Review

Issues and challenges in meeting well-being concerns of sows and litters

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Abstract

The objective of this review is to provide an overview on the most frequent health and welfare issues that could compromise the health and well-being of sows and their litters on intensive production systems. Also, some farm challenges are discussed that might to be faced by producers, veterinarians and scientists in order to promote the balance in the hard equation between welfare and productivity that represent a way to respond to the demands of the regulatory bodies and markets, and also to the concerns of contemporary society.

Keywords: swine, behaviour, welfare assessment, housing systems

Review Methodology: Our review was based on searching in different databases, such as CAB Abstracts, Agris and Agricola, using terms such as pig, sow, piglet, litters, behavior, environment, welfare assessment, health and well-being, swine production systems, and resource and management to give a current overview on the field. The database research regarding to the year of publication was restricted to the last decade but with no restriction as to language. Some references were also consulted from the articles obtained by this method in order to obtain some more relevant material.

Introduction

The production and consumption of pork meat has increased dramatically all over the world, in association with the exponential rise of the world population and *per capita* income rise. In this context, huge changes were registered in swine husbandry with systems modifying from small and outdoor labour-dependent enterprises into large and indoor capital-dependent operations [1], in which the close confinement of sows in barren environmental conditions implies in real challenges for producers and rises to major public concerns for their welfare [1, 2].

Genetic selection and better control of the pig environment have resulted in improvement in performance traits that in consequence may lead to deterioration in health and welfare, as highly productive pigs have difficulties in coping with environmental challenges, so they are at risk of behavioural, physiological and immunological problems [3, 4]. For this reason, pig-breeding corporations can use the selection index method to derive weights for breeding goal traits with non-economic but societal importance [5]. Also, the use of different technological innovation may cause some health and welfare problems for farms, such as alterations in the environment and aggressions to the well-being of pigs that can cause production diseases [6], such as teat, skin, foot, limb and body lesions, callosities, claw lesions and lameness and immune dysfunction that can cause detrimental effects on sows and piglets welfare [7–15].

The aim of this review is to discuss some issues and challenges faced by the modern swine industry, from the perspective of pigs, producers and society with emphasis on the main critical points that cause health problems and welfare impairment or stress for sows and their litters reared in different confinement systems.

Behaviour as an indicator of swine welfare

The domestic pig is highly motivated to use its snout to explore for food and other resources in order to meet its

immediate needs, and also to explore for new objects and changes in the environment [16, 17]. According to Studnitz *et al*. [17], it is important to stimulate the exploratory behaviour of the pig over a long period and to use complex, changeable, destructive, manipulable and distributed edible materials [17]. If the sow cannot follow her natural behavioural need, when no material is available, she redirects her nest-building behaviour towards the pen or crate equipment, and the pen mates [16, 18], which may result in stereotypical behaviour and stress, followed by a reduced reproductive performance. Brazilian studies showed that the behaviour of pre-parturient sows was considerably affected by the husbandry system with the incidence of lower environmental stress, stereotypes and aggressive interactions in pregnant sows kept in collective pens housing systems [19, 20].

The pre-partum behaviour of sows is mainly characterized by nest-building activities, resulting in a nest that provides shelter for the piglets [18]. In this context, substrate is particularly important for sows during the pre-farrowing phase to satisfy nest-building motivation, but it also has properties that provide thermal and physical protection for the piglets, physical comfort for the sow and behavioural enrichment for developmental functions of piglets (reviewed by [21]). However, gestation crates are still common in swine production imposing restriction of space and causing injuries for sows. As behaviour is important for sows, posture, frequency of posture changes, contact with the stall and udder extension beyond the boundary of the stall were observed for 24 h at 4 and 14 weeks of gestation in gilts, small, medium and large sows. It was observed that sows spent less time standing and more time sitting in the narrower compared with wider stalls; also, the proportion of lying time spent in lateral recumbency was greater for larger than for smaller sows and larger sows made fewer postural changes, and the proportion of sows touching both sides of the stall, or with their udder extending into the adjacent tall, was affected by the interaction of stall width and sow size [22].

Factors such as parity order and environmental temperature can interfere in the behavioural interactions between lactating sows and litters once all sows became more restless during the warmest periods of the day, reducing the frequency of posture in lateral decubitus and the number of suckling by the piglets [23]. However, there was no significant difference between sows grouped and individually housed in total number of nursing, number of nutritive nursing or in proportion of nursing initiated by the sows, despite the fact that grouped sows terminated higher proportion of nursing and allowed piglets' post ejection massage for a shorter time, and that nursing synchronization was higher among grouped sows than individual stalled sows [24].

Lactating piglets are more vulnerable to crushing in the first 24 h of life, when they spend much of their time near the udder and have relatively poor mobility to move away from the high-risk posture changes of the sow [25]. It means that piglet survival is reduced when sows are confined, since the mother has little interaction with the piglets except for presenting the teats or sniffing some piglets that are within her small space [26]. Sows that did not crush any of their piglets within one lactation period showed a more protective mothering style and were socially more flexible in a grouping situation than sows that crushed several piglets [26].

The evaluation of how socialized piglets before weaning affects behaviour of lactating sows and the pre and post-weaning behaviour and performance of piglets demonstrated that socialization of unfamiliar piglets at that time and stress resulting from mixing could at least be distanced in time from the other burdens of weaning, thereby improving performance [27]. Additionally, it was postulated that Intermittent suckling regimen applied either with 6 h separation or with 12 h separation intervals may provide a gradual adaptation to the post-weaning state by stimulating eating behaviour, without causing obvious behavioural distress [28].

On-farm welfare assessment of confined sows and litters

Among the many issues involved on swine welfare, it is those involving the use of gestation stalls and farrowing crates for sows in barren environments which have risen to the greatest public concern. It is associated with the frustration of strongly motivated behaviours, such as absence of a foraging substrate, by a restrictive environment [2].

The assessment of behaviour, welfare and farrowing performance of sows in loose housing or individual stalls showed that loosing system improved the manoeuvring ability and comfort of sows in the farrowing crate with beneficial implications for skin health [29]. However, sows in large groups on deep litter faced greater welfare challenges in the early stages of gestation based on the findings of increased scratches, a higher rate of return to oestrus and a trend for higher cortisol levels, all possible as a consequence of aggression, in contrary with challenges faced by stalled sows in late gestation showing a higher incidence of lameness and an increased neutrophil: lymphocyte ratio as a consequence of increased stress [30]. In connection with this, it was identified that gestating sows housed in groups in deep-bedded barns will perform comparably to sows housed in individual gestation stalls [31].

The evaluation of stress in pregnant gilts kept penned in groups or individual stalls by comparing production, physiology and behaviour measures of the piglets showed advantages to housing first parity females in groups [32]. A comparison between conventional farrowing crate (5.0 m^2), Trapez pen (6.7 m^2, with a crate opened 2 days after farrowing) and modified FAT2 pen (6.7 m^2;

loose-housing system with nest and dunging area) concluded that health and behaviour of farrowing and lactating sows are negatively affected when being housed in conventional pens with crates and slatted flooring [9]. In contrary, the effects of width (0.6 m versus 0.75 m) and length (2.0 m versus 2.2 m versus 2.4 m) of gestation stalls, plus a tether-stall negative-control treatment measured via parameters of behaviour, stress physiology, immunology and gait score showed that a stall width of 0.6 m was better for sow welfare, based on significantly lower total and free cortisol concentrations, reduced responsiveness to ACTH and increased immunoresponsiveness [33]. According to an American research, physiological indicators such as cortisol response, although often used in stress assessment, are limited in that there is no specific level suggestive of stress [34]. As housing systems always focused on efficient use of space, it was demonstrated that well-managed groups of gestating sows increase resting behaviour and decrease stereotypes at similar productivity and tissue damage levels [35]. Recently, 12 alternative indoor systems were compared against one another, conventional crates and outdoor systems, to assessing how well these systems satisfy criteria for meeting the animals' biological needs by means of a developed welfare design index, and the evaluation of welfare and economic performance pointed out that designed pen appears to offer the best indoor alternative to conventional farrowing crates [21].

An on-farm study investigated management factors, pen design and abnormalities of the integument of 1177 pregnant sows, concluding that skin abnormalities are not only pathological findings, but also are indicators of the quality of a multifactorial relationship between an animal and its environment [36]. It was previously indicated by a Danish investigation where skin lesions and lying-down behaviour were associated with flooring and other herd-specific factors as well as the sow condition regarding body condition and leg disorders [7]. More research has shown large differences in the prevalence of abrasions and lameness in piglets according to the type of floor; so in terms of welfare, a deep litter system provided a soft and good floor for piglets, in comparison with the systems with concrete floor [14]. British studies demonstrated that lactating sows there is an increased risk of limb and body lesions when housed on slatted floors compared with those on solid concrete floors with bedding [10], and that no one floor type was ideal to minimize all piglet foot and limb injuries, being slatted floors associated with an increased risk of sole bruising and swollen joints or claws abrasions but were associated with reduced risk of skin abrasion in young piglets [11]. Furthermore, slatted floors provide the animals with a number of particular challenges – an uneven walking surface, a reduced weight-bearing surface, lack of bedding and sharp slat edges – that increase the risk of injury and lameness [12].

Decubital shoulder ulcers in sows reflect a welfare problem because the painful condition prevents the normal ability of the animals' adaptation. The extension of this problem cannot be fully determined until a valid *ante-mortem* classification system is available, and knowledge about the duration of the condition as well as possible consequences in terms of pain or discomfort have been established [37]. An association between type of housing group and sow-related factors with lameness showed that the risk of this clinical disorder was lower while the risk of claw lesions was higher in older sows, suggesting that a balanced parity distribution of sows will be important for productivity as well as to avoid problems of locomotion [38].

Several initiatives were taken to address the assessment of piglet welfare. The assumption that in indoor farrowing systems, the newborn piglets will leave their mother after suckling to enter a heated and bedded creep area did not increase time spent away from the sow, nor did it reduce piglet mortality [39]. Two methods of tooth resection (tooth clipping with pliers and tooth grinding with a rotating grindstone) on their own teeth, on skin lesions of piglets and of sow udders as well as on litter growth and survival indicated that this procedure has little effect on sows' udder and litter performance, but it allows a reduction in piglet skin damage especially when tooth resection is performed by clipping. However, this reduction is counterbalanced by the damages to their own teeth [40]. On the other hand, the stress response of alternative methods for performing different procedures: teeth resection – clipping versus grinding; tail docking – cold versus hot clipping; identification – ear notch versus tag; iron administration – injection versus oral and castration – cords cut versus torn pointed out that responses to teeth resection, tail docking and identification were shown to be altered by the procedural method, whereas responses to iron administration and castration did not differ [41].

The common incidence of fighting in piglets mixed before weaning (age between 5 and 26 days) showed no significant relationship between age and the likelihood that pair of piglets would fight during the first 75 min after mixing, also that younger pigs shown 80% fewer injuries from the fighting [42]. In determining how co-mingling affect piglets' pre-weaning growth, ear injuries, suckling behaviour and responses to behavioural tests used to measure coping abilities, it was viewed that co-mingling litters affects social behaviour of piglets, by primarily decreasing aggressive interactions during social challenges ([43].

Resource and management inputs as guidance to improve welfare on sow housing systems

Recently policies have been changed around the world, with emphasis in Europe and the USA, preventing the use of crates during pregnancy and lactation in intensive swine systems, in order to minimize health and welfare

problems, such as poor hygiene, urinary infections, body lesions, leg disorders and stereotypes in crated sows.

A study with sows housed in dynamic, twice-mixed and static groups of different sizes in pens showed that the total injury score was significantly higher in the dynamic group 2 weeks after mixing, concluding that this higher score and lower number of non-agonistic social interactions are indicators that welfare was compromised in the dynamic group as compared with the other groups [44]. On the other hand, the effects of pen versus crated housing systems and drop- versus trickle-fed feeding were evaluated on sow productivity, occurrence of lesions during farrowing and weaning, immune measures and behavioural responses during two consecutives gestating periods. The conclusion was that the environments evaluated did not have major effects on gilt or sow physiology or reproductive performance [45]. According to some researchers, the restriction of space in gestation crates is a serious cause of injuries for sows. In connection with this, different floor space allowances for dry, pregnant sows in pens were evaluated to determine the impacts of space on performance, productivity and body lesions during two consecutive farrowings. Although the effects of gestation system were found and lesion scores often were greater as space decreased, differences in productivity traits were unremarkable with respect to sow welfare or performance compared with industry norms [8].

It was pointed out that grouped sows are involved in more aggressive encounters than stall-housed females, so for groups of gestating sows special attention should be directed towards feeding management to avoid excessive aggression and possible adverse effects on welfare [46]. In agreement, the social rank of pregnant gilts and group-housed sows and fed by an electronic sow feeding system was evaluated and indicated that the social rank of the sow affects her own body weight gain and loss as well as growth and behaviour of her offspring. It was suggested that pig breeders that apply group housing during pregnancy should pay attention to reducing competition around the feeding area, which may reduce aggression among the sows and minimize differences between high and low social ranking sows [47]. Another study has posited that management (static versus dynamic), state of gestation at introduction, familiarity within the group and age of sow did not have impact on sows during gestation. However, the stage of gestation and parity should be considered along with the dynamic group as it can impact aggression and access to resources [48]. It is important to identify social strategies when mixing gilts with older sows during gestation and the impact of inter-individual differences on their offspring. Individual gilts varied in the degree to which they either interacted aggressively with sows and received skin lesions, or avoided sows by spending time in the feeders. There were associations between the skin lesions received by gilts at their first mix and a number of characteristics of their offspring [49]. The fact that stall systems do not provide freedom of movement for sows to perform their normal patterns of behaviour means that increased space is likely to reduce aggressive interactions and total skin lesion score and decrease physiological indicators of stress such as free plasma cortisol concentrations [50].

It was shown that sows housed on deep litter faced greater welfare challenges in the early stages of gestation based on the findings of increased scratches, a higher rate of return to oestrus and a trend for higher cortisol concentration: all possibly a consequence of aggression. In contrast, sows in stalls faced greater welfare challenges later in gestation based on a higher incidence of lameness and an increased neutrophil:lymphocyte ratio perhaps as a consequence of increased stress, suggesting welfare advantages and disadvantages for both housing systems [30]. Recently, a survey carried out to list the most likely success and risk factors for group housing of sows in early pregnancy concluded that especially factors causing chronic stress and a low feed intake may impact reproductive performance; also, that factors such as quality of floor is important for leg problems and longevity, and gradual familiarization of unfamiliar animals, sufficient space and pen structure during initial mixing, minimizing opportunities for dominant sows to steal food from subordinates, provision of a good quality floor and use of straw bedding can avoid aggression among sows [51].

The combined effects of allowing sows access to a getaway area separated from the piglets, where they could mingle with other two sows, and litters had access to a crawling area where they could mingle with piglets from two other litters showed that this housing system provides welfare advantages for the sow (time away from the piglets, reduced demands for nursing, opportunities for socialization) and piglets (reduced growth check and aggression at weaning) while allowing for high levels of production consistent with confinement systems [52]. Recently, the monitoring of lactating sows housed in farrowing crates with continuous, concrete flooring on 75% of the surface and a type of grate in the defecation area for sows and piglets to use (25%) and housed in improved farrowing crates featuring discontinuous plastic flooring on the entire surface of the box, respectively, concluded that the number of sows in the first group displayed skin more lesions (59%) in the former compared with the latter group (41%), whereas skin lesions in piglets were 65% for the second group compared with 35% for the first one. The welfare indicators monitored recorded variations for both housing systems, showing a depreciation of the animal welfare [53].

An investigation was carried out to quantify variability between sows and consistency across parities in crushing mortality, and to examine the effect of the environment on variability. It provides evidence that sows exhibit large differences between individuals in their propensity to crush piglets; and that these individual differences have been partially masked by the use of farrowing crates, and that individual differences show some consistency

over parities [54]. Characteristics of sow behaviour and parturition related to early piglet mortality in loose-housed farrowing sows were identified. Different causes of mortality were linked to different behavioural variables during the periparturient period and grouped into three categories: the first was associated to stillbirth (positively related to the variation of the inter-birth interval and negatively related to the percentage of piglets that suckled during the first 8 h after birth of first piglet(BFP)) and other causes, the second with piglet crushing (positively related to much lateral lying the last 4 h before BFP), and the last one with death owing to a lack of colostrum injections (linked to the time of parturition and sow rectal temperature on days 1 and 2 after farrowing) [55].

Swedish records of playing, fighting and biting behaviour made with grouped lactating sows (GH) and their litters kept in a large straw-bedded pen, and in individual housing farms (IH) with each sow and litter kept in a pen with less straw showed that there was no difference between GH and IH farms in the frequency of these behaviours, and also that weaning age was not affected by either treatment [56].

A free farrowing pen (left anti-crushing bar, a detachable right anti-crushing bar on the sides of the sow lying area, and a 10 cm-high anti-crushing bar in the non-lying area) was designed to overcome the drawbacks of both farrowing crates and farrowing pens. It was found that farrowing duration and the mean piglet birth intervals were longer for the sows in farrowing crates; piglet stillbirth rate was higher for the sows in farrowing crates and crushing mortality was higher among piglets in farrowing pens. Sows in free farrowing pens were found to be more protective of their piglets [57]. A cohort study carried out on 112 pig farms in England shown that farrowing crates reduced the risk of preweaning live born mortality attributable to crushing but piglets in this system were at increased risk of death from other causes [58].

Data from a Swiss sow recording scheme (UFA2000) were analysed and showed that the greater litter size at birth, significantly more losses occurred for all reasons (total, crushed, others).Total piglet mortality and losses for reasons other than crushing were significantly higher in older sows. Losses were therefore mainly attributable to sow-related characteristics rather than to the design of the farrowing pen [59]. An investigation was done to find out whether the same piglet traits contributed to the same causes of neonatal piglet mortality in crates (CT) and pens (PN). The results emphasize that the microclimate in the PN for newborn piglets and its heat preserving properties are more important for survival than whether the sow is crated or penned [60].

A study evaluated the economics of pig production in the PigSAFE farrowing pen, with focus on four points: identification of prevalent UK sow farrowing systems; estimation of the cost of production in different farrowing systems; exploration of how sensitive these costs were to changes in outputs, and finally the estimation of the uptake of high-welfare farrowing systems by the UK pig industry. In conclusion, the current farrowing systems are dominated by the farrowing crate; also, pig producers may seek premium revenue to encourage them to invest in alternative farrowing systems, but they remain cautious about large-scale investment in these systems, despite the reported welfare advantages for the sow [61]. Indeed, an ideal alternative system would maximize piglet survival, allow sows to perform their natural patterns of behaviour, reduce labour and provide a good working environment and incur lower capital requirements compared with conventional systems [62].

Perception of farmers, suppliers and consumers in relation to welfare in intensive piggeries

In the last decade, several initiatives were taken to address animal welfare issues. Specifically in terms of swine production, welfare in the future will be driven by many of the same things that create welfare status today: human virtue, social ethics, economics of production, scientific information and the standards of an international community [63]. In this context, there has been an increase in public concerns related to animal welfare around the world, as consumers from different countries have been using animal welfare as an indicator of food quality and safety. Consumer awareness has led processors, retailers and politicians to pay a greater attention to the animal welfare and environmental issues associated with the production and supply of food [64]. A particular issue facing the US swine industry is the possible elimination of production practices condemned by some consumers to be animal-unfriendly, and pressure is mounting for the industry to cease using gestation crates [65].

According to a Dutch research [66], farmers within different quality assurance schemes had very similar perceptions about markets, consumers and social expectations. Thus, farmers' approaches to animal welfare on their farms are not just a question of attitudes or ethical views. The choices available within specific production methods are also constrained by economic factors that are directly related to the market in which they operate. In Sweden, most of the farmers join schemes with demands above and beyond the legal requirements, and they join two or more schemes; diversity in perspectives was found between conventional and organic farmers, male (physical comfort view) and female (natural behaviour view), and between farmers with higher and lower levels of education [67]. From the UK pig industry point of view, farm assurance provides assurances to the market over food safety, animal welfare and environmental concerns. The principle of including welfare outcome measures within farm assurance schemes is expected to provide a more meaningful way of assessing animal welfare than the existing resource assessments [68].

Another critical view point in swine production systems is related to surgical castration of piglets to eliminate the risk of boar taint. However, this procedure is the subject of much debate and criticism as a result of its negative implications for piglet welfare, integrity and health [69]. The alternative of immunocastration as opposed to surgical castration has not emerged as a problem in terms of consumer acceptance. However, special attention should be paid to consumers' perception of pricing, food safety and the taste of the meat from immunocastrated pigs [69].

Despite all of this, breeding companies and farmers focus their goals in genetic improvements of production and reproduction traits and also implement the confinement of sows in gestation and/or farrowing crates, which means an emphasis on growth rate, meat percentage, feeding efficiency and piglet production, considering these traits are seen as economically relevant [5]. Today, the current challenge is to raise awareness about animal welfare in the society in order to achieve a balance based on market and societal trends respecting consumer preferences and citizens' concerns.

Future outlook on swine welfare production

To address animal welfare in the long term, advantages of current housing systems should be retained while making improvements to overcome identified problems. Improvements should be adopted as soon as technology is sound enough for producers to adopt it with confidence, the skills needed to operate the systems are understood and available, and systems are economically viable [70]. The immediate need is for industry to advance housing and management practices in ways that will improve the welfare of sows while providing producers with practical and reliable methods [70]. However, in a very competitive industry, producers can only operate within the boundaries of profitability, so initiatives that reduce net margin are not sustainable and any systems which significantly reduce output or increase capital or running costs are only viable if associated with a protected market or reliable product premium revenue [2]. It is accepted that new livestock housing systems designed to improve animal welfare will only receive large-scale commercial adoption if they improve profitability, or are at least cost-neutral to the farm business. In connection with this, economic evaluation of new systems development is therefore essential to determine their effect on cost of production and hence the extent of any market premium necessary to stimulate adoption [61].

Conclusion

Intensive production systems, based on high productivity of sows, promote drastic changes, since the adaptation of animals to a new social and physical environment represents a stressful situation, which induces adverse behavioural reactions and multifactorial pathologies. It should be considered that the new genotypes are more sensitive to stress and discomfort caused by the type of management, equipment and environment of confinement operations. In this context, issues and challenges related to the decline in standards of welfare for swine should be recognized by producers, veterinarians, scientists, governments and society, resulting in the elaboration of legislations and guidelines based on indicators that express the ability of adjustment (meet the behavioural and physiological needs) or failure (appearance of production diseases such as stress, abnormal behaviour, pain, suffering and poor performance) in their adaptation to the confinement systems. Obviously, the current systems of pig production (conventional or alternative) must be analysed from different perspectives, to ensure animal welfare and meet the economic and social interests of producers, food suppliers and consumers.

References

1 Kittawornrat A, Zimmerman JJ. Toward a better understanding of pig behavior and pig welfare. Animal Health Research Reviews 2011;12(Part 1):25–32.

2 Edwards S. Balancing sow and piglet welfare with production efficiency. In London Swine Conference – Facing the New Reality; 2008. p. 17–26.

3. Prunier A, Heinonen M, Quesnel H. High physiological demands in intensively raised pigs: impact on health and welfare. Animal 2010;4(Part 6):886–98.

4. Baxter EM, Jarvis S, Sherwood L, Farish M, Roehe R, Lawrence AB, *et al.* Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow. Applied Animal Behaviour Science 2011;130:28–41.

5. Kanis E, De Greef KH, Hiemstra A, van Arendonk JAM. Breeding for societally important traits in pigs. Journal of Animal Science 2005;83:948–57.

6. Costa AN, Martins TDD. Aspectos técnicos e éticos da produção intensive de suínos. In: I Congresso Brasileiro de Bioética e Bem-Estar Animal; 2008 April 16–18; Recife, Brasil; 2008. p. 49–53.

7. Bonde M, Rousing T, Badsberg JH, Sorensen JT. Associations between ying-down behaviour problems and body condition, limb disorders and skin lesions of lactating sows housed in farrowing crates in commercial sow herds. Livestock Production Science 2004;87:179–87.

8. Salak-Johnson JL, Niekamp SR, Rodriguez-Zas SL, Ellis M, Curtis SE. Space allowance for dry, pregnant sows in pens: body condition, skin lesions, and performance. Journal of Animal Science 2007;85:1758–69.

9. Verhovsek D, Troxler J, Baumgartner J. Peripartal behaviour and teat lesions of sows in farrowing crates and in a loose-housing system. Animal Welfare 2007;16:273–7.

10. Kilbride AL, Gillman CE, Ossent P, Green LE. A cross sectional study of prevalence, risk factors, and population attributable fractions for limb and body lesions in lactating sow

on commercial farms in England. BMC Veterinary Research 2009;5(30):13.

11. Kilbride AL, Gillman CE, Ossent P, Green LE. A cross sectional study of prevalence, risk factors, population attributable fractions and pathology for foot and limb lesions in preweaning piglets on commercial farms in England. BMC Veterinary Research 2009;5(31):12.

12. Kilbride AL, Gillman CE, Ossent P, Green LE. Impact of flooring on the health and welfare of pigs. In Practice 2009;31:390–5.

13. Rolandsdotter E, Westin R, Algers B. Maximum lying bout duration affects the occurrence of shoulder lesions in sows. Acta Veterinaria Scandinavica 2009;51:44–50.

14. Zoric M, Nilsson E, Mattsson S, Lundeheim N, Wallgren P. Abrasions and lameness in piglets born in different farrowing systems with different types of floor. Acta Veterinaria Scandinavica 2008;50:9.

15. Lewis E, Boyle LA, O'Doherty JVO, Brophy P, Lynch PB. The effect of floor type in farrowing crates on piglet welfare. Irish Journal of Agricultural and Food Research 2005;44:69–81.

16. Smulders D, Verbeke G, Mormède P, Geers R. Validation of a behavioural observation tool to assess pig welfare. Physiology and Behavior 2006;89:438–47.

17. Studnitz M, Jensen MB, Pedersen LJ. Why do pigs root and what will they root? A review on the exploratory behaviour of pigs in relation to environmental enrichment. Applied Animal Behaviour Science 2007;107:183–97.

18. Wischner D, Kemper N, Krieter J. Nest-building behaviour in sows and consequences for pig husbandry. Livestock Science 2009;124:1–8.

19. Hotzel MJ, Machado Filho LCP, Costa OAD. Behaviour of pre-parturient sows housed in intensive outdoor or indoor systems. Pesquisa Agropecuária Brasileira 2005;40(2):169–74.

20. Silva IJO, Pandorfi H, Piedade SMS. Influência do sistema de alojamento no comportamento e bem-estar de matrizes suínas em gestação. Revista Brasileira de Zootecnia 2008;37(7):1319–29.

21. Baxter EM, Lawrence AB, Edwards SA. Alternative farrowing accommodations: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal 2012;6(Part 1):96–117.

22. Li YZ, Gonyou HW. Effects of stall width and sow size on behaviour of gestating sows. Canadian Journal of Animal Science 2007;87:129–38.

23. Martins TDD, Costa AN, Silva JHV, Valença RMB, Ludke JV. Postura e comportamento lactacional de matrizes suínas mantidas sob condições de, temperatura ambiente elevada. Revista Biotemas 2008;21(Part 4):137–45.

24. Silerová J, Spinka M, Sárová R, Algers B. Playing and fighting by piglets around weaning on farms, employing individual or group housing of lactating sows. Applied Animal Behaviour Science 2010;124:83–9.

25. Marchant-Forde JN, Broom DM, Corning S. The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. Animal Science 2001;72:19–28.

26. Andersen IL, Berg S, Boe KE. Crushing of piglets by the mother sow (Sus scrofa) purely accidental or a poor mother? Applied Animal Behaviour Science 2005;93:229–43.

27. Hessel EF, Reiners K, Van den Weghe HFA. Socializing piglets before weaning: effects on behavior of lactating sows, pre- and postweaning behavior, and performance of piglets. Journal of Animal Science 2006;84:2847–55.

28. Berkeveld M, Langerdijk P, Bolhuis JE, Koets AP, Verheidjen JHM, Taverne MAM. Intermittent suckling during an extended lactation period: effects on piglet behaviour. Journal of Animal Science 2007;85:3415–24.

29. Boyle LA, Leonard FC, Lynch PB, Brophy P. Effect of gestation housing on behaviour and skin lesions of sows in farrowing crates. Applied Animal Behaviour Science 2002;76:119–34.

30. Karlen GAM, Hemsworth PH, Gonyou HW, Fabrega E, Strom AD, Smits RJ. The welfare of gestating sows in conventional stalls and large groups on deep litter. Applied Animal Behaviour Science 2007;105:87–101.

31. Lammers PJ, Honnman MS, Mabry JW, Harmon JD. Performance of gestating sows in bedded hoop barns and confinement stalls. Journal of Animal Science 2007;85:1311–7.

32. Sorrells AD, Eicher SD, Scott KA, Harris MJ, Pajor EA, Lay Jr DC, *et al.* Postnatal behavioral and physiological responses of piglets from gilts housed individually or in groups during gestation. Journal of Animal Science 2006;84:757–66.

33. Barnett JL, Hemsworth PH, Butler KL, Schirmer BN, Borg SS, Cronin GM. Effects of stall dimensions on the welfare of pregnant sows. Animal Production Science 2011;51:471–80.

34. Anil L, Anil SS, Deen J, Baidoo SK. Cortisol, behavioral responses, and injury scores of sows housed in gestation stalls. Journal of Swine Health and Production 2006;14(Part 4):196–201.

35. Chapinal N, Ruiz de la Torre JL, Cerisuelo A, Gasa J, Baucells MD, Coma J, *et al.* Evaluation of welfare and productivity in pregnant sows kept in stalls or in 2 different group housing systems. Journal of Veterinary Behavior 2010;5:82–93.

36. Leeb B, Leeb Ch., Troxler J, Schuh M. Skin lesions and callosities in group-housed pregnant sows: animal-related welfare indicators. Acta Agriculturae Scandinavica, Section A, Animal Science 2001;51(Suppl. 30):82–7.

37. Herskin MS, Bonde MK, Jorgensen E, Jensen KH. Decubital shoulder ulcers in sows: a review of classification, pain and welfare consequences. Animal 2011;5(Part 5):757–66.

38. Pluym L, Van Nuffel A, Dewulf J, Cools A, Vongroenweghe F, Van Hoorebeke S, *et al.* Prevalence and risk factors of claw lesions and lameness in pregnant sows in two types of grouping housing. Veterinarni Medicina 2011;56:101–9.

39 Vasdal G, Glaerum M, Melisová M, Boe KE, Broom DM. Increasing the piglets' use of the creep area – a battle against biology? Applied Animal Behaviour Science 2010;125:96–102.

40. Gallois M, Le Cozler Y, Prunier A. Influence of tooth resection in piglets on welfare and performance. Preventive Veterinary Medicine 2005;69:13–23.

41. Marchant-Forde JN, Lay Jr DC, McMunn KA, Cheng HW, Pajor EA, Marchant-Forde RM. Postnatal piglet husbandry practices and well-being: the effects of alternative techniques delivered separately. Journal of Animal Science 2009;87:1479–92.

42. Pitts AD, Weary DM, Pajor EA, Fraser D. Mixing at young ages reduces fighting in unacquainted domestic pigs. Applied Animal Behaviour Science 2000;68:191–7.

43. Kanaan VT, Pajor EA, Lay Jr DC, Richert BT, Garner JP. A note on the effects of co-mingling piglet litters on pre-weaning growth, injuries and responses to behavioural tests. Applied Animal Behaviour Science 2008;110:386–91.

44. Anil L, Anil SS, Deen J, Baidoo SK, Walker RD. Effect of group size and Structure on the welfare and performance of pregnant sows in pens with Electronic sow feeders. The Canadian Journal of Veterinary Research 2006;70:128–36.

45. Hulbert LE, McGlone JJ. Evaluation of drop versus trickle-feeding systems for crated or group-penned gestating sows. Journal of Animal Science 2006;84:1004–14.

46. Jansen J, Kirkwood RN, Zanella AJ, Tempelman RJ. Influence of gestation housing on sow behavior and fertility. Journal of Swine Health and Production 2007;15(Part 3):132–6.

47. Kranendonk G, Van der Mheen H, Fillerup M, Hopster H. Social rank of pregnant sows affects their body weight gain and behavior and performance of the offspring. Journal of Animal Science 2007;85:420–9.

48. Strawford ML, Li YZ, Gonyou HW. The effect of management strategies and parity on the behaviour and physiology of gestating sows housed in an electronic sow feeding system. Canadian Journal of Animal Science 2008;88:559–67.

49. Ison SH, D'Eath RB, Robson SK, Baxter EM, Ormandy E, Douglas AJ, *et al.* Subordination style' in pigs? The response of pregnant sows to mixing stress affects their offspring's behaviour and stress reactivity. Applied Animal Behaviour Science 2010;124:16–27.

50. Whitaker AL, Wettere WHV, Hughes PE. Space requirements to optimize welfare and performance in group housed pigs – a review. American Journal of Animal and Veterinary Sciences 2012;7(Part 2):48–54.

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

52. Weary DM, Pajor EA, Bonenfant M, Fraser D, Kramer DL. Alternative housing for sows and litters. Part 4. Effects of sow-controlled housing combined with a communal piglet area on pre- and post-weaning behaviour and performance. Applied Animal Behaviour Science 2002;76:279–90.

53. Andronie V, Parvu M, Andronie I, Dumitru A. Implications of farrowing crates on welfare lactating sows. Bulletin UASVM, Veterinary Medicine 2011;68(Part 1):37–41.

54. Jarvis S, D'Eath RB, Fujita K. Consistency of piglet crushing by sows. Animal Welfare 2005;14:43–51.

55. Pedersen LJ, Jorgensen E, Heiskanen T, Damm BI. Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition. Applied Animal Behaviour Science 2006;96:215–32.

56. Silerová J, Spinka M, Sárová R, Algers B. Playing and fighting by piglets around weaning on farms, employing individual or group housing of lactating sows. Applied Animal Behaviour Science 2010;124:83–9.

57. Gu Z, Gao Y, Lin B, Zhong Z, Liu Z. Impacts of a freedom farrowing pen design on sow behaviours and performance. Preventive Veterinary Medicine 2011;102:296–303.

58. KillBride AL, Mendl M, Statham P, Held S, Harris M, Cooper S, *et al.* A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Preventive Veterinary Medicine 2012;104:281–91.

59. Weber R, Keil NM, Fehr M, Horat R. Factors affecting piglet mortality in loose farrowing systems on commercial farms. Livestock Science 2009;124:216–22.

60. Pedersen LJ, Berg P, Jorgensen G, Andersen IL. Neonatal piglet traits of importance for survival in crates and indoor pens. Journal of Animal Science 2011;89:1207–18.

61. Guy JH, Cain PJ, Seddon YM, Baxter EM, Edwards SA. Economic evaluation of high welfare indoor farrowing systems for pigs. Animal Welfare 2012;21(S):19–24.

62. Vosough Ahmadi B, Stott AW, Baxter EM, Lawrence AB, Edwards SA. Animal welfare and economic optimization of farrowing systems. Animal Welfare 2011;20:57–67.

63. Lay Jr DC, Marchant-Forde JN. Future perspectives of the welfare of pigs. The Welfare of Pigs, Animal Welfare, vol. 7(Chapter 11); Springer, 2009. p. 331–42.

64. Hubbard C, Bourlakis M, Garrod G. Pig in the middle: farmers and the delivery of farm animal welfare standards. British Food Journal 2007;109(Part 11):919–30.

65. Tonson GT, Olynk N, Wolf C. Consumer preferences for animal welfare attributes: the case of gestation crates. Journal of Agricultural and Applied Economics 2009;41(Part 3):713–30.

66. van Huik MM, Bock BB. Attitudes of Dutch pig farmers towards animal welfare. British Food Journal 2007;109(Part 11):879–90.

67. Bruckmeier K, Prutzer M. Swedish pig producers and their perspectives on animal welfare: a case study. British Food Journal 2007;109:906–18.

68. Mullan S, Butterworth A, Whay HR, Edwards S, Main DCJ. Consultation of pigs farmers on the inclusion of some welfare outcome assessments within UK farm assurance. Veterinary Record 2010;166:678–80.

69. Vanhonacker F, Verbeke W, Tuyttens FAM. Belgium consumers' attitude towards surgical castration and immuno-castration of piglets. Animal Welfare 2009;18:371–80.

70. Rhodes RT, Appleby MC, Chinn K, Douglas L, Firkins LD, Houpt KA, *et al.* A comprehensive review of housing for pregnant sows. Journal of American Veterinary Medical Association 2005;277(Part 10):1580–90.