Acknowledgments

This project is funded by the National Research Council of Thailand (NRCT) (N42A660892 and N21A660997).

References

Adi YK, Boonprakob R, Kirkwood RN and Tummaruk P 2024. Factors associated with farrowing duration in hyperprolific sows in a free farrowing system under tropical conditions. Animals. 12: 2943.

Adi YK, Boonprakob R, Kirkwood RN and Tummaruk P 2024. Factors affecting birth weight and stillbirth in sows housed in a tropical environment. Reprod Domest Anim. 59: e14500.

Akkhaphan T, Boonprakob R, Grahofer A and Tummaruk P 2025. Seasonal effect on farrowing duration in sows within a temporarily confined farrowing system under tropical climates. Theriogenology. 238: 117364.

Angermann E, Raoult CMC, Wensch-Dorendorf M, Frenking S, Kemper N and von Borell E 2021. Development of a group-adapted housing system for pregnant sows: A field study on performance and welfare aspects. Agriculture. 11: 28.

Anil L, Anil SS, Deen J, Baidoo SK and Walker RD 2006. Effect of group size and structure on the welfare and performance of pregnant sows in pens with electronic sow feeders. Can J Vet Res. 70: 128–136.

Arey D and Edwards S 1998. Factors influencing aggression between sows after mixing and the consequences for welfare and production. Livest Prod Sci. 56: 61–70.

Baxter EM, Adeleye OO, Jack MC, Farish M, Ison SH and Edwards SA 2015. Achieving optimum performance in a loose-housed farrowing system for sows: The effects of space and temperature. Appl Anim Behav Sci. 169: 9–16.

Baxter EM, Moustsen VA, Goumon S, Illmann G and Edwards SA 2022. Transitioning from crates to free farrowing: A roadmap to navigate key decisions. Front Vet Sci. 9: 998192.

Bortolozzo FP, Zanin GP, Ulguim RD and Mellagi APG 2023. Managing reproduction in hyperprolific sow herds. Animals. 13: 1842.

Brajon S, Ahloy-Dallaire J, Devillers N and Guay F 2021. Social status and previous experience in the group as predictors of welfare of sows housed in large semi-static groups. PLoS One. 16: e0244704.

Brito AA, da Silva NAM, Alvarenga Dias ALN and Nascimento MRBM 2022. Heat wave exposure impairs reproductive performance in primiparous sows and gilts in a tropical environment. Int J Biometeorol. 66: 2417–2424.

Bumpenkul R and Imboonta N 2021. Genetic correlations between gestation length and litter traits of sows. Thai J Vet Med. 51: 675–682.

Capoferri R, Parati K, Puglisi R, Moscati L, Sensi M, Lombardi G, Sandri G, Briani C and Galli A 2021. Comparison between single- and group-housed pregnant sows for direct and indirect physiological, reproductive, welfare indicators and gene expression profiling. J Appl Anim Welf Sci. 24: 246–259.

Ceballos MC, Góis KCR, Parsons TD and Pierdon M 2021. Impact of duration of farrowing crate closure on physical indicators of sow welfare and piglet mortality. Animals. 11: 969.

Chapinal N, de la Torre JLR, Cerisuelo A, Gasa J, Baucells MD, Coma J, Vidal A and Manteca X 2010a. Evaluation of welfare and productivity in pregnant sows kept in stalls or in 2 different group housing systems. J Vet Behav. 5: 82–93.

Chapinal N, Ruiz-De-La-Torre JL, Cerisuelo A, Gasa J, Baucells MD and Manteca X 2010b. Aggressive behavior in two different group-housing systems for pregnant sows. J Appl Anim Welf Sci. 13: 137–153.

Chidgey KL, Udomteerasuwat N, Morel PCH and Castillo-Alcala F 2022. Animal welfare compromises associated with causes of death in neonatal piglets. Animals. 12: 2933.

Choe J, Kim S, Cho JH, Lee JJ, Park S, Kim B, Kim J, Baidoo SK, Oh S, Kim HB and Song M 2018. Effects of different gestation housing types on reproductive performance of sows. Anim Sci J. 89: 722–726.

Cronin G, Barnett J, Hodge F, Smith J and McCallum T 1991. The welfare of pigs in two farrowing/lactation environments: cortisol responses of sows. Appl Anim Behav Sci. 32: 117–127.

Cunha ECP, Menezes TD, Bernardi ML, Mellagi APG, Ulguim RD, Wentz I and Bortolozzo FP 2018. Reproductive performance, offspring characteristics, and injury scores according to the housing system of gestating gilts. Livest Sci. 210: 59–67.

D’Eath RB and Turner SP 2009. The natural behaviour of the pig. In: The Welfare of Pigs. Marchant-Forde JN (ed). Dordrecht: Springer 13–45.

Damm BI, Forkman B and Pedersen LJ 2005. Lying down and rolling behaviour in sows in relation to piglet crushing. Appl Anim Behav Sci. 90: 3–20.

Damm BI, Lisborg L, Vestergaard KS and Vanicek J 2003. Nest-building, behavioural disturbances and heart rate in farrowing sows kept in crates and Schmid pens. Livest Prod Sci. 80: 175–187.

de Castro Lippi IC, Caldara FR, de Lima Almeida Paz IC and Odakura AM 2022. Global and Brazilian scenario of guidelines and legislation on welfare in pig farming. Animals. 12: 2615.

Dumniem N, Boonprakob R, Panvichitra C, Thongmark S, Laohanarathip N, Parnitvoraphoom T, Changduangjit S, Boonmakaew T, Teshanukroh N and Tummaruk P 2024. Impacts of fiber supplementation in sows during the transition period on constipation, farrowing duration, colostrum production, and pre-weaning piglet mortality in the free-farrowing system. Animals. 14: 854.

Dumniem N, Parsons TD and Tummaruk P 2025. Feeding levels during early gestation in a group-housing system for primiparous sows: Impact on piglet birthweight and litter uniformity. Anim Biosci. 38: 360–370.

Dumniem N, Boonprakob R, Parsons TD and Tummaruk P 2023. Pen versus crate: A comparative study on the effects of different farrowing systems on farrowing performance, colostrum yield and piglet preweaning mortality in sows under tropical conditions. Animals. 13: 233.

Einarsson S, Sjunnesson Y, Hulten F, Eliasson-Selling L, Dalin AM, Lundeheim N and Magnusson U 2014. A 25 years experience of group-housed sows-reproduction in animal welfare-friendly systems. Acta Vet Scand. 56: 37.

Estienne MJ and Harper AF 2010. Type of accommodation during gestation affects growth performance and reproductive characteristics of gilt offspring. J Anim Sci. 88: 400–407.

Ferreira SV, Rodrigues LA, Ferreira MA, Alkmin DV, Dementshuk JM, Almeida RFCL and Fontes DO 2021. Plane of nutrition during gestation affects reproductive performance and retention rate of hyperprolific sows under commercial conditions. Animal. 15: 100153.

Glencorse D, Plush K, Hazel S, D'Souza D and Hebart M 2019. Impact of non-confinement accommodation on farrowing performance: A systematic review and meta-analysis of farrowing crates versus pens. Animals. 9: 957.

Goumon S, Illmann G, Moustsen VA, Baxter EM and Edwards SA 2022. Review of temporary crating of farrowing and lactating sows. Front Vet Sci. 9: 811810.

Gourdine JL, Quesnel H, Bidanel JP and Renaudeau D 2006. Effect of season, parity and lactation on reproductive performance of sows in a tropical humid climate. Asian-Australas J Anim Sci. 28: 290–302.

Greenwood EC, Plush KJ, van Wettere WHEJ and Hughes PE 2016. Group and individual sow behavior is altered in early gestation by space allowance in the days immediately following grouping. J Anim Sci. 94: 385–393.

Gu ZB, Gao YJ, Lin BZ, Zhong ZZ, Liu ZH, Wang CY and Li BM 2011. Impacts of a freedom farrowing pen design on sow behaviours and performance. Prev Vet Med. 102: 296–303.

Hemsworth PH, Rice M, Nash J, Giri K, Butler KL, Tilbrook AJ and Morrison RS 2013. Effects of group size and floor space allowance on grouped sows: Aggression, stress, skin injuries, and reproductive performance. J Anim Sci. 91: 4953–4964.

Hulbert LE and McGlone JJ 2006. Evaluation of drop versus trickle-feeding systems for crated or group-penned gestating sows. J Anim Sci. 84: 1004–1014.

Illmann G, Chaloupková H and Melisová M 2016. Impact of sow prepartum behavior on maternal behavior, piglet body weight gain, and mortality in farrowing pens and crates. J Anim Sci. 94: 3978–3986.

Jang JC, Jung SW, Jin SS, Ohh SJ, Kim JE and Kim YY 2015. The effects of gilts housed either in group with the electronic sow feeding system or conventional stall. Asian-Australas J Anim Sci. 28: 1512–1518.

Jarvis S, Lawrence AB, McLean KA, Deans LA, Chirnside J and Calvert SK 1997. The effect of environment on behavioural activity, ACTH, (β-endorphin and cortisol in pre-farrowing gilts. Anim Sci. 65: 465–472.

Jensen MB, Pedersen LJ, Theil PK and Knudsen KEB 2015. Hunger in pregnant sows: Effects of a fibrous diet and free access to straw. Appl Anim Behav Sci. 171: 81–87.

Jensen TB, Bonde MK, Kongsted AG, Toft N and Sorensen JT 2010. The interrelationships between clinical signs and their effect on involuntary culling among pregnant sows in group-housing systems. Animal. 4: 1922–1928.

Jeong Y, Choi Y, Kim D, Kim J, Min Y, Jung H and Kim Y 2020. Improving behavior characteristics and stress indices of gestating sows housed with group housing facility. J Anim Sci Technol. 62: 875–883.

Johnston LJ and Li YZ 2013. Performance and well-being of sows housed in pens retrofitted from gestation stalls. J Anim Sci. 91: 5937–5945.

Juthamanee P and Tummaruk P 2021. Factors associated with colostrum consumption in neonatal piglets. Livest Sci. 251: 104630.

Kielland C, Wisloff H, Valheim M, Fauske AK, Reksen O and Framstad T 2018. Preweaning mortality in piglets in loose-housed herds: etiology and prevalence. Animal. 12: 1950–1957.

Kim KH, Hosseindoust A, Ingale SL, Lee SH, Noh HS, Choi YH, Jeon SM, Kim YH and Chae BJ 2016b. Effects of gestational housing on reproductive performance and behavior of sows with different backfat thickness. Asian-Australas J Anim Sci. 29: 142–148.

Kinane O, Butler F and O'Driscoll K 2021. Freedom to grow: Improving sow welfare also benefits piglets. Animals. 11: 1181.

Kinane O, Butler F and O'Driscoll K 2022. Freedom to move: Free lactation pens improve sow welfare. Animals. 12: 1762.

Kirkwood RN, Langendijk P and Carr J 2021. Management str Management strategies for impr ategies for improving sur ving survival of piglets fr al of piglets from hyperprolific sows. Thai J Vet Med. 51: 629–636.

Knox R, Salak-Johnson J, Hopgood M, Greiner L and Connor J 2014. Effect of day of mixing gestating sows on measures of reproductive performance and animal welfare. J Anim Sci. 92: 1698–1707.

Koketsu Y and Iida R 2017. Sow housing associated with reproductive performance in breeding herds. Mol Reprod Dev. 84: 979–986.

Lagoda ME, Marchewka J, O'Driscoll K and Boyle LA 2022. Risk factors for chronic stress in sows housed in groups, and associated risks of prenatal stress in their offspring. Front Vet Sci. 9: 883154.

Lagoda ME, O'Driscoll K, Marchewka J, Foister S, Turner SP and Boyle LA 2021. Associations between skin lesion counts, hair cortisol concentrations and reproductive performance in group housed sows. Livest Sci. 246: 104463.

Langendijk P 2021. Latest advances in sow nutrition during early gestation. Animals. 11: 1720.

Laothong K, Kamlangsaeng S, Laipasu K, Tirakarn K and Tummaruk P 2024. Colostrum intake and neonatal characteristics in piglets experiencing varying lengths of expulsion phase. Theriogenology. 227: 128–137.

Li X, Baidoo SK, Li YZ, Shurson GC and Johnston LJ 2014. Interactive effects of distillers dried grains with solubles and housing system on reproductive performance and longevity of sows over three reproductive cycles. J Anim Sci. 92: 1562–1573.

Loftus L, Bell G, Padmore E, Atkinson S, Henworth A and Hoyle M 2020. The effect of two different farrowing systems on sow behaviour, and piglet behaviour, mortality and growth. Appl Anim Behav Sci. 232: 105102.

Maes D, Pluym L and Peltoniemi O 2016. Impact of group housing of pregnant sows on health. Porcine Health Manag. 2: 17.

Maria N, Jinhyeon Y, Shah HS, Stefan B, Anna V, Nicoline S, Chantal F and Olli P 2023. Sow nest-building behavior in communal farrowing relates to productivity and litter size. Appl Anim Behav Sci. 269: 106117.

McGlone JJ 2013. Updated scientific evidence on the welfare of gestating sows kept in different housing systems. Prof Anim Sci. 29: 189–198.

Melchior R, Zanella I, Lovatto PA, Lehnen CR, Lanferdini E and Andretta I 2012. Meta-analysis on the relationship among feeding characteristics, salivary and plasmatic cortisol levels, and performance of pregnant sows housed in different systems. Livest Sci. 150: 310–315.

Min Y, Choi Y, Kim J, Kim D, Jeong Y, Kim Y, Song M and Jung H 2020. Comparison of the productivity of primiparous sows housed in individual stalls and group housing systems. Animals. 10: 1940.

Muns R, Nuntapaitoon M and Tummaruk P 2016. Non-infectious causes of pre-weaning mortality in piglets. Livest Sci. 184: 46–57.

Muns Vila R and Tummaruk P 2016. Management strategies in farrowing house to improve piglet pre-weaning survival and growth. Thai J Vet Med. 46: 347–354.

Oliviero C, Heinonen A, Valros A, Hälli O and Peltoniemi OAT 2008. Effect of the environment on the physiology of the sow during late pregnancy, farrowing and early lactation. Anim Reprod Sci. 105: 365–377.

Olsson AC, Andersson M, Botermans J, Rantzer D and Svendsen J 2011. Animal interaction and response to electronic sow feeding (ESF) in 3 different herds and effects of function settings to increase capacity. Livest Sci. 137: 268–272.

Peltoniemi O, Bjorkman S and Maes D 2016. Reproduction of group-housed sows. Porcine Health Manag. 2: 15.

Perini JEGN, Ludtke CB, Tanure CB, Seixas L, Peripolli V and McManus C 2021. Effect of housing system during pregnancy on reproductive parameters of sows. Arq Bras Med Vet Zootec. 73: 123–131.

Plush KJ, Hewitt RJ, D'Souza DN and van Barneveld RJ 2024. Review: Towards truly stall free pork production?. Animal. 18: 101002.

Prasomsri P 2022. Effect of lameness on daily milk yield in dairy cow. Thai J Vet Med. 52: 679–687.

Razdan P, Tummaruk P, Kindahl H, Rodriguez-Martinez H, Hulten F and Einarsson S 2004. Hormonal profiles and embryo survival of sows subjected to induced stress during days 13 and 14 of pregnancy. Anim Reprod Sci. 81: 295–312.

Ren P, Yang XJ, Railton R, Jendza J, Anil L and Baidoo SK 2018. Effects of different levels of feed intake during four short periods of gestation and housing systems on sows and litter performance. Anim Reprod Sci. 188: 21–34.

Rhodes RT, Appleby MC, Chinn K, Douglas L, Firkins LD, Houpt KA, Irwin C, McGlone JJ, Sundberg P, Tokach L and Wills RW 2005. A comprehensive review of housing for pregnant sows. J Am Vet Med Assoc. 227: 1580–1590.

Ryan EB, Fraser D and Weary DM 2015. Public attitudes to housing systems for pregnant pigs. PLoS One. 10: e0141878.

Salak-Johnson JL 2017. Social status and housing factors affect reproductive performance of pregnant sows in groups. Mol Reprod Dev. 84: 905–913.

Sánchez-Salcedo JA and Yáñez-Pizaña A 2024. Effects of free farrowing system on the productive performance and welfare of sows and piglets. J Appl Anim Welf Sci. 27: 1–11.

Schalk C, Pfaffinger B, Schmucker S, Weiler U and Stefanski V 2018. Effects of repeated social mixing on behavior and blood immune cells of group-housed pregnant sows (*Sus scrofa domestica*). Livest Sci. 217: 148–156.

Schütz A, Busch G and Sonntag WI 2023. Systematically analyzing the acceptability of pig farming systems with different animal welfare levels when considering intra-sustainability trade-offs: Are citizens willing to compromise?. PLoS One. 18: e0282530.

Schwarz T, Malopolska M, Nowicki J, Tuz R, Lazic S, Kopyra M and Bartlewski PM 2021. Effects of individual versus group housing system during the weaning-to-estrus interval on reproductive performance of sows. Animal. 15: 100122.

Séguin MJ, Barney D and Widowski TM 2005. Assessment of a group-housing system for gestating sows: Effects of space allowance and pen size on the incidence of superficial skin lesions, changes in body condition, and farrowing performance. J Swine Health Prod. 14: 89–96.

Spoolder HAM, Geudeke MJ, Van der Peet-Schwering CMC and Soede NM 2009. Group housing of sows in early pregnancy: A review of success and risk factors. Livest Sci. 125: 1–14.

Sporri-Vontobel C, Simmler M, Wechsler B and Scriba MF 2023. Risk factors differ for viable and low viable crushed piglets in free farrowing pens. Front Vet Sci. 10: 1172446.

Stevens B, Karlen GM, Morrison R, Gonyou HW, Butler KL, Kerswell KJ and Hemsworth PH 2015. Effects of stage of gestation at mixing on aggression, injuries and stress in sows. Appl Anim Behav Sci. 165: 40–46.

Thiengpimol P, Koonawootrittriron S and Suwanasopee T 2024. Assessing reproductive performance and predictive models for litter size in Landrace sows under tropical conditions. Anim Biosci. 37: 1333–1344.

Tripipat T, Saeng-Chuto K, Madapong A, Stott CJ, Tantituvanont A, Kaewprommal P, Piriyapongsa J and Nilubol D 2021. Dynamics and evolution of genotype 1 porcine reproductive and respiratory syndrome virus following its introduction into a herd concurrently infected with genotypes 1 and 2. Thai J Vet Med. 51: 519–529.

Tummaruk P, De Rensis F and Kirkwood RN 2023. Managing prolific sows in tropical environments. Mol Reprod Dev. 90: 533–545.

Tummaruk P, Tantasuparuk W, Techakumphu M and Kunavongkrit A 2010. Seasonal influences on the litter size at birth of pigs are more pronounced in the gilt than sow litters. J Agric Sci. 148: 421–432.

Tuyttens FAM, Van Gansbeke S and Ampe B 2011. Survey among Belgian pig producers about the introduction of group housing systems for gestating sows. J Anim Sci. 89: 845-855.

Vandresen B and Hotzel MJ 2021. "Mothers should have freedom of movement"-Citizens' attitudes regarding farrowing housing systems for sows and their piglets. Animals. 11: 3439.

Verdon M, Hansen CF, Rault JL, Jongman E, Hansen LU, Plush K and Hemsworth PH 2015. Effects of group housing on sow welfare: a review. J Anim Sci. 93: 1999–2017.

Verdon M, Morrison R, Rice M and Hemsworth P 2016. Individual variation in sow aggressive behavior and its relationship with sow welfare. J Anim Sci. 94: 1203–1214.

Visetnoi S and Nelles W 2014. Higher education and sustainability in Thailand: a review of National Research University roles in sustainable agriculture education. Int Soc Sci J. 65: 185–198.

Visetnoi S and Nelles W 2023. Can organic pork help achieve sustainable development goals in Thailand?. Agriculture. 13: 1822.

Weber R, Keil NM, Fehr M and Horat R 2009. Factors affecting piglet mortality in loose farrowing systems on commercial farms. Livest Sci. 124: 216–222.

Yun J, Swan KM, Farmer C, Oliviero C, Peltoniemi O and Valros A 2014. Prepartum nest-building has an impact on postpartum nursing performance and maternal behaviour in early lactating sows. Appl Anim Behav Sci. 160: 31–37.

Yun J, Swan KM, Oliviero C, Peltoniemi O and Valros A 2015. Effects of prepartum housing environment on abnormal behaviour, the farrowing process, and interactions with circulating oxytocin in sows. Appl Anim Behav Sci. 162: 20–25.

Yun J, Swan KM, Vienola K, Farmer C, Oliviero C, Peltoniemi O and Valros A 2013. Nest-building in sows: Effects of farrowing housing on hormonal modulation of maternal characteristics. Appl Anim Behav Sci. 148: 77–84.

Zeng FW and Zhang SQ 2023. Impacts of sow behaviour on reproductive performance: current understanding. J Appl Anim Res. 51: 256–264.

Zhao Y, Flowers WL, Saraiva A, Yeum KJ and Kim SW 2013. Effect of social ranks and gestation housing systems on oxidative stress status, reproductive performance, and immune status of sows. J Anim Sci. 91: 5848–5858.

Zhou Q, Sun Q, Wang G, Zhou B, Lu M, Marchant JN, Yang X and Zhao R 2014. Group housing during gestation affects the behaviour of sows and the physiological indices of offspring at weaning. Animal. 8: 1162–1169.