Animal xxx (xxxx) xxx

Contents lists available at ScienceDirect

Animal
The international journal of animal biosciences

Review: Towards truly stall-free pork production?

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A R T I C L E I N F O

Article history:
Received 15 May 2023
Revised 20 September 2023
Accepted 28 September 2023
Available online xxxx

Keywords:
Boars
Crates
Sows
Stalls
Welfare

A B S T R A C T

The individual housing of sows and boars within stalls is still frequent in commercial pork production, especially when the risk for impaired reproduction or welfare is high. Whilst many countries have either removed stall housing in gestation or are working towards this through the successful adoption of group housing, stalls are still used around weaning and mating and in farrowing crates for sows. In this review, we describe the stages in which stall use still occurs and why this is so, with the aim of determining whether stall-free pork production can realistically be achieved through successful industry adoption. Group housing during the period around weaning, oestrus and mating will present several issues such as sow aggression, riding and mounting. This will result in injuries and reduced reproductive performance for the animals, and an unsafe work environment for stock people if not adequately addressed. The second, most obvious stage of the reproductive cycle where stalls are used and removal would result in substantial detriment is in the farrowing crate, where associated high preweaning mortalities still plague both experimental and commercial outcomes. The use of temporary confinement has received renewed interest recently to reduce this mortality, but still involves the strategic use of a stall when piglets are at greatest risk of crushing. To transition towards complete removal of stalls around farrowing, we suggest that space allowance, in combination with animal and staff experience, are areas of opportunity. If the concerns identified during these two final reproductive stages can be addressed to limit poor animal welfare and productivity impacts, the use of stalls could be completely removed from pork production.

Implications

Many pork industries have reduced reliance on stalls through the adoption of group housing during gestation. The two stages representing risk for animal welfare and productivity if stall use was discontinued remain around mating and during farrowing. We propose that aspects learned from group gestation housing could be adapted to manage sows after weaning, in combination with technology to solve unique problems to this period such as oestrus and mating management. The removal of stalls from farrowing results in increased piglet mortality. This problem may be reduced when functional areas are combined to reduce space, and when stockperson and animal experience are considered.

Introduction

Stall housing involves confinement of a pig within a restrictive space (usually only just greater than the size of the pig itself), and occurs because it allows for individual animal care and feeding, improved space utilisation within units, better hygiene, and a safe work environment for stock people to operate in (Koketsu and Iida, 2017). The use of stalls does however come at a significant cost to the animal due to the impairment of behavioural freedom; the pig cannot turn around, perform species-specific, intrinsic behaviours, thermoregulate appropriately, or interact with conspecifics. There is repeated evidence that this results in behavioural abnormalities such as stereotypies, chronic stress, increased incidence of disease and reduced performance (Barnett et al., 2001). These all have obvious, deleterious consequences for animal welfare, and farm productivity.

The use of stalls is becoming increasingly hard to justify with improving knowledge in welfare assessment and so our understanding of implications associated with stall housing, for example, The Five Domains Model which now includes mental or affective state (Mellor and Beausoleil, 2015). As a result of this advancement in science and increasing societal pressure (Weaver and Morris, 2004), legislative changes are becoming more frequent outside of Europe (recent examples include Proposition 12 in the United States, NAWAC Draft Code in New Zealand, etc.; summarised in Table 1) that will severely reduce or even completely inhibit the

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https://doi.org/10.1016/j.animal.2023.101002
1751-7311/

Table 1
Environmental scan of proposed or future legislation of pigs for the use of stalls in sow and boar housing.

	Sows			
Country	Timeline	Gestation	Lactation	Boars
Australia (https://australianpork.com.au/apiq/apiq-notifications/apiq-standards-manual-effective-1-august-2022)	Current Model Code of Practice, Pigs published in 2007. Standards and guidelines review pending. Retailer specifications included in Australian Pork Industry Quality Assurance Programme.	Retailer specification can be inseminated in stalls for a period of no longer than 24 h, housed in groups at 1. 5 m^2, provided with manipulable and rootable material for at least part of breeding cycle.	Retailer specification use of farrowing crate permitted.	Retailer specification not kept in stalls, allowed 6 m^2.
New Zealand (https://www.mpi.govt.nz/dmsdocument/50923/direct)	Current Code of Welfare for Pigs reviewed by the National Animal Welfare Advisory Committee in 2022, with revised options proposed.	Option includes use of stall for the purpose of insemination for no more than three hours at a time, for a maximum of three times per oestrus cycle, access to materials that can be manipulated.	Option A free farrowing, Option B temporary crating for 72 h after nest building, both with 6.5 m^2 and access to 2 kg of long-stemmed straw or equivalent volume of alternative with similar properties no less than 48 h before expected farrowing.	Must not be kept in stalls and provided with enough space so they can stand up, turn around and lie comfortably in a natural position.
United States of America (https://nppc.org/prop12/)	Proposition 12 Californian law requiring breeding pigs, veal calves and laying hens be housed in confinement systems that comply with specific standards for freedom of movement, cage-free design and minimum space, implemented 2024.	Stall housing banned unless under veterinary prescription which then allows six hours within 24 h period and no more than 24 h in 30 days, housed in groups at 2.2 m^2.	Farrowing crate allowed from five days prior to expected due date until piglets weaned.	Not specifically mentioned, use of terminology 'breeding pig' defined as female pig kept for the purpose of commercial breeding who is six months or older or pregnant, so excludes boar. Assume stall still permitted.
Canada (https://www.nfacc.ca/codes-of-practice/pigs)	Code of Practice for the Care and Handling of Pigs published in 2014, reviewed in 2019. Review recommendations to implemented by 2029.	Stall housing for up to 28 d after insemination, and an additional seven days permitted to manage grouping, gilts provided 1.4–1.7 m^2 and sows 1.8–2.2 m^2 in groups, functional and effective enrichment for sows that remain in stalls.	Not mentioned in review, farrowing crate permitted.	Not kept in stalls and housed in individual pens with sufficient space to turn around.
United Kingdom (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/908108/code-practice-welfare-pigs.pdf)	Code of Practice for the Welfare of Pigs published 2020, specific mention of new systems to 'protect the welfare of the sow'.	Stall housing during insemination, reintroduced to group between inseminations, space allowance of 1.64–2.25 m^2, all pigs must have permanent access to materials such as straw, hay, wood, sawdust, mushroom compost, peat.	Farrowing crate allowed, provided with suitable nesting material in sufficient quantity unless slurry system prevents.	Housed in pens, allowed to turn around and hear, smell and see other pigs at 6 m^2.
Netherlands (https://wetten.overheid.nl/BWBR0030250/2013–01-01#Hoofdstuk11)	European Union Minimum Standards for the Protection of Pigs published in 2008. Commission preparing proposals for animal welfare legislation, expected in 2023. Country specific variations outlined in the Animal Welfare Act.	Stall use permitted from weaning until four d following insemination.	Farrowing crate currently permitted, but use expected to be restricted in EU Commission review. Must be provided with enrichment the week before farrowing.	Housed in pens, allowed to turn around and hear, smell and see other pigs at 6 m^2.
Denmark (https://agricultureandfood.dk/danish-agriculture-and-food/animal-welfare)	European Union Minimum Standards for the Protection of Pigs published in 2008. Commission preparing proposals for animal welfare legislation, expected in 2023. Country specific variations outlined in the Danish Animal Protection Act.	Stall housing allowed for 28 d	Farrowing crate currently permitted, but use expected to be restricted in EU Commission review. Must be provided with enrichment the week before farrowing.	Housed in pens, allowed to turn around and hear, smell and see other pigs at 6 m^2.
Germany (https://www.gesetze-im-internet.de/tierschnutztv/BJNR275800001.html)	European Union Minimum Standards for the Protection of Pigs published in 2008. Animal Welfare Act amended 2020, with 8- and 15-year transition periods for gestating and lactating sows respectively.	Stall use permitted only during insemination, with 5 m^2 provided during the wean-to-service period.	Temporary crating allowed for five days with 6.5 m^2, all pigs have access to organic and fibre-rich employment material.	Housed in pens, allowed to turn around and hear, smell and see other pigs at 6 m^2.

Table 1 (*continued*)

Country	Sows			Boars
	Timeline	Gestation	Lactation	
Austria (https://info.bml.gv.at/en/topics/agriculture/agriculture-in-austria/animal-production-in-austria/animal-welfare-act.html)	European Union Minimum Standards for the Protection of Pigs published in 2008. Federal Law Gazette II to be enacted 2033.	Stalls permitted for the first ten days after service.	Temporary crating allowed for 'critical period of piglets life' with 5.5 m^2, suitable nesting material in sufficient quantities provided week prior to expected due date unless slurry system limits feasibility.	Housed in pens, allowed to turn around and hear, smell and see other pigs at 6 m^2.

use of stalls across pork production systems. Within Australia, the voluntary phase out of gestation stalls (APL, 2017) has led to a substantial decrease in the amount of time sows spend in this type of housing but there are still periods in which their use is still commonplace, usually around 'high risk' events. Standards from supermarket retailers limit stall use further, with greater market-driven restrictions expected.

Stalls are still routinely used when sows are weaned and mated in insemination stations, during early pregnancy, give birth to and rear young piglets in farrowing crates, and when boars are housed on sow units. The reason for their continued use will be explored further in later sections, and historically, is often for good reason. But with increased experience and confidence in group gestation systems, there may be an opportunity to examine whether there is indeed a requirement for stall use in any stage of pork production. In this review of the literature, we focus on the phases of the reproductive cycle in which the use of the stall is still routine to critically examine whether there is an opportunity to completely remove its use. The aim of this review is to determine whether stall-free pork production is achievable, and if not so immediately, identify knowledge gaps that once addressed, should position the industry well to move away from stall use over time.

Weaning and mating

Weaning of sows involves several events that when not managed correctly, can result in stress (Pedersen et al., 1993) ultimately negatively impacting on welfare and reproduction. These include separation from the litter, aggression whilst a social hierarchy is formed, competition for feed and other resources, and unavoidable oestrus behaviours such as flank nosing and riding from pen mates. For these reasons, sows were, and in many cases still are, weaned into individual stalls to negate the occurrences around breeding. To eliminate the requirement for stalls in the period between weaning and mating, each of these factors needs to be adequately addressed.

Mixing into groups

Mixing sows at weaning uncouples the negative link between social stress and reproduction, as the stressors occur prior to the mating event when sows are managed in stable groups. Reviews on the impact of grouping sows are voluminous (Barnett et al., 2001; Spoolder et al., 2009) and so only discussed briefly here. Aggression in sows is highest during hierarchy establishment which acts to deter long-term fighting for limited resources (Verdon et al., 2015). Increasing space allowance is effective at reducing aggression at mixing (Hemsworth et al., 2013), and whilst difficult to implement throughout gestation for economic arguments, is justifiable during the wean to mate period given the short timeframe (less than seven days) required. In this example, aggression was decreased linearly when space increased from 1.4 to 3.0 m^2 per sow, although no further reduction in circulating cortisol concentrations were reported above 1.8 m^2 per sow. Additional strategies that are effective at reducing aggression at mixing include sorting sows into homogeneous parity groups (Li et al., 2012) and the strategic use of enrichment such as nutritional blocks (Muller et al., 2017). The most important limiting resource to a weaned sow is feed, and so increasing feed allowance before breeding acts to reduce fighting (Whittakera et al., 1996), as well as improve ovulation rate and litter size (King and Williams, 1984).

When the above considerations are employed, aggression during hierarchy formation should subside within the first 24 h as reviewed by Verdon et al. (2015). After this point, observed oestrus behaviours (mounting, levering and nosing) pose several issues; the effects of these behaviours on pen mates, adequate detection of these sows for insemination, and mating management that secures stock-person safety. Oestrus behaviours are observed most frequently two to five days following weaning (Rault et al., 2014) and last up to 48 h in gilts and 72 h in sows (Kraeling and Webel, 2015). High-ranking sows are often those that are larger and older, and these sows exhibit mounting behaviours more often (Pedersen et al., 1993) which has obvious ramifications for leg, claw and hip damage and in many instances lameness. The effects of group housing during gestation on injuries and lameness have been well reported (Karlen et al., 2007) but impacts around breeding associated with oestrus behaviours have not been adequately addressed. The previously reported impacts of space allowance and group size (Hemsworth et al., 2013), flooring (Elmore et al., 2010), escape zones (Greenwood et al., 2019) and parity segregation (Li et al., 2012) during gestation would be expected to have similar outcomes during the wean-to-service period. Mating pens should therefore house small groups of sows sorted for parity or size, with larger space allowances, flooring that prevents slipping, and structures that facilitate protection. What is unknown is the impacts of peak oestrus activity on health and welfare outcomes in grouped sows.

Oestrus behaviours and detection

Perhaps the biggest concern when sows are group housed at weaning is adequate detection of oestrus for a mating that results in successful pregnancy and reduced non-productive days. Whilst some suggest that 'positive stress' acts to stimulate oestrus, others such as the review by Kemp et al. (2005) argue that the effect of grouping is equivocal. The ability to detect oestrus may be improved in groups because of increased freedom of behavioural expression (Peltoniemi et al., 2016), but the exhibition of oestrus behaviour is dependent on social rank (Pedersen and Jensen, 1989), and so subordinate sows are at a higher risk of 'silent oestrus' (Kemp et al., 2005). Impaired oestrus detection may limit reproductive output, and so whilst still important in stall-weaned sows, becomes even more crucial in group-housed systems. To successfully invoke receptive behaviour in sows, olfactory, auditory and tactile stimuli are required in combination (Langendijk et al., 2006). Common practice is for the boar to provide the smell and sound component, whilst the stockperson conducts the 'back pressure test' (explored later). There is individual variation in the ability of the boar to induce the behavioural response in sows required for oestrus detection (Pearce and Hughes, 1987), and so the use of a mature, vasectomised boar with high libido is essential. Housing sows adjacent to boars negatively affects oestrus expression and detection (Knox et al., 2004), and so should be avoided to prevent habituation and the negative effect of refractory behaviours. Interestingly, the use of artificial boars may remove individual variation in the ability of boars to stimulate required oestrus behaviours in sows for detection. Lei et al. (2021) used a silicone nose that emitted sounds and scents of a boar. Sows were curious of the device, with a mean contact time of 8 s over a 3-min test period, but when in oestrus, this increased to 30 s. The authors concluded that the device was an innovative technology to detect sows in heat but such technologies require commercial validation before recommendations can be made.

Ultimately, the stockperson is still responsible for heat detection and the decision of when to mate the sow. This decision is based on the sow's response to the 'back pressure test' using tactile stimulation (rubbing of flanks and pressing on back) in the presence of a boar. A positive response is recorded when the sow stands still and cocks its ears. The ability of the stockperson to select the appropriate boar, provide adequate boar contact and tactile stimulation, and recognise the signs of oestrus is therefore crucial. Even the way in which sows are handled by stock people becomes important in group systems. Positive handling of sows in lactation has been shown to improve oestrus behaviour following weaning, and so likelihood to detect oestrus (Pedersen et al., 2003). The level of stockperson skill is highly variable, and with labour shortages common across pork production systems (Daigle and Ridge, 2018), technology may provide a more accurate way of heat detection in grouped sows.

With the advancement of technology, automation of oestrus detection is becoming more achievable under commercial conditions, with systems now commonplace in other livestock such as dairy cows (Mottram, 2016; Stygar et al., 2021). Group-housed sows have increased freedom of movement, and so the detection of behavioural changes is a commonly studied field. As reviewed by Cornou (2006), accelerometer tags, global positioning systems and computer vision have been used to detect the increases in activity that sows on heat exhibit, as well as the occurrence and duration of time spent in proximity to boar pens. The use of machine learning is also being applied to automate oestrus detection (Lei et al., 2021), as well as the analyses of acoustic data via convolutional neural network algorithms (Wang et al., 2022) with both technologies exhibiting an accuracy of 98%. More objective changes in physiology can be utilised to address stockperson skill variability and include increases in vulval temperature using thermal imaging (Simões et al., 2014), three-dimensional (**3D**) imaging of vulva size (De la Cruz-Vigo et al., 2022), changes in vaginal impedance (Řezáč, 2008) and glycoprotein levels in cervical secretions (Pluta et al., 2011). It is suggested that using these technologies in combination increases the sensitivity and specificity (Cornou, 2006) and so with time and improved adoption, may be an attractive alternative to the manual 'back pressure test' conducted by stock people in group-weaned sow.

Insemination procedures

When oestrus is identified, mating the sow outside a stall becomes problematic. As reviewed by Peltoniemi et al. (2016), moving small groups of sows to a dedicated detection mating area is the most appropriate way to conduct artificial insemination, but even these authors conclude that this requires a great deal of labour and so is a costly exercise. Moving the boar to the sow pens would appear to be a less laborious alternative for at least mature sows. What is clear is that small group sizes (four to six sows) are preferred (Peltoniemi et al., 2016), as to ensure stockperson safety, all sows in oestrus within a pen should be mated concurrently whilst in standing heat. This then raises an issue with regards to the insemination technique. Postcervical insemination (**PCAI**) involves the deposition of semen past the cervix. Advantages include a reduced spermatozoa concentration per dose which has implications for genetic improvement, but importantly a substantial reduction in the amount of time taken to conduct the procedure, and results in significant labour advantages over cervical insemination (García-Vázquez et al., 2019). These authors mention that there is substantial industry concern as to the use of PCAI in the presence of boars as cervical contractions can impair correct placement of the inner catheter. But as discussed, the improvements in catheter materials have increased the success of PCAI in gilts, and so perhaps this mating technique could be tested in grouped sows in standing heat to increase the speed of insemination. Hormonal control of oestrus and ovulation is also something that could reduce labour associated with mating in groups (De Rensis and Kirkwood, 2016) although market acceptance is questionable (Ufer et al., 2019).

Performance of grouped sows

There have been very few, recent investigations that directly compare the performance of group housing to stalls during the weaning to mating period. Rault et al. (2014) examined the sexual behaviour, aggression, stress and reproduction of sows grouped either immediately after weaning or following insemination. Group-weaned sows were given substantial space allowance (4.4 m^2 per sow) but protected during feeding and insemination times using stalls. Stall-housed sows were managed identically in terms of feeding and mating management. Key findings from this study were that sows weaned into groups had higher cortisol and so stress levels prior to mating. Injuries were highest at the point of mixing after weaning in grouped sows and following mating in stalled sows. An extended wean-to-service period was identified in the group-weaned sows compared to those in stalls and was explained by inhibited oestrus detection (higher incidence of 'silent oestrus'), with no differences in the farrowing rate or litter size. Schwarz et al. (2021) utilised a higher sample size over a two-year period to better understand the cumulative impacts of grouping at weaning on reproductive traits. In this design, sows were weaned into small groups of eight and again given ample space allowance (3.0 m^2 per sow), mated in stalls at standing heat, and only grouped again after pregnancy confirmation at approximately 28 days of gestation. Significant improvements in conception and farrowing rate, litter size and farrowing interval were identified which all contributed to a 0.8 increase in liveborn pigs per sow per year in group-weaned compared to stall-weaned sows. However, in both investigations, strategic use of stalls was still employed. Even in countries in which stalls are banned, lockable feeding stations are still used for insemination (Einarsson et al., 2014). Based on the literature, we conclude that the scientific evaluation of a true 'stall-free' system in which sows are weaned, fed and bred exclusively in group pens is yet to be investigated thoroughly.

Gestation

As the topic of mixing sows and the ensuant aggression has been described above and reviewed extensively, will only be summarised briefly. Factors to be considered and optimised include space allowance and pen design, feed delivery and frequency, group composition, and environmental enrichment as reviewed by Verdon et al. (2015). This section will instead focus on how to deliver the individual animal care that was facilitated by stall housing, but under group pen conditions to sows in gestation. The rapid identification of sows that are unwell, not receiving adequate nutrition, or require any other intervention or movement, is difficult and requires skilled stock people, superior management systems and well-designed infrastructure to ensure animal welfare and productivity outcomes. This individual animal management in groups is becoming easier through better use of existing infrastructure, or integration of new technologies. The electronic sow feeder (**ESF**) is not a new concept and was originally developed to allow sows to eat whilst protected ensuring they receive daily nutritional requirements. Adaptations mean this feeder can now monitor sow weight and align feeding regimes to body condition, blend diets during varying stages of gestation to better meet sow and foetal requirements (Buis, 2016), detect sows that return to oestrus (Cornou et al., 2008) and those that are lame (Briene et al., 2021) and even predict poor farrowing house performance (Vargovic et al., 2021). The use of ESFs also allows for the implementation of dynamic gestation housing, where a very large group of sows at varying stages of gestation can be maintained within a group at similar welfare standards as small groups (Strawford et al., 2008), but providing savings in space and internal pen fittings. As ESFs reduce the level of human interaction, care should be given to sows as fear of humans has been shown to differ in gestation systems (Marchant-Forde et al., 2003), and this fear may have negative impacts during other stages of the reproductive cycle such as oestrus and farrowing as discussed in earlier and subsequent sections, respectively. Outside of ESFs, solutions in development to better manage individual sows under group housing conditions include vision, tag-based accelerometer, microphone, and load cell technologies, often in combination with electronic ear tags (Gómez et al., 2021). Better use of data that are already being generated by utilised technologies such as ESFs to manage sows individually should be adopted by the industry rapidly (and in some instances has already).

Farrowing and lactation

The modern sow is larger in size (Moustsen et al., 2011) and gives birth to a higher number of piglets at increased risk of mortality as reviewed by Rutherford et al. (2013), primarily from being crushed during sow movement. Because of this, sows are restrained by a stall within the farrowing crate which acts to reduce the freedom of movement and slow the transition between postures to improve piglet survivability. There are also additional staff safety benefits as the risk of aggression by the sow towards stock people is high around farrowing (Marchant, 2002). Scientific attention in free farrowing is not new, but widescale, commercial adoption is absent outside a few European countries in which it is legislated (Sweden, Norway and Switzerland). This is primarily because free farrowing results in increased piglet mortality (Glencorse et al., 2019), having obvious negative animal welfare and financial ramifications. The increased space requirement of free farrowing systems is also heavily implicated in adoption failure as reviewed by Baxter et al. (2022). There is renewed interest in better understanding temporary crating options (Goumon et al., 2022) which involve the confinement of a sow within a stall only during the time of greatest risk for piglet mortality (usually the first seven to ten days of lactation (Condous et al., 2016)). This reduces the length of time a sow spends within a stall during lactation but does not eliminate its use. As argued by Plush and Nowland (2022), the most important period to increase the freedom of movement for sows is immediately preceding farrowing when intrinsic factors drive nesting behaviours. These authors summarised that when nesting is inhibited, increased stress response, increased farrowing duration, increased intra-partum piglet death, reduced maternal bond, and reduced piglet colostrum and milk intake have been reported. As types of nesting substrate and associated costs and benefits have been discussed extensively in this review, they will not be reported here. Rather, the level of confinement will be explored. If labour availability was unrestricted for continual sow observation at farrowing, performance can be maintained or even improved when sows are allowed to farrow free but confined immediately after farrowing completion (Nowland et al., 2017). However, when standard working hours are maintained (0700–1600), timing from farrowing completion until crating can be extended, and has been shown to increase piglet mortality in the range of 0.5–1.5 pigs per litter (Condous et al., 2016). To remove the need for stalls during farrowing and lactation, a fresh look on the old question of space requirement needs to occur to address preweaning survival of piglets and facilitate greater industry uptake. Additionally, a better understanding of the role of experience of both the stockperson and the sow is required.

Size and design

It is commonly cited that for sow welfare and performance to be optimised in free farrowing, large space allowances are required. This is because when sows are given adequate space, they can perform gathering behaviours which involve locating and grouping the litter so that the risk of piglet mortality during posture changes is minimised (Weber et al., 2009). A higher space allowance also increases pen hygiene as the provision of nesting materials often requires some solid flooring to negate complications with drainage systems (Plush and Nowland, 2022) resulting in a nest, and a separate dunging area that is slatted. Often however, the feeder is contained within the nest, and as sows will turn away from the feeder to defecate (Andersen and Pedersen, 2011), this nest area can become soiled, creating a wet and dirty environment both for the sow and her litter. Sharing these functional zones has been suggested as a possible way to decrease the required space (Baxter et al., 2022), and the use of fully slatted flooring (assuming nesting substrates are managed appropriately) is one way in which this can be achieved. In this scenario, nesting and dunging zones can be combined reducing the overall footprint of the free farrowing pen.

When solely investigating the size of the nesting area (excluding the slatted, dunging section), there appears to be a positive relationship between space and piglet mortality; the more space provided, the higher the chance of a piglet dying. With the hypothesis that more space would improve maternal behaviour, Baxter et al. (2015) investigated two nest sizes at 3.3 and 4.0 m^2 and demonstrated that whilst farrowing kinetics of sows (farrowing duration and piglet birth interval) did not differ, liveborn mortality was highest in the large pen (18.1 vs 10.9%). Similar results have been reported more recently. Andersen and Ocepek (2022) compared two pens (nest area 3.84 m^2 and dunging 3.84 m^2 to give total area 7.7 m^2 vs nest 5.78 m^2 and dunging 2.48 m^2 for total area 8.3 m^2) across two farms, with both reporting a reduction in liveborn mortality when the nest area was reduced (2–2.5%). Nicolaisen et al. (2019) compared farrowing crates to free farrowing pens and a group lactation system in which sows were confined to individual pens for the first five days of lactation. The nest area was 6.5 in the free farrowing pens and 4.2 m^2 in the group pens and all data were collected prior to grouping in this final treatment allowing for a comparison between large and small nest areas, and to stalled sows in a farrowing crate. Mortality of piglets was lowest in crates (12.3%) and highest in the pens (small 19.9 vs large 25.6%). Over 70% of deaths were crushing events in pens, which was double in comparison to crates. In large pens, almost 70% of crushing events were caused by rolling, but this was less frequent in the smaller pen (38%). The majority of crushing happened in the first three days (90%) and whilst approximately 30% happened per day in the large pen, almost all happened on day one in the small pen. Baxter et al. (2015) also concluded that the difference in piglet mortality between large and small nests was due to the rolling behaviour of sows. Sow rolling would appear to either be more frequent, or riskier in large pens. Increased risk is a more likely scenario, with the risk involving piglets being in close proximity to the sow at the time of the rolling event.

In farrowing accommodation, there is a dedicated piglet zone (creep) that sows cannot access, creating a safe area that when used appropriately, reduces the risk of sow crushing of piglets (Berg et al., 2006). This creep is attractive to piglets because of a higher ambient temperature that better meets thermal requirements. Piglets locate this creep using thermal gradients (Morello et al., 2019), and so in large nests, perhaps piglets are less likely to be drawn to this safe zone, instead using the sow's body heat for warmth. Supporting this, Nicolaisen et al. (2019) demonstrated more piglets in large pens were observed to rest near the sow when rolling occurred compared to the smaller pen, and piglets from the small pen were more often observed in the creep area. Of note is the seasonality in free farrowing performance, exacerbated under natural ventilation conditions commonly utilised in countries that experience warmer climatic conditions (Morrison and Baxter, 2015). Higher preweaning mortality is observed when shed temperatures are warm, and although changes in sow behaviour across seasons have been reported (King et al., 2018), the diminished thermal gradient between the risky sow area and the safe creep is a likely explanation (Burri et al., 2009). Even in countries where fully ventilated systems are more commonplace, the crushing of piglets by the sow is higher in warmer months (Weber et al., 2009). Perhaps the use of slatted flooring in the nest area to create cooler conditions in the pen is one way to make the creep attractive to piglets during warmer conditions. The negative impacts on preweaning survival caused by free farrowing may be alleviated when the pen size available to the sow is reduced (3.3–4.0 m^2) by combining nesting and dunging areas using slatted flooring, resulting in improved creep usage by piglets. This should be validated as a possible means to eliminate the use of a stall during farrowing and throughout lactation.

The role of the stock-person

Whilst there is a requirement for increased labour in free farrowing systems (Quendler et al., 2009), surprisingly, the impact of the individual stock-person on the welfare and performance of sows and piglets in free farrowing systems has not been directly assessed. Hemsworth et al. (1994) clearly demonstrated that correct training involving cognitive-behavioural intervention changed the attitudes of stock people, reduced negative interactions resulting in reduced fear in pigs, and ultimately resulted in improved overall farm reproductive performance in commercial systems. This pivotal piece of research directly implicated the importance of people as drivers of improved animal welfare and performance and so should be applied to free farrowing. There is some evidence that stock people can impact the performance of farrowing pens. Hales et al. (2014) in their analyses of three herds with slightly different pen designs (5.6–6.3 m^2 range in space, differing feeder location and two out of three farms provided a straw rack) showed that overall, mortality was higher in farrowing pens, but the magnitude changed between herds, from double to almost comparable. In addition to other management factors, staff training and motivation may have played a role in these herd differences. Andersen and Ocepek (2022) reported a reduction in preweaning mortality over time from 15 to 12% and explained this reduction in mortality by increasing staff experience with the system. Whilst confounded with the use of auditory enrichment, the use of positive human interaction with stock people improved preweaning piglet survival in pen systems (De Meyer et al., 2020). In this study, sows were given 15 s of back-scratching from entry to the pen until farrowing (along with music) and preweaning mortality was reduced from 13 to 10% thought to be attributed to reduced startling behaviour in sows driven by fear of humans. A better understanding of stock-person behaviour when working in free farrowing, specific training interventions, and impacts on performance requires assessment.

Sow experience (genotype, rearing, and experiential learning)

As with the stock-person, sow experience in free farrowing systems should be expected to play a significant role in success, with the use of the term experience referring to the genotype, rearing conditions and repeated learning environment. There is a genetic background to maternal traits important for offspring survival, and so whilst gain is possible, behavioural traits are often difficult to record with the frequency required to do so (Grandinson, 2005), and may actually be negatively associated with rearing ability (Appel et al., 2016). Whilst maternal behaviour is a causative factor for piglet survival, measuring the trait itself provides more opportunity for implementation. Survival traits have been difficult to implement in genetic programmes as the heritability is often low (Knol et al., 2002). However, with the advancement of genomics, maternal selection indices now routinely include some focus on preweaning survival (Samorè and Fontanesi, 2016) either directly or indirectly. It has been suggested that because the stall housing of a sow within a farrowing crate reduces piglet crushing, genetic progress made in piglet survivability may not be applicable to free farrowing systems (Jarvis et al., 2005). Applying genomic selection pressure to piglet survival when sows are housed in free farrowing pens at the nucleus level may offer a rapid genetic solution for improved performance in stall-free farrowing, but this will be driven by demand from industry needs.

Following birth, the level of maternal care that offspring receive can form future behaviours (Poindron, 2005). With this in mind, Chidgey et al. (2016) were able to demonstrate that gilts born into a pen, and that reared their own litter in a pen, contacted their piglets and made vocalisations more frequently than those born into a crate environment. These epigenetic shifts in maternal behaviour show promise, but the effects of rearing environment on free farrowing performance are still to be examined. The environment the gilt farrows her first litter into has also been shown to influence maternal behaviours in later parities. Compared to crated gilts, those who experienced the first parity in a pen performed improved nesting, less ventral and increased lateral lying, reduced sitting and risky posture changes during farrowing, and improved nursing behaviour as second parity sows who farrowed in pens (King et al., 2018). In this example, impacts on preweaning survival have been examined, with free farrowing first parity sows recording reduced early mortality from crushing despite having an improved litter size in the second parity (King et al., 2019). This last point raises an important issue in that there may be other advantages of free farrowing systems that eliminate stalls in gestation and lactation over time, such as improvements in reproductive performance and health. Increases in sow retention rates because of stall elimination would have positive economic benefits, but these are difficult to quantify experimentally, given the scale required.

Boars

Boars are large in size, sometimes aggressive to other pigs and humans, and pose a risk of injury to both conspecifics and stock people (Svab, 2004), explaining why they have been individually housed in stalls. The use of stalls for boars is estimated to be as high as 90% in countries such as the United States (Knox et al., 2008), but has been eliminated in some European countries (Table 1). As previously discussed, boars are still an essential component of the breeding herd structure as they are required for puberty stimulation in gilts, as well as oestrus and return detection in sows. There are considerably fewer boars required, and this likely explains why research into the impacts of stall vs pen housing in males is less frequent than in females. Stud boars, whilst not contained within the breeding herd *per se*, still contribute to overall reproductive performance, and so a comparison between housing systems is required. From a welfare perspective, stall-housed boars have been shown to perform more stereotypic behaviours than those housed in pens, and when housed in pens with enrichment, the difference in diurnal cortisol concentrations was larger in enriched pens than crates (Almeida, 2021). The semen of the boars housed in stalls showed differences in micro-RNA abundance which the authors hypothesised may have lifelong, negative impacts on progeny, but this remains to be tested. Boars held in stalls have poor opportunity for behavioural thermoregulation of testicles, and so a recent investigation hypothesised that semen quality would be improved when boars were housed in pens (Bernardino et al., 2022). They tested ten-month-old boars in pens and stalls for a period of ten weeks. Stall housed boars recorded higher scrotal temperatures and had more vascularisation of the parenchyma than penned boars. Semen from boars housed in stalls moved in a more circular pattern and were more clumped but showed no difference in defects. The authors argue that these negative effects would be exacerbated when housing treatments were applied over a longer period. So perhaps not surprisingly, housing boars in stalls restricts behaviour, reduces semen quality, and even has the potential to have lifelong adverse impacts on progeny. There is no work examining the effects of pen design aspects on boar welfare and performance, but most current and upcoming legislation has indicated a minimum of 6.0 m^2 be made available (Table 1).

Conclusions

Even when use is minimised, stalls are still strategically used in sow units during breeding and early pregnancy, in farrowing crates during birthing and lactation, and in some cases, for boars. Whilst there are arguments for the complete removal of stall housing, there are still some fairly significant obstacles that need to be addressed in order to maintain animal welfare and farm productivity. Management of oestrus behaviours, oestrus detection and mating procedures for grouped sows are all areas for scientific attention as they will be a significant hurdle to overcome. There is increasing focus on individual animal care in group-housed animals, and this has not escaped breeding sow herds. Whilst technologies are available to better deliver individual sow management, widescale implementation remains to be seen and so should be a focus. At farrowing and during lactation, preweaning piglet mortality has severely hindered the uptake of free farrowing systems, but perhaps reducing space allowance provides an opportunity to remove stalls from this stage of production. Lastly, the experience of both the stockperson and the pig will play an important role in the success of stall elimination.

Recommendations

The removal of stalls during the wean-to-service period is likely to occur quickly as knowledge gained from previous work in group gestation housing can be applied instantaneously to manage aggression. Additionally, this will not involve much capital expenditure as the pork industry has experience in retrofitting existing facilities. Oestrus detection may be more difficult in penned sows, but there are already technologies, such as accelerometer tags, that have been implemented in other livestock species and could easily be adapted for use in sows. Additionally, insemination technologies that are common in stall systems like PCAI could be modified to solve the issues presented when sows are mated in groups. Eliminating stall use during farrowing and lactation will be a slower process because of the associated costs with replacing the farrowing crate with expensive free farrowing pens and the reduced piglet survival associated with these systems. If space allowance can be preserved to reduce cost, and have simultaneous benefits in productivity, this would speed the rate of adoption. Longer-term research is required when examining free farrowing as both animal and human experience in the system will have biased investigations to date.

Ethics approval

Not applicable.

Data and model availability statement

Data or models were not deposited in an official repository. No new datasets were created.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

None.

Acknowledgements

None.

Financial support statement

This research received no specific grant from any funding agency, commercial or not-for-profit section.

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