EU Reference Centre for Animal Welfare *Pigs*

Review on alternatives to stalls for sows after weaning and in early pregnancy

Antje Schubbert, Herman M. Vermeer, Hans A.M. Spoolder, Lene J. Pedersen

info.pigs@eurcaw.eu

www.eurcaw-pigs.eu

Review on alternatives to stalls for sows after weaning and in early pregnancy

Antje Schubbert[1], Herman M. Vermeer[2], Hans A.M. Spoolder[2], Lene J. Pedersen[3]

[1] *Friedrich-Loeffler-Institute, Germany*

[2] *Wageningen Livestock Research, The Netherlands*

[3] *Aarhus University, Denmark*

October 2022

This review is a publication of the European Union Reference Centre for Animal Welfare Pigs (EURCAW-Pigs). EURCAW-Pigs was designated by the European Union on 5 March 2018 through Regulation (EU) 2018/329, in accordance with Articles 95 and 96 of Regulation (EU) 2017/625.

Colophon and disclaimer

Access to document at https://doi.org/10.5281/zenodo.7307997. Also to be downloaded at https://edepot.wur.nl/580339

This review addresses important events from weaning, oestrus and implantation in the sow's reproductive cycle and provides measures to reduce the risks associated with group-housing. The review ends with a compilation of examples of group-housing systems for sows after weaning and in early pregnancy.

info.pigs@eurcaw.eu

www.eurcaw-pigs.eu

WAGENINGEN UNIVERSITY & RESEARCH

AARHUS UNIVERSITY

FRIEDRICH-LOEFFLER-INSTITUT FLI Bundesforschungsinstitut für Tiergesundheit Federal Research Institute for Animal Health

Co-funded by the European Union

Contents

1 Executive Summary

In 2021, the EU Commission announced it intends to phase out stalls for sows after weaning and in early pregnancy by 2027. The announcement was part of the Commission's response to the European Citizens' Initiative "End the Cage Age" launched in 2018, which joined over 170 organizations and gained over 1.6. million signatures calling for a ban on crating farmed animals in the EU (www.endthecageage.eu). At the present time, EU regulations still allow sow stalls from weaning until four weeks after service (see Council Directive 2008/120/EC, Article 3, Point 4.). A change of existing EU animal welfare legislation will most likely further reduce the possibility for farmers to use sow stalls, thus relying more on alternatives to sow stalls, also during early pregnancy. However, group-housing at this reproductive stage harbours risk, such as injuries or reproductive failure due to agonistic and oestrus behaviours (e.g. mounting).

This review addresses important events from weaning, oestrus and implantation in the sow's reproductive cycle and provides measures to reduce the risks associated with group-housing. The review ends with a compilation of examples of group-housing systems for sows after weaning and in early pregnancy.

2 Introduction

Sows are social animals and live in small groups under semi-natural environments. They only separate from their social group before parturition until 10 days after (Jensen, 1986). Although in 2013 the EU phased out sow stalls for pregnant sows from four weeks after service up to one week before farrowing, confinement of sows from one week before farrowing until four weeks after service is still allowed (see Council Directive 2008/120/EC, Article 3, Point 4.). In commercial housing systems, sows enter the mating unit after weaning, where they are often kept individually to protect them from any disturbances which might cause reproductive failure. Maternal recognition of pregnancy and implantation of embryos take place from 10- 19 days after fertilization and are crucial processes in establishing pregnancy (Waclawik et al., 2017). Both events can be negatively affected by different stressors, which may lead to embryo mortality (Spoolder et al., 2009). Another reason for individual housing is that sows are highly motivated to perform oestrus behaviour after weaning, including; mounting which, in particular, can provoke severe injuries or can distress subordinate sows (Pedersen, 2007).

Most sow stalls measure 60-70 cm x 200-210 cm and are equipped with a feeding trough and nipple drinker in front of the head of the sow (EFSA, 2007). Within the stalls, sows are fed 1-3 times per day, sometimes manually but mostly automatically. The flooring is mostly partially slatted (EFSA, 2007). The sow stalls are mostly in a row, located next to each other, separated by metal bars. Due to these partitions, only very limited social interactions between sows are possible (Jensen, 1984).

The main welfare concern regarding individual sow stalls relates to the restricted space allowance. In individual sow stalls, the sow is not able to turn around or to distinguish her lying area from her feeding or dunging area, and is forced to deposit her excreta in a fixed location (EFSA, 2007). Different studies on the body dimensions of breeding sows suggest that individual stalls do not provide sufficient space for sows to lie comfortably or to perform unhindered lying down behaviour. Especially for older sows (5th parity and more), the stalls are often too small (Curtis et al., 1989; McGlone et al., 2004; Meyer, 2015; Moustsen et al., 2011; Nielsen et al., 2018; O'Connell et al., 2007). It should be noted that sows which are crated from weaning until four weeks after service have more or less the same welfare issues as sows crated over their entire pregnancy (EFSA, 2007). Implications for sows' health due to individual housing in crates relate mainly to adverse effects on the cardiovascular systems (Marchant et al., 1997; Rhodes et al., 2005), muscular-skeletal system (Marchant & Broom, 1996; Rhodes et al., 2005; Schenck et al., 2008) and the development of stereotypies (Geverink et al., 2003; Rushen, 1984; Schouten & Wiepkema, 1991). In addition, around oestrus sows have a higher level of activity and are highly motivated for social interactions. When they are crated during this period, they are not able to express their internally-driven motivation for social interaction, which can provoke stress and frustration (EFSA, 2007).

Because of the implications for sows' health and welfare, some member states in the EU have already implemented a total or partial ban of crates (EU Commission, 2021). For instance, in Sweden sow stalls are already completely banned since 1988, in the Netherlands sow stalls are banned from 4 days after insemination and in Austria from 10 days after insemination. In Germany sow stalls will be banned from 2029, except around the time of insemination. In Denmark, sow stalls were banned in new buildings since 2015, with a possibility to stall sows for a maximum of 3 days during oestrus, and will be fully banned from the time of weaning with full effect from 2035 (Compassion in Word Farming Trust, 2000; EU Commission, 2021). In addition, customers are requesting more animal-friendly housing systems (EU Commission, 2016). In 2018 the European Citizens' Initiative "End the Cage Age" was launched, which joined over 170 organizations and gained over 1.6 million signatures calling for a ban on crating farmed animals in the EU (www.endthecageage.eu). In response to this, in 2021 the EU Commission announced they will propose to phase out farrowing crates and sow stalls by 2027. In the opinion of the Commission, the Citizens' Initiative reflects the need for more ethical and sustainable farming systems, which can only be achieved on the basis of new animal welfare legislation (EU Commission, 2021).

Changes to the EU animal welfare legislation are likely to result in increased use of group-housing systems for sows after weaning and in early pregnancy. After weaning, sows need sufficient space for both engaging in and avoiding agonistic interactions, as well as performing oestrus behaviour. In early pregnancy, sows have the same behavioural needs as in late pregnancy. This means sufficient space is required for them to engage in social behaviour as well as safe feeding places and access to comfortable lying places (see EURCAW-pigs "Review on group housing and mixing of sows", Schubbert et al. (2020)). Alternatives to sow stalls have to allow for sows' high motivation to express oestrus behaviour, while minimizing risks of injuries and distress. In addition, group-housing systems after weaning until four weeks after service have to provide a protective working environment for stockpersons to perform reproductive measures, such as artificial insemination and pregnancy detection. Thus, the current review addresses key events in the sow's reproductive cycle from weaning until four weeks after service which may impact the success of group-housing for sows in this period. It will describe behavioural patterns and the complexity of endocrine and physiological changes that sows are faced with at this reproduction stage. It will provide knowledge on risk factors and various measures to avoid or mitigate risks from group-housing from weaning until four weeks after service. Although very relevant for the reproductive performance of sows and their ability to cope with group housing, this review will not cover any aspects of nutritional supply or the physical fitness of sows after weaning and in early pregnancy. Nutritional needs of sows in pregnancy are described in part in the EURCAW-Pigs "Review on hunger induced behaviours: aggression and stereotypies", Hoorweg et al. (2022).

3 Scientific knowledge on stall housing of sows from weaning until four weeks after service

3.1 Weaning in nature and under commercial conditions

Wild and feral sows give birth to their piglets in farrowing nests, which they build at a sheltered place (Jensen, 1986). The sow remains together with her offspring in the nest for the first week after birth. During the first week after parturition, a sow nurses her piglets almost 30 times a day (Weary et al., 2008), but she also steadily increases the time she will stay away from the farrowing nest, for example to forage or for social contact with other sows of her social group (Stolba & Wood-Gush, 1989). Around 10 days after parturition, the sow will leave the farrowing nest, together with her piglets, and they will join the group of other sows with their piglets. Over time, the piglets spend increasing time away from their mother to socialize with other group members, and the strong mother-offspring bond gradually breaks up (reviewed by Marchant-Forde et al., 2020). In parallel with the piglets' process of becoming independent of the sow, the nursing frequency initiated by the sow decreases (Jensen & Recén, 1989). Jensen and Recén (1989) reported that sows decrease nursing bout length, and increase termination of a nursing bout as lactation progresses. The sow will increasingly end nursing bouts by standing up abruptly or will perform nursing in a standing position. Furthermore, physical condition allows piglets increasingly for foraging and individually development of feeding, which lowers pressure on the sow's lactational output and thus facilitates gradual weaning. Under natural conditions, weaning comprises a slow and gradual process and weaning will be finished at about 2 to 5 months. In addition, during the process of weaning there are no dramatic changes in the physical or social environment, neither for the sow nor for the piglets (Jensen & Recén, 1989; Newberry & Wood-Gush, 1985).

In modern housing conditions, piglets will be weaned at an age of about 3 to 4 weeks and weaning often includes the abrupt separation from their mother and transfer to the rearing pen, where they are grouped with unfamiliar piglets in unfamiliar surroundings. Further, they have to cope with solid food or new diets at an age they normally do not consume much solid food (reviewed by Brooks & Tsourgiannis, 2003). This early maternal separation leads to distress and provokes a lot of animal welfare problems in piglets (reviewed by Weary et al., 2008). For the sow, weaning means an abrupt loss of her piglets at a time when milk production, due to prolactin, is still at its peak (Farmer et al., 2007; Kim et al., 2001). Abrupt weaning is associated with mammary involution and dramatic histological and structural changes in the mammary gland (Farmer, 2019; Ford et al., 2003). In particular during the first two days, abrupt weaning is associated with milk stasis and marked loss of mammary gland mass. Finally, mammary involution ends on day 7 after weaning (reviewed by Farmer, 2019), whereas in natural weaning this process will be finished within 2-3 days after two consecutive days of non-suckling (Jensen & Recén, 1989). When artificially weaned in commercial housing conditions, the sow additionally has to cope with social stress due to mixing with unfamiliar sows (see EURCAW-pigs "Review on group housing and mixing of sows", Schubbert et al. (2020)).

3.2 Oestrus (day 4 - 7 after weaning)

Weaning is accompanied by endocrine changes inducing oestrus in the sow. Oestrus is the period in the female sexual cycle during which ovulation takes place. It is inhibited by suckling during the lactation period and by pregnancy (reviewed by Soede et al., 2011). Oestrus in sows typically occurs 4 to 7 days after weaning (Bates et al., 2000) and lasts between 1 to 4 days (reviewed by Soede & Kemp, 1997). At the onset of oestrus, sows are increasingly active, restless and they show a strong internally-driven motivation for social interaction (Pedersen, 2007). When a sow is approaching oestrus, her vulva becomes reddish and swells (reviewed by Soede & Kemp, 1997). In addition, sows in oestrus show sexual behaviours such as increased general activity, ano-genital sniffing, flank nosing and mounting (*Figure 3.2.1*) (reviewed by Pedersen, 2007). Oestrus in sows can be stimulated by the presence of a mature boar or by other sows in oestrus (reviewed by Pedersen, 2007). The main characteristic of sows' oestrus is the standing response in presence of a boar (or a human when any contact is applied to the sow, typically pressure on the back) (Soede & Kemp, 1997), which is an expression of sexual receptivity and is used in practice to predict insemination time (Soede et al., 2011).

Figure 3.2.1: Mounting behaviour in sows (© LSZ Boxberg)

In group housing systems, sexual interactions between sows around oestrus may result in social stress, often in addition to stress due to mixing with unfamiliar sows after weaning (see EURCAW review "Group housing and mixing", Schubbert et al. (2020) https://edepot.wur.nl/537021). For instance, Pedersen and Jensen (1989) observed that sows mount other sows up to 40 times per day for several days, whereby especially lower ranked sows are mounted. If these are not in oestrus themselves they may suffer from social stress (reviewed by Pedersen, 2007). Furthermore, subordinated sows in standing oestrus showed fear related behaviours, such as fleeing or squealing when faced with boar stimulation or mounting attempts by a boar (Pedersen et al., 2003). In contrast, Rault et al. (2014) observed increased fleeing from sexual behaviour independent of a sow's social rank. However, social stress and fear-related behaviour is often considered to impair reproductive parameters in sows, although such effects have been found only for prolonged stressors, as for instance unpleasant handling or housing in crowded conditions, in few studies (reviewed by Spoolder et al., 2009; Turner et al., 2005). Referring to Rault et al. (2014), sexual interactions of grouped sows increase progressively from day 2 to 5 after weaning and, in particular, mounting is described as a potentially injurious behaviour. When a sow mounts another sow, she lifts her two front-legs and places them on the back of the receiver (Pedersen, 2007). Although leg injuries are mostly associated with agonistic behaviour in group housing systems (reviewed by Spoolder et al., 2009), it can be assumed that mounting (or fleeing from being mounted) can also result in leg problems, especially on slippery floors.

Although oestrus lasts for several days, duration of ovulation is very short (1 to 5 hours) and its timing is difficult to predict because it varies between 24 to 60 h after onset of oestrus (reviewed by Soede & Kemp, 1997). Still, accurate oestrus detection is crucial for the timing of insemination because failure in timing of insemination has a negative impact on fertility results (Drickamer et al., 1997). In group housing systems, sows in oestrus may be easier to spot because the behavioural changes are clearly visible. However, when sows can freely move in the group pen, each individual has to be checked for a standing response, and detection of oestrus may be more time-consuming (and pose some health and safety risks) for stockpersons in the complex group housing environment compared to individually-housed or temporarily fixated sows. Furthermore, the ease with which any returns to oestrus (i.e. failure to hold serve) or abortions are detected is an important part of determining reproductive performance and a challenge in group housing systems (Spoolder et al., 2009). Thus, teaser boars are often used for oestrus detection, but habituation to teaser boars can result in a lower proportion of sows in oestrus and a shorter duration of oestrus, especially if the sows are housed adjacent to the boars (Knox et al., 2004; Tilbrook & Hemsworth, 1990). Thus, contact with boars for stimulation and detection of oestrus in sows should be limited. Although teaser boars are used for oestrus stimulation and detection, artificial insemination (AI) is the most popular insemination method in commercial systems (Knox, 2016; Roca et al., 2006) and females are usually artificially inseminated 2-3 times per oestrus (Soriano-Úbeda et al., 2013). Natural methods (natural mating) for reproduction are often used in alternative or organic systems, but lower reproductive performance is reported in comparison to AI (Adegbeye, 2020; Am-in et al., 2010; Kongsted & Hermansen, 2008), presumed AI is carried out correctly.

3.3 Early pregnancy and implantation (day 1 – 19 after insemination)

As polytocous animals (having more than one offspring at birth), sows ovulate 15-30 oocytes in one oestrus (Soede et al., 2011). At insemination, billions of spermatozoa are deposited in the cervix from where they make their way to the place of fertilization, the uterotubal junction (Roca et al., 2006; Soriano-Úbeda et al., 2013). For intra-cervical insemination, which is the common insemination procedure in pigs, an insemination dose contains approximately 2500 x 10^6 spermatozoa to guarantee successful farrowing rate and litter size. The high number of spermatozoa is necessary because, after deposition in the cervix, approximately 30-40 % of the semen flows out of the genital tract within 1 h of insemination in the majority of female pigs (reviewed by Roca et al., 2006). Furthermore, the transport of semen in the female genital tract is very complex and is regulated by many different factors (reviewed by Soriano-Úbeda et al., 2013). Finally, approximately 1-3 x 10^5 spermatozoa reach the uterotubal junction, where they bind on epithelial cells of the oviduct and create a sperm reservoir for 36-48h, depending on time of oestrus (reviewed by Soriano-Úbeda et al., 2013). Around ovulation, the spermatozoa are released from the sperm reservoir (Soriano-Úbeda et al., 2013). Due to thermotactic and chemotactic mechanisms, spermatozoa will reach the ovulated oocyte and fertilize it. After fertilization, any redundant spermatozoa will be phagocytosed in the female genital tract (reviewed by Soriano-Úbeda et al., 2013). At fertilization, the sperm enters the oocyte through the zona pellicuda and fuses with the oocyte to produce a one-cell zygote, representing the first single cell-stage of embryonic development (Yanagimachi, 1994). The zygote splits into a two-cell zygote after 26 h following fertilization and enters the pig uterus at the 4-8-cell stage 22-30 h later. The 8-cell stage, the so-called morula, develops into a blastocyst, which is differentiated into an embryonic disc, trophectoderm and extra-embryonic endoderm (reviewed by Johnson et al., 2021). From the blastocyst the conceptus is formed, which undergoes morphological changes to an 800-1000 mm filamentous form, and finally attaches to the uterine luminal epithelium for implantation. Although in pigs the term implantation is misleading, because placentation is epitheliochorial and less "intimate" than for instance in humans, where the embryo penetrates the uterine luminal epithelium to invade the uterine stroma (Ochoa-Bernal & Fazleabas, 2020), the term is used in literature to describe the initial stages of placental development (reviewed by Johnson et al., 2021). The attachment of the conceptus to the uterine luminal epithelium is supported by conceptus' secretion of estrogens, that initiate maternal recognition of pregnancy around 10-13 days post-oestrus (Waclawik et al., 2017). Maternal recognition of pregnancy is accomplished with many hormonal changes to ensure the required development of uterine receptivity for conceptus' adhesion on the surface of the uterine luminal epithelium (Waclawik et al., 2017). The implantation of embryos takes place 14-19 days post-oestrus (Waclawik et al., 2017). Implantation in pigs ends with the successful adhesion of the conceptus on the surface of the luminal epithelium and the development of interdigitation microvilli between conceptus' trophectoderm and uterine luminal epithelium to ensure nutritional exchange for fetal-placental development throughout pregnancy (reviewed by Johnson et al., 2021). However, maternal recognition and implantation are both crucial processes in establishing early pregnancy. Highest mortality rates of embryos are reported for this early stage of pregnancy, whereby the majority of embryos die with 20-30 % by day 21 and with 10-15 % by day 35 (reviewed by Waclawik et al., 2017). Early loss of embryos in the polytocous pig happens quite often and early embryonic mortality can result from different causes (Geisert & Schmitt, 2002). Survival of embryos depends on ovulation rate and uterine capacity in the sow (Ford et al., 2002; Foxcroft et al., 2006). Geisert and Schmitt (2002) pointed to three critical phases related to early embryonic loss: the rapid trophoblastic elongation, the estrogen synthesis by the conceptus, and the placental attachment to the uterine epithelial surface. Furthermore, conceptus elongation is asynchron and embryos can compete within the uterus. Geisert and Schmitt (2002) reviewed several studies indicating that the secretion of estradiol from tubular and elongation conceptus can alter the uterine environment. Lesser-developed littermates' then can be less able to elongate or to obtain sufficient space in the uterus to survive. This early siblicide is a well-known pattern in pigs. In addition, the concept of maternal investment plays a role in embryonic loss, i.e. the trade-off between the sow's investment in her piglets in relation to her own survival and fecundity in future (reviewed in Baxter et al., 2018).

In addition to the factors described above, other factors also may impair reproductive performance in early pregnancy. Among others, one stressor is mixing of unfamiliar sows (see EURCAW-pigs "Review on group housing and mixing of sows", Schubbert et al. (2020)) after weaning. Commercial sows are generally mixed either at weaning, shortly after insemination or after pregnancy detection at around 28 days post insemination (Verdon et al., 2015). Time of mixing can affect reproductive performance and level of aggression, which depend on hormonal changes during pregnancy (reviewed by Kongsted, 2004; Spoolder et al., 2009; Verdon et al., 2015). Verdon et al. (2015) reviewed different studies on the impact of time of mixing on agonistic interactions, stress and skin lesions and conclude that these factors for sows are most detrimental when mixed early after insemination. It is also suggested that because of the period of maternal recognition of pregnancy and implantation (day 10-19 post-oestrus), stress should be avoided from week 2 to 3 after insemination (Salak-Johnson, 2017). Thus, mixing is recommended at weaning, but sows should not be mixed later than one week after insemination. However, so far, results on the impact of group housing and time of mixing on reproductive performance are inconsistent (Kongsted, 2004; Spoolder et al., 2009; Verdon et al., 2015). Further, results of studies comparing reproductive parameters between individual stalls and group housing are not always clear: parity of sows, genotype, time of grouping or housing conditions differ widely between studies (reviewed by Kongsted, 2004; Spoolder et al., 2009). However, when sows were grouped directly after weaning, reproductive parameters were improved by one more live-born piglet per sow per year in comparison to individually housed sows (Schwarz et al., 2021). Moreover, most of the sows which remain pregnant until five weeks after insemination will stay pregnant until farrowing (Spoolder et al., 2009).

4 Measures to avoid negative consequences of group housing

Group-housing systems for weaned and early pregnant sows have to consider different design aspects. Early pregnant sows have the same species-specific needs compared with sows in late pregnancy. Thus, group-housing has to provide e.g. sufficient space, safe access to food and water resources, a good climate and resting comfort sows (see EURCAW-pigs "Review on group housing and mixing of sows", Schubbert et al. (2020)). However, after weaning sows on heat will try to mount each other, and unfamiliar sows are motivated to develop a social rank order, thus they need extra space in this period. They can suffer from injuries or fear due to these agonistic and sexual interactions if space and design aspects are not sufficiently considered in housing. The negative welfare consequences of these behavioural interactions can be decreased by the provision of e.g. extra space, protective walls and sufficient bedding. Group housing systems also have to provide a protective working environment for insemination and the detection of pregnancy, which can be achieved by temporarily confining sows in stalls for these tasks. A good group housing system and management strategy also facilitates the detection of returns to oestrus. In addition, due to the early separation from their litter and the dramatic physiological and endocrine changes sows are faced with, the prevention of additional stress is the ultimate aim in the design of group-housing systems. Therefore, in the following chapter measures to reduce the negative consequences of group housing will be presented. The chapter ends with a compilation of examples of group-housing systems for sows after weaning and in early pregnancy.

4.1 Sufficient space

When unfamiliar sows have to establish their social relationship at mixing, the amount of space in group-housing systems will have an effect on the level and duration of agonistic behaviours (Baxter, 1985). For instance, insufficient space and/or narrow passages can provoke repeated fights between two individuals, as they may be pushed against barriers and have to terminate their fight before the rank is established. In addition, in pens with insufficient space sows cannot express nor recognize submissive behaviour, such as fleeing from the attacker, nor can they easily express ritualised behaviour (e.g. parallel walking) thought to be an assessment of likely contest success (Camerlink et al., 2016; Hemsworth et al., 2013). This means they will repeat or persevere in their fight (Baxter, 1985). Thus, frequencies of agonistic interactions increase and the establishment of the social relationship is prolonged unnecessarily. However, the exact amount of space needed for fighting and fleeing is difficult to estimate. One attempt to determine the space needed for a fight between two sows was made by Baxter (1985). He estimated the amount of space for two sows engaged in a two-sided fight to be $0.11 * W^{0.667}$ where W is the body weight of the pigs. For example, two sows in first parity with a mean body weight of 217 kg (Moustsen et al., 2011) will need 4 m² space to fight and two fully grown sows (≥ 5th parity) with a mean body weight of 317 kg (Moustsen et al., 2011) will need 5.1 m² space.

It is not only the total available space which has to be considered, but also the distances sows need when they flee from the attacker or chase the victim. Kay et al. (1999) measured flight distances in an arena (18x10.5 m) with 31 m² per sow during the first two days of mixing. They measured distances up to 13.6 m in 95 % of all flights. The distances sows chased victims in 95 % of all attacks measured up to 6.8 m. Thus, after weaning, accommodation in specific mixing pens is recommended (reviewed by Verdon et al., 2015). These pens should provide sufficient space (open areas of at least 4-6 m² per sow) for fighting, whilst also allowing sows to achieve a flight distance of at least 10-12 m (Spoolder et al., 2009). This can be quite a large pen (4.1.1). However, the need for a large flight distance can be reduced by applying visual barriers within the pens to support avoidance of fights, as they can hide from dominant sows (Spoolder et al., 2009; Verdon et al., 2015). Edwards et al. (1993) reported that such barriers reduced total aggression by nearly 30 % in the 12 h after mixing. For further information on the design of a mixing pen, see EURCAW-pigs "Review on group housing and mixing of sows", Schubbert et al. (2020).

Figure 4.1.1: An example of a mixing pen built using a large tent (© LSZ Boxberg)

In general, sows are kept in a mixing pen for the first 2-3 days after mixing. After they establish their social relationships, they are transferred to dry sow accommodation where they can be served. Good service accommodation can be equipped with individual free-access feeding stalls. Individual feeding after weaning allows sows to recover from body weight loss during lactation and to reach good body condition for insemination and subsequent pregnancy (Langendijk, 2021). Further, the feeding stalls provide a protective working environment for stockpersons around inseminations and for pregnancy detection. However, the space sows need to perform oestrus behaviour, such as mounting, is scientifically not determined. Some countries have nevertheless indicated what they consider a minimum space allowance: e.g. the revised German law on livestock welfare and husbandry (TierSchNutztV, 2021) states that from 2029 each sow has to be provided with 5m² of unobstructed area from weaning until insemination. Given that 5.1 m² has been suggested as the space required for two fully grown sows to perform a side-by-side fight (allowing circling whilst inverse parallel pressing), it can be assumed that an unobstructed area of 5 m² per sow might also be sufficient for two individuals to perform mounting behaviour (in standing position).

A potential practical approach would be to have the 'best of both worlds' by combining a mixing pen with feeding stalls in one compartment (4.1.2). In most cases, an activity area is behind the feeding stalls or in between two rows of feeding stalls. Recommendations for size and dimensions of such a pen come from consideration of the activities described above. Distances for fleeing and chasing are known, as mentioned above with the latest evidence suggesting, width should be more than 3 m, allowing sows to avoid each other or to flee from fights (Feller et al. (2021).

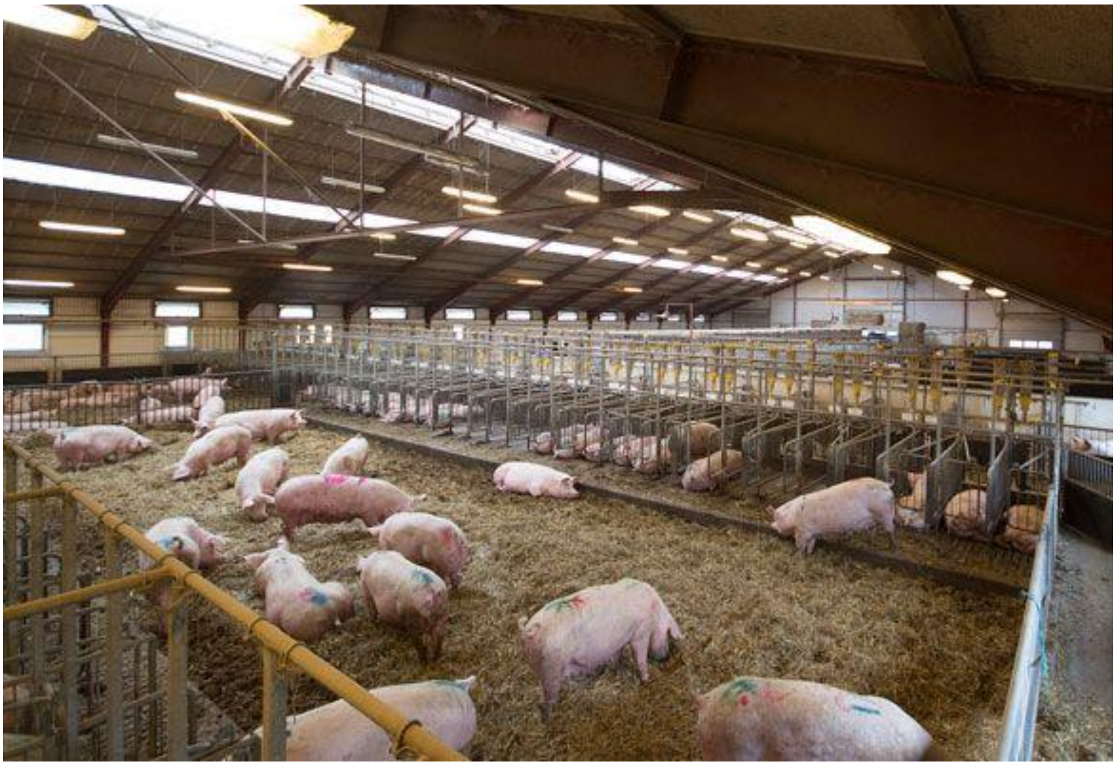

Figure 4.1.2: An example of a mating unit with feeding stalls and free access to an activity area (© Lene Juul Pedersen)

4.2 Types of flooring

In group housing systems, leg disorders occur more often in comparison to individual housing (Cador et al., 2014). Especially as inadequate floors in group-housing systems are often linked with claw and leg lesions, which can result in lameness (KilBride et al., 2009; Pluym et al., 2011). For instance, Cador et al. (2014) investigated risk factors associated with leg disorders in group-housing systems for pregnant sows and suggested concrete slatted floors as a high-risk factor. Floor characteristics relevant to injuries are slipperiness, abrasiveness, hardness, surface profile and thermal properties (Webb & Nilsson, 1983). In group-housing for dry sows, weaning and oestrus occur as temporary events in a sow's reproduction cycle and floor characteristics are even more important at these times. The performance of agonistic and sexual behaviour includes locomotory events, like pushing, circling, mounting, chasing and fleeing, which need a good foothold. For instance, when sows experience unsure foothold they interrupt fights, with adverse effect on the frequency of agonistic interactions (Walker & Beattie, 1994).

Although the impact of mixing on the prevalence of lameness is contradictory (Heinonen et al., 2013; Pluym et al., 2017), grouping can provoke at least claw lesions in gilts on solid floors (Olsson et al., 2016). Thus, Spoolder et al. (2009) recommended the provision of straw at times when agonistic interactions occur, e.g. in the mixing pen, to reduce the risk of leg disorders. Several studies reported a lower risk for leg disorders, when straw bedding was provided in group-housing systems (e.g. Andersen & Boe, 1999; Cador et al., 2014). However, KilBride et al. (2009) reported abnormal gait in fattening pigs even on solid floors with sparse bedding, suggesting that bedding should be provided in sufficient quantity. The impact of sexual interactions on leg injuries is scientifically not investigated so far, but it can be assumed that sexual interactions like mounting may provoke leg lesions on inadequate flooring, especially on slippery floors. Thus, around oestrus as well, bedding is recommended to ensure good foothold during sexual interactions.

In housing systems which are not suitable for the use of straw (bedding) due to a vacuum slurry system and slatted floors, the use of rubber mats in parts of the pen can be considered as an alternative (Tuyttens et al., 2008). Some studies report a preference for sows to lie on rubber mats in comparison to hard solid or slatted floors (e.g. Díaz et al., 2013; Elmore et al., 2010; Huneau-Salaün et al., 2021). However, there is disagreement on the question of whether mats reduce the risk of leg lesions, especially of lameness (Bos et al., 2016; Díaz et al., 2013; Huneau-Salaün et al., 2021). So far, studies are lacking on the impact of (slatted) rubber mats covering the activity area on foothold during agonistic or sexual interactions. Only Baumann (2014) reported that sows prefer walking in alleys covered with slatted rubber mats in the activity area, compared to walking on concrete fully slatted floors. However, according to Baumann (2014) sows stand preferentially on rubber mats for urination and defecation, which induced a slurry surface because urine and manure did not easily pass through the slats. This observation is in line with Díaz et al. (2013) and Huneau-Salaün et al. (2021), who reported that pens covered with slatted rubber mats were more soiled in comparison to concrete slat pens due to insufficient slurry drainage. This adverse effect on sows due to soiling with manure on the body may depend on perforation level of rubber mats, because Huneau-Salaün et al. (2021) reported severely soiled sows with manure on the body on non-perforated rubber mats. In contrast, Díaz et al. (2013) assessed the level of soiling with manure in sows housed on slatted rubber mats in comparison to concrete slats and found no differences between treatments. Nevertheless, Baumann (2014) concluded that slatted rubber mats covering part of the activity area may provide enough slip resistance despite soiling, and may improve the welfare of the sows. Díaz et al. (2013) found a slurry film on slatted rubber mats, and doubted that they were less slippery in comparison to concrete slats. They also highlighted, referring to Pedersen and Ravn (2008), that in case a sow slips or falls, rubber mats may absorb more of the shock than concrete floors will. It seems that no clear conclusion can be drawn regarding the welfare benefits of using rubber mats in slurry-based systems. What can be said is that the use of pens with partly-slatted floor and partly-solid floor areas, combined with a mechanical scraper system in the slurry channel, will allow provision of sufficient bedding material and is therefore to be preferred.

4.3 Environmental enrichment

Environmental enrichment in farmed sows includes the enrichment of pens by improving physical and thermal comfort (Elmore et al., 2012; Elmore et al., 2011) and/or the provision of access to different enrichment materials (objects or substrates) (Durrell et al., 1997; Horback et al., 2016). In pens with slatted floors, enrichment materials are mostly provided as point source enrichment at a fixed position in the pen due to their compatibility with the slurry system below (Roy et al., 2019). However, research on effective enrichment for gestating sows in group housing is scarce (Galli et al., 2021). Sows value enrichment independent of their social status, but social status has an effect on frequency of enrichment use (Elmore et al., 2011; Roy et al., 2019). For instance, dominant sows spent more time with enrichment use and displaced subordinate sows from sources of enrichment (Elmore et al., 2011). In contrast, subordinate sows used enrichment sources at non-peak times (Elmore et al., 2011) or when dominant sows valued more important resources, as for instance gaining food from an Electronic Sow Feeder (ESF) (Roy et al., 2019).

Some authors assume that the provision of enrichment mitigates agonistic interactions around mixing. Durrell et al. (1997) reported that sows housed in enriched pens, in comparison to barren pens, showed a lower frequency of overall agonistic interactions on day 1 after mixing, but not on day 2-14. In contrast, several other authors (Greenwood et al. (2019); Stewart et al. (2011) and Horback et al. (2016)) were unable to detect any effects of provision of enrichment on agonistic behaviour during mixing. Horback et al. (2016) argued that the motivation to establish social relationships is greater than the motivation to access sources of environmental enrichment. The inability of enrichment to reduce post weaning aggression was also underlined by Elmore et al. (2012a; b), who reported that sows' motivation to gain access to additional food was higher than gaining access to enrichment. Thus, the impact of enrichment on agonistic interactions around mixing should not be overestimated.

Nevertheless, around mating and in early pregnancy sows do have a need for foraging and exploring. A barren environment, in particular in combination with the marked reduction in feed/energy provision after weaning, is strongly related to severe animal welfare problems, such as stereotypies (see EURCAW-Pigs "Review on hunger induced behaviours: aggression and stereotypies", Hoorweg et al. (2022)). It has been shown that sows respond better to enrichment materials that are renewed frequently to avoid habituation (Roy et al., 2019). An appropriate enrichment has to be investigable, manipulatable, chewable and edible (Studnitz et al., 2007). Further, enrichment material has to be provided in a sufficient amount for sows, allowing all sows simultaneous access, because otherwise enrichment can become a limited resource and may provoke agonistic interactions. In addition, substrates should be delivered regularly during the day in order to minimize times of absence, allowing subordinate sows to use enrichment at non-peak times. Pigs prefer substrates on the floor rather than point source objects or 'toys' which are suspended or lie on the floor (Roy et al., 2019). They also value the simultaneous provision of different substrates eliciting different foraging behaviours like rooting, grazing, biting and chewing (Moser et al., 2019)

The enrichment of pens can also be achieved by the division into different functional areas and/or the provision of access to an outdoor run (Newberry, 1995), to provide pigs greater choice and therefore greater agency (Mellor, 2015) (*Figure 1*.3.1). Although outdoor runs are not easy to implement in existing buildings, they can be considered in future buildings and have benefits from an animal welfare point of view. Outdoor runs provide pigs extra space for escape behaviour, exploration and foraging, and the provision of additional substrates or roughages (e.g in racks) in the outdoor run encourages pigs to spend activity time in the outdoor area (reviewed by Wimmler et al., 2022)

Figure 1.3.1: Outdoor run under a roof with enough space for escape behaviour and with access to a straw rack for exploration and foraging (© Bernhard Feller)

4.4 Reproductive Management

In group-housing systems, the methodology used for detection of oestrus and insemination can differ depending on the system and therefore the decision on how oestrus detection and insemination will be managed has to be taken individually for each farm. Management decisions might depend on size of the sow herd and spatial conditions of the group-housing. In any case, assessing the reproductive status in group-housed sows carries some risk for the stockpersons, because around oestrus a sow's activity and motivation for sexual interaction increases. Stockpersons may be pushed, run over or otherwise injured (LSZ Boxberg, 2021). Therefore the use of feeding stalls is recommended to provide the possibility for temporary fixation during insemination and ensure a protective working environment (Pedersen, 2018).

The common method for oestrus detection is a behavioural test, the Back Pressure Test (Cornour, 2006). For this, the stockperson presses on the back and sides of the sow to provoke a standing response. The sow stands still even when pushed, she will slightly arch (hollow) her back and some breeds of sows will prick their ears. If the stockperson can apply substantial downward pressure on her hind quarters without the sow moving away, she is on heat and can be inseminated (Cornour, 2006; Soede et al., 2011). In group-housing, oestrus can be checked either in freely moving sows or during temporary fixation in feeding stalls. When sows are not confined during oestrus detection, the standing response is easier to detect as she can move away if she is not on heat (LSZ Boxberg, 2021). On the other hand, oestrus detection in temporarily stalled sows, e.g. around feeding, can be checked more time-efficiently e.g. after feeding. It may, however, more often lead to misinterpretation as she cannot move away from the stockperson. In either situation, if the sow responds with a standing response, she can be inseminated in the group pen or the feeding stall. If individual sows need to be inseminated in a group situation (*Figure 4.4.1*), other sows may disturb the stockpersons during artificial insemination. All sows are therefore sometimes shut in feeder stalls, to allow insemination of those that are on heat. However, it should be noted that sows in oestrus are not easy to move to the stalls (as they perform a standing response when contact is made), which is why fixation for insemination outside normal feeding times is more labour intensive (LSZ Boxberg, 2021). Thus, in practice, sows are temporarily stalled during feeding, followed by an oestrus check and insemination of sows which are on heat. However, the insemination can only be conducted after feeding and all sows might be confined for a prolonged period due to preparation of measures before insemination.

Figure 4.4.1: Insemination of freely moving sows on heat in the group pen, © LSZ Boxberg

Regardless which management measure a stockperson decides, boars can help to detect or re-detect a sow's oestrus, because sows in oestrus better express receptive behaviour in sight of boars. In addition, during artificial insemination sows can be stimulated by a teaser boar. Boar stimulation should be easy to impose and the level of stimulation depends on the visibility of the boar by the sows. Inclusion of specific insemination pens in the housing design can facilitate boar stimulation. However, such pens will function better if only considered for a few sows at a time, because the contact area is often small and might be occupied easily by only a subgroup of sows (Figure 4.4.3). Insemination pens are more sufficient when sows will be inseminated freely. In contrast, in group-housing with feeding stalls and a boar alley (Figure 4.4.2) visibility of the boar to all sows can be established simultaneously during temporary fixation (LSZ Boxberg, 2021). In addition, the alley in front of the stalls allows a teaser boar to walk along the sows for stimulation (Feller et al., 2021). Furthermore, such alleys allow stockpersons to easily lock sow stalls during feeding (Levis & Connor, 2013), which may reduce labour time for reproductive measures.

Figure 4.4.2: Teaser boar walking along a boar alley to stimulate sows during artificial insemination(© LSZ Boxberg)

Figure 4.4.3: Insemination pen with boar contact (© LSZ Boxberg)

For future group-housing, automated assessments may help to reduce labour time for oestrus detection and their development should proceed. For instance, Cornour (2006) mentioned in his review different methods of automated oestrus detection including possibilities for measuring behavioural, physical and physiological traits automatically. Automatic detection of physical and physiological traits related to oestrus have several limitations regarding sensitivity, as seen through conflicting result of basic traits (e.g. body temperature) or technical impracticability (e.g. assessing of vulva reddening). Automated behavioural monitoring, such as visits to the boar pen, showed the best results in terms of sensitivity and might be a promising approach for future research.

4.5 Examples of group-housing for weaned and early pregnant sows

In general, group-housing systems for sows from weaning until four weeks after service have to consider three major design criteria: (1) the provision of sufficient space to allow sows to engage in or avoid agonistic and/or sexual behaviours, (2) the provision of a protective working environment for stockpersons during reproductive management and (3) ensuring individual feeding and avoidance of competitive behaviour for food. Design criteria (2) and (3) can be achieved with the implementation of free access feeding stalls. To avoid hindrance of movement (criteria (1)), length of pens should be longer than 7 meters and width of alleys, where sows cross each other's path, should measure more than 3 meters (Feller et al., 2021). Once the three major design criteria are set, remaining measures to avoid negative consequences of group housing can be considered for pen design, which include for instance suitable flooring, environmental enrichment etc..

The following examples of different group-housing systems fulfil the three design criteria as described above. It should be noted that the following compilation is not complete, and EURCAW-Pigs cannot substitute for advice from specialist pig housing designers who livestock farmers should consult when (re)planning buildings. However, the following examples can be considered as illustrating "good practice", based on state-of-the-art knowledge presented above. As successful operation of breeding units is dependent on multiple factors (i.e. management, genotype, housing system) adopting these examples does not guarantee success.

Example 1: Free access feeding stalls

Around mixing, some simple ad lib feeders, for instance implemented in a group mixing pen, can restore sows' body reserves and the satiation can reduce aggression (Marchant & Marchant-Forde, 2005). However, when sows are restrict-fed, competitive feeding systems can cause welfare risks particularly for subordinate sows (Brouns & Edwards, 1994). Thus, group-housing for sows to be inseminated or in early pregnancy which is equipped with free access feeding stalls, allows individual feeding, ensuring sufficient nutrient intake by the individual and decreasing competitive behaviour for food. At the same time, free access stalls provide a protective working environment for insemination. Free access feeding stalls can be designed as one or two rows of stalls. In the so-called "I-configuration", feeding stalls include a mostly slatted area in between two or one row of stalls. This limits the sows' ability to separate the pen area into functional zones, since there is no distinctive lying area outside the feeding stalls. In any case, the area has to be designed with at least 3 m width, so that sows can perform agonistic and sexual interactions (Figure 4.5.1). When it is not possible to design a new housing system the existing barns are not wide enough for these activity areas, it is possible to upgrade/retrofit existing pens with an outdoor run that is bedded with straw. This preferably should be included in a novel pen design. The outdoor run allows sow to escape from agonistic and sexual interaction and provides a good foothold due to straw bedding (LSZ Boxberg, 2021). Nevertheless, in two-row stall designs, sows are often observed occupying feeding stalls for almost the entire time due to the absence of a resting area. Thus, in "I configuration" stalls, one row of feeding stalls is preferred, because a resting area can be implemented as a third functional area, behind the feeding stalls and the activity area (Levis & Connor, 2013). The lying area can be established with a partially slatted flooring, a solid concrete floor with bedding or comfortable rubber mats.

Figure 4.5.1: Area allowing sows to perform agonistic and sexual interactions in an area between two rows of feeding/insemination stalls (© Bernhard Feller)

To provide an undisturbed area for resting outside the stalls, a "T" or "L" configuration of free access feeding stalls could be considered. The "T-configuration" is characterized by an open area at the end of the stall rows (Figure 4.5.2). Sows will typically use this area for resting since it provides an undisturbed area outside the stalls (Levis & Connor, 2013). The lying area can be established with a partially slatted flooring, a solid concrete floor which may be bedded or with comfortable rubber mats for lying.

Figure 4.5.2: An example of a T-shaped pen design with feeding stalls. At the end of two rows of stalls an undisturbed area with partly solid floor is provided for undisturbed resting (© Lene Juul Pedersen)

The "L configuration" has an alley (totally slatted or solid floor with bedding) behind the stalls, that leads down to a communal resting area across the end of one row of stalls (Levis & Connor, 2013). However, group size and group dynamics are important determinants of whether or not these L or T shaped designs provide enough space for all sows to access the lying area. For some further aspects of group size and group dynamic as well as resting comfort, see EURCAW-pigs "Review on group housing and mixing of sows", Schubbert et al. (2020).

Example 2: Pens with separation of functional areas

These pens are characterized by the separation of the functional areas for feeding, dunging and lying, and the establishment of a covered lying area. In standard stalls, the number of feeding stalls in a row determines the length of the stall area and limits possibilities to structure the pen appropriately. However, in these pens, a lying area is implemented behind the feeding stalls with a dunging alley in between. Sows will distinguish between dunging and lying areas, and they use the lying area for resting (Feller et al., 2021). The lying area should be spatially and climatically separated from the feeding and dunging areas. To achieve this it is often covered, separated with curtains, partially enclosed or equipped with a hut. In addition, no water or enrichment material should be provided in the lying area, because lying sows might be disturbed by the activities of other sows. Pens with separation of functional areas are recommended for smaller groups and can be implemented in heat -insulated barns or in an outdoor climate.

Figure 4.5.3: An example of a housing system with separated functional areas in an outdoor climate (© LSZ Boxberg)

Example 3: Deep Straw Pen

Straw bedding provides a good foothold during sexual interactions. However, deep straw bedding can challenge thermoregulation, since newly weaned sows have a high metabolism and thus a high heat production (Williams et al., 2013). Since the straw bedding, over time, may produce heat due to composting, deep straw bedding needs to be combined with a cooler surface area for thermoregulation during hot periods. Also, the design of pens with deep straw bedding must include wide alleys, which allow the use of machinery for placement of straw bales and cleaning between batches. In addition, ceilings should be high enough for the operation of machines (Feller et al., 2021). It is recommended that pens with deep straw bedding are combined with feeding stalls (or electronic sow feeders) to allow individual feeding. Feeding stalls would provide a cooler resting area.

Figure 4.5.4: An example of a deep straw pen with individual feeding stalls and air supply via eaves and air dampers (© LSZ Boxberg)

Acknowledgements

We would like to thank Sandra Edwards and Emma Baxter for their valuable contributions to this review. And we would like to thank Bernhard Feller from the German Chamber of Agriculture in North Rhine Westphalia as well as Andrea Wild and Sabrina Möbius from the German Education and Knowledge Centre Boxberg, National Institute for pig breeding (LSZ Boxberg), who provided pictures for this review.

5 References

Adegbeye, M. J. (2020). Effect of artificial insemination and natural mating on reproductive parameters in pigs of warm-humid climate region. *The Indian Journal of Animal Science, 90*(3), 372-374.

Am-in, N., Tantasuparuk, W., & Techakumphu, M. (2010). Comparison of artificial insemination with natural mating on smallholder farms in Thailand, and the effects of boar stimulation and distance of semen delivery on sow reproductive performance. *Tropical Animal Health and Production, 42*(5), 921-924, doi:https://doi.org/10.1007/s11250-009-9508-3.

Andersen, I. L., & Boe, K. E. (1999). Straw bedding or concrete floor for loose-housed pregnant sows: Consequences for aggression, production and physical health. *Acta Agriculturae Scandinavica Section a-Animal Science, 49*(3), 190-195, doi:https://doi.org/10.1080/090647099424105.

Bates, R. O., Kelpinski, J., Hines, B., & Ricker, D. (2000). Hormonal therapy for sows weaned during fall and winter. *Journal of Animal Science, 78*(8), 2068-2071, doi:https://doi.org/10.2527/2000.7882068x.

Baumann, S. (2014). Gummimatten für den Liege- und Laufbereich in der Gruppenhaltung von Sauen. (Thesis). University Hohenheim, Stuttgart. Retrieved from http://opus.uni-hohenheim.de/volltexte/2015/1076/pdf/Diss_Stefanie_Baumann_VDI_MEG_543.pdf

Baxter, E. M., Andersen, I. L., & Edwards, S. A. (2018). Sow welfare in the farrowing crate and alternatives. In: M. Špinka (Ed.), *Advances in Pig Welfare* (pp 27-72). Woodhead Publishing.

Baxter, M. (1985). Social space requirements of pigs. In: *Social Space for Domestic Animals* (pp 116-127). Dordrecht, Martinus Nijhoff Publishers.

Bos, E.-J., Maes, D., van Riet, M. M. J., Millet, S., Ampe, B., Janssens, G. P. J., & Tuyttens, F. A. M. (2016). Locomotion disorders and skin and claw lesions in gestating sows housed in dynamic versus static groups. *PloS one, 11*(9), 1-17, doi:https://doi.org/10.1371/journal.pone.0163625.

Brooks, P. H., & Tsourgiannis, C. A. (2003). Factors affecting the voluntary feed intake of the weaned pig. In: J. R. Pluske, J. Le Dividich, & M. W. A. Verstegen (Eds.), *Weaning the pig - concepts and consequences* (pp 81 - 116). Wageningen, Wageningen Academic Publishers.

Brouns, F., & Edwards, S. A. (1994). Feed-related aggression amongst sows of different social rank in situations of high and low competition for food. *Applied Animal Behaviour Science 41*, 269-279.

Cador, C., Pol, F., Hamoniaux, M., Dorenlor, V., Eveno, E., Guyomarc'h, C., & Rose, N. (2014). Risk factors associated with leg disorders of gestating sows in different group-housing systems: a cross-sectional study in 108 farrow-to-finish farms in France. *Preventive Veterinary Medicine, 116*(1-2), 102-110, doi:https://doi.org/10.1016/j.prevetmed.2014.05.004.

Camerlink, I., Arnott, G., Farish, M., & Turner, S. P. (2016). Complex contests and the influence of aggressiveness in pigs. *Animal Behaviour, 121*, 71-78, doi:https://doi.org/10.1016/j.anbehav.2016.08.021.

Compassion in Word Farming Trust. (2000). *The welfare of Europe's sows in close confinement stalls*. Retrieved from Hampshire UK. https://www.ciwf.org.uk/research/species-pigs/the-welfare-of-eu-sows-in-close-confinement-stalls/

Cornour, C. (2006). Automated oestrus detection methods in group housed sows: Review of the current methods and perspectives for development. *Livestock Science, 105*(1-3), 1-11.

Curtis, S. E., Hurst, R. J., Gonyou, H. W., Jensen, A. H., & Muehling, A. J. (1989). The physical space requirement of the sow. *Journal of Animal Science, 67*, 1242-1248.

Díaz, J. A. C., Fahey, A. G., Kilbride, A. L., Green, L. E., & Boyle, L. A. (2013). Longitudinal study of the effect of rubber slat mats on locomotory ability, body, limb and claw lesions, and dirtiness of group housed sows. *Journal of Animal Science, 91*(8), 3940-3954, doi:https://doi.org/10.2527/jas.2012-5913.

Drickamer, L. C., Arthur, R. D., & Rosenthal, T. L. (1997). Conception failure in swine: Importance of the sex ration of a female's birth litter and tests of other factors. *Journal of Animal Science, 75*(8), 2192-2196.

Durrell, J., Sneddon, I. A., & Beattie, V. E. (1997). Effects of enrichment and floor type on behaviour of cubicle loose-housed dry sows. *Animal Welfare, 6*(4), 297-308.

Edwards, S. A., Mauchline, S., & Stewart, A. H. (1993). Designing pens to minimise aggression when sows are mixed. *Farm Building Progress, 113*, 20-23.

EFSA. (2007). *Scientific report on animal health and welfare aspects of different housing and husbandry systems for aduld breeding boars, pregnant, farrowing sows, and unweaned piglets*. Retrieved from European Food Safety Authority. https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/j.efsa.2007.572

Elmore, M. R., Garner, J. P., Johnson, A. K., Kirkden, R. D., Richert, B. T., & Pajor, E. A. (2012). If you knew what was good for you! The value of environmental enrichments with known welfare benefits is not demonstrated by sows using operant techniques. *Journal of Applied Animal Welfare Science, 15*(3), 254-271, doi:https://doi.org/10.1080/10888705.2012.683982.

Elmore, M. R. P., Garner, J. P., Johnson, A. K., Kirkden, R. D., Richert, B. T., & Pajor, E. A. (2011). Getting around social status: Motivation and enrichment use of dominant and subordinate sows in a group setting. *Applied Animal Behaviour Science, 133*(3), 154-163, doi:https://doi.org/10.1016/j.applanim.2011.05.017.

Elmore, M. R. P., Garner, J. P., Johnson, A. K., Richert, B. T., & Pajor, E. A. (2010). A flooring comparison: The impact of rubber mats on the health, behavior, and welfare of group-housed sows at breeding. *Applied Animal Behaviour Science, 123*(1), 7-15, doi:https://doi.org/10.1016/j.applanim.2009.11.012.

EU Commission. (2016). *Special Eurobarometer 442 - Attitudes of Europeans towards Animal Welfare*. Retrieved from. https://europa.eu/eurobarometer/surveys/detail/2096

EU Commission. (2021). *Annex to the Communication from the Commission on the European Citizen's Initiative 'End of Cage Age'*. Retrieved from. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12842-Animal-welfare-%E2%80%98End-the-Cage-Age%E2%80%99-European-citizens%E2%80%99-initiative_en

Farmer, C. (2019). Review: Mammary development in lactating sows: the importance of suckling. *Animal, 13*(1), 20 - 25, doi:https://doi.org/10.1017/s1751731118003464.

Farmer, C., Knight, C., & Flint, D. (2007). Mammary gland involution and endocrine status in sows: Effects of weaning age and lactation heat stress. *Canadian Journal of Animal Science, 87*, 35-43, doi:https://doi.org/10.4141/A06-083.

Feller, B., Franke, G., Bauer, T., Böhmfeld, J., Formowitz, B., Fritzsche, S., Grimm, E., Häuser, S., Jais, C., Janssen, H., Lösel, D., Meyer, C., Meyer, E., Meyer-Hamme, S., Neser, S., Paulke, T., Peperkorn, K., Preißinger, W., Sandhäger, A., Scholz, A., Schrader, H., Weber, M., & Zacharias, T. (2021). *Gesamtbetriebliches Haltungskonzept Schwein - Sauen und Ferkel*. Retrieved from BonnBundesanstalt für Landwirtschaft und Ernährung (BLE). https://www.ble-medienservice.de/0073/gesamtbetriebliches-haltungskonzept-schwein-sauen-und-ferkel

Ford, J. A., Jr., Kim, S. W., Rodriguez-Zas, S. L., & Hurley, W. L. (2003). Quantification of mammary gland tissue size and composition changes after weaning in sows. *Journal of Animal Science, 81*(10), 2583-2589, doi:https://doi.org/10.2527/2003.81102583x.

Ford, S. P., Vonnahme, K. A., & Wilson, M. E. (2002). Uterine capacity in the pig reflects a combination of uterine environment and conceptus genotype effects. *Journal of Animal Science, 80*, E66-E73.

Foxcroft, G. R., Dixon, W. T., Novak, S., Putman, C. T., Town, S. C., & Vinsky, M. D. (2006). The biological basis for prenatal programming of postnatal performance in pigs. *Journal of Animal Science, 84 Supplement*, E105-E112, doi:https://doi.org/10.2527/2006.8413_supplE105x.

Galli, M. C., Gottardo, F., Contiero, B., Scollo, A., & Boyle, L. A. (2021). The changing face and associated drivers of research on welfare of the gestating sow. *Italian Journal of Animal Science, 20*(1), 2174-2187, doi:https://doi.org/10.1080/1828051X.2021.2002732.

Geisert, R. D., & Schmitt, R. A. M. (2002). Early embryonic survival in the pig: Can it be improved? *Journal of Animal Science, 80 Supplement*, E54-E65, doi:https://doi.org/10.2527/animalsci2002.0021881200800ES10009x.

Geverink, N. A., Schouten, W. G. P., Gort, G., & Wiegant, V. M. (2003). Individual differences in behaviour, physiology and pathology in breeding gilts housed in groups or stalls. *Applied Animal Behaviour Science, 81*(1), 29-41, doi:https://doi.org/10.1016/S0168-1591(02)00253-8.

Greenwood, E. C., Van Wettere, W. H. E. J., Rayner, J., Hughes, P. E., & Plush, K. J. (2019). Provision Point-Source Materials Stimulates Play in Sows but Does Not Affect Aggression at Regrouping. *Animals, 9*(1), 8, doi:https://doi.org/10.3390/ani9010008.

Heinonen, M., Peltoniemi, O., & Valros, A. (2013). Impact of lameness and claw lesions in sows on welfare, health and production. *Livestock Science, 156*(1), 2-9, doi:https://doi.org/10.1016/j.livsci.2013.06.002.

Hemsworth, P. H., Rice, M., Nash, J., Giri, K., Butler, K. L., Tilbrook, A. J., & Morrison, R. S. (2013). Effects of group size and floor space allowance on grouped sows: aggression, stress, skin injuries, and reproductive performance. *Journal of Animal Science, 91*(10), 4953-4964, doi:https://doi.org/10.2527/jas.2012-5807.

Horback, K. M., Pierdon, M. K., & Parsons, T. D. (2016). Behavioral preference for different enrichment objects in a commercial sow herd. *Applied Animal Behaviour Science, 184*, 7-15, doi:https://doi.org/10.1016/j.applanim.2016.09.002.

Huneau-Salaün, A., Bougeard, S., Balaine, L., Eono, F., Eveno, É., Guillermic, M., Thomas, R., Rose, N., & Pol, F. (2021). Do rubber floor mats prevent lameness in gestating sows housed in large groups? A field experiment on three commercial farms in France. *Animals, 11*(11), 3160, doi:https://doi.org/10.3390/ani11113160.

Jensen, P. (1984). Effects of confinement on social interaction patterns in dry sows. *Applied Animal Behaviour Science, 12*(1), 93-101, doi:https://doi.org/10.1016/0168-1591(84)90099-6.

Jensen, P. (1986). Observations on the maternal behaviour of free-ranging domestic pigs. *Applied Animal Behaviour Science, 16*(2), 131-142, doi:https://doi.org/10.1016/0168-1591(86)90105-X.

Jensen, P., & Recén, B. (1989). When to wean — Observations from free-ranging domestic pigs. *Applied Animal Behaviour Science, 23*(1), 49-60, doi:https://doi.org/10.1016/0168-1591(89)90006-3.

Johnson, G. A., Bazer, F. W., & Seo, H. (2021). The Early Stages of Implantation and Placentation in the Pig. In: R. D. Geisert & T. Spencer (Eds.), *Placentation in Mammals* (pp 61-89). Cham, Springer International Publishing.

Kay, R. M., Burfoot, A., Spoolder, H. A. M., & Docking, C. M. (1999). The effect of flight distance on aggression and skin damage of newly weaned sows at mixing. *Proceedings of the British Society of Animal Science, 1999*, 14-14, doi:https://doi.org/10.1017/S1752756200001691.

KilBride, A. L., Gillman, C. E., & Green, L. E. (2009). A cross-sectional study of the prevalence of lameness in finishing pigs, gilts and pregnant sows and associations with limb lesions and floor types on commercial farms in England. *Animal Welfare, 18*(3), 215-224.

Kim, S., Easter, R., & Hurley, W. (2001). The regression of unsuckled mammary glands during lactation in sows: the influence of lactation stage, dietary nutrients, and litter size. *Journal of Animal Science, 79*, 2659-2668, doi:https://doi.org/10.2527/2001.79102659x.

Knox, R. V. (2016). Artificial insemination in pigs today. *Theriogenology, 85*(1), 83-93, doi:https://doi.org/10.1016/j.theriogenology.2015.07.009.

Knox, R. V., Breen, S. M., Willenburg, K. L., Roth, S., Miller, G. M., Ruggiero, K. M., & Rodriguez-Zas, S. L. (2004). Effect of housing system and boar exposure on estrus expression in weaned sows. *Journal of Animal Science, 82*(10), 3088-3093, doi:https://doi.org/10.2527/2004.82103088x.

Kongsted, A. (2004). Stress and fear as possible mediators of reproduction problems in group housed sows: A review. *Acta Agriculturae Scandinavica Section A-Animal Science 54*, 58-66, doi:https://doi.org/10.1080/09064700410032031.

Kongsted, A. G., & Hermansen, J. E. (2008). The mating behaviour and reproduction performance in a multi-sire mating system for pigs. *Theriogenology, 69*(9), 1139-1147.

Langendijk, P. (2021). Latest Advances in Sow Nutrition during Early Gestation. *Animals, 11*(1720), doi:https://doi.org/10.3390/ani11061720.

Levis, D. G., & Connor, L. (2013). *Group Housing Systems: Choices and Design*. Retrieved from National Pork Board. https://porkcdn.s3.amazonaws.com/sites/all/files/documents/2013SowHousingWebinars/1%20-%20Group%20Housing%20Systems.Choices%20and%20Designs%20-03643.pdf

LSZ Boxberg. (2021). *Gruppenhaltung von zu belegenden Sauen - Erfahrungen und Beispiele aus der Praxis*. Retrieved from LSZ Boxberg. https://lsz.landwirtschaft-bw.de

Marchant-Forde, J. N., Duttlinger, A. W., Richert, B. T., & Johnson, J. S. (2020). Stressors and weaned pig welfare: impact and mitigation. In: C. Farmer (Ed.), *The suckling and weaned piglet* (pp 277-295). Wageningen, Wageningen Academic Publishers.

Marchant, J., & Broom, D. (1996). Effect of dry sow housing conditions on muscle weight and bone strength. *Animal Science, 62*, 105-113, doi:https://doi.org/10.1017/S1357729800014387.

Marchant, J. N., & Marchant-Forde, R. M. (2005). Minimizing inter-pig aggression during mixing. *Pig News and Information, 26*, 63-71.

Marchant, J. N., Rudd, A. R., & Broom, D. M. (1997). The effects of housing on heart rate of gestating sows during specific behaviours. *Applied Animal Behaviour Science, 55*(1), 67-78, doi:https://doi.org/10.1016/S0168-1591(97)00022-1.

McGlone, J. J., Vines, B., Rudine, A. C., & DuBois, P. (2004). The physical size of gestating sows. *Journal of Animal Science, 82*(8), 2421-2427, doi:https://doi.org/10.2527/2004.8282421x.

Mellor, D. J. (2015). Enhancing animal welfare by creating opportunities for positive affective engagement. *New Zealand Veterinary Journal, 63*(1), 3-8, doi:https://doi.org/10.1080/00480169.2014.926799.

Meyer, E. (2015). Studies on the physical development of breeding sows and consequences for housing in gestation crates. *Landtechnik, 70*, 9-14.

Moser, J., Burla, J. B., & Gygax, L. (2019). Executing specific foraging behaviours does not represent a general goal state of foraging in dry sows (Sus scrofa). *Behavioural Processes, 164*, 115-122, doi:https://doi.org/10.1016/j.beproc.2019.05.005.

Moustsen, V. A., Lahrmann, H. P., & D'Eath, R. B. (2011). Relationship between size and age of modern hyper-prolific crossbred sows. *Livestock Science, 141*(2), 272-275, doi:https://doi.org/10.1016/j.livsci.2011.06.008.

Newberry, R., & Wood-Gush, D. (1985). The suckling behaviour of domestic pigs in a semi-natural environment. *Behaviour, 95*, 11-25, doi:https://doi.org/10.1163/156853985X00028.

Newberry, R. C. (1995). Environmental enrichment: Increasing the biological relevance of captive environments. *Applied Animal Behaviour Science, 44*(2), 229-243, doi:https://doi.org/10.1016/0168-1591(95)00616-Z.

Nielsen, S. E., Kristensen, A. R., & Moustsen, V. A. (2018). Litter size of Danish crossbred sows increased without changes in sow body dimensions over a thirteen year period. *Livestock Science, 209*, 73-76, doi:https://doi.org/10.1016/j.livsci.2018.01.015.

O'Connell, M. K., Lynch, P. B., Bertholot, S., Verlait, F., & Lawlor, P. G. (2007). Measuring changes in physical size and predicting weight of sows during gestation. *Animal, 1*(9), 1335-1343, doi:https://doi.org/10.1017/S1751731107000559.

Ochoa-Bernal, M. A., & Fazleabas, A. T. (2020). Physiologic Events of Embryo Implantation and Decidualization in Human and Non-Human Primates. *International Journal of Molecular Sciences, 21*(6), 1-21, doi:https://doi.org/10.3390/ijms21061973.

Olsson, A.-C., Svendsen, J., Botermans, J., & Bergsten, C. (2016). An experimental model for studying claw lesions in growing female pigs. *Livestock Science, 184*, 58-63, doi:https://doi.org/10.1016/j.livsci.2015.12.005.

Pedersen, L. J. (2007). Sexual behaviour in female pigs. *Hormones and Behaviour, 52*(1), 64-69, doi:https://doi.org/10.1016/j.yhbeh.2007.03.019.

Pedersen, L. J. (2018). Overview of commercial pig production systems and their main welfare challenges. In: M. Špinka (Ed.), *Advances in Pig Welfare* (pp 3-25). Woodhead Publishing Series in Food Science, Technology and Nutrition.

Pedersen, L. J., Heiskanen, T., & Damm, B. I. (2003). Sexual motivation in relation to social rank in pair-housed sows. *Animal Reproduction Science, 75*(1-2), 39-53, doi:https://doi.org/10.1016/s0378-4320(02)00208-7.

Pedersen, L. J., & Jensen, K. H. (1989). The influence of housing-systems for pregnant sows on the reproductive behaviour at oestrus. *Acta Agriculturae Scandinavica, 39*(3), 331-343, doi:https://doi.org/10.1080/00015128909438525.

Pedersen, S., & Ravn, P. (2008). Characteristics of slatted floors in pig pens: Friction, shock absorption, ammonia emission and heat conduction. *Agricultural Engineering Interantional: CIGR Journal, Manuscript BC 08 005 (X)*.

Pluym, L., Van Nuffel, A., Dewulf, J., Cools, A., Vangroenweghe, F., Van Hoorebeke, S., & Maes, D. (2011). Prevalence and risk factors of claw lesions and lameness in pregnant sows in two types of group housing. Veterinarni Medicina, *56*, 101-109, doi:https://doi.org/10.17221/3159-VETMED.

Pluym, L. M., Maes, D., Van Weyenberg, S., & Van Nuffel, A. (2017). Risk factors for development of lameness in gestating sows within the first days after moving to group housing. *The Veterinary Journal, 220*, 28-33, doi:https://doi.org/10.1016/j.tvjl.2016.11.008.

Rault, J. L., Morrison, R. S., Hansen, C. F., Hansen, L. U., & Hemsworth, P. H. (2014). Effects of group housing after weaning on sow welfare and sexual behavior. *Journal of Animal Science, 92*(12), 5683-5692, doi:https://doi.org/10.2527/jas.2014-8238.

Rhodes, R., Appleby, M., Chinn, K., Douglas, L., Firkins, L., Houpt, K., Irwin, C., McGlone, J., Sundberg, P., Tokach, M., & Wills, R. (2005). A comprehensive review of housing for pregnant sows. *Journal of the American Veterinary Medical Association, 227*, 1580-1590, doi:https://doi.org/10.2460/javma.2005.227.1580.

Roca, J., Vázquez, J. M., Gil, M. A., Cuello, C., Parrilla, I., & Martínez, E. A. (2006). Challenges in pig artificial insemination. *Reproduction in Domestic Animals, 41 Supplements 2*, 43-53, doi:https://doi.org/10.1111/j.1439-0531.2006.00768.x.

Roy, C., Lippens, L., Kyeiwaa, V., Seddon, Y. M., Connor, L. M., & Brown, J. A. (2019). Effects of Enrichment Type, Presentation and Social Status on Enrichment Use and Behaviour of Sows with Electronic Sow Feeding. *Animals, 9*(6), 369, doi:https://doi.org/10.3390/ani9060369.

Rushen, J. (1984). Stereotyped behaviour, adjunctive drinking and the feeding periods of tethered sows. *Animal Behaviour, 32*(4), 1059-1067, doi:https://doi.org/10.1016/S0003-3472(84)80222-5.

Salak-Johnson, J. L. (2017). Social status and housing factors affect reproductive performance of pregnant sows in groups. *Molecular Reproduction and Development, 84*(9), 905-913, doi:https://doi.org/10.1002/mrd.22846.

Schenck, E. L., McMunn, K. A., Rosenstein, D. S., Stroshine, R. L., Nielsen, B. D., Richert, B. T., Marchant-Forde, J. N., & Lay, D. C., Jr. (2008). Exercising stall-housed gestating gilts: effects on lameness, the musculo-skeletal system, production, and behavior. *Journal of Animal Science, 86*(11), 3166-3180, doi:https://doi.org/10.2527/jas.2008-1046.

Schouten, W. G. P., & Wiepkema, P. R. (1991). Coping styles of tethered sows. *Behavioural Processes, 25*(2), 125-132, doi:https://doi.org/10.1016/0376-6357(91)90015-R.

Schwarz, T., Małopolska, M., Nowicki, J., Tuz, R., Lazic, S., Kopyra, M., & Bartlewski, P. M. (2021). Effects of individual versus group housing system during the weaning-to-estrus interval on reproductive performance of sows. *Animal, 15*(2), 100122, doi:https://doi.org/10.1016/j.animal.2020.100122.

Soede, N. M., & Kemp, B. (1997). Expression of oestrus and timing of ovulation in pigs. *Journal of Reproduction and Fertility Supplement, 52*, 91-103.

Soede, N. M., Langendijk, P., & Kemp, B. (2011). Reproductive cycles in pigs. *Animal Reproduction Science, 124*(3-4), 251-258, doi:https://doi.org/10.1016/j.anireprosci.2011.02.025.

Soriano-Úbeda, C., Matás, C., & Garcia-Vazquez, F. (2013). An overview of swine artificial insemination: Retrospective, current and prospective aspects. *Journal of Experimental and Applied Animal Sciences, 1*, 67-97, doi:https://doi.org/10.20454/jeaas.2013.709.

Spoolder, H. A. M., Geudeke, M. J., Van der Peet-Schwering, C. M. C., & Soede, N. M. (2009). Group housing of sows in early pregnancy: A review of success and risk factors. *Livestock Science, 125*(1), 1-14, doi:https://doi.org/10.1016/j.livsci.2009.03.009.

Stewart, C. L., Boyle, L., & O'Connell, N. (2011). The effect of increasing dietary fibre and the provision of straw racks on the welfare of sows housed in small static groups. *Animal Welfare, 20*, 633-640.

Stolba, A., & Wood-Gush, D. G. M. (1989). The behaviour of pigs in a semi-natural environment. *Animal Science, 48*(2), 419-425, doi:https://doi.org/10.1017/S0003356100040411.

Studnitz, M., Jensen, M. B., & Pedersen, L. J. (2007). Why do pigs root and in what will they root?: A review on the exploratory behaviour of pigs in relation to environmental enrichment. *Applied Animal Behaviour Science, 107*(3), 183-197, doi:https://doi.org/10.1016/j.applanim.2006.11.013.

TierSchNutztV. (2021). *Verordnung zum Schutz landwirtschaftlicher Nutztiere und anderer zur Erzeugung tierischer Produkte gehaltener Tiere bei ihrer Haltung*. Retrieved from Bundesministerium der Justiz. https://www.gesetze-im-internet.de/tierschnutztv/

Tilbrook, A. J., & Hemsworth, P. H. (1990). Detection of oestrus in gilts housed adjacent or opposite boars or exposed to exogenous boar stimuli. *Applied Animal Behaviour Science, 28*(3), 233-245, doi:https://doi.org/10.1016/0168-1591(90)90102-J.

Turner, A. I., Hemsworth, P. H., & Tilbrook, A. J. (2005). Susceptibility of reproduction in female pigs to impairment by stress or elevation of cortisol. *Domestic Animal Endocrinology, 29*(2), 398-410, doi:https://doi.org/10.1016/j.domaniend.2005.02.031.

Tuyttens, F. A. M., Wouters, F., Struelens, E., Sonck, B., & Duchateau, L. (2008). Synthetic lying mats may improve lying comfort of gestating sows. *Applied Animal Behaviour Science, 114*(1), 76-85, doi:https://doi.org/10.1016/j.applanim.2008.01.015.

Verdon, M., Hansen, C. F., Rault, J. L., Jongman, E., Hansen, L. U., Plush, K., & Hemsworth, P. H. (2015). Effects of group housing on sow welfare: a review. *Journal of Animal Science, 93*(5), 1999-2017, doi:https://doi.org/10.2527/jas.2014-8742.

Waclawik, A., Kaczmarek, M. M., Blitek, A., Kaczynski, P., & Ziecik, A. J. (2017). Embryo-maternal dialogue during pregnancy establishment and implantation in the pig. *Molecular Reproduction and Development, 84*(9), 842-855, doi:https://doi.org/10.1002/mrd.22835.

Walker, N., & Beattie, V. E. (1994). *Welfare of sows in loose housed systems.* Paper presented at the 67th Annual Report of the Agricultural Research Institute of Northern Ireland, Hillsborough, UK.

Weary, D. M., Jasper, J., & Hötzel, M. J. (2008). Understanding weaning distress. *Applied Animal Behaviour Science, 110*(1), 24-41, doi:https://doi.org/10.1016/j.applanim.2007.03.025.

Webb, N. G., & Nilsson, C. (1983). Flooring and Injury - An Overview. In: S. H. Baxter, M. R. Baxter, & J. A. D. MacCormack (Eds.), *Farm animal housing and welfare* (pp 226-259). Bosten The Hague Dordrecht Lancaster, Martinus Nijhoff Publishers.

Williams, A. M., Safranski, T. J., Spiers, D. E., Eichen, P. A., Coate, E. A., & Lucy, M. C. (2013). Effects of a controlled heat stress during late gestation, lactation, and after weaning on thermoregulation, metabolism, and reproduction of primiparous sows. *Journal of Animal Science, 91*(6).

Wimmler, C., Vermeer, H. M., Leeb, C., Salomon, E., & Andersen, H. M. L. (2022). Review: Concrete outdoor runs for organic growing-finishing pigs – a legislative, ethological and environmental perspective. *Animal, 16*(1), 100435, doi:https://doi.org/10.1016/j.animal.2021.100435.

Yanagimachi, R. (1994). Fertility of mammalian spermatozoa: its development and relativity. *Zygote, 2*(4), 371-372, doi:https://doi.org/10.1017/s0967199400002240.

EU Reference Centre for Animal Welfare *Pigs*

About EURCAW-Pigs

EURCAW-Pigs is the first European Union Reference Centre for Animal Welfare. It focuses on pig welfare and legislation, and covers the entire life cycle of pigs from birth to the end of life. EURCAW-Pigs' main objective is a harmonised compliance with EU legislation regarding welfare in EU Member States. This includes:

- for pig husbandry: Directives 98/58/EC and 2008/120/EC;
- for pig transport: Regulation (EC) No 1/2005;
- for slaughter and killing of pigs: Regulation (EC) No 1099/2009.

EURCAW-Pigs supports:

- inspectors of Competent Authorities (CA's);
- pig welfare policy workers;
- bodies supporting CA's with science, training, and communication.

Website and contact

EURCAW-Pigs' website www.eurcaw-pigs.eu offers relevant and actual information to support enforcement of pig welfare legislation.
Are you an inspector or pig welfare policy worker, or otherwise dealing with advice or support for official controls of pig welfare? Your question is our challenge! Please, send us an email with your question and details and we'll get you in touch with the right expert.

info.pigs@eurcaw.eu

www.eurcaw-pigs.eu

Services of EURCAW-Pigs

- **Legal aspects**
  European pig welfare legislation that has to be complied with and enforced by EU Member States;
- **Welfare indicators**
  Animal welfare indicators, including animal based, management based and resource based indicators, that can be used to verify compliance with the EU legislation on pigs;
- **Training**
  Training activities and training materials for inspectors, including bringing forward knowledge about ambivalence in relation to change;
- **Good practices**
  Good and best practice documents visualising the required outcomes of EU legislation;
- **Demonstrators**
  Farms, transport companies and abattoirs demonstrating good practices of implementation of EU legislation.

Partners

EURCAW-Pigs receives its funding from DG SANTE of the European Commission, as well as the national governments of the three partners that form the Centre:

- Wageningen Livestock Research, The Netherlands
- Aarhus University, Denmark
- Friedrich-Loeffler-Institut, Germany

WAGENINGEN UNIVERSITY & RESEARCH

AARHUS UNIVERSITY

FRIEDRICH-LOEFFLER-INSTITUT
FLI
Bundesforschungsinstitut für Tiergesundheit
Federal Research Institute for Animal Health

Co-funded by the European Union