Universitat Autònoma de Barcelona

ALTERNATIVE HOUSING CONDITIONS TO IMPROVE WELFARE AND PERFORMANCE OF SOWS AND PIGLETS

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Tesis doctoral presentada per

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Que la memòria titulada **"Alternative Housing Conditions to Improve Welfare and Performance of Sows and Piglets"**, presentada per Heng-Lun Ko amb la finalitat d'optar al grau de Doctor en Veterinària, ha estat realitzada sota la seva direcció i, considerant-la acabada, autoritzen la seva presentació per que sigui jutjada per la comissió corresponent.

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Dr. Xavier Manteca Vilanova Dr. Pol Llonch Obiols

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“The ‘pig-ness’ of the pig,

the ‘cow-ness’ of the cow,

and the ‘chicken-ness’ of the chicken.”

Joel Salatin

It has finally arrived – the time when I sit down and reflect on this PhD journey, recalling those who accompanied me through this unforgettable adventure. For those who also went through it can definitely agree with me that, it is no exaggeration to use the word 'adventure' when one is pursuing for a doctoral degree, especially when pursuing it abroad.

When I was young, I used to take people's kind gestures as granted, especially from the closed ones. Not until my sister taught me that they are not obligated to be kind to you, did I realize the preciousness of the human interactions. Later when I grew older as an undergraduate student, starting to read scientific papers, the acknowledgement section still did not resonate me. Now, here I am at this very right moment, writing the acknowledgement of my doctoral thesis – troubling to keep it short and secretly complaining that two pages are not enough to express all my gratitude. There are simply unimaginable numbers of people involved, and missing any role would have not made this PhD journey possible.

First and foremost, I would like to thank my PhD supervisors, Xavier Manteca and Pol Llonch. Thank you for the endless patience, the full support, and the helpful guidance along my PhD journey. Thank you for always being attentive to answer my doubts and fast responding to my emails. Thank you for giving me sufficient freedom of course training and ideas for experimental design. Thank you, Xavi, for introducing Pol to me in the first place when I was still an MSc student. Thank you, Pol, for everything, I mean, really, everything, from the starting to the end, from assisting me to apply for the doctoral fellowship, to now, still assisting me to continue to stay in the group. I will never forget the very first meeting of my PhD with three of us in Xavi's office, which was filled with jokes, laughter, and hope.

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Thirdly, I would like to thank all the friends I met in La Vila. We are all away from our hometown, so we feel homesick together, we celebrate our festivals back home here, we cook our food back home here, and we watch movies back home here. A routine gathering has truly made me think that this is my second home, and you guys are my family here.

Lastly, I would like to thank my family (dad, mom, and my sisters) and my friends for life who are scattered around the globe: 青蛙, 阿尖, Mia, 瀛, Allen, Tiki, 花, 屁姿, 蔡東, 阿阿, 一喜. Thank you for picking up my calls whenever I need to talk, for having me in your lives, for giving me suggestions whenever I have doubts about my (daily) life, for sharing food recipes with me, for traveling and exploring the world with me, and for so much more. I used to think Skype calling my parents at least once every week is an obligation, but now I can't wait to call you and listen to your weekly stories every Saturday! Thank you, my two best friends and sisters 香嘎 and 柔嘎, for always being there no matter how busy you are. I am indeed very lucky to grow up with two awesome big sisters! I love you all! <3

Summary

Conventional farrowing crate systems were designed to maximize production but did not consider the pigs' biological needs, and therefore, compromise the welfare of sows and piglets. On one hand, farrowing crates do not allow sows to build a nest prior to farrowing, and they restrict the body movements and the interactions with their piglets during lactation. On the other hand, piglets are raised in a barren environment without sufficient sensory and social stimulations, which limits the development of their behavioral repertoire, including exploration, play and a variety of social skills, and that of their stress regulation system.

The aim of this thesis was to study the effect of an improved housing environment during lactation on the welfare and performance of sows and piglets in intensive production systems. Two trials were conducted, each on a different commercial farm: Trial 1 focused on the implications of an improved environment during lactation from birth to slaughter, whereas Trial 2 focused on the behavior and welfare assessment of sows and piglets housed in either farrowing pens with temporary crating system or conventional crates until shortly after weaning. A similar methodology was used in both trials: direct observation to study behavioral differences, skin lesion scoring to study the aggression level, salivary stress biomarkers to monitor the stress response, and weight gain to study performance.

In Trial 1, two treatment groups were differentiated during lactation: CON (control) and ENR (enriched). CON piglets were raised in conventional farrowing pens where sows were crated. ENR piglets were raised in the same farrowing pens but six enrichment objects for piglets were installed in each pen from birth, and the barriers between two ENR adjacent pens were removed at 14 days after farrowing to allow piglet socialization. Pigs in two treatment groups were raised in the same way after weaning until being slaughtered. There were both short- and long-term benefits of raising piglets in an improved environment. The facilitation of social and play behaviors during lactation assisted ENR piglets to adapt better to weaning, by displaying less aggression, and showing a lower stress response after weaning. Social skills obtained at the early age persisted until pigs were slaughtered, which was evidenced by a higher short-term weight gain after two regrouping events, and fewer skin lesions on carcasses after pre-slaughter mixing.

In Trial 2, three farrowing systems were tested: FC (conventional crate), and two commercial farrowing pens with temporary crating system (TC), SWAP (Sow Welfare And Piglet protection) and JLF15. FC sows were crated from entry to weaning, while SWAP and JLF15 sows were crated for 5 to 6 days during the peripartum. TC sows interacted with piglets more frequently than FC sows, whereas FC piglets interacted with littermates more frequently than TC piglets. The day of crate opening facilitated exploration in TC sows, compared to FC sows. There was a higher crushing rate in TC. SWAP piglets adapted better to weaning stress as they showed a lower stress response.

The results of this thesis suggest that creating an improved housing environment during lactation (i.e. environmental enrichment and early socialization, or temporary crating environment) facilitates play in piglets as well as exploration and mother-young interactions in sows and piglets. An improved housing environment during lactation broadens the behavioral repertoire of sows and piglets, which can contribute to pigs' resilience when facing weaning or regrouping challenges later in their lives. Housing conditions that consider the pigs' biological needs, improve some welfare and performance traits of sows and piglets, which indicates feasible improvement strategies in intensive pig production.

Resumen

Las jaulas maternidad se diseñaron para maximizar la producción, pero no consideraron las necesidades biológicas y pueden comprometer el bienestar de las cerdas y los lechones. Las jaulas de parto no permiten que las cerdas construyan un nido antes del parto, restringen los movimientos de la cerda y las interacciones con sus lechones durante la lactancia. Adicionalmente, los lechones se crían en un entorno con pocos estímulos sensoriales y sociales, lo que limita el desarrollo de su sistema de regulación del estrés y habilidades sociales.

El objetivo de esta tesis fue estudiar el efecto de la mejora de las condiciones de alojamiento en el bienestar y rendimiento de las cerdas y los lechones durante la lactación. Se llevaron a cabo dos ensayos: el primero se centró en las implicaciones de la mejora del entorno en la lactancia para el bienestar desde el nacimiento hasta el sacrificio. El segundo se centró en la evaluación del comportamiento y bienestar de cerdas y lechones alojados en corrales de maternidad con sistema de jaula temporal o en jaulas de maternidad convencionales hasta después del destete. En ambos ensayos se realizó observación directa del comportamiento, recuento de lesiones cutáneas para estudiar la agresividad, biomarcadores de estrés saliva para estudiar la respuesta de estrés, y la ganancia de peso para estudiar el rendimiento.

En el ensayo 1, se diferenciaron dos grupos de tratamiento durante la lactancia: los lechones control (CON) criados en corrales de maternidad convencionales donde las cerdas estaban en jaulas, y los lechones enriquecidos (ENR) criados en corrales similares pero con objetos de enriquecimiento ambiental durante la lactación. Además, la separación entre dos corrales ENR adyacentes se levantó a los 14 días postparto para permitir la socialización entre lechones. Después del destete, todos los lechones recibieron el mismo manejo. La facilitación de los comportamientos sociales y de juego durante la lactancia ayudó a los lechones ENR a adaptarse mejor al destete, mostrando menor agresividad y respuesta de estrés postdestete. Las habilidades sociales obtenidas en periodo neonatal persistieron hasta que los cerdos fueron sacrificados, evidenciado por un mayor aumento de peso después de la mezcla de animales y menos lesiones cutáneas en las canales.

En el ensayo 2, se probaron tres sistemas de alojamiento durante el parto: FC (corral de parto convencional con jaula), y dos corrales de parto comerciales con sistema de jaulas temporales (TC). Las cerdas FC se mantuvieron en jaulas desde el ingreso a la maternidad hasta el destete, mientras que las cerdas TC se alojaron en jaulas durante 5 a 6 días durante el periparto. Hubo una mayor interacción de las cerdas TC con sus lechones, mientras que los lechones FC interactuaron con sus compañeros de camada con más frecuencia. El día de la apertura de la jaula facilitó la exploración en las cerdas TC, comparado con las FC. Sin embargo, hubo una mayor tasa de aplastamiento en TC.

Los resultados de esta tesis sugieren que la mejora de las condiciones de alojamiento durante la lactancia (enriquecimiento ambiental, la socialización temprana, o una reducción del tiempo en jaula de la cerda) facilitan las interacciones sociales madre-cría y entre lechones. La mejora del entorno de alojamiento durante la lactancia amplía el repertorio de comportamiento de las cerdas y los lechones, lo que puede contribuir a la resiliencia frente a los desafíos del destete o reagrupamientos. Las condiciones de alojamiento que tienen en cuenta las necesidades biológicas de los cerdos mejoran algunos rasgos de bienestar y rendimiento de cerdas y lechones, lo que indica que la mejora del alojamiento durante la lactación es una estrategia efectiva en producción porcina intensiva.

Resum

Les gàbies maternitat es van dissenyar per a maximitzar la producció, però no van considerar les necessitats biològiques i poden comprometre el benestar de les truges i els garrins. Les gàbies de part no permeten que les truges construeixin un niu abans de el part, restringeixen els moviments de la truja i les interaccions amb els seus garrins durant la lactància. Addicionalment, els garrins es crien en un entorn amb pocs estímuls sensorials i socials, cosa que limita el desenvolupament del seu sistema de regulació de l'estrès i habilitats socials.

L'objectiu d'aquesta tesi va ser estudiar l'efecte de la millora de les condicions d'allotjament en el benestar i rendiment de les truges i els garrins durant la lactació. Es van dur a terme dos assajos: el primer es va centrar en les implicacions d'un entorn millorat durant la lactància des del naixement fins al sacrifici. El segon es va centrar en l'avaluació del comportament i benestar de truges i garrins allotjats en corrals de maternitat amb sistema de gàbia temporal o en gàbies de maternitat convencionals fins després del deslletament. En tots dos assajos es va realitzar observació directa del comportament, recompte de lesions cutànies per estudiar l'agressivitat, biomarcadors d'estrès saliva per estudiar la resposta d'estrès, i el guany de pes per estudiar el rendiment.

En l'assaig 1, es van diferenciar dos grups de tractament durant la lactància: els garrins control (CON) criats en corrals de maternitat convencionals on les truges estaven en gàbies, i els garrins enriquits (ENR) criats en corrals similars però amb objectes d'enriquiment ambiental des del naixement. A més, la separació entre dos corrals ENR adjacents es va treure als 14 dies postpart per permetre la socialització entre garrins. Després del deslletament tots els garrins van rebre el mateix maneig. La facilitació dels comportaments socials i de joc durant la lactància va ajudar als garrins ENR a adaptar-se millor al

deslletament, mostrant menor agressivitat i una millor resposta d'estrès postdeslletament. Les habilitats socials obtingudes en període neonatal van persistir fins que els porcs van ser sacrificats, evidenciat per un major augment de pes després de la mescla d’animals i menys lesions cutànies en les canals.

En l'assaig 2, es van provar tres sistemes d'allotjament durant el part: FC (corral de part convencional amb gàbia), i dos corrals de part comercials amb sistema de gàbies temporals (TC). Les truges FC es van mantenir en gàbies des de l'ingrés a la maternitat fins al deslletament, mentre que les truges TC es van allotjar en gàbies durant 5 a 6 dies durant el peripart. Hi va haver una major interacció de les truges TC amb els seus garrins, mentre que els garrins FC van interactuar amb els seus companys de ventrada amb més freqüència. El dia de l'obertura de la gàbia va facilitar va facilitar l'exploració a les truges TC, en comparació a les FC. No obstant això, hi va haver una major taxa d'aixafament en TC.

Els resultats d'aquesta tesi suggereixen que la millora de les condicions d'allotjament durant la lactància (enriquiment ambiental, la socialització primerenca, o una reducció del temps en gàbia de la truja) faciliten les interaccions socials mare-cria i entre garrins. La millora de l'entorn d'allotjament durant la lactància amplia el repertori de comportament de les truges i els garrins, el que pot contribuir a la resiliència enfront dels desafiaments del deslletament o mescla d’animals. Les condicions d'allotjament que tenen en compte les necessitats biològiques dels porcs milloren alguns trets de benestar i rendiment de truges i garrins, el que indica que la millora de l'allotjament durant la lactació és una estratègia.

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CHAPTER 1.

GENERAL INTRODUCTION

1.1. Concept and assessment of animal welfare science

Charles Darwin once stated that animals are sentient beings in two of his books published in 1871 and 1872, acknowledging that animals can express a variety of emotions (Dawkins, 2006). 'Sentient beings' means they are able to suffer (Temple and Manteca, 2020) and experience both positive and negative affective states (Duncan, 2006). In 2009, the European legislation amended and have recognized that animals are sentient beings (Lisbon Treaty, 2009).

Animal welfare science became a scientific discipline after the 1980s (Broom and Fraser, 2015). Following the publications of *Animal Machines* from Ruth Harrison in 1964 (Harrison, 1964), and *Animal Suffering* from Marian Dawkins in 1980 (Dawkins, 1980), a growing ethical concern from the society towards farm animals, especially those that were intensively reared, triggered the scientific interest in animal sentience and welfare (Temple, 2012). Nowadays, animal welfare is one of the most essential components in modern livestock production. Welfare scientists have discovered that understanding how farm animals behave or feel can assist farmers with tackling the welfare issues in the farm (Duncan, 2006). As many welfare issues often lead to poor production, improving farm animal welfare would bring benefits like better performance (Temple and Manteca, 2020). Within the One Welfare framework, improving farm animal welfare also improves human food safety, by reducing stress-induced immunosuppression in animals, preventing infectious diseases from animals, avoiding the risk of being a reservoir of zoonotic pathogens in the farms, and cutting down the use of antibiotics and medicines on animals (Pinillos, 2018). Additionally, due to the growing awareness and interest of animal welfare from the society, an increasing number of consumers are translating their care towards animal welfare into their purchasing behavior, when buying animal-derived food products (Verbeke, 2009). Animal welfare thus becomes one of the criteria for product quality, so proper welfare assessment and label monitoring are also essential for the acceptance by the public and the marketplace these days (Verbeke, 2009).

Although lots of research and development in animal welfare science have been carried out since the 1980s, there is no single unified definition of animal welfare so far. One of the reasons is that different stakeholders emphasize animal welfare on different perspectives like animal functionality, animal-human relationship, or animal-environmental interaction (Mellor et al., 2009). Even so, three general orientations (i.e. viewpoints) of animal welfare can be outlined: *biological function*, *affective state*, and *natural state* (Fraser, 2003; Mellor et al., 2009).

The *biological function* viewpoint is that when farm animals are healthy, growing, and reproducing well (i.e. good growth and reproductive performance), then there is good welfare (Mellor et al., 2009). As mentioned earlier, animals are sentient beings, so the *affective state* viewpoint sees animal welfare as the absence of negative experiences/emotions and the presence of positive experiences/emotions (Temple, 2012). Good animal welfare therefore indicates that farm animals are reared without suffering and/or with positive experiences in their lives, while interacting with other animals, humans, and the environment (Mellor et al., 2009).

The last viewpoint, the *natural state*, is based on 'the concept of harmony between the animal and its environment and the consequent ability to perform normal patterns of behavior' (Temple, 2012). To put it another way, whether animal welfare is good or bad depends on the degree of deviation of the rearing conditions from the original natural habitat of their ancestor, and to what extent can the species express most of their natural behaviors in this given environment (Mellor et al., 2009). Normal patterns of behavior refer to the behaviors that are performed by the majority of the conspecifics under natural conditions, and the ability to perform and the frequency of these behaviors under confined conditions determine the welfare state of these confined animals (Temple, 2012). In this *natural state* viewpoint, it is particularly common to see literature mentioning the 'ethological/behavioral/biological needs,' which implies that the inability to perform some species-specific behavioral needs (e.g. rooting behavior in pigs, sucking behavior in piglets, consummatory and nest-building behaviors in sows) may compromise the welfare of the animals (Hughes and Duncan, 1988).

When attempting to assess animal welfare, the outcomes of judgements are likely to differ from scientist to scientist, depending on which of the three orientations is focused most (Fraser, 2003). Animal welfare status can be assessed by several approaches, such as how well an animal attempts to cope with its environment (Broom, 1986), whether an animal's ethological needs are met in its environment (Dawkins, 1983), or the capacity of avoiding suffering and sustaining fitness for survival and reproductive success of an animal in its environment (Mellor et al., 2009; Temple, 2012). Despite various definitions of animal welfare and approaches to assess animal welfare, the Five Domains Model, originally proposed in 1994 (Mellor and Reid, 1994), has now become one of the most common ways to assess animal welfare (Mellor et al., 2020). The Five Domains Model is constantly updated, but the structure of the domains remains similar since its first appearance: (1) Nutrition, (2) Physical environment, (3) Health, (4) Behavioral interactions, and (5) Mental state, in which the first four domains are associated with physical or functional perspective, while the last domain is associated with mental perspective (Mellor et al., 2009). By considering the Five Domains altogether, scientists are able to evaluate animal welfare in a more holistic approach. All in all, even though there is no unified assessment of animal welfare so far, there is a consensus on the most important elements, for instance, consideration of both physical and mental health of an animal, and a spectrum-like characteristic, which ranges from very good to very poor.

1.2. Pig production at a glance in Europe and in Spain

Approximately 1.3 billion heads of pigs were slaughtered all over the world in 2019 and on average, each person consumed about 16 kg of pork in the year of 2013, accounting for the most consumed animal in human's diet, which is followed by 15 kg of poultry meat (FAO, 2021). The European Union (EU) is now the 2nd largest pig producer in the world, only after China, and the biggest exporter of pork and pork products, which mainly exports to East Asia, especially China (European Commission, 2021). There are currently 150 million pigs reared in the EU. Over 75% of the pigs are reared in large-scale intensive production systems, and only 3% of the pigs are kept in backyard farms in the EU (European Parliamentary Research Service, 2020).

Spain as the 4th largest pig producer in the world and the 2nd largest in the EU, producing 4.6 million tons of pork in 2019, has increased its production capacity by 1% in tons and 2% in number of heads, compared to the year of 2018 (MAPA, 2020). Over the past 5 years, pig production in Spain has grown by 20%, indicating a skyrocketing growth of pig production at the national level (MAPA, 2020). Moreover, intensive farming has always been the dominant production system for the last decade, representing nearly 80% of the pig farms in Spain (MAPA, 2020). Spain has approximately 31 million of live pigs, which is only behind China, the United States, and Brazil in 2019 (FAO, 2021).

1.3. Brief history of pig housing in Western Europe

Based on the archeological findings, animal domestication started 14,000 years ago, and 10,500 years ago, in the case of pigs (Hartung, 2013; Frantz et al., 2019). In the ancient times, pigs were predominantly kept outdoors except during wintertime. In the 1st century AD, a prominent Roman writer Columella wrote twelve books of *On Agriculture (De Re Rustica)*, and in Book VII, he advised the farmers that pregnant sows should be kept in shelters separately, in an individual wooden pen with a bar at the entrance, permitting the sow to enter and exit freely while prohibiting the piglets to exit until they were big enough to cross over it (**Figure 1.1**, Benecke, 2003, in Hartung, 2013). As Hartung (2013) described, it is interesting to see that such advice given to the farmers in the past is still valid and can still be seen in the outdoor system nowadays.

LOS DOCE LIBROS

DE AGRICULTURA

QUE ESCRIBIÓ EN LATIN

LUCIO JUNIO MODERATO COLUMELA,

traducidos al castellano

POR

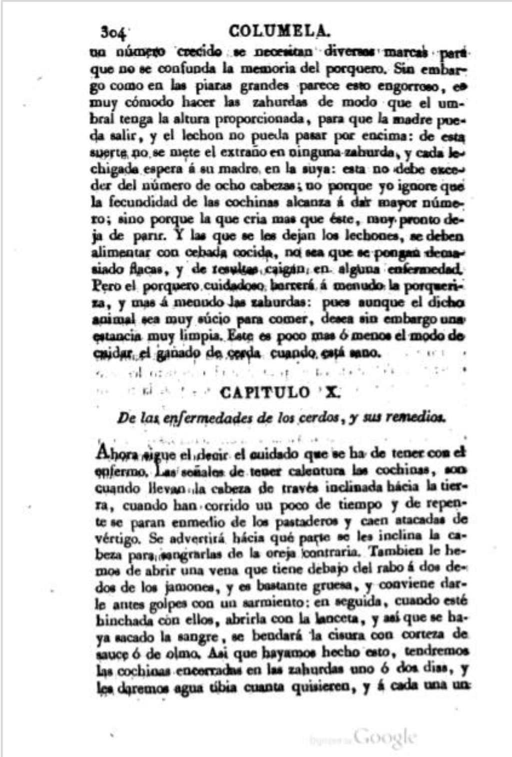
D. JUAN MARIA ALVAREZ DE SOTOMAYOR Y RUBIO.

TOMO I.

Comprende los siete primeros libros.

MADRID 1824,

IMPRENTA DE D. MIGUEL DE BURGOS.



304 COLUMELA.

un número crecido se necesitan diversas marcas para que no se confunda la memoria del porquero. Sin embargo como en las piaras grandes parece esto engorroso, es muy cómodo hacer las zahurdas de modo que el umbral tenga la altura proporcionada, para que la madre pueda salir, y el lechon no pueda pasar por encima: de esta suerte no se mete el extraño en ninguna zahurda, y cada lechigada espera á su madre en la suya: esta no debe exceder del número de ocho cabezas; no porque yo ignore que la fecundidad de las cochinas alcanza á dar mayor número; sino porque la que cria mas que éste, muy pronto deja de parir. Y las que se les dejan los lechones, se deben alimentar con cebada cocida, no sea que se pongan demasiado flacas, y de resultas caigan en alguna enfermedad. Pero el porquero cuidadoso barrerá á menudo la porqueriza, y mas á menudo las zahurdas: pues aunque el dicho animal sea muy súcio para comer, desea sin embargo una estancia muy limpia. Este es poco mas ó menos el modo de cuidar el ganado de cerda cuando está sano.

CAPITULO X.

De las enfermedades de los cerdos, y sus remedios.

Ahora sigue el decir el cuidado que se ha de tener con el enfermo. Las señales de tener calentura las cochinas, son cuando llevan la cabeza de través inclinada hácia la tierra, cuando han corrido un poco de tiempo y de repente se paran enmedio de los pastaderos y caen atacadas de vértigo. Se advertirá hácia qué parte se les inclina la cabeza para sangrarlas de la oreja contraria. Tambien le hemos de abrir una vena que tiene debajo del rabo á dos dedos de los jamones, y es bastante gruesa, y conviene darle antes golpes con un sarmiento: en seguida, cuando esté hinchada con ellos, abrirla con la lanceta, y así que se haya sacado la sangre, se bendará la cisura con corteza de sauce ó de olmo. Asi que hayamos hecho esto, tendremos las cochinas encerradas en las zahurdas uno ó dos dias, y les daremos agua tíbia cuanta quisieren, y á cada una un

Figure 1.1 The front matter (left) and the excerpt of the housing and management for lactating sow and suckling piglets (right) from *On Agriculture (De Re Rustica)* in Spanish translation (source: http://bibliotecadigital.econ.uba.ar/download/Pe/180425.pdf, retrieved on 20/September/2021).

The management of pigs from the Middle Ages to the 17th century remained similar (Hartung, 2013). Due to the low price of meat, the motivation to intensify pig production was not common (Seidl, 1995 in Hartung, 2013). Pigs were raised extensively, in which they mainly depended on natural food resources and were fed with by-products by the farmers from time to time (White, 2011). Indoor housing was reserved for sensitive individuals like farrowing sows, and during wintertime, when natural food resources were relatively limited

(Hartung, 2013). However, because of the increasing popularity of pork consumption in several parts of the Central Europe later on, and the introduction of the crop rotation system in agriculture (Benecke, 2003, in Hartung, 2013), pigs were started to keep indoors for a longer period and this drove pig farming moving towards a higher productivity (Hartung, 2013; Seidl, 1995 in Hartung, 2013).

Livestock production has boosted significantly since the 1960s (Thornton, 2010). Food shortage in post-World Wars made the production of sufficient and affordable food the primary goal of agriculture, which quickly transformed livestock production into scale enlargement and intensification (Eijrond et al., 2019). Livestock farming since then, including pigs, can be characterized by specialization and intensification: specialization as in one single farm animal species is bred for specific purposes and raised in specialized farms; and intensification as in year-round indoor housing, high stocking density, high degree of mechanization and automation, and low labor input which results in rapid turnover (Harrison, 1964; Hartung, 2013).

Thanks to intensive animal production, family budget for food expenses, in Spain for example, fell considerably, from 48.7% in 1960 to 16.8% in 2015 (González de Molina et al., 2017). Among animal products, the price of pork in particular has dropped dramatically, due to cheap feed import and increasing scale of intensive pig farms in Spain (González de

Molina et al., 2017). Bruinsma (2003) estimated a global shift from multiple purposes of production system to specialized intensive system in livestock production towards the year of 2030.

Despite the advantage of high efficiency, intensive animal production is often associated with poor animal management, including lack of space, light, and environmental stimulations, which restricts farm animals to express their natural behaviors (Bruinsma, 2003). Taking pigs as an example, intensive pig production is currently facing several welfare challenges, some examples are close confinement (e.g. gestation/farrowing crates, high stocking density), lack of enrichment, mutilations of neonatal piglets (e.g. tail-docking, teeth-clipping/grinding, surgical castration), frequent regrouping events with associated aggression problems, and breeding for hyperprolific traits (Pedersen, 2018). These poor practices often cause discomfort, stress, injury, pain, or behavioral problems, for instance, excessive aggression and abnormal behaviors (e.g. tail/ear-biting, bar-biting, sham chewing) (Pedersen, 2018). A pioneering book reporting such welfare issues was *Animal Machines*, written by Ruth Harrison in 1964, which created a profound impact on intensive animal production and raised public awareness of farm animal welfare, first in the United Kingdom and then the rest of the world. To date, based on an official survey in 2015, an absolute majority (94%) of the EU citizens held a view that ‘it is important to protect the welfare of farmed animals' (European Commission, 2016). A well-recognized importance of farm animal welfare in the EU has therefore driven by all stakeholders, from producers and governors to consumers and scientists (Bracke et al., 2005). Among the studies of farm animal welfare science, space allowance and confinement are often the two commonly appearing topics, irrespective of farm animal species (Vanhonacker et al., 2009). Nowadays, loose housing systems for dairy cows, laying hens, and gestating and farrowing sows have been regulated or introduced in the EU. However, unrestricted farrowing crates for sows, for example, are still under research in several EU countries but not yet being enforced in the EU regulation.

1.4. Behavior of farrowing and lactating sows and suckling piglets in natural conditions

In natural conditions, sows live in a small group which consists of related females and their offspring throughout the year. Fall is the mating season, in which a mature boar joins the group and mate, giving the sows to deliver piglets around spring when there is abundant food supply in the environment (Baxter et al., 2018). Based on the observational study carried out by Jensen (1986), the maternal behavior of free-ranging pigs can be divided into six different phases: (1) *nest-site seeking*; (2) *nest-building*; (3) *farrowing*; (4) *nest occupation*; (5) *social integration of the young*; and (6) *weaning*.

Nest-site seeking: Shortly before parturition, the sow increases her locomotor activity and leaves the group. The sow can travel for many kilometers (between 2.5 and 6.5 km in Jensen (1986), and in pens equivalent to 30 km in Baxter (1991)) to seek for an enclosed site for isolation. The sow wanders for 4 to 6 hours between different potential sites and often builds 'mock-nests' during the search, with one being chosen in the end (Jensen, 1986). It is reported that the chosen nest-site is often far from the usual roaming area (Jensen, 1986) and the excretory area after farrowing (Wiepkema, 1986). When given the possibility to choose, the sow opts for forest or forest border habitats but not grass areas (Stolba and Wood-Gush, 1984), and she also prefers the site against a solid wall (Hunt and Petchy, 1987). Keeping feces and urine away from the nest and concentrated in some areas may serve as a territorial signal, but also it helps to prevent diseases (Baxter et al., 2011). The biological function for isolation is essential: risk of disturbance is minimized during farrowing, colostrum intake from the new-born instead of older piglets from other litters is guaranteed, udder competition with older piglets in the early days is avoided, and risk of disease transmission from older piglets is reduced (Baxter et al., 2018).

Nest-building: The sow starts to build the nest about 24 hours before farrowing, and the most intensive period is 12 to 6 hours before farrowing (Algers and Uvnäs-Moberg, 2007). The onset of nest-building behavior (i.e. preparation of the nest site) is triggered by endogenous hormonal reaction during the prepartum (i.e. decrease of progesterone, and increase of prolactin and prostaglandin F2alpha (PGF2α)) (Castrén et al., 1993; Jensen, 1993; Algers and Uvnas-Moberg, 2007) and the next phase of nest-building behavior (i.e. gathering and arranging nest materials) is largely dependent on exogenous environmental stimuli (i.e. availability of the nest-building materials) (Widowski and Curtis, 1990; Jensen, 1993; Chaloupková et al., 2011) until the completion of the nest. Nest-building behavior consists of several organized sequences of behaviors (Johnson and Marchant-Forde, 2009). Firstly, the sow starts rooting and pawing to make 5 to 10 cm depth of a shallow hole (Jensen, 1986; Wischner et al., 2009). Secondly, branches, grasses, leaves, and other organic materials collected from the nature are arranged along the edges of or in the nest (Jensen, 1993). In the study of Zanella and Zanella (1993), a single nest was built with 225 kg of plant materials by free-range sows in Brazil. While constructing the nest, the behaviors of the sow include circling, rooting, pawing, and lying (Yun and Valros, 2015; Baxter et al., 2018), and some specific behaviors are found to be associated with some hormones, for instance, pawing and gathering are correlated with the changes in the concentrations of progesterone, prolactin, and somatostatin (Algers and Uvnas-Moberg, 2007). The biological function for nest-building is essential: retention of heat and newborn piglets, as well as avoidance from predators (Yun and Valros, 2015). Although risk factors like heat loss, nutrient deficiency, and predators do not seem to be a big concern in modern intensive pig production, nest-building behavior is still performed by domestic sows confined in farrowing crates with no possibility to nest-build, but it is redirected towards bars, floors, and drinkers (Lawrence et al., 1994; Yun and Valros, 2015). Gustafsson et al. (1999) also reported that there is no difference in the frequency and the patterns of nest-building behavior between domestic sows and wild boar sows. Nest-building behavior is known to be a biological need for sows before farrowing (Baxter et al., 2010), and unable to perform this behavior results in stress (Yun and Valros, 2015), which will be further discussed in Chapter 1 section 1.4.

Farrowing: Once the nest is ready, farrowing often starts in few hours (Johnson and Marchant-Forde, 2009). The sow does not change her posture much during farrowing. A typical farrowing process in domestic sows takes roughly 2 to 3 hours, and the sow mostly maintains at lateral lying and udder exposure posture in the nest (Baxter et al., 2018). The sow does not lick her offspring like other farm mammal species, but does stand, turn, and have nose-to-nose contact with her first-born piglets (Jensen, 1986), and the inspection of the piglets declines when more are born. New-born piglets are precocial – the sow does not help them to remove the fetal membrane, they search for the udder of the sow by themselves, and the umbilical cord is torn off by itself when the piglet moves around the udder. The biological function of the passivity in farrowing sows is to reduce the unnecessary risk of accidental crushing if the sow performs maternal behavior towards a large litter of piglets individually, as proposed in Jensen (1988).

Nest occupation: The nest is used for 7 to 10 days after farrowing. Neither the sow nor the piglets leave the nest on the first day of farrowing (Jensen, 1986). The sow spends most of her time lying in the nest (up to 90%), and only leaves the nest briefly for foraging and excretion during the first days of post-farrowing (Baxter et al., 2018). Götz (1991) also observed that sows kept in farrowing crates spent 85.4% of her time in lateral lying in the first week of lactation. Later, the need to spent time away from the nest gradually increases as the sow requires food to feed herself and to produce milk to sustain her growing piglets (Jensen, 1986; Baxter et al., 2018). Trips for foraging are getting more frequent for the sow, so the piglets begin to follow her, which was observed from day 7 after farrowing in Jensen (1986), and the activity area away from the nest also gradually expands.

While being outside of the nest and exploring the environment, piglets spend a large amount of time walking (Johnson et al., 2001). In addition, exploration towards the soil, plants, and other materials from the nature, and playing (including hopping, scampering, head tossing, and pivoting) are as well commonly seen in outdoor piglets (Johnson et al., 2001). Early environment has a life-long impact on modulating piglets' developments of behavior, brain, cognition, and stress regulation system (Telkänranta and Edwards, 2018).

A complex and diverse environment can provide appropriate physical and social environmental stimuli needed for the piglets' development (Telkänranta and Edwards, 2018). On one hand, physical environment contains a variety of sensory stimuli, information of spatial dimension, and interactions with substances and novelty, which can contribute to a normal development of brain, cognition, muscle, and bone (Horback, 2014; Telkänranta and Edwards, 2018). On the other hand, social environmental stimuli (e.g. presence of mother, siblings) can assist the piglets to form a strong bonding with the sow, which can guarantee the piglets to gain access of milk and warmth from the mother (Telkänranta and Edwards, 2018). The biological function of exploration and play in piglets is suggested to be essential for the coordination of body movements, understanding the extrinsic and intrinsic values of the surroundings (e.g. food and water resources, social group), evaluating dangerous situations, and encouraging behavioral flexibility (e.g. avoiding conflicts in the future) (Johnson et al., 2001; Horback, 2014).

Occupying the nest without other sows and piglets for a couple of days establishes the mother-offspring bond, which is important because of the next stage – social integration of the young (Jensen and Redbo, 1987).

Social integration of the young: The nest is abandoned approximately after 10 days postpartum (Jensen and Redbo, 1987). While the sow rejoins the group for morning feeding

7 days after farrowing, the piglets stay in the nest for 2 to 3 days more, until the nest is discarded by both the sow and the piglets (Johnson and Marchant-Forde, 2009). As Jensen and Redbo (1987) described, the litter seems to gradually turn from a hider to a follower, which is determined by the changes in mother-young interactions (decreased frequency of nasal contacts and increased frequency of auditory contacts) and the timing of abandoning the nest. The litter is then introduced to the herd and the sow renews her social relationship with other females (Baxter et al., 2018). The increasing foraging bouts and home range of the sow encourage her piglets to start exploring the environment and consuming solid organic matters apart from the sow's milk from the 4^{th} week of age (Jensen, 1995). This gradual transition to be independent from the sow is facilitated by the socialization of the piglets from different litters, which not only increases the social interactions between piglets of a similar age (Petersen et al., 1989), but also help forming piglet foraging groups (Baxter et al., 2018). During the first 2 weeks of social integration, piglets are observed to first perform play fight and agonistic interactions. After the establishment of dominance hierarchy, piglets are frequently engaging in 'trotting, scampering, and circling with other piglets' (i.e. social play) around 2 to 6 weeks of age (Newberry and Wood-Gush, 1988). The frequency of the social interactions between piglets decreases to a steady level after 8 weeks (Johnson and Marchant-Forde, 2009). The gradual change of the social dynamics (i.e. close sow-piglet bonding of one litter → distancing between the sow and the piglets →

integration of/rejoin the herd) provides the piglets a relatively less stressful and injurious opportunity to learn important social skills by involving in shorter and more decisive fights and minimal bullying (D'Eath, 2005) in their early ages, which can effectively prevent the social trauma related to abrupt introduction of foreign members (Johnson et al., 2001).

Weaning: In natural conditions, weaning occurs progressively. The sow first distances herself from her piglets to forage at 20 m away in the 2nd week of postpartum, at 30 m away in the 4th week, and in the 8th to 10th weeks, the sow and the piglets are simply too dispersed and far away to measure the distance (Jensen, 1986). By the 8th week of age, solid food becomes the major proportion of the piglets' diet (Jensen, 1995). The decreasing nursing and suckling frequencies and the increasing independence of the piglets from the sow, lead to a complete weaning around 8 weeks to 19 weeks of postpartum (Newberry and Wood-Gush, 1985; Jensen and Recén, 1989; Jensen and Stangel, 1992). This gradual progress of weaning and the presence of a dominant boar stimulate the sow to come back to estrus and to prepare for the next reproduction cycle (Baxter et al., 2018). Weaning involves a complex dynamic of behavioral responses between the sows and the piglets to a full weaning, and if the housing environment allows them to perform these behaviors, they can still be seen in modern domestic pigs (Bøe, 1991; Baxter et al., 2018).

1.5. Welfare issues of sows and piglets in current conventional farrowing systems

Under intensive conditions, approximately 1 week before parturition, pregnant sows are shifted to individual farrowing pens and are confined in farrowing crates. 'The standard farrowing crate is usually a tubular metal construction fixed within a pen of about 2.2 m x 1.5 m, with recommended dimensions of around 2.2 m long, 0.6 m wide, and 1.0 high,' described in Johnson and Marchant-Forde (2009). There are horizontal metal bars across the whole length of the crate and some across the front two-third width of the crate to avoid the sow climbing upwards. The rear of the crate is adjustable with a removable frame, based on the body size of the sow. This system has a built-in feed trough and a nipple drinker at the front for the sow, another nipple drinker closer to the floor also at the front for the piglets, and a creep area (about 0.5 m^2) for the piglets which provides warmth from either a heated mat or an overhead heat lamp, or both (Johnson and Marchant-Forde, 2009). The space allowance for the sow is minimal as she is confined in the crate (1.32 m^2 crate within 3.3 m^2 pen) (Baxter et al., 2018), and the slatted floors greatly reduce manual labor to remove manure and provide drainage for urine and soiled drinking water (Johnson and Marchant-Forde, 2009), making this system easy to inspect the animals and to maintain pen cleanliness.

Farrowing crates appeared in the 1950s (Mellor, 2009), when pig production was turning intensive due to urgent demand of sufficient and cheap food, including meat. Little knowledge of natural behavior and welfare of sow during farrowing and lactation was available in the 1950s, so the primary aim of the farrowing crate was to reduce live-born piglet mortality by having a better control over sow posture change and avoid piglet crushing (Mellor, 2009; Baxter et al., 2018), which will be discussed later in this section. It is considered as a highly cost-effective farrowing system, and it quickly became the most common sow housing method worldwide between the 1960s and 1970s since then (Pedersen et al., 2013).

Despite the structure of the farrowing crate gives the piglets the protection against sow crushing, it imposes physical restriction on the sows which compromises their welfare. Based on the six phases of the maternal behavior in free-range pigs described in Chapter 1 section 1.4, current intensive farm practices and the farrowing crate *per se* limit the sows to express most of the behaviors. To start with, conventional farrowing systems in a fixed location and without nest-building materials, prohibit them to *seek for a nest-site* and *build a nest in isolation* (Johnson and Marchant-Forde, 2009). Although the sows are housed individually, meaning physical contact is avoided, total isolation, such as free of visual, auditory, and olfactory isolations, from other sows is not possible. Additionally, as the sows are confined in farrowing crates, it is not possible for them to seek for their ideal nest sites. In the study of Arey et al. (1992), even though the sows were previously well-acquainted with each other, aggression increased in pair-housed sows when farrowing approached, possibly due to the frustration caused by the inability to isolate herself.

Nest-building is an innate behavior in domestic pigs, which is also found in all the members of the *Suidae* family except the common warthog (*Phacochorerus africanus*) (Baxter et al., 2011). Nest-building is triggered by endocrine changes (as reviewed in Algers and Uvnäs-Moberg, 2007) and unable to perform nest-building behavior may result in stress (Johnson and Marchant-Forde, 2009). Lawrence et al. (1994) and Jarvis et al. (2001) discovered that crated sows showed an elevated plasma cortisol level. Sows in open crates were reported to express more elaborated nest-building behavior and less fragmented than those in crates (Johnson and Marchant-Forde, 2009). Previous studies have indicated that the feedback from constructing and completing the nest can affect the neuro-endocrine regulation system associated with maternal behaviors during farrowing in sows (Castrén et al., 1993; Damm et al., 2003; Pedersen et al., 2003; Algers and Uvnäs-Moberg, 2007). In other words, evidence has shown that satisfactory nest-building behavior can lead to positive parturient maternal behavior (e.g. high nest-building activity → low risk of piglet crushing; high completion and function of the nest → long duration of inactivity during farrowing) (Arey et al., 1991; Jensen, 1993; Damm et al., 2003; Pedersen et al., 2003; Baxter et al., 2011). Sows without confinement during *farrowing* and lactation has been found to bring several benefits: shorter farrowing duration due to improved oxytocin circulating activity (Vestergaard and Hansen, 1984; Oliviero et al., 2008, 2010; Gu et al., 2011) leads to lower stillborn rates (Arey et al., 1992; Oliviero et al., 2008, 2010; Gu et al., 2011); less posture changes (Damm et al., 2002) and more positive maternal behaviors during parturition (Arey et al., 1991; Jensen, 1993; Damm et al., 2003; Pedersen et al., 2003) lead to less crushing incidents; less posture changes during parturition lead to shorter interval between the birth and the first suckling of the piglet (Rohde Parfet and Gonyou, 1988); higher plasma oxytocin level leads to improved maternal behavior and nursing performance (Yun et al., 2013); better sow metabolic status leads to greater successful colostrum intake, which is reflected on the serum IgG level in piglets (Yun et al., 2014).

The fear of abolishing farrowing crate systems from the producers is because of the fear of increased pre-weaning piglet mortality due to crushing and hence the increased economic loss from the live-born death. However, crushing is often the secondary cause of death, which is due to sudden movement or posture change (e.g. from standing to lying, rolling) of the sow (Baxter et al., 2011). Although posture change of the sow can be associated with her farrowing and nursing environment, as well as her maternal behavior

(Baxter et al., 2011), the primary cause which leads to crushing are often hypothermia and/or starvation of piglets (Edwards, 2002). This phenomenon is called ‘chilling-starvation-overlying-disease complex’ (Edwards, 2002). Newborn piglets prefer to lie near the udder in the first 24 hours after birth (Baxter et al., 2011). Undernourished piglets (i.e. usually low birth weight piglets) stay in close proximity to the sow for quicker access to colostrum/milk due to low body energy, which greatly increases the risk of being crushed (Mainau et al., 2015). The lowest critical temperature required for newborn piglets is 34°C (Mount, 1968) and they are born with little fat, which means that seeking for an immediate heat source after birth is extremely important for their survival (Baxter et al., 2011). Not maintaining sufficient colostrum/milk intake leads to hypothermia, making piglets more lethargic and less competitive to fight for functional teats, which results in less consumption of colostrum/milk, and thus the interactive event of chilling-starvation-overlying complex forms. Therefore, the crate structure may be important to restrict a certain degree of sow body movement, but selection for better maternal behavior of sows, promotion for smaller litter size and high piglet vitality, and creation of creep area with thermal comfort, are as well crucial to prevent piglet crushing (Marchant et al., 2001; Jarvis et al., 2005; Weber et al., 2009; Baxter et al., 2018).

During the phases of *nest occupation*, *social integration of the young*, and *weaning*, crated sows are not able to gradually distance themselves from the piglets as they are confined in farrowing crates until the moment of weaning. Loose sows would prefer to defecate away from the piglets and reduce the contact with the piglets overtime (Pajor et al., 2000). A crating period of 28 to 35 days at the same space (i.e. 1 week habituation of farrowing crates + 21 to 28 days of lactation) often results in urinary infection due to a soiled place for urination and defecation repeatedly (Vestergaard, 1984); muscle and bone deterioration (Gravas, 1981; Marchant and Broom, 1996) and the development of decubitus ulcers (Bonde et al., 2004) due to lack of movement; teat damage, lameness and leg abrasions (Edwards and Lightfoot, 1983; Karlen et al., 2007; Verhovsek et al., 2007) also due to lack of movement and the slatted flooring. Sows in loose pens were observed to be calmer during nursing, had a longer nursing duration (i.e. 1.8 seconds more), terminated fewer nursing bouts, and allowed piglets for longer post-massage, which all reflected on a higher weight gain in piglets (Pedersen et al., 2011).

As for the piglets, current conventional farrowing system is barren – the sow is crated which limits the interactions with the piglets, there is little or none of the environmental stimuli (e.g. provision of enrichment materials), and piglets are raised in a single litter until weaning. Not having the possibility to socialize with non-littermates in piglets before weaning causes social stress and aggression at weaning (Johnson and Marchant-Forde, 2009). Several studies have consistently found that previously socialized piglets during lactation largely reduce aggression at weaning, which results in better growth performance post-weaning (Wattanakul et al., 1997; Weary et al., 1999, 2002; Bünger et al., 2000; North and Stewart, 2000; Cox and Cooper, 2001; Hotzel et al., 2004; Hessel et al., 2006). Socialized piglets were involved in the amount of aggression eight time less (Weary et al., 2002), showed five-fold reduction of aggression (Hotzel et al., 2004), and had five-to-eight-time fewer skin lesions (Wattanakul et al., 1997; North and Stewart, 2000) after weaning. Moreover, piglets kept in conventional farrowing crate showed more aggression later in life, compared to those with either rootable materials available (O'Connell and Beattie, 1999; Munsterhjelm et al., 2009), or combined with enlarged space (Chaloupková et al., 2007) during lactation.

Table 1.1 summarizes the negative impacts of conventional farrowing systems on sows and piglets in different phases during the peripartum and lactation periods when some of the biological needs (i.e. the expression of some natural behaviors) are not met.

Table 1.1 Summary of the negative consequences when sows and piglets are raised in conventional farrowing systems due to some biological needs (specially focus on natural behaviors) are not met.

Subject	Phase	Biological needs (i.e. natural behaviors)	Negative consequences if not met
Sow	Nest-site seeking	Locomotion, complete isolation	- frustration, stress ↑ - aggression ↑
	Nest-building and farrowing	A sufficient space to perform a sequence of nest-building behaviors with nest-building materials	- stress ↑ - impaired oxytocin circulating level - poor maternal behavior (e.g. restlessness, savaging) - risk of crushing ↑ - farrowing duration ↑ - stillborn rate ↑

Subject	Phase	Biological needs (i.e. natural behaviors)	Negative consequences if not met
Sow	Early lactation and nest departure	Freedom to move around and change postures, social interactions with the piglets, gradual separation from the piglets	- stress ↑ - impaired oxytocin circulating level - poor maternal behavior and mother-young bonding (e.g. prolonged nest-building activity, nose-to-nose contacts with the piglets ↓, early termination of nursing bouts and post-massage from the piglets, less responsive to piglet distress calls) - disturbed nursing bouts (e.g. poor udder access) - poor maternal performance and metabolic status (e.g. shorter duration of milk letdown) - health problem due to confinement (e.g. urinary infection, muscle and bone deterioration, decubitus ulcers, leg abrasions, teat damage, lameness) - poor thermoregulation due to confinement

Subject	Phase	Biological needs (i.e. natural behaviors)	Negative consequences if not met
Piglet	-	Social interactions with the sow	- poor mother-young bonding (e.g. nose-to-nose contacts with the sow ↓, risk of being crushed ↑) - disturbed suckling bouts (e.g. teat fights ↑, missing milk letdown ↑) - colostrum/milk intake ↓, immunoglobulins ↓, weight gain ↓
		Social interactions with non-littermates	- poor social skills learnt (e.g. fighting duration ↑, aggression-associated skin lesions ↑ during mixing)
		Exploration (e.g. foraging, rooting) and play	- stress ↑ - poor development of behavior and brain - impaired functioning of cognitive flexibility and stress regulation system - impaired immune function - low resilience towards new challenges

1.6. Public and producers' opinions on current conventional farrowing systems

Since the invention of the farrowing crate in the mid-20th century, the majority of sows are now kept in the farrowing crate during farrowing and lactation periods worldwide (e.g. 95% in the EU, 83% in the US, and 70% in the UK) (Johnson and Marchant-Forde, 2009).

As far back in 2007, the European Food Safety Authority (EFSA) published the Scientific Opinion reviewing the health and welfare aspects of different housing systems for pigs at different production stages. It concluded that housing farrowing sows in crates not only 'severely restricts' the freedom of movement but also limits the expression of nest-building behavior (EFSA, 2007). As nest-building behavior is initiated and regulated by the internal hormones of the sows, the motivation to build a nest is high regardless of the housing conditions, and therefore, unable to move freely and access to nest-building materials can 'increase the risk of frustration' and are 'very likely to cause stress and impaired welfare' (EFSA, 2007). Thus, in this report, the experts' opinions about the housing system for farrowing sows included 'the farrowing systems should allow for the handling of destructible nest material to enable investigation and manipulative activities' (EFSA, 2007).

A recent study conducted in Brazil investigated the public's attitude towards farrowing crates (Vandresen and Hötzel, 2021). No matter the participants (total n = 1939) have a pet/pets (i.e. dogs or cats) or not, 75% of them were opposed to the use of farrowing crates.

Among those, females, city dwellers, pet owners, those that are not involved with livestock, and those see their pet as their child or a family member, were having the most negative attitudes towards farrowing crates. Vandresen and Hötzel (2021) concluded that with the increasing population of urban citizens, pet owners, and the detachment livestock production, confined housing practice, such as the use of farrowing crates, may be conflicting with the societal values in the near future. Similar finding was found in Germany where the public evaluated the images of farrowing crates very negatively, suggesting that in order to achieve an accepted method of livestock production in a long-term, adding an increased space availability and some sort of outdoor access for the animals will be necessary (Busch and Spiller, 2018).

Having the EFSA's Scientific Opinion and the opposition in farrowing crates from the public and local/international animal welfare organizations, several Western countries have prohibited or are in the course of prohibiting the use of farrowing crates. At the national level, only Sweden (announced in 1988), Switzerland (announced in 1997), and Norway have completely banned the use of farrowing crates. Austria (announced in 2012) will ban the permanent use of farrowing crates by 2033. Temporary crating will be permitted only around the critical period for piglets' survival, and the minimum farrowing pen size will be 5.5 m^2. Germany (announced in 2020) allows a transition period of 15 years to ban the permanent use of farrowing crates. Temporary crating will be permitted for a maximum of five days around farrowing, and the minimum farrowing pen size will be 6.5 m^2. In the same year, New Zealand also declared that they will phase out farrowing crates by 2025. Denmark was the first country to set the target of having 10% of the sows being loose housed by 2020. Although this goal was not achieved, eliminating farrowing crates by 2030 is being considered. Besides, a bill advocating for a ban on farrowing crates has progressed to a second reading in the UK Parliament this March 2021. If it becomes the law, the UK will be expected to phase out farrowing crates by 2027.

At the regional level, a European citizens' initiative (ECI) 'End the Cage Age' (**Figure 1.2**), which was launched on September 2018 by Compassion in World Farming, called for an end of animal farming in cages, including the use of farrowing crates. This ECI 'End the Cage Age' had successfully collected over 1.5 million of signatures in a year, making it the top 3rd ECI of the highest signature count and the 1st valid ECI for farm animal welfare on the record, indicating a strong preference of eliminating the use of cages in animal farming for the European citizens at the present time. To respond to the ECI 'End the Cage Age' campaign, the European Commission held a public hearing this April 2021 and a plenary debate this June 2021 in the European Parliament. The proposal which includes the duration of the transition period will be expected by 2023, and the proposed legislation may come into force by 2027. All in all, these regional and national movements appear to indicate a trend of eliminating farrowing crates in the forthcoming decades in the EU.

Figure 1.2 Official webpage of the European Citizens' Initiative, END THE CAGE AGE, launched in 2018 by Compassion in World Farming (source: https://www.endthecageage.eu/, retrieved on 20/September/2021).

Pig producers' opinions on the use of farrowing crates and the willingness to change, on the other hand, vary widely. Interviews with 44 Brazilian farmers in Albernaz-Gonçalves et al. (2021), discovered that the main motivation to change (e.g. phasing out the crates) appeared to be driven by the industry. Being one of the stakeholders in the pig production sector, farmers seem to be less engaged in consumers' expectations and be less informed in companies' commitments, which can create an economic risk for farmers (Albernaz-Gonçalves et al., 2021). Interviews with 20 Canadian producers revealed that the advantages of farrowing crates include piglet protection from crushing and the ability of early piglet castration (Spooner et al., 2013). Canadian producers valued the use of farrowing crates for animal welfare as it is a necessary compromise to obtain greater piglet survival rate. However, Spooner et al. (2013) also found that the producers welcomed science-based approaches to improve animal welfare. Although Hungarian pig farmers who use confinement and non-confinement systems shared similar key ideas of animal welfare, such as health and nutrition, only those with alternative system and confinement system with medium scale (400 to 600 sows) agreed that unconfined and semi-natural environments are important for animal welfare. In the same study, three large producers that have more than 1000 farmed sows expressed strong confidence in confinement methods (Molnár and Fraser, 2021).

The petitions and legislation bills to for a more humane treatment of confined farm animals are usually advocated and driven by the citizens, not the pig producers (Centner, 2009; Spooner et al., 2013). However, pig producers may often have different concerns on animal practice and care (Spooner et al., 2013). Producers' opinion can differ due to the country's attitude towards animal welfare, the farmers' position (e.g. independent or employee), or the farmers' attitude towards animal welfare, as reported above. Within the framework of One Welfare, in order to remedy the imbalance and reconnect different human, animal, and environmental interests, it is indispensable to reach similar perception of farm animal welfare between the consumers, the industry, and the producers (Albernaz-Gonçalves et al., 2021).

1.7. Alternatives to current conventional farrowing system

Despite thousands of years of artificial selection and domestication, the natural behaviors of domestic sows and piglets which are kept extensively during the peripartum and lactation periods, does not vary much with that of their wild relatives (Andersson et al., 2011; Baxter et al., 2011). With the goal of improving the welfare and performance of sows and piglets, it is fundamental to meet their welfare needs by understanding their basic biology, including behavioral patterns and physiological responses (Baxter et al., 2011), and to optimize the design of the farrowing system and the management of the sows and piglets (Baxter et al., 2011; Baxter et al., 2018). However, it is a difficult conundrum to construct an appropriate farrowing environment which satisfies the needs of all the three roles who are involved in, including the sow, the piglet, and the stockworker (**Figure 1.3**), and therefore an optimal farrowing system remains uncertain and is still an ongoing research question.

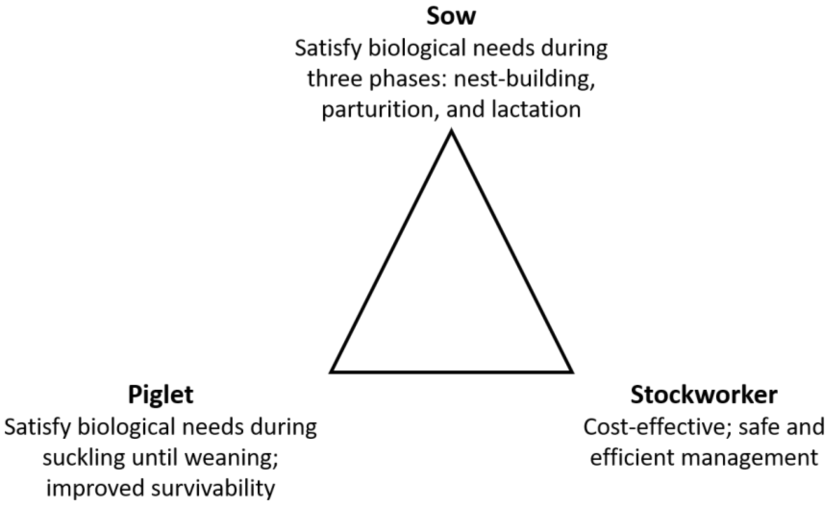


Figure 1.3 Design criteria of farrowing systems to balance and satisfy the triangle of needs between the sow, the piglet, and the stockworker. Figure and content adapted from Baxter et al. (2011) and *Indoor Free-Farrowing Systems for Sows – Practical Options* by Compassion in World Farming.

Even though the 'golden design' of the farrowing system does not exist, both the academia and the pig industry have collaborated to come up with different types of farrowing systems. A growing societal pressure has pushed a variety of alternative farrowing systems to be developed and even to be installed and used in commercial farms. Currently, there are many options available, depending on how much weigh the developer put on which side of the triangle of needs. Still, alternative farrowing systems can be grouped into different categories according to similar features (Baxter et al., 2018, **Figure 1.4**):

Temporary crating: In contrast to the conventional farrowing crate, which confines the sow from entry to weaning (with the range of 21 to 35 days), this type of system only confines the sow temporarily around farrowing when piglets are newly born and the most vulnerable to crushing. After this period, the sow is loose for the rest of the lactation period. Extra features for sow posture change and piglet protection are often installed in the pen. Temporary crating also allows the farmer to confine the sow temporarily for examination or intervention of the sow and piglets.

Zero-confinement pen: The sow is housed individually without a crate, meaning that she is loose from entry to weaning. Zero-confinement pen includes two types of pens, which are simple pen and designed pen. Extra features for sow posture change and piglet protection are installed in both types of pens, while there are defined areas, including separate lying and dunging areas, only in the designed pen.

Group system: As its name implies, sows are group-housed, and litters are mixed before weaning. It may be called as multi-suckling system sometimes. Depending on the system, sows may farrow separately in individual pens and are integrated into groups later between 10 and 21 days after farrowing. Group system intends to mimic the seminatural conditions to fulfill the biological needs of the sows and piglets.

Outdoor system: The sow and her litter are housed individually in either a hut or an ark outdoor, with access to individual or group paddocks. Outdoor system requires proper soil type for drainage but requires minimum stockworker intervention.

Table 1.2 briefly summarizes whether the biological needs of the sow and the piglets can be met in each category of alternative farrowing system.

(a)  (b) 

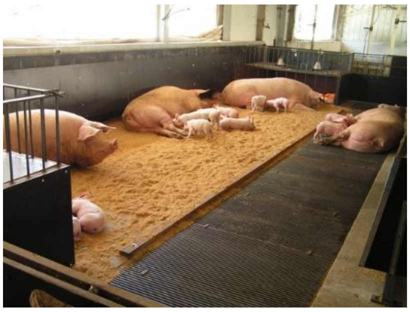
(c)  (d) 

Figure 1.4 Pictures of some alternative farrowing systems: **(a)** Temporary crating, **(b)** Zero-confinement pen, **(c)** Group system, and **(d)** Outdoor system (source: https://www.freefarrowing.org/farrowing-systems/, retrieved on 20/September/2021).

Table 1.2 Summary of whether the biological needs of the sow and piglets can be met in each category of alternative farrowing system. 'v' indicates 'yes', 'x' indicates 'no', and '~' indicates 'depends on the system or the management'.

Biological needs of the sow and the piglets		Temporary crating	Zero-confinement pen	Group system	Outdoor system
Sow	Perform nest-site seeking (i.e. locomotion)	x	~	v	v
	Provision of isolated nesting area	x	~	v	v
	Provision of nest-building materials & ability to perform nest-building behaviors	v / ~ (if crate left open prepartum)	v / v	v / v	v / v
	Provision of separate dunging area	~	~	v	v
Piglet	Perform social interactions with non-littermates	~	~	v	v
	Socialize (i.e. co-mingle) with non-littermates	x	x	v	v
Sow, Piglet	Perform mother-young interactions	v	v	v	v
	Provision of environmental enrichment materials	~	~	v	v
	Possibility to practice gradual weaning	x	x	v	v

Although alternative farrowing systems yielded a better welfare design index (i.e. how well the system meets the animals' biological needs) (2.20 for group system, 1.64, for designed pen system, 1.10 for outdoor system, and 0.95 for conventional crate system), a higher piglet mortality was recorded in group system, compared to designed pen, outdoor, and conventional crate systems (Baxter et al., 2011). Group system also accompanies a higher production cost (92% and 249% more than farrowing crate and outdoor system, respectively), mostly due to extra building/land provided per animal (Baxter et al., 2011). On the other hand, designed pen system had a moderately higher production cost (17.5% higher) than conventional crate system. Another economic evaluation suggested that there is a higher production cost in indoor non-crate systems, compared to conventional crate system (1.6, 1.7, and 3.5% higher per sow, in 360° Freedom Farrower (temporary crating), Danish (zero-confinement pen), and PigSAFE (zero-confinement pen), respectively) (Guy et al., 2012). In the same study, outdoor system had the lowest production cost. Bedding cost is significantly higher in the outdoor system, whereas labor and building/land costs are significantly lower in all the indoor systems. Differences in production cost between conventional crate and the three alternative farrowing systems are mainly because of a higher building/land cost as well as additional metal furniture inside the pens (Guy et al., 2012). When considering welfare and economic perspectives of farrowing systems, designed pen system appears to be the optimal indoor alternative farrowing system (Baxter et al., 2011). Combining appropriate staff training, breeding sows with good maternal traits, subsidies from government support, or a premium in the marketspace, may all motivate the producers to phase out conventional crate system and to transit faster to alternative farrowing systems (Baxter et al., 2011; Guy et al., 2012).

Alternative farrowing systems mentioned above may seem to primarily focus on the biological needs of the sows, which emphasize the ability to perform nest-building behavior, and the freedom of movement, posture change, or even the location to stay at during the peripartum and lactation periods. However, compared to conventional crate, alternative farrowing systems also meet some of the biological needs of the piglets, which benefits the welfare of the piglets during the suckling period. Overall, suckling behavior can be properly performed when the sow is not confined (Newberry and Wood-Gush, 1985), from pre-massage and silent suckling (i.e. before milk ejection), to rapid suckling and post-massage (i.e. after milk ejection) (Jensen et al., 1991). Suckling not only fulfills the nutritional needs of the piglets but also facilitate the establishment and reaffirmation of the sow-piglet bond during lactation (Baxter et al., 2011). Baxter et al. (2011) also suggested that frequent interaction with the piglets (e.g. nose-to-nose contacts) starting from their early ages, enhances the development of sows' maternal behaviors (Cronin et al., 1996), which may reduce the risk of piglet crushing (Anderson et al., 2005). Additionally, the complexity of the early environment in alternative farrowing systems (e.g. nest-building materials as an enrichment, more interactions with the sow, social contacts with non-littermates and other sows, or outdoor access) can have a long-term impact on piglets' behavioral development (Baxter et al., 2011; Martin et al., 2015). Studies have shown that piglets raised in a more enriched environment better cope with novel challenges later in their lives, such as social integration (e.g. weaning in commercial farm practice), by being less engaged in aggression during mixing with unfamiliar conspecifics (D'Eath, 2005; Hessel et al., 2006), and more engaged in feeding behavior and thus better weight gain (Pajor et al., 1999; Kutzer et al., 2009).

Farrowing crate is one of the welfare 'hot-spots' lately, as the indoor rearing conditions are far from the outdoor natural or semi-natural environment that is preferred by the sows and the piglets, which permits them to fulfill their biological needs during the peripartum and lactation periods. Scarce research has been carried out to study the life-long effect of physically and socially enriched early environment in pigs under commercial conditions, and the experience of farrowing pens with temporary crating system under commercial conditions in the Mediterranean region is lacking. The aim of this PhD thesis was therefore formed, which focused on the effects of alternative housing conditions on the welfare and performance of sows and piglets in intensive production systems.

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CHAPTER 2.

OBJECTVIES

The general objective of this doctoral thesis was to study the effects of alternative farrowing housing conditions on the welfare and performance of sows and piglets in intensive production systems. Two welfare related issues commonly seen on commercial farms were tackled. The first one was the housing conditions of piglets during lactation and their life-long impact on the welfare and performance of pigs. The second one was the housing of sows during the peripartum and its effect on the welfare and performance of sows and piglets until the post-weaning period.

To achieve this general objective, two trials were conducted separately on two commercial farms with the following specific objectives listed below each trial:

Trial 1. Implications of improved environment during lactation for the welfare and performance of pigs from birth to slaughter. The specific objectives were:

- To investigate the short-term effects of socialization and environmental enrichment during lactation on behaviors, aggression-associated skin lesions, and salivary stress biomarkers in piglets before and after weaning (Chapter 3).

- To investigate the long-term effects of socialization and environmental enrichment during lactation on abnormal behaviors during the nursery period and at slaughter, and on aggression-associated skin lesions at pre-slaughter mixing (Chapter 3).

- To investigate the long-term effects of socialization and environmental enrichment during lactation on growth performance in pigs from birth to slaughter (Chapter 4).

Trial 2. Welfare and performance of sows and piglets in farrowing pens with temporary crating system or conventional crates during lactation and shortly after weaning. The specific objectives were:

- To compare the reproductive performance and salivary stress biomarkers of sows, the growth performance, foreleg abrasion and crushing of piglets, and the behaviors of sows and piglets during lactation, between farrowing pens with temporary crating and conventional crates (Chapter 5).

- To compare the behaviors and salivary stress biomarkers of sows and piglets, and the aggression-associated skin lesions of piglets before and after weaning, between farrowing pens with temporary crating and conventional crates (Chapter 6).

CHAPTER 3.

Pre-weaning socialization and environmental enrichment affect life-long response to regrouping in commercially-reared pigs

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Highlights

- Enriched pens (ENR) had enrichment objects and were socialized, in contrast to CON
- Pigs were followed from birth to slaughter and were regrouped three times
- ENR showed more exploration pre-weaning and less aggression post-weaning
- ENR had fewer lesions and an insignificant rise of stress biomarkers post-weaning
- Carcass lesions implied less reciprocal fighting but more bullying in ENR than CON

Abstract

Weaning and other regrouping events as routine work in commercial farms cause stress to pigs and compromise their welfare. Several studies found positive outcomes to mitigate weaning stress when piglets were socialized (i.e. co-mingled) or raised with enrichment materials in research settings. However, research in commercial settings is lacking. We aimed to investigate the effects of early-life socialization and environmental enrichment on pigs' life-long response to regrouping under commercial conditions via behavioral observations, aggression-associated skin lesions, ear biting lesions, and salivary stress biomarkers. A total of 661 Danbred pigs were studied from birth to slaughter. Two treatments were differentiated pre-weaning: the control group (CON; 24 litters), where sows and their litters were individually housed in barren farrowing pens; and the enriched group (ENR; 24 litters), where six enrichment objects per litter were provided from birth and two neighboring litters were socialized from Day (D) 14. Pigs were regrouped on D25 (weaning), on D71 (finishing), and at pre-slaughter, while keeping animals from the same treatment together, except at pre-slaughter. Behavioral observation took place on D15, D22, D29 and D36. Lesions were scored on D13, D15, D24, D26, D27 and on carcasses. Saliva was sampled on D24, D26 and D27. Ear biting lesions were scored on D69 and on carcasses. ENR showed 1.6-times more pen and object exploration ($P = 0.03$) pre-weaning, and CON showed 2-times more agonistic behavior ($P = 0.01$) post-weaning. Lesions increased after socialization and weaning in both treatments ($P < 0.0001$), but the increase after weaning was 3.3-times greater in CON ($P < 0.01$). Salivary cortisol (CORT) and chromogranin A (CgA) increased after weaning in both treatments but the rise was significant only in CON (CORT: 1.5-times; CgA: 6.2-times, both $P < 0.0001$). Salivary α-amylase increased after weaning in CON ($P = 0.05$) but decreased in ENR ($P < 0.0001$). On carcasses, CON had more lesions on the head ($P = 0.05$) and front parts ($P = 0.02$) whereas ENR had more lesions on the rear ($P = 0.05$). Ear biting was unaffected and ear biting lesions did not differ between treatments on D69 and on carcasses. The present study showed a lasting positive effect of enriching the neonatal environment both physically and socially, on piglet object exploration pre-weaning, mitigation of weaning stress, and reduced aggression post-weaning until slaughter. These results, obtained under commercial conditions, provide a promising avenue for improving life-long welfare of pigs.

Keywords: aggression, commercial practice, play behavior, salivary stress biomarker, skin lesion, weaning

3.1. Introduction

Good housing and management are key elements to ensure pig welfare. There is often lack of welfare consideration when it comes to intensive pig farming, which includes abrupt weaning, frequent regrouping and barren rearing conditions. These processes generally lead to aggression (Peden et al., 2018) or abnormal behaviors such as ear and tail biting (e.g. Taylor et al., 2010), which may cause stress, fear, pain and injury (Campbell et al., 2013). Regrouping (i.e. mixing) is a common routine practice for adjusting the stocking density or to homogenize a group by body size, and weaning is usually the first regrouping event for pigs in commercial farms. Weaning is unarguably known as one of the biggest challenges throughout pigs' lives due to the combination of multiple stress factors: abrupt and premature separation from the sow, mixing with unfamiliar individuals, a sudden diet change, human handling and transportation stress, and alteration of housing facilities (reviewed by Campbell et al., 2013). As a consequence, abrupt weaning results in vigorous fighting (Peden et al., 2018), elevated level of stress-related hormones (Held and Mendl, 2000), suppressed immunity, a growth check, and sometimes even death (Campbell et al., 2013).

When pigs are given an outdoor enclosure and are raised extensively, weaning is a rather gradual process which could take three to four months to complete (Newberry and Wood-Gush, 1985; Jensen and Recén, 1989). Piglets start socializing with unfamiliar piglets from about two weeks of age when their mother returns to her original group (Jensen and Redbo, 1987). Although very little research has focused on the function of the early physical environment in domestic piglets, environmental enrichment is known to contribute to brain development in wild boar piglets (Telkänranta and Edwards, 2018) and in pigs exposed to enrichment materials post weaning (Brown et al., 2017). A wide range of environmental inputs enables normal brain development, which includes spatial and dimensional learning, interaction with novel materials and sensory stimulation (Telkänranta and Edwards, 2018). Martin et al. (2015) reported the substantial impact of early physical and social environment on piglets' socio-cognitive development. A complex environment during this critical pre-weaning period is known to positively influence behavioral development and stress adaptation later in life, by equipping piglets with the appropriate social skills and stress coping capabilities (Brunson et al., 2003). Piglets raised in a more complex environment were less reactive towards novelty (Oostindjer et al., 2010), had lower cortisol levels (De Jonge et al., 1996), and were less aggressive towards unfamiliar conspecifics after weaning (Beattie et al., 2000; Camerlink et al., 2018). Previously-socialized piglets were observed to establish a stable hierarchy faster by engaging in more decisive agonistic interactions (D'Eath, 2005; Camerlink et al., 2018), and these social skills may persist in later life (Camerlink et al., 2018) and even until slaughter (Petersen et al., 1989). These positive outcomes suggest that stress, fear, pain and injury can be mitigated by a biologically relevant neonatal environment, and may increase the resilience of pigs towards challenging situations such as weaning and regrouping events.

An investigation into the effect of neonatal enrichment in a commercial setting is necessary (Salazar et al., 2018; Yang et al., 2018), as prior studies were conducted mostly in research facilities and are unlikely to reflect commercially relevant farming systems. Advantages offered by the enrichment method must be demonstrated under commercial conditions before being recommended to the farming industry (as advocated for example in Peden et al., 2018).

We aimed to study the effects of socialization and environmental enrichment during the suckling stage in piglets via behavioral observations, the accumulation of aggression-associated skin lesions, and the level of salivary stress biomarkers before and after weaning. We also aimed to study the life-long consequences of these effects on ear biting lesions during the nursery stage and at slaughter, and aggression-associated skin lesions from pre-slaughter mixing. We hypothesized that enriching the neonatal environment would reduce aggression and the stress response during regrouping, with a general reduction of abnormal behavior (e.g. ear biting). Furthermore, we also hypothesized that it would improve the life-long adaptability of pigs to novel environment and social encounters.

3.2. Materials and Methods

The study was conducted on a commercial farm in Lleida, Spain. Animals were followed from birth (June 2017) to slaughter (January 2018). The farm was run compliant with the EU welfare standards. Management of newborn piglets, such as teeth grinding, tail docking and male castration were performed routinely under veterinary prescription by experienced farm staff. All experimental procedures were approved by the ethical committee of Universitat Autònoma de Barcelona (UAB) (FUE-2016-00441221).

3.2.1. Animals and housing

3.2.1.1. Suckling stage (from birth to 25 days of age)

Forty-eight sows (21 primiparous and 27 multiparous) were confined in farrowing crates (190 x 62.5 cm^2) from seven days before expected farrowing date until weaning. They were randomly distributed across six rooms, with ten pens per room. Farrowing pen size was 253 x 168 cm. Farrowing was synchronized (Planate®, MSD) and cross-fostering was performed within 24 hours after parturition in order to standardize the litter size between 13 to 14 piglets. One day after birth, piglets were individually identified with ear-tags as per treatment group (hereafter referred to as CON and ENR for the two treatments, see section 2.2. for details). A total of 661 Danbred piglets (n_{CON} = 324; n_{ENR} = 337) were studied. Sows were fed twice a day with commercial feed and *ad libitum* water; piglets were provided with *ad libitum* water, and *ad libitum* creep feed from two weeks of age. Room temperature was programed at 30 ± 2 °C. During this stage, 113 piglets were lost to follow-up due to death or removal from the staff.

3.2.1.2. Nursery stage (from 25 to 71 days of age)

Piglets were weaned at 25 days of age. On the day of weaning, the staff first removed the sows and then transported the piglets by truck to a nursery approximately 400 m away. Five-hundred-forty-eight weaners (n_{CON} = 262; n_{ENR} = 286) were allocated to a nursery room of 16 pens as per treatment group, based on similar body size and irrespective of gender. They were grouped into 16 pens (320 x 200 cm), providing a stocking density of ~0.20 m^2/animal. The weaning process was completed within 2 hours. Weaners had *ad libitum* commercial feed and water. Room temperature was programmed at 25 ± 2 °C. During this stage, 69 weaners were lost to follow-up and 37 died.

3.2.1.3. Growing/finishing stage (71 days of age to slaughter)

At 71 days of age, pigs were transported by truck to a growing/finishing unit 500 m away. In total, 442 pigs (n_{CON} = 208; n_{ENR} = 234) were allocated to 33 pens (314 x 266 cm) as per treatment group, based on similar body size and irrespective of gender, providing a stocking density of ~0.62 m^2/animal. Animals remained in the same pen until slaughter and they were fed with *ad libitum* commercial liquid feed. Growing pens were provided with two 100 cm-long iron chains.

3.2.1.4. Slaughterhouse

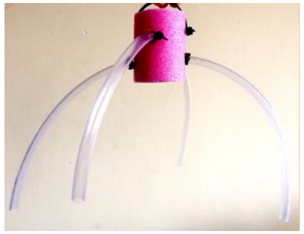
Due to infrastructure at the slaughterhouse, 100 pigs were lost to follow-up. Pigs (n_{CON} = 153; n_{ENR} = 189) were slaughtered between December 4th and January 18th. They were individually selected by the farmer according to their body condition and transported to a commercial slaughterhouse situated 6 km away one day before slaughter. Upon arrival, pigs were unloaded and housed in a lairage of two pens, irrespective of treatment and gender, with *ad libitum* water. The slaughterhouse was operated in compliance with the EU regulation.

3.2.2. Experimental design

Sows were randomly assigned to two treatments, in which parity (primiparous/multiparous) and pen distribution were balanced. In the control treatment (CON; n = 24 litters), each sow and her litter were individually housed in a barren farrowing pen until weaning. In the enriched treatment (ENR; n = 24 litters), social and environmental enrichment were applied during the suckling stage. From D1 to weaning, six enrichment objects, including two hemp ropes, two rubber chew toys and two handmade toys, were supplied to each ENR pen (see **Table 3.1** for details of the enrichment objects). All objects were placed away from the sows to prevent destruction of the objects. One rubber chew toy was chained on the slatted floor whereas the remaining five objects were equally distributed around the pens and suspended either from the posterior end of the crate or from the wall to the piglet's eye level. The height of the objects from above the floor was adjusted every week until weaning. The distribution of the six enrichment objects was similar in all pens, detailed in **Figure 3.1**. Missing or broken enrichment objects were immediately replaced. Additionally, in the ENR, from D14 to weaning, the barrier between two adjacent pens was removed to allow the co-mingling of the two litters after examining the health status of the sows and piglets (in order to safeguard their welfare).

Table 3.1 Detailed descriptions and figures of the enrichment objects supplied to the Enriched treatment during the suckling stage.

Enrichment object	**Dimension (length x width)**	**Object properties and location in the farrowing pen**
Hemp rope	28 x 2 cm	A braided natural fiber rope that is destructible and flexible; characteristics of materials known to be attractive to domestic pigs (Zonderland et al., 2003). Two hemp ropes per pen suspended from each of the posterior end of the farrowing crate using a nylon string and a cable tie. 
Rubber chew toy	15.3 x 13 cm	A commercially available dog chew toy (Petstages Hearty chew, Illinois, United States) that consists of a hollow rubber ball with a bumpy surface, with three nylon ropes (knotted on both ends) threaded through. It was previously used in Yang et al. (2018) as an enrichment object for piglets.

		Two rubber chew toys were provided per pen: one chained on the slatted floor using a metal chain and a cable tie; the other one suspended from the wall using a nylon string and a cable tie. 
Handmade toy	23 x 27 cm	A handmade toy consisting of two transparent, flexible 6” plastic pipes that were threaded through a segment of pool noddle (cylindrical polyethylene foam). Plastic pipes have been broadly used as an enrichment material for pigs in practice and scientific research (Godyń et al., 2019) and the interest of manipulating the toy was also previously tested in a pilot study. Two handmade toys were provided per pen and were suspended from the wall using a nylon string and a cable tie. 

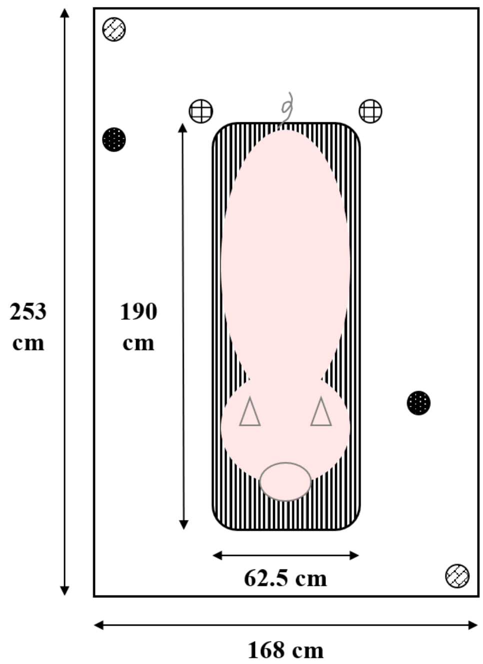


Figure 3.1 Diagram of the farrowing pen and the crate. Placement of the enrichment objects in the Enriched treatment are indicated in circles with different fillings. ⊘ , ● and ⊕ represent handmade toy, rubber chew toy and hemp rope, respectively.

3.2.3. Selection of the focal litters and the animals for behavioral observation, lesion scoring and saliva sampling from suckling to nursery stage

Seventeen litters (balanced by parity and room) per treatment were randomly selected for lesion scoring, saliva sampling and behavioral observation. From these litters, six piglets per litter were selected for lesion scoring and saliva sampling, which were a male and female piglet of the heaviest (H), the lightest (L) and the middle (M) birth weight of its litter average.

3.2.4. Behavioral observation in pre- and post-weaning

A 5-minute scan sampling with 2-minute interval was carried out to observe exploration and social behavior at pen level from 08:00 h to 13:00 h by two observers. The inter-observer reliability was analyzed by Pearson's correlation model, and determined as acceptable ($r = 0.97$, $P < 0.001$). Behavioral observations were conducted on D15, D22 (pre-weaning), D29 and D36 (post-weaning). During the suckling stage, two neighboring pens of the same treatment were observed simultaneously in one scan. The focal pens were observed twice by two observers per day, with approximately 2 hours in between. A pre-weaning ethogram of behavior categories is indicated in **Table 3.2**. For the post-weaning period, pen exploration and object exploration were combined into one category as exploration. Resting was recorded as number of resting animals.

Table 3.2 Pre-weaning ethogram with behavior categories and a detailed description for each category, adapted from Temple et al. (2011).

Category		**Behavior Description**
Active	Positive social and locomotor play behaviors	Gentle physical contact (such as nudging or sniffing) with no reaction from the recipient. Play behaviors such as hop, scamper and pivot with or without another individual.
	Negative social behavior	Head knocking, biting, or pushing with a response from the recipient. Fighting, where a rapid chain of agonistic behaviors are performed between two or more active individuals.
	Pen exploration	Nudging, chewing, biting or sniffing of pen fixtures (walls, floors, feeders, etc.).
	Object exploration	Nudging, chewing, biting or sniffing of any enrichment object.
	Other active behaviors	Eating, drinking, air sniffing, in contact with the sow's teats, or other active behaviors not detailed in the ethogram.
Inactive	Resting	Pig is inactive (standing, lying down, eyes closed and without movement).

3.2.5. Lesion scoring and physiological measures before and after weaning

3.2.5.1. Skin lesion scoring

The intensity of agonistic interactions between animals after regrouping, including early-life socialization in the ENR and weaning in both treatments, was estimated from the number of skin lesions, validated by Turner et al. (2006). The number of skin lesions was scored separately from six areas of each piglet, including the front (head, neck, shoulder and front leg), middle (flank and back) and rear (rump and hind leg) of both left and right sides. Only fresh and unbroken linear lesions were counted. During the suckling stage, lesions were counted on 1D pre-socialization and 1D post-socialization, and at weaning lesions were counted on 1D pre-weaning (-1D), 1D (+1D) and 2D post-weaning (+2D). Two previously trained assessors scored the lesions throughout the assessment, with a deemed acceptable agreement of Pearson's correlation r = 0.72 ($P < 0.001$) in an inter-observer reliability test (n = 30 piglets).

3.2.5.2. Saliva collection and analysis

Saliva samples were collected on -1D, +1D and +2D of weaning using a cotton swab provided in the Salivette® tube (Sarstedt, Aktiengesellschaft & Co., Nümbrecht, Germany) in the piglet’s mouth for approximately 1 minute. Samples were immediately centrifuged

(J20 XPI, Beckman Avanti®, United States) for 10 minutes at 3000 rpm and stored at -20°C until analysis.

Samples were collected to detect salivary cortisol (CORT) (µg/dL), chromogranin A (CgA) (µg/mL) concentration and α-amylase (sAA) (UI/L) activity. CORT was analyzed by an automated chemiluminescence immunoassay (Immulite 1000 cortisol, Siemens Medical Solutions Diagnostics, Los Angeles, CA, USA) as previously validated in Escribano et al. (2012). The intra- and inter-assay coefficients of variations (CVs) were lower than 16% and the detection limit was 0.016 µg/dL. CgA was determined by time-resolved immunofluorometry assays (TR-IFMA) as previously validated in Escribano et al. (2013). The intra- and inter-assay CVs were lower than 10% and the detection limit was 4.27 ng/mL. sAA activity was measured by an automatic analyzer for biochemical assay (Olympus UA600, Olympus Diagnostica GmbH) with a colorimetric commercial kit (Alpha-Amylase, Beckman Coulter Inc.) following the International Medicine (IFCC) method (van der Heiden et al., 1999). The kit was previously validated for pigs by Fuentes et al. (2011) with the intra- and inter-assay CVs lower than 10% and the detection limit was 11.65 U/L.

3.2.6. Ear biting assessment on D69 and on carcasses

Due to known problems with ear biting but not tail biting at the farm, only ear lesions were scored. Ear biting lesions were scored individually by two assessors on a Yes (1) / No

(0) basis on D69 and on carcasses: “0” indicates no damaged ear(s) and “1” indicates damaged ear(s), including superficial necrosis, bleeding wounds, or missing tissue on an ear.

3.2.7. Skin lesion scoring on carcasses

The number of aggression-associated skin lesions after regrouping was assessed on carcasses during evisceration by two previously trained assessors. The scoring method was adapted from Dalmau et al. (2009). The body was divided into eight areas: head, front (neck, shoulder and front leg), middle (flank and back) and rear (rump and hind leg) of both the left and right sides. Only reddish and unbroken linear lesions were counted, and areas that were ≥ 10 lesions were recorded as 10 lesions.

3.2.8. Statistical analysis

Statistical analyses were performed in RStudio version 1.2.5001 (R Foundation, Austria). The individual was the experimental unit for skin lesions, salivary stress biomarkers and ear biting lesions. Farrowing pen was the experimental unit for behavioral observations. Statistical significance was accepted when $P < 0.05$ and a tendency was considered when $0.05 < P < 0.10$. Results were reported as means with standard error (± SE).

3.2.8.1. Behavioral observations

Scan sampling data from behavioral observations were summed for each behavior category per pen (except resting), and divided by the total number of sample points. Each behavior category was expressed as a proportion of total active behavior. Active behavior included all behavior categories and excluded resting. This generated the proportion of time spent on each active behavior as detected by the observer. Resting was removed from the dataset due to concerns about the accuracy of recording.

For data in the pre-weaning period, pen exploration and object exploration were combined into one category as exploration. The proportion of all the behaviors were not normally distributed after arcsine square root transformation. Therefore, untransformed data was used in a non-parametric Wilcoxon Rank-Sum test to compare the differences in the proportion of each active behavior between treatments.

For data in the post-weaning period, the proportion of exploration was normally distributed. A linear mixed-effects model (LMM) was applied for analyzing the exploration, with the proportion of exploration as the response variable, the treatment and observation day as fixed variables, sex ratio as the covariate, and nursery pen as the random factor. The rest of the post-weaning behaviors (positive social, negative social and other active behaviors) were not normally distributed after arcsine square root transformation. Therefore, untransformed data was used in a non-parametric Wilcoxon Rank-Sum test to compare the differences in the proportion of each active behavior between treatments.

3.2.8.2. Number of skin lesions

Lesion scores were not normally distributed after square root transformation. A GLMM with a Poisson distribution was applied for analyzing all the untransformed data of the lesion scores.

For data collected before and after early-life socialization and weaning, the total number of lesions was summed by individual due to low number of lesions observed in each body part. The model was as follows: total number of lesions as the response variable, and the treatment, scoring day (pre-mixing, 1D and 2D post-mixing), sex and birth weight (H/M/L) as fixed variables. Individual piglet and litter origin were considered as random factors, and nursery pen was included when comparing number of skin lesions during weaning.

For data collected on carcasses, left and right lesions of the same body part were summed. The model was as follows: the number of lesions as the response variable, with the treatment, body part (head/front/middle/back) and sex as fixed variables, and carcass weight as the covariate. Individual pig, growing pen and observer (two observers) were considered as random factors.

3.2.8.3. Concentration of salivary stress biomarkers

Concentration of CORT, CgA and activity of sAA was not normally distributed so they were log transformed. Samples collected on 1D pre-weaning were taken as basal levels. A LMM was applied, with the concentration of CORT/concentration of CgA/activity of sAA as the response variable, the treatment and sampling day (-1D, +1D and +2D) as fixed variables, and the basal level as the covariate. Sampling hour, farrowing pen and nursery pen were considered as random factors.

3.2.8.4. Ear biting lesions on D69 and carcasses

Ear biting lesions were scored on a binary scale and were therefore analyzed in a GLMM with a binomial distribution. Lesion score (0/1) was the response variable, and treatment, sampling day (D69/after slaughter) and sex as the fixed variables. Nursery pen was included as the random factor for the lesions on D69, and growing pen was included as the random factor for lesions at slaughter.

3.3. Results

One sow and her litter in CON were discarded due to lameness of the sow prior to parturition, which resulted in decreased feed intake and low number of piglets born alive. Average litter size was 14.1 ± 0.1 piglets in CON and 14.0 ± 0.1 in ENR. There were 10 primiparous sows in each treatment and 13 and 14 multiparous sows in CON and ENR respectively. Due to the treatment design including socialization, ENR had more familiar pen mates (3.9 ± 0.1 familiar pen mates; 10.3 ± 0.3% pigs/pen were familiar) post-weaning than pigs in CON (1.7 ± 0.1 familiar pen mates; 4.7 ± 0.2% pigs/pen were familiar) (t-test, $P < 0.0001$).

3.3.1. Suckling and nursery (around weaning) stages

3.3.1.1. Behavior in pre- and post-weaning

The activity budget of pre- and post-weaning periods by treatments is presented in **Figure 3.2**. Irrespective of the treatment, piglets spent a large proportion of time doing other active behaviors (pre-weaning: 70 – 80%; post-weaning: 50 – 60% of activity budget). The activity budget before weaning did not differ between treatments, except for exploration of the pen and the enrichment objects, in which ENR showed more than CON ($P = 0.03$). In the post-weaning period, CON showed more negative social behaviors ($P = 0.01$) than ENR whereas ENR showed more other active behaviors ($P = 0.003$).

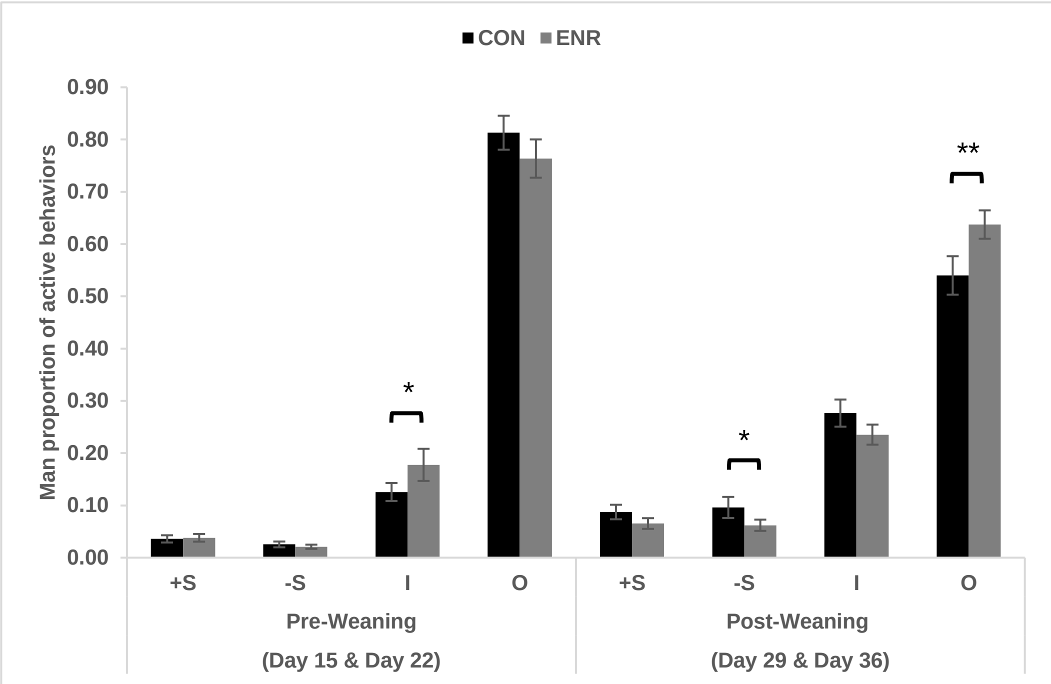


Figure 3.2 A comparison in the proportion of active behaviors during pre- and post-weaning by the control (CON) and enriched (ENR) treatment groups. Active behaviors include positive social and locomotor play behaviors (+S), negative social behavior (-S), pen and object exploration (E) and other active behaviors (O). The asterisk represents a significant difference between treatments of the same behavior category (* $P < 0.05$; ** $P < 0.01$).

3.3.1.2. Number of skin lesions after mixing in early-life socialization and weaning

The number of skin lesions before and after mixing, including early-life socialization and weaning, is presented by treatment in **Figure 3.3**. The number of skin lesions was higher after mixing than before mixing, including early-life socialization ($P < 0.0001$) and weaning ($P < 0.0001$), irrespective of treatment. During early-life socialization, there were more lesions counted in ENR than CON on both scoring days (pre-mixing: $P = 0.03$; post-mixing: *P* = 0.0001). During weaning, there was no difference between treatments prior to mixing (*P* = 0.14), but there were more lesions counted in CON than ENR on both 1D (+1D) (*P* = 0.004) and 2D post-weaning (+2D) (*P* = 0.0002). From +1D to +2D, the number of skin lesions kept increasing in CON (*P* < 0.0001) whereas that of skin lesions in ENR remained the same (*P* = 0.58).

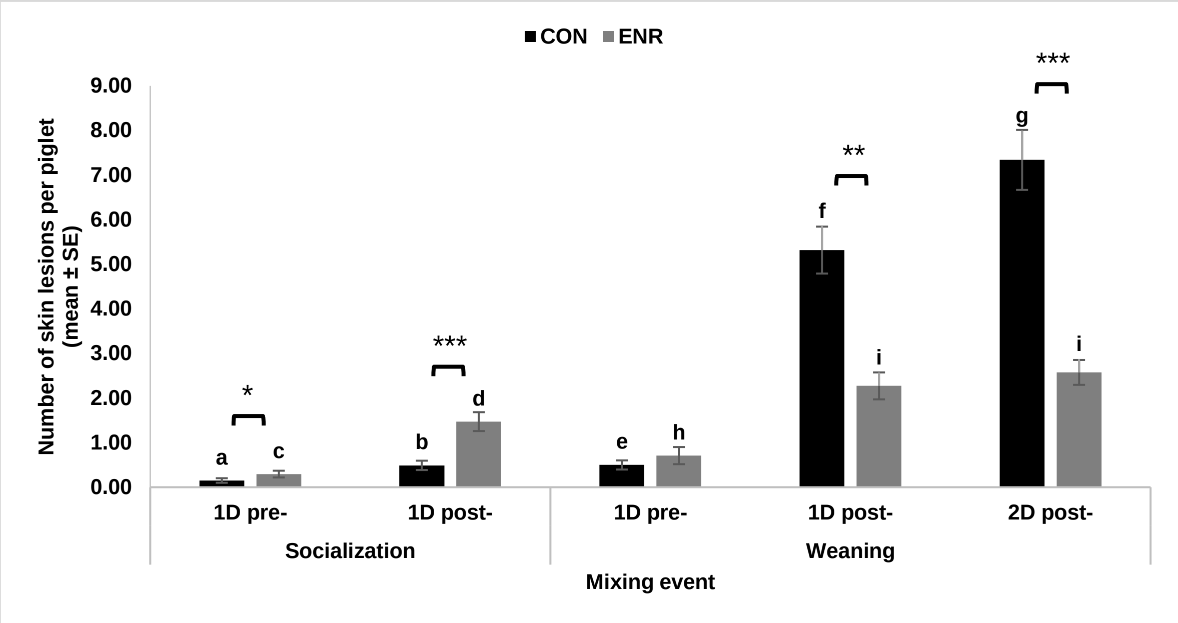


Figure 3.3. Number of aggression-associated skin lesions per piglet during regrouping (socialization and weaning), scored on 1D pre-mixing, 1D and 2D post-mixing by the control (CON) and enriched (ENR) treatment groups. Values with a different subscript correspond to a significant difference (*P* < 0.05) between sampling days in the same treatment and mixing event. The asterisk represents a significant difference between treatments on the same sampling day (* *P* < 0.05; ** *P* < 0.01; *** *P* < 0.001).

3.3.1.3. Concentration of cortisol (CORT) and chromogranin A (CgA), and activity of α-amylase (sAA)

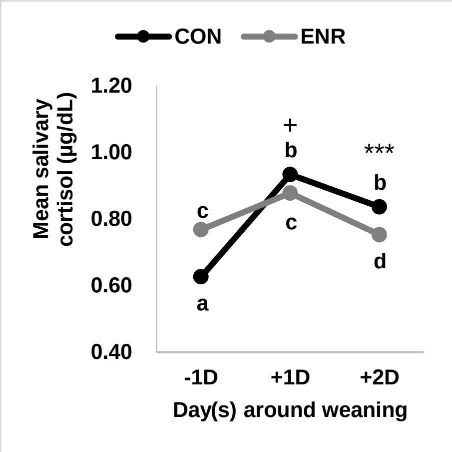
CORT, CgA and sAA during weaning between treatments is presented in **Figure 3.4**.

For CORT, concentration of 1D pre-weaning (-1D) and +1D between treatments was not significantly different (-1D: $P > 0.05$; +1D: $P = 0.07$) whereas that of +2D between treatments did differ ($P < 0.0001$). In the CON, CORT increased from -1D to +1D ($P < 0.0001$) and from -1D to +2D ($P < 0.0001$). In the ENR, there was no significant difference from -1D to +1D ($P = 0.83$), but a decrease in +2D as compared to the previous days (both $P < 0.001$).

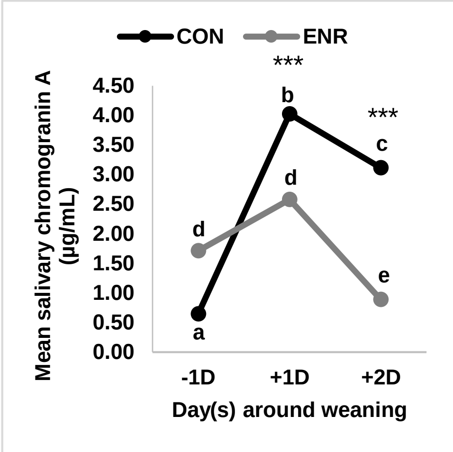
For CgA, the concentration of -1D did not differ between treatments ($P > 0.05$) whereas CON had higher CgA on both +1D and +2D as compared to ENR (both $P < 0.0001$). In the CON, there was an increase from -1D to +1D ($P < 0.0001$), followed by a decrease from +1D to +2D ($P < 0.002$). In the ENR there was no significant difference from -1D to +1D ($P = 0.85$), but a decrease on +2D as compared to the previous days (both $P < 0.0001$).

For sAA, activity of -1D did not differ between treatments ($P > 0.05$). CON had higher sAA on both +1D and +2D as compared to ENR (+1D: $P = 0.02$; +2D: $P = 0.002$). In the

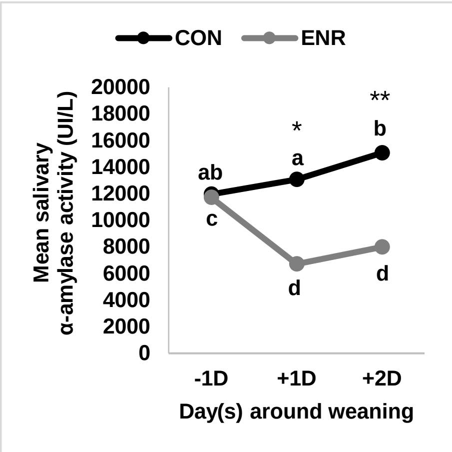
CON, there was an increase from +1D to +2D (P = 0.05). In the ENR, there was a decrease on +1D and +2D, compared to -1D (-1D *vs.* +1D: P < 0.0001; -1D *vs.* +2D: P = 0.0004).



(a)



(b)



(c)

Figure 3.4 Concentration of salivary **(a)** cortisol and **(b)** chromogranin A, and **(c)** activity of α-amylase (untransformed data) during weaning by the control (CON) and enriched (ENR) treatment groups. Samples were collected on 1D pre-weaning (-1D), 1D (+1D) and 2D post-weaning (+2D). Statistical analysis was run with log-transformed data. Values with a different subscript correspond to a significant difference (P < 0.05) between sampling days in the same treatment. The asterisk represents a significant difference between treatments on the same sampling day (+ $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

3.3.2. Nursery stage (D69) and at slaughter

3.3.2.1. Prevalence of ear biting lesions on D69 and on carcasses

The prevalence of ear biting lesions on D69 and on carcasses did not differ between treatments (D69: $P = 0.24$; At slaughter: $P = 0.89$). On D69, it was 0.18 ± 0.04 (n = 209) in CON and 0.27 ± 0.04 (n = 239) in ENR. On carcasses, the prevalence was 0.05 ± 0.02 (n = 153) in CON and 0.06 ± 0.02 (n = 190) in ENR.

3.3.2.2. Number of skin lesions on carcasses

The number of skin lesions after pre-slaughter mixing is presented in **Table 3.3**. Lesions on the head and the front parts were higher in the CON pigs (Head: $P = 0.05$; Front: $P = 0.02$) whereas those on the back part were higher in the ENR pigs ($P = 0.05$). There was no difference between treatments in the total number of skin lesions ($P > 0.05$). Irrespective of treatments, the middle part had the most lesions, followed by the front and the head parts, and then the back part.

Table 3.3 Number of skin lesions (mean ± SE) per pig after pre-slaughter mixing on carcasses in four body parts (head; front: neck, shoulder and front legs; middle: flank and back; rear: rump and hind legs) by the control (CON) and enriched (ENR) treatment groups.

Body Part	**CON**	**ENR**	***P*-value**
Head	11.01 ± 0.51	9.36 ± 0.48	0.05
Front	11.38 ± 0.53	9.48 ± 0.45	0.02
Middle	14.05 ± 0.56	13.13 ± 0.45	0.37
Back	2.91 ± 0.23	3.59 ± 0.23	0.05
Total	36.21 ± 1.45	34.73 ± 1.26	0.63

3.4. Discussion

We investigated the long-term effects of enriching the early physical and social environment on the adaptability to regrouping in pigs. In contrast to the majority of previous studies, this research was conducted in a commercial farm, where the results are more likely to reflect real world situations. The study indicated that before weaning, enriched piglets spent more time engaging in pen and object exploration, and after weaning, they spent less time in agonistic interactions, had fewer skin lesions and a lower stress response. This supported our hypothesis that physical and social enrichment in early-life would help piglets to adapt to novel conditions better. However, ear biting was unreduced, which may be because oral manipulative behavior has a different motivational background than the social behaviors that are commonly improved by pre-weaning socialization (Prunier et al., 2020). Data on skin lesions on the carcasses suggested that better social skills persisted until the moment of slaughter. Namely, ENR pigs had fewer lesions on the front of the carcass compared to CON, which is indicative of fewer reciprocal fights (Turner et al., 2006). Instead, they had more lesions on the rear which indicates avoidance of fights by retreat (Turner et al., 2006), when both ENR and CON pigs were grouped together at pre-slaughter. Overall, our results showed a consistent pattern in behavioral change and the related stress response whereby ENR pigs from the suckling stage until slaughter responded both behaviorally and physiologically better to regrouping situations.

3.4.1. Pre- and post-weaning behavior

Positive social and locomotor play behaviors were unaffected by the early social and environmental enrichment. Prior studies reported that increased play behavior may have been stimulated by additional space, substrate or unfamiliar conspecifics (Chaloupková et al., 2007; Martin et al., 2015; Yang et al., 2018). In this study, locomotor play behavior was not distinguished from affiliative behavior and therefore it is difficult to draw any conclusions on the effect of the treatment on play behavior.

In contrast to previous accounts of neonatal enrichment resulting in increased agonistic behavior due to mingling with unfamiliar individuals (Parratt et al., 2006; Salazar et al., 2018), or competition over enrichment objects (Docking et al., 2008), elevated aggression was not reflected in our study. This could be explained by the different methodologies used to observe behavior. Salazar et al. (2018) measured social behavior on the day of socialization, whereas in this study, behavior was observed one day later. Aggression from pre-weaning socialization is frequent but short-lived, leading to a rapid return to basal level after a hierarchy is established (Jensen, 1994; Pitts et al., 2000; D'Eath, 2005). Foreign piglets in the study of Wattanakul et al. (1997) were observed to rapidly integrate into the group within few hours, and agonistic behavior from mixing in the study of Weary et al. (2002) decreased after 24h. The provision of enrichment objects did not contribute to agonistic behavior although competition may have stimulated aggression, especially since the use of enrichment is synchronized (Docking et al., 2008). The chosen objects could be manipulated by at maximum four pigs simultaneously and with six objects per pen, the chance of resource competition was small.

Regarding exploration, ENR and CON piglets were found to spend a similar proportion of time (8 - 11%) manipulating pen fixtures. ENR piglets spent an additional 4% of the active time interacting with enrichment objects. Previous studies reported less exploration towards penmates and pen fixtures, and more interaction with the enrichment material compared to barren piglets (Beattie et al., 2000; Lewis et al., 2006). However, as our treatment included socialization, which also increased the amount of space available to the enriched piglets, this could have stimulated additional exploration.

The enrichment objects were successful in sustaining the suckling piglets' interests. Pigs prefer edible, chewable and deformable objects, which better satisfied foraging motivations (van de Weerd et al., 2003), as well as fixed objects close to the ground as most exploration are performed at floor level, engaging the pig's natural rooting behavior (Lewis et al., 2006). As an overall higher proportion of exploration was observed in ENR piglets, it can be argued that they experienced better welfare due to fulfillment of their behavioral needs and the alleviation of boredom during the pre-weaning period.

The proportion of negative social behavior was higher in the CON than ENR on D29 and D36 after weaning. A complex pre-weaning environment could allow piglets to develop a variety of social skills (Weng et al., 1998; Kanaan et al. 2012; van Nieuwamerongen et al., 2017) and engage less in agonistic behavior after regrouping (Hessel et al., 2006; Li and Wang, 2011). Another possible explanation for the higher proportion of other active behaviors in ENR could be the increased prevalence of feeding behavior, although this was not specifically measured in this study. Many studies found that piglets raised in an enriched suckling environment showed a better growth rate after weaning (Hessel et al., 2006; Kutzer et al., 2009), and the effect could last for at least two weeks (Weary et al., 1999).

3.4.2. Aggression-associated lesions during regrouping

ENR pigs showed a significant lower level of aggression after weaning compared to the CON, which is in agreement with most of the studies conducted in research settings (D'Eath, 2005; Morgan et al., 2014; Camerlink et al., 2018) as well as in commercial settings (Salazar et al., 2018). This may be due to improved social recognition (Kanaan et al., 2012) and rapid establishment of dominance hierarchy because of increased social experience (D'Eath, 2005) that led to fewer, shorter and less intense fights between pigs. However, ENR pigs did have more familiar pigs in the nursery pens than CON pigs, which may reduce agonistic behaviors, although this does not always reduce the amount of aggressive interactions (Jensen and Yngvesson, 1998; Puppe, 1998). Our results supported our hypothesis that early life socialization has positive effects on the social behavior of piglets post-weaning, resulting in less aggression-related injuries.

In contrast to Salazar et al. (2018), we observed a significant increase of skin lesions in the ENR after socialization, but which is in line with research studies on socialization (e.g. Camerlink et al., 2018). The reasons for this could be more intense establishment of dominance relationships (Meese and Ewbank, 1973), for example due to increased competition over sows' udders (Pedersen et al., 1998), or due to higher levels of play fighting (Šilerová et al., 2010; Weller et al., 2019). The level of aggression seemed to stabilize after 24 h post-weaning in the ENR whereas it was still increasing in the CON.

When pigs are involved in aggression, reciprocal fighting often results in lesions to the anterior (ear, head and neck) and central (flank) regions of the body, whereas the receipt of unilateral bullying results in lesions to the posterior region (Turner et al., 2006). At pre-slaughter mixing, we observed more lesions on the head and front parts in the CON and that of the back part in the ENR, indicating that CON pigs were more engaged in reciprocal fighting and ENR pigs were receiving more unilateral bullying. Treatment effect could not be fully separated at this stage as pigs from both groups were grouped together for practical reason. However, this did provide more insight in their aggressive behavior, whereby having mixed groups of pigs from different treatments (CON and ENR) – the ENR were arguably the recipients of aggression whereas the CON were the aggressors. However, it would have been favorable to obtain the basal level of skin lesions to compare the increase between treatments. Socialization and repeated regrouping experiences have previously shown to have longer lasting effects (Camerlink et al., 2018; van Putten and Buré, 1997) but more research under commercial conditions is necessary to confirm the long-term benefits on reducing aggression by early-life socialization.

3.4.3. Salivary stress biomarkers

In the present study, CORT and CgA in the CON group increased significantly from -1D to +1D. During stress, two major brain networks are activated: the SAM (Sympathetic-Adrenal-Medullary) and HPA (Hypothalamic-Pituitary-Adrenal) axes (Godoy et al., 2018). Salivary cortisol (CORT) is widely used to indicate the activation of the HPA axis, whereas salivary chromogranin A (CgA) and α-amylase (sAA) indicate the activation of the SAM axis (Martínez-Miró et al., 2016). Our results confirmed that both HPA and SAM axes were activated due to weaning stress.

Similar results were reported in Salazar et al. (2018) and Yang et al. (2018), where socialized or enriched piglets with substrate had a smaller increase of CORT after weaning, compared to the control animals in a conventional suckling environment. Based on the change of the three biomarkers, it took less than 48 hours for ENR piglets to recover from the weaning stress, while for CON piglets, the consequences of the weaning were still noticeable after 48 hours post-weaning. Considering the accumulation of skin lesions after weaning, it could be assumed that CON piglets were still engaged in a high degree of agonistic interaction after 48 hours post-weaning (as also shown in Salazar et al., 2018). Previously, it was recommended to combine CORT, CgA and number of skin lesions as indicators when detecting social stress response in piglets (Escribano et al., 2019). Indeed, using these indicators together we could demonstrate that ENR piglets were less engaged in agonistic behaviors after weaning.

On +2D, CgA of the CON group decreased significantly from +1D, while CORT of the CON group on +2D still remained similar with +1D, in line with the type of stress (short- *vs.* long-term) (Godoy et al., 2018). The trend lines of CgA and sAA during weaning in our study were different from each other. CgA is increasingly used as an indicator for the acute stress response because of its reliability and stability across age, gender and circadian rhythms in pigs (Escribano et al., 2014), while sAA (more commonly used in humans) can represent not only physical stress but also psychological stress (Nater and Rohleder, 2009). The different trend lines could be due to a high inter-individual variability of sAA activity, which was observed in many species (Rohleder and Nater, 2009; Fuentes et al., 2011; Fuentes-Rubio et al., 2015; Contreras-Aguilar et al., 2018). Hence, the significant increase of sAA of CON from +1D to +2D may indicate an increased social stress response. In order to confirm the association between sAA activity and psychological stress caused by weaning in piglets, further research of sAA behind the stress mechanism in pigs, and a comparative study between different salivary stress biomarkers is needed.

3.4.4. Abnormal behavior (ear biting)

We found ear biting lesions in both CON and ENR pigs on D69, in line with other research showing that ear biting often appears between 5 to 12 weeks of age (Diana et al., 2019). The development of the damaging behavior has various origins, including boredom, failure to perform natural behavioral repertoire like exploration and foraging, or frustration due to inability to access food or other resources (Prunier et al., 2020). Neither on D69 nor on carcasses did we find tail biting lesions in our study. This could be explained by the redirected oral manipulation from tails to ears in our pigs, which had short-docked tails (Diana et al., 2019). The study of Goossens et al. (2008) also observed an increased frequency of ear biting behavior in pigs with similar morphology. However, tail biting lesions can in other farms still be a relevant measure to include, depending on whether ear biting or tail biting is prevailing. The degree of occurrence of damaging behavior is closely related to the degree of complexity of the current housing conditions (Peterson et al., 1995; van de Weerd et al., 2006; Telkänranta et al., 2014). As we found no differences in ear biting lesions between treatments, it seemed that the additional physical and social enrichment within the multitude of other stressors pre-weaning are not sufficient to reduce this behavior. However, as also concluded in the recent review by Prunier et al. (2020), a thorough study focusing on the development of ear biting behavior in pigs, as well as the long-term impact to reduce damaging behavior by enriching early-life environment, should be considered in the future.

3.5. Conclusions

Our results found that creating a physically and socially enriched environment in early-life for pigs improved their weaning adaptability in commercial settings. The facilitation of exploration and object play behaviors, and exposure to unfamiliar individuals during the suckling stage, led to a decrease of aggression and stress response after weaning. This suggested that a low cost, practical enrichment strategy can impart significant benefits to pig welfare under commercial farming conditions. Enriching the neonatal environment did not affect the incidence of abnormal behavior (ear biting) later in life, whereas at slaughter, skin lesions indicated that enriched pigs had fewer reciprocal fights and were instead avoiding aggression. Although at slaughter the two treatment groups were mixed, the results did provide support for a long-term effect on the pig's social skills. Given the beneficial consequences for pig production, further investigation across commercial farms would be warranted to support the current findings that indicated the life-long benefits of the enriched neonatal environment.

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CHAPTER 4.

Short communication:

Preweaning socialization and environmental enrichment affect short-term performance after regrouping in commercially reared pigs

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Abstract

On-farm practices like premature weaning and frequent regrouping induce stress to pigs. Early socialization or environmental enrichment in piglets reduce weaning stress, as suggested in previous studies. Little research with both effects and in commercial settings was found. The aim was to investigate the effects of pre-weaning socialization and environmental enrichment on life-long performance in 661 Danbred pigs. Two treatments were distinguished during the suckling period: control (CON, 24 litters) and enriched (ENR, 24 litters). CON piglets were raised in barren farrowing pens; ENR piglets were provided with six enrichment objects from birth, and two neighboring litters were socialized from Day (D) 14. Pigs were regrouped on D25 (weaning) and D71 (fattening), while keeping the same treatment. Individual body weight was recorded on D1, 14, 23, 27, 31, 38, 69, 79, and after slaughter (carcass weight, CW). Pigs were slaughtered in six batches. Estimated slaughter weight (ESW) was calculated by CW x 1.25. BW, CW and average daily gain (ADG) were analyzed by linear mixed models. Slaughter age was analyzed by Wilcox Rank-Sum test. BW and ESW were adjusted to non-linear models to obtain the predicted growth curves of CON and ENR, from birth to the targeted market weight (TMW, 105 kg). ADG during the suckling, nursery, and fattening periods, and from birth to slaughter, did not differ between treatments. However, ADG of ENR when moving pigs from farrowing to nursery (4-day-period) and from nursery to fattening (10-day-period), revealed a better performance than

CON (+20.6 g/day, P = 0.02; +53 g/day, P = 0.03, respectively). ENR pigs tended to be slaughtered 2.8 days earlier than CON (P = 0.08). On the other hand, the predicted growth curves showed a non-significant 2-day window of reaching TMW between treatments (P = 0.23). Results suggested that enriching the neonatal environment improved the short-term performance after regrouping, and may benefit the life-long performance by reducing time to reach TMW.

Keywords: growth rate, intensive production, life-long performance, mixing, welfare

4.1. Introduction

Intensive pig farming is often associated with poor animal welfare. Pigs are confined in stimulus-poor captive conditions, which failed to meet their ethological needs and thwarted the expression of key behaviors such as foraging and exploration (Godyń et al. 2019). These problems are exacerbated by stressful practices like early weaning and frequent mixing, resulting in poor performance and disease susceptibility (Godyń et al. 2019).

Prior research reported that enrichment of the neonatal environment can increase the resilience of piglets towards challenging situations (Godyń et al. 2019). Even minor modifications such as mixing with unfamiliar piglets (Salazar et al. 2018), or provision of enrichment objects (Yang et al., 2018) can reduce stress and aggression without compromising productivity. These strategies are of great interest in swine industry, as they require few resources and installation.

We aimed to study the effects of pre-weaning socialization and environmental enrichment on life-long performance in pigs. We hypothesized that physical and social enrichment of neonatal environment improves the life-long adaptability of pigs to novel regrouping events, which leads to a higher growth and a shorter time to reach the targeted market weight (TMW), compared to those in the barren environment.

4.2. Materials and Methods

4.2.1. Animals, housings and diets

4.2.1.1. Animals and housings

The study was conducted in a commercial farm in Lleida, Spain. A batch of 661 piglets from 48 Danbred sows (21 primiparous and 27 multiparous) were studied. Sows were moved to farrowing rooms prior to parturition. Piglets were individually ear-tagged and litter size was standardized between 13 to 14 piglets after parturition. Each farrowing pen was equipped with a feeder and a drinker (*ad libitum* water) in the front of the crate for the sow, and a nipple drinker (*ad libitum* water) in the lower part of the crate for the piglets. At weaning, 548 piglets (average 25 days of age) were moved to a nursery room, where they were regrouped according to treatment and body weight (BW), irrespective of litter origin and sex. Each pen was equipped with three feeders (two automatic and one manual) and five nipple drinkers (*ad libitum* water).

At the growing-finishing period, 442 pigs (average 71 days of age) were moved to a fattening unit until they were slaughtered. Pigs were regrouped according to treatment and BW, irrespective of nursery pen origin and sex. Each pen was equipped with a concrete box feeder containing ad libitum liquid feed. See Ko et al. (2020) for more details regarding general management and housing conditions of each production stage. Pigs were selected by the farmer periodically and were transported by truck 1 day before slaughter. There were six slaughter batches in total, with 45 days of difference between the first and the last batch.

4.2.1.2. Diet

Sows were fed with a pelleted lactation diet (2450 Kcal/kg) twice a day. Piglets were fed with a mashed creep feed from the 2nd week until weaning. In the nursery, pigs were fed ad libitum with pelleted diets following a three-phase feeding program (2480, 2470 and 2460 Kcal/kg). In the growing-finishing period, pigs were fed with ad libitum liquid feed diet following a two-phase feeding program (2488 and 2477 Kcal/kg).

4.2.2. Experimental design

When piglets were born on Day (D) 1, litters were balanced by sow parity and randomly assigned to two treatments: control (CON; n = 24 litters) and enriched (ENR; n = 24 litters). CON piglets were raised in barren farrowing pens until weaning. ENR piglets were provided with six enrichment objects per pen from birth (two hemp ropes, two rubber chew toys and two handmade toys) and two neighboring pens were socialized from D14 until weaning (see Ko et al. (2020) for details regarding the enrichment objects).

4.2.3. Weighing

Pigs were individually weighed on 1, 14, 23, 27, 31, 38, 69 and 79 days of age. BW_{1-69} was obtained by Balanzas Cobos PB-4040-60 (Spain) scale [precision: 10/5 g]. BW_{79} was obtained by Meier Brakenberg (Germany) scale [precision: 100 g]. Carcass weight (CW) was obtained after the carcasses were split longitudinally [precision: 10 g].

4.2.4. Statistical analysis

Data were analyzed in R (R Foundation, Austria). The individual was the experimental unit. Statistical significance was set at $P \leq 0.05$; a tendency was considered when $0.05 < P \leq 0.10$. Results are reported as means ± standard error.

4.2.4.1. Body weight, carcass weight and average daily gain

Estimated slaughter weight (ESM) was calculated by CW x 1.25, assuming an 80% of carcass yield. Linear mixed model was the main model to compare different response variables between treatments. Details regarding the response variable, fixed effects, covariate and random effects of each linear mixed model are presented in **Table 4.1**.

Table 4.1 Variables for the linear mixed models of body weight (BW), carcass weight (CW), estimated slaughter weight (ESW), and average daily gain (ADG) of pigs.

Response variable	Fixed effects	Covariate	Random effect(s)
BW_1	Treatment, sex	-	Sow
$BW_{14, 23}$	Treatment, sex	BW_1	Sow
$BW_{27, 31, 38, 69}$	Treatment, sex	BW_1	Nursery pen
BW_{79}, ESW	Treatment, sex	BW_1	Fattening pen
CW	Treatment, sex	Slaughter batch	Fattening pen
$ADG_{1\text{-}14, 14\text{-}23, 1\text{-}23}$	Treatment, sex	BW_1	Sow
$ADG_{23\text{-}27, 27\text{-}69}$	Treatment, sex	BW_1	Nursery pen
$ADG_{69\text{-}79, 79\text{-}ESW}$	Treatment, sex	BW_1	Fattening pen
$ADG_{1\text{-}ESW}$	Treatment, sex	BW_1	Sow, nursery pen, fattening pen

4.2.4.2. Slaughter age and predicted growth curves

Slaughter age (i.e. days from birth to slaughter) was not normally distributed. A Wilcox Rank-Sum test was applied to compare the slaughter age between treatments. To predict the time to reach TMW of 105 kg (T105, d), the double exponential Gompertz model in

López-Vergé et al. (2018) was applied, by adjusting all BW and ESW into the following formula.

$$BW = A*e^{-e^{(b-(c*t))}}$$

A, *b* and *c* are the parameters of the curve. *t* refers to the time (days).

4.3. Results

One CON sow was removed because of lameness before farrowing. CON had 10 primiparous and 13 multiparous sows, and ENR had 10 primiparous and 14 multiparous sows. Average litter size was 14.1 ± 0.1 (CON) and 14.0 ± 0.1 (ENR). During the suckling and nursery periods, 40 and 69 piglets were lost to follow-up, and 73 and 37 died, respectively. At slaughter, 100 pigs lost their traceability.

4.3.1. Body weight, carcass weight and average daily gain

Average BW and average daily gain (ADG) in different stages, and CW are presented in **Table 4.2**. No difference ($P > 0.1$) of BW and CW was found between treatments. BW_1 had a significant effect on all BW ($P < 0.0001$), ESW ($P = 0.03$) and all ADG ($P \leq 0.001$). ADG in the suckling, nursery, and fattening periods, and from birth to slaughter, did not differ between treatments. However, when moving pigs from one facility to another (from farrowing to nursery, and nursery to fattening), ADG of ENR were higher than those of CON ($P = 0.02$ and $P = 0.03$, respectively) after regrouping. There was an interaction between treatment and sex in ADG from farrowing to nursery (*P* = 0.04), where ENR female performed better than ENR male (*P* = 0.02, +21.3 g/day).

Table 4.2 Descriptive statistics of body weight (BW), carcass weight (CW), and average daily gain (ADG) of pigs by two treatments (control (CON); enriched (ENR)) and sex.

Item	Treatment	*n*	df	Mean	Sex		SEM	F-value	*P*-value
					Male	Female			
Suckling period									
BW_1, kg	CON	324	3	1.38	1.43	1.34	0.02	0.04	0.85
	ENR	337		1.40	1.42	1.38	0.02		
BW_{14}, kg	CON	264	4	3.43	3.43	3.43	0.06	0.01	0.49
	ENR	287		3.45	3.44	3.46	0.06		
BW_{23}, kg	CON	244	4	5.06	5.08	5.04	0.09	0.63	0.63
	ENR	286		4.91	4.90	4.93	0.08		
Nursery period									
BW_{27}, kg	CON	262	4	5.11	5.15	5.09	0.09	2.31	0.18
	ENR	286		5.25	5.23	5.26	0.08		
BW_{31}, kg	CON	253	4	5.34	5.38	5.34	0.09	3.24	0.12
	ENR	278		5.45	5.48	5.42	0.08		
BW_{38}, kg	CON	252	4	6.25	6.31	6.22	0.11	1.06	0.48
	ENR	278		6.40	6.48	6.31	0.11		
BW_{69}, kg	CON	209	4	15.36	14.87	15.67	0.25	0.14	0.81
	ENR	239		15.29	15.47	15.10	0.23		

Item	Treatment	*n*	df	Mean	Sex		SEM	F-value	*P*-value
					Male	Female			
Fattening period									
BW_{79}, kg	CON	208	4	17.35	16.78	17.71	0.29	0.76	0.50
	ENR	234		17.85	17.90	17.80	0.28		
CW, kg	CON	153	4	91.09	90.62	90.72	0.62	0.05	0.84
	ENR	187		90.48	90.34	90.59	0.59		
ESW, kg[1]	CON	153	4	113.86	113.28	113.40	0.78	0.04	0.78
	ENR	187		113.10	112.92	113.24	0.74		
Suckling period									
ADG_{1-14}, kg/d	CON	264	4	0.154	0.151	0.156	0.004	0.14	0.49
	ENR	287		0.158	0.156	0.160	0.003		
ADG_{14-23}, kg/d[2]	CON	244	4	0.179	0.176	0.182	0.004	1.80	0.23
	ENR	285		0.162	0.161	0.164	0.004		
ADG_{1-23}, kg/d	CON	224	4	0.165	0.164	0.166	0.004	0.48	0.63
	ENR	286		0.160	0.158	0.161	0.003		
ADG_{23-27}, g/d[3]	CON	231	4	53.3	59.4	48.3	4.7	5.08	0.02
	ENR	271		73.9	63.3	84.6	5.7		
Nursery period									
ADG_{27-69}, kg/d	CON	207	4	0.249	0.241	0.253	0.005	0.14	0.60
	ENR	237		0.241	0.245	0.238	0.004		
ADG_{69-79}, kg/d[4]	CON	206	4	0.201	0.187	0.209	0.012	4.62	0.03
	ENR	232		0.254	0.247	0.261	0.013		

Item	Treatment	*n*	df	Mean	Sex		SEM	F-value	*P*-value
					Male	Female			
Fattening period									
$ADG_{79\text{-}ESW}$, kg/d	CON	146	4	0.809	0.809	0.809	0.007	1.32	0.36
	ENR	171		0.822	0.832	0.812	0.007		
Global ADG									
$ADG_{1\text{-}ESW}$, kg/d	CON	146	4	0.568	0.565	0.570	0.004	0.70	0.43
	ENR	172		0.575	0.578	0.571	0.004		

[1] Estimated slaughter weight (ESW) = CW x 1.25.

[2] After pre-weaning socialization in ENR.

[3] After regrouping (weaning) in CON and ENR.

[4] After regrouping (from nursery to fattening) in CON and ENR.

4.3.2. Slaughter age and predicted growth curves

ENR tended to be slaughtered 2.8 days sooner than CON (194.9 ± 1.03 and 197.7 ± 1.28, P = 0.08). **Figures 4.1 (a) and (b)** present the predicted growth curves by treatment and sex effect, respectively. The horizontal line corresponds to TMW (105 kg). Neither treatment nor sex affected the time to reach TMW (P = 0.23 and P = 0.43, respectively). Numerically, ENR (192.2 ± 1.08) reached TMW 2 days earlier than CON (194.2 ± 1.21), and male (192.6 ± 1.21) reached TMW 1.3 days earlier than female (193.9 ± 1.08). There was no interaction between treatment and sex on the time to reach TMW (P = 0.36).

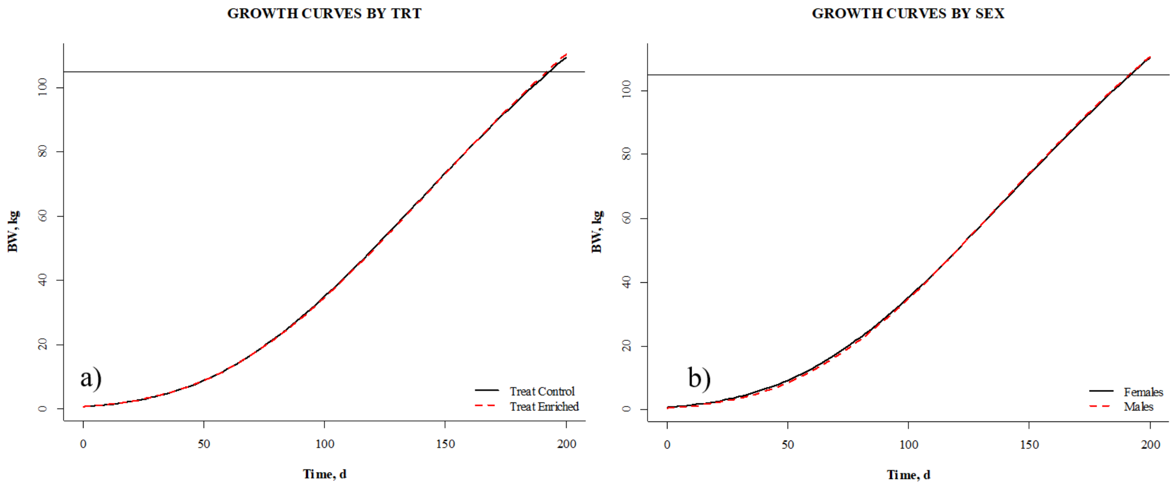

Figure 4.1 Average growth curves of pigs by **(a)** treatment (TRT) (Control *vs.* Enriched) and **(b)** sex (Male *vs.* Female) from birth to slaughter (n_{CON} = 133, n_{ENR} = 159; n_{Male} = 132; n_{Female} = 160). Targeted market weight was fixed at 105 kg, as the horizontal line shows.

4.4. Discussion

We investigated the effects of enriching neonatal environment physically and socially on life-long performance in pigs without modifying the routine management. Based on the results, ENR showed an improved ADG after two regrouping events, and a tendency of 2.8-day reduction to be slaughtered, compared to CON. As evidenced in Ko et al. (2020), piglets reared in an enriched environment in their early-life were better adapted to novel environments and social encounters, and in this study, we found that these benefits also suggested a steady weight gain after regrouping.

A lack of difference in ADG between treatments during the suckling period, indicated that pre-weaning environmental manipulations had no impact on performance. Similar result was reported in literature (socialization: Camerlink et al., 2018; Salazar et al., 2018; enrichment: Yang et al., 2018). The trend of post-weaning growth check and subsequent improvement in 2 weeks after weaning, corresponds to Kanaan et al. (2012).

A 4-day-period of ADG from farrowing to nursery in ENR was higher than CON, agreeing with the results within 1-week post-weaning in Weary et al. (2002) and Hessel et al. (2006). It was likely due to reduced aggression (Salazar et al., 2018) and smaller stress (Yang et al., 2018; Ko et al., 2002) after weaning in ENR, leading to an improved performance. In Weary et al. (2002), previously socialized weaners consumed more feed, resulting in greater weight gain post-weaning. As ENR exhibited 1.3-times more pre-weaning exploration than CON (Ko et al., 2020), the stimulation of chewing may be facilitated by the provision of enrichment objects (Oostindjer et al., 2010), which could contribute to a better adaptation to solid feed post-weaning.

A 10-day-period of ADG from nursery to fattening in ENR was still higher than CON. This could be due to a better adaptability to regrouping, including a faster establishment of dominance relationships and less agonistic interactions when encountering unacquainted pigs. According to Camerlink et al. (2018), social skills learned from socialization or repeated regrouping events could last for a long time. Godyń et al. (2019) also concluded that piglets provided with enrichment at the neonatal stage were shown to perform better social behavior later in their lives.

As we didn’t find a conclusive effect on long-term performance, improving pre-weaning rearing condition might not be an ultimate solution to optimize pig’s welfare and productivity throughout the cycle. Providing constant enrichment could contribute to successful socio-cognitive development, lower stress level, and enhanced social skills, which in turn ensures the long-term benefits regarding welfare and productivity (Godyń et al., 2019). However, our study suggested that a low-cost and easy-to-implement strategy could benefit pigs in a short-term without major reconstruction of current facilities. Further investigation to develop strategies with similar features is worthy to enhance welfare and productivity of commercially-reared pigs.

4.5. Implications

An improved performance demonstrates a crucial economic interest and a reliable welfare indicator. It is not clear whether the benefits of early environmental manipulations persist under commercial conditions, as most studies were conducted in research facilities. According to the study, raising commercially-reared piglets in a physically and socially enriched environment, showed a sustainable weight gain after regrouping, and a tendency to be slaughtered earlier, compared to those in a barren neonatal environment. This represented a cheap and pragmatic strategy to ensure a better adaptability of regrouping events in commercial farms.

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CHAPTER 5.

Welfare and performance of sows and piglets in farrowing pens with temporary crating system on a Spanish commercial farm

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Highlights

- Newborn piglets in farrowing crates (FC) interacted with littermates twice more than those in temporary crating systems (TC).
- TC newborn piglets initiated nose-to-nose contacts with sows five-time more than FC.
- TC sows interacted with piglets six-time more than FC in mid-lactation.
- TC sows explored the pen ten-time more than FC one day after the crate opened.
- The risk of crushing did not change when TC sows were crated or loose.

Abstract

The study aimed to assess the effect of farrowing system (farrowing crate (FC) *vs.* farrowing pen with temporary crating (TC)) on the welfare and performance of sows and piglets during lactation. One batch of crossbred Duroc were followed in every season. Three systems were tested: one FC and two commercially available TC, SWAP and JLF15. There were 183 piglets from 18 sows in FC, 243 piglets from 23 sows in SWAP, and 237 piglets from 23 sows in JLF15. The farrowing day was Day (D) 0 and weaning occurred on D24. Crating period (days) was from entry to weaning in FC, and from 1-day pre-expected farrowing day to D3 in TC. Social interactions between littermates, between sows and piglets, and exploration by sows and piglets were observed on D2, D4, D12, and D23. Video recordings of the crushing events which led to piglets' death were studied. Piglets were weighed on D3 and D19, and foreleg abrasions were assessed on D19. Sow saliva samples were collected on 1 day before and 1 day after confinement, D2, D4, D12, and D23 to evaluate cortisol (CORT) and chromogranin A (CgA) levels. TC piglets initiated naso-naso contacts with sows more frequently than FC on D2 ($P \leq 0.01$). TC sows interacted with piglets more frequently than FC on D12 ($P \leq 0.05$). TC sows explored the pens more frequently than FC on D4 ($P \leq 0.05$). Crushing rate (i.e. number of piglets per sow) of SWAP (1.2 ± 0.3) was higher than those of JLF15 (0.6 ± 0.2) and FC (0.3 ± 0.1) ($P \leq 0.02$), and crushing rate of JLF15 was higher than that of FC ($P < 0.0001$). Crushing happened similarly when SWAP and JLF15 sows were crated (34.7%) or loose (40.8%) ($P = 0.54$). Crushing rate in autumn was lower than in other seasons ($P < 0.001$). The percentage of using a support from the pen when changing posture but still crushed the piglets was higher in FC than in TC ($P = 0.05$). No difference of growth and foreleg abrasion in piglets were found between systems. CORT in SWAP peaked on D2 ($P = 0.02$), and CgA in JLF15 peaked on D4 and remained elevated until D12 ($P \leq 0.05$). CORT and CgA in FC remained similar during lactation. Our results suggested that despite a higher risk of crushing, TC facilitated the mother-young interactions. Sows changed their posture differently between systems and seasons. The practice of temporary crating did not alter the level of salivary stress biomarkers in sows.

Keywords: crushing, farrowing system, maternal behavior, mother-young interaction, stress biomarker, temporary crating

5.1. Introduction

Farrowing crates (FC) were first developed in the 1950s and became popular since then (Mellor et al., 2009). This space-saving design of the farrowing pen allows more sows to farrow per unit, permits easy inspection and safe intervention on sows and piglets by farm staff (Chidgey et al., 2015), and most importantly, it restricts sows' posture changes with the purpose of reducing piglet crushing (Baxter et al., 2018). As the loss of piglets is an economic and welfare concern (Chidgey et al., 2015), this highly cost-effective system has therefore been widely accepted and installed on pig farms all over the world (Hales et al., 2016). Within the European Union in particular, it is estimated that 95% of the pig farms are using FC (Johnson and Marchant-Forde, 2009). However, while it effectively prevents piglet's death from crushing (Nicolaisen et al., 2019), FC presents some welfare concerns for the sows because it limits the performance of some natural behaviors such as: body movement, nest building and maternal behavior (i.e. interaction with the piglets) (Baxter et al., 2012).

In natural conditions, the sow seeks an enclosed site to build a protective nest prior to giving birth (Jensen, 1986). Nest-building behavior is still observed in domestic pigs (Jensen, 1986), even when the sow is confined in FC, with redirected behavior towards the pen fixtures like floor, bars, and drinker, which is associated with nest-building (Baxter et al., 2018).

Research has found that the structure of FC prevents sows from fully expressing nest-building behavior, as it narrows sows' movements down to standing, sitting, lying, and rolling (Chidgey et al., 2016), which later may reflect on their poor reproductive performance, although not always (Hales et al., 2015; Hansen et al., 2017; Nowland et al., 2019; Lohmeier et al., 2020). Sows in FCs were found to have a longer farrowing duration (93 min. longer in Oliviero et al., 2008; 77.6 min. longer in Gu et al., 2011) and higher stillborn rates (Oliviero et al., 2010; Gu et al., 2011), compared with loose pen sows. On the other hand, satisfactory nest-building behavior has been associated with lower risk of crushing (Pedersen et al., 2003; Andersen et al., 2005), and greater suckling success for piglets due to an increased secretion of oxytocin by sows (Yun et al., 2013). The welfare concerns over farrowing sows have resulted in various designs of alternative farrowing systems in the past decades, farrowing pen with temporary crating system (TC) being one example. With the aim of improving the welfare of both sows and piglets, TC allows the sows to be loose during lactation, except for a few days during peripartum to limit the sows' most dangerous movements to reduce piglet mortality (Moustsen et al., 2013; Hales et al., 2015), although it is difficult to reach the same level of mortality as in FC (Chidgey et al., 2015). Although TC has started to be implemented in some European countries, experience with these systems is still very limited. There are currently many commercially available TC in the market, but most of the studies compared the farrowing systems between FC and TC (e.g. Chidgey et al., 2015; Hales et al., 2015), or FC and loose pen (e.g. Hales et al., 2014), rather than between different designs of TC. The objective of the present study was to assess the effect of farrowing systems, including one FC and two types of TC, on the welfare and performance of sows and piglets on a commercial farm in Spain.

5.2. Materials and Methods

5.2.1. Housing and experimental design

The study was conducted on a farrow-to-finish commercial farm (Gerfam SL; Girona, Spain). One week before the expected farrowing day, sows were moved from the gestation unit to one of the three farrowing systems tested in the present study: one conventional system with a FC (FC) and two commercially available TC: Sow Welfare and Piglet protection pen (SWAP) and JLF15 (both produced by Jyden; Sæby, Denmark). There were five FC pens in one farrowing unit, and six SWAP pens and six JLF15 pens in another farrowing unit. **Figure 5.1** illustrates the pen distribution and the key features of each farrowing system. The floor of both farrowing units was adapted to deep slurry system which is the commercial conditions in Spain. SWAP and JFL15 were equipped with plastic solid flooring for the creep area and the straw rack area, cast-iron slat flooring for the crating area, and plastic slat flooring for the rest of the pen. FC had cast-iron slat flooring for the sows, plastic slat flooring for the rest of the pen, and a heat mat for piglets. Two heat mats were installed at the floor of the creep area of SWAP and JLF15, and a lid at the top to retain the heat and to facilitate daily inspection of the piglets. A lock-in practice of the piglets is possible in SWAP and JLF15 by closing the creep area with a gate when necessary. Above the heat mat of FC and the creep area of SWAP and JLF15, lamps (150W) as an additional heat source for piglets were installed. The straw racks in SWAP and JLF15 were refilled with hay twice a day (08:00 and 18:00 h) from sow entry to weaning. The temperature in the farrowing units was kept constant at ~20°C, and the light was on from 07:00 to 18:00 h every day.

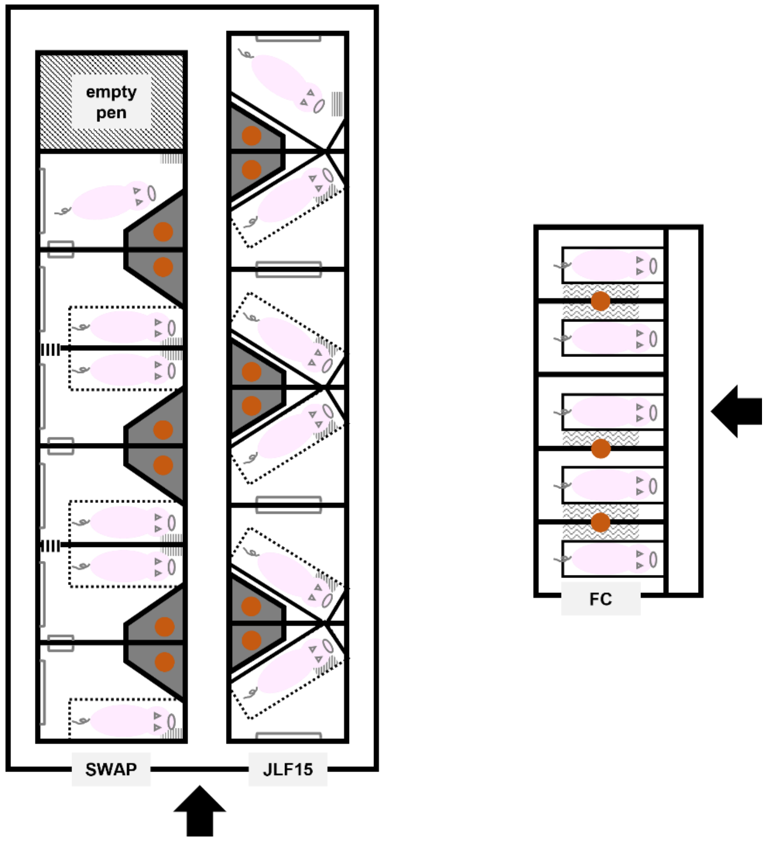


Figure 5.1 Distribution of the farrowing systems tested in the present study. There were five pens of conventional system with farrowing crates (FC) in one farrowing unit, and six SWAP pens and six JLF15 pens which are the temporary crating systems in another farrowing unit. The arrows indicate the entrances to the farrowing units. The pig drawings indicate the location of the sows when being crated, except those on the top pens of SWAP and JLF15. The top pens of SWAP and JLF15 indicate the area available to the loose sows. The squares which confine the sows indicate the farrowing crates (the solid lines are the fixed sides, and the round-dotted lines are the swing-sides which are adjustable) (crating period for FC: from entry to weaning; for SWAP and JLF15: from 1-day pre-expected farrowing date to 3 days after farrowing). The orange circles indicate the lamps for piglets. The grey

trapezoids in SWAP and JLF15 pens indicate the creep areas for piglets. The squares with the zig zag pattern filling in FC pens indicate the heating mats for piglets. The squares with the narrow vertical stripe pattern filling in SWAP and JLF15 pens indicate the straw racks. The bracket shapes in SWAP and JLF15 pens indicate the piglet protection rails. The squares with the dark vertical stripe pattern filling indicate the metal-barred gates in SWAP pens. The sloping walls in SWAP pens which are not indicated in the figure are installed at the fixed sides of the crates. Technical details of the pen and the creep sizes for each farrowing system are presented in **Table 5.1**.

Four batches of crossbred Duroc sows (*n* = 68) were randomly allocated to the three farrowing systems (FC, SWAP and JLF15) in all four seasons between 2018 and 2019: autumn (November), winter (February), spring (May) and summer (July). Parity of the sows in each batch was balanced between the farrowing systems (FC: 3.2 ± 0.5; SWAP: 3.2 ± 0.4; JLF15: 3.3 ± 0.3). The study period started from sow entry and ended at weaning. The day of the farrowing of each pen was considered as Day (D) 0. Crating period of FC sows was from entry to weaning while that of SWAP and JLF15 was from 1-day pre-expected farrowing date to 3 days after farrowing (i.e. the crate opened on D3). **Table 5.1** summarizes the technical details of each farrowing system.

Table 5.1 Technical details of each farrowing system tested in the study, including one conventional farrowing crate (FC) and two commercially available farrowing pens with temporary crating (SWAP and JLF15).

	FC	**SWAP**	**JLF15**
Farrowing system	Farrowing crate	Farrowing pen with temporary crating	Farrowing pen with temporary crating
Crating period	From entry to weaning	From 1 day before expected farrowing date to 3 days postpartum (D3[1])	From 1 day before expected farrowing date to 3 days postpartum (D3[1])
Number of pens per batch	5	6	6
Pen size (m x m)	2.65 x 1.50	3.00 x 2.00	2.40 x 2.40
Crate size (including the feed trough, m x m)	2.2 x 0.6	2.35 x 0.86	2.40 x 0.62
Creep area (m^2)	None, but a heating mat of 0.4	0.9	0.9
Straw rack (cm x cm x cm)	None	Yes, 50 x 50 x 21 (square shape)	Yes, 45 x 35 x 11 (half circle shape)
Piglet protection features from crushing	None	Two protection rails (130 and 50 cm) and one sloping wall (158 x 50 cm^2)	One protection rail (130 cm)

[1] The day of the farrowing was considered as Day (D) 0. Crates in SWAP and JLF15 were opened on D3.

5.2.2. Animals and management

Management routines and handling of sows and piglets were conducted in accordance with the routine husbandry of the farm. Disinfectant powder and shredded newspaper were provided at the end of the crate in all pens, and the creep areas of SWAP and JLF15 pens before farrowing. The hygiene and the temperature of the creep areas were monitored frequently for the newborn piglets. Litter size was standardized at 10 piglets by cross-fostering within 72 h after birth. Piglets received an iron injection and were teeth-clipped following veterinary recommendation on D3 before the SWAP and JLF15 sows were set loose. Treatments and manual interventions during farrowing followed the usual routine of the farm and were performed by the same person. When the time interval between the birth of two piglets exceeded 1 h and the cervical canal was dilated, 1 mL of oxytocin (Hormonipira, HipraSA; Girona, Spain) was injected.

Lactating sows were fed twice a day (07:00 and 18:00 h). Piglets were supplemented with complementary liquid feed (Re-hydralab, Labiana; Terrassa, Spain) and creep feed (Nuscience; Ghent, Belgium) from D10 to weaning. Both sows and piglets had free access to water during the study period.

A total of 674 piglets, identified individually by a numeric ear tag, were included in the study. Piglets were weaned at 24 days of age and were moved to another unit of the farm equipped with conditioned infrastructures for young weaners.

5.2.3. Direct behavioral observations

Social interactions between sows and piglets, play in piglets, and exploration in piglets and sows, were recorded through direct observations by one observer. Behavioral observation took place on D2, D4, D12 and D23. Each observation day comprised six sessions, three in the morning (from 10:00 to 13:30 h) and three in the afternoon (from 14:00 to 17:30 h). Each pen was observed six times per observation day. Behaviors were recorded by using 30-second scan-sampling for 3 minutes per pen (i.e. 3 minutes per pen per session). The observation order was rotated between the farrowing systems until all the pens were observed. Behavioral categories are described in **Table 5.2**.

Table 5.2 Behavior categories recorded through direct observations using scan sampling.

Category	Subject	Behavior	Description
Social interaction	Piglet towards piglet(s)	Social behavior (SB)	Piglet performing any physical contact, including positive and negative, with one or more piglets. Fighting, a chain of agonistic interactions by at least two individuals; the number of the event is recorded as the number of the individuals involved in the event. Positive and negative social interactions were pooled into one category due to the low number of events in each category observed in the pilot study.
	Piglet towards sow	Naso-naso contact (NNC)	Snout of the piglet approaching or gently touching the snout of its mother or the neighbor[1] sow.
		Sow contact (SC)	Piglet performing any physical contact with its mother or the neighbor[1] sow, such as nudging, chewing, climbing on another individual or huddling. Any behavior directed to the sow's snout or udder was excluded.
		Resting with sow contact (RSC)	Number of piglets resting next to the sow or approaching towards the sow to rest during the behavioral observation.

	towards	Sow	Mother-young interaction (MYI)	Sow performing any physical contact with minimal or moderate force towards her piglet(s) or her neighbor's[1] piglet(s) such as naso-naso contact, sniffing or nudging. Nursing is excluded.
	towards	Sow	Mother-mother interaction (MMI)	Sow performing any social interaction or physical contact with the neighbor[2] sow, such as naso-naso contact, sniffing, nudging or aggression. MMI is not possible in the conventional farrowing crates (FC).
Non-social interaction		Piglet	Locomotor/object play and exploration (PPE)	Piglet performing any locomotor play behaviors including scampering, pivoting, head tossing, flopping, hopping, rolling or gamboling (see Martin et al. (2015) for each definition); object play and exploratory behaviors including sniffing or manipulating the nest-building materials, newspaper, pen facilities or other items; piglet's feed and water are excluded. Locomotor/object play and exploration were pooled into one category due to the low number of events in each category observed in the pilot study.
		Sow	Exploration (SEB)	Sow performing exploratory behavior including sniffing or manipulating the nest-building materials (i.e. hay), newspaper, pen facilities or other items; sow's feed and water are excluded. Sow performing exploratory behavior continuously for 5 seconds would count as one event.

[1] Metal-barred gates were installed in SWAP pens, so SWAP sows and piglets of the adjacent pens could interact with each other through the gates. JLF15 piglets could lift their upper part of the bodies through one of the piglet protection rails to interact with the sow from the adjacent pen.

[2] In both SWAP and JLF15 pens, sows of the adjacent pens could interact with each other when they were loose, as both types were installed with low solid walls of 90 cm (SWAP pens) or 50 cm (JLF15 pens) and two or three horizontal metal bars above the walls.

Intra-observer reliability was calculated based on three pre-recorded 3-minute videos of each farrowing system (i.e. nine 3-minute videos in total), and carried out seven repetitions of the video behavioral observation at different points of the study.

5.2.4. Saliva collection and stress biomarker analysis in sows

Saliva samples were collected by introducing the cotton swabs, provided in the Salivette® tubes (Sarstedt, Aktiengesellschaft & Co., Nümbrecht, Germany), into the sows' mouths for 1 minute. Six sampling points were determined: 1-day pre-expected farrowing day (i.e. 1-day before crating the SWAP and JLF15 sows, FC sows remained crated), 1-day post-expected farrowing day (i.e. 1-day after crating the SWAP and JLF15 sows, FC sows remained crated), D2 (i.e. 1-day before opening the crate of the SWAP and JLF15 sows, FC sows remained crated), D4 (i.e. 1-day after opening the crate of the SWAP and JLF15 sows, FC sows remained crated), D12 and D23 between 09:00 and 10:00. Saliva samples of the SWAP and JLF15 sows were obtained by introducing a long stick with the cotton swab attached on a clamp, without the sampler entering their pens. Saliva samples of the FC sows were obtained by the same technique (i.e. cotton swab on a clamp) but without the long stick and without entering their pens. All the sows were trained to be accustomed to the sampling technique before the first collection commenced. Samples were immediately centrifuged (Heraeus™ Labofuge™ 200 Centrifuge, Thermo Fisher

Scientific GmbH, Dreieich, Germany) for 10 min. at 3000 rpm and stored at −20°C until analysis.

Cortisol (CORT) and chromogranin A (CgA) were selected as salivary stress biomarkers for measuring the crating stress in sows. CORT was detected by an automated chemiluminescence immunoassay (Immulite 1000 cortisol, Siemens Medical Solutions Diagnostics, Los Angeles, CA, USA) (as validated in Escribano et al., 2012). The intra- and inter-assay coefficients of variations (CVs) were lower than 16% and the detection limit was 0.016 μg/dL. CgA was detected by time-resolved immunofluorometry assays (TR-IFMA) (as validated in Escribano et al., 2013). The intra- and inter-assay CVs were lower than 10% and the detection limit was 4.27 ng/mL.

5.2.5. Video recordings of the crushing events

Crushing events which led to the death of the piglets were confirmed by surveillance cameras (resolution: 1920 x 1080, 30 FPS) (IMX291, Megapixel Starvis, Sony). Surveillance cameras (*n* = 9) were installed on the ceiling of the farrowing units to monitor the sows and the piglets during the study, with three cameras covering all the pens in each farrowing system. Crushing events were analyzed through parameters listed in **Table 5.3**.

Table 5.3 Parameters used in the study to analyze piglet crushing events.

Parameter	**Description**
Batch	'Autumn', 'winter', 'spring', or 'summer'.
Parity	'Primiparous' or 'multiparous'.
Time	'Daytime' (07:01 – 18:00 h), 'nighttime' (18:01 – 07:00 h), or 'unknown'.
Day	'Before Day 3', 'Day 3', or 'after Day 3'. Day 0 was the day of farrowing. Crates in farrowing pens with temporary crating were opened on Day 3.
Crated or loose	Sow was 'crated' or 'loose' when crushing occurred. Sows in the conventional farrowing crates (FC) could only be crated during the study.
Body part of the sow	Sow's body part which crushed the piglet: 1) front (head to front legs); 2) middle (trunk); 3) back (hind legs to tail); 4) unknown.
Posture change (from posture 1 to posture 2)	List of sow postures adopted from Wischner et al. (2009): 1) standing; 2) sitting; 3) lateral recumbency; 4) sternal/ventral recumbency; 5) unknown.
Did the sow use the pen fixture as an aid while changing the posture?	'Yes' or 'no'. Sows in FC could only use the crate structure to change the posture during the study.

5.2.6. Weighing and foreleg abrasion assessment in piglets

After cross-fostering was completed, piglets were ear-tagged and weighed individually on D3. To calculate the average daily gain (ADG) in the pre-weaning period, piglets were weighed individually again on D19. On D3, piglets in SWAP and JLF15 were weighed first before their sows were set loose. Sows in SWAP and JLF15 were crated temporarily again on D19 during the weighing of their piglets. Additionally, while weighing piglets on D19, skin abrasion on the forelegs of the piglets was examined on a Yes (1) / No (0) basis (Johansen et al., 2004): "0" indicated no skin abrasion on any forelegs of the piglet, and "1" indicated at least one skin abrasion with a minimum size of 1 cm was observed on one of the forelegs of the piglet (see examples in **Figure 5.2**).

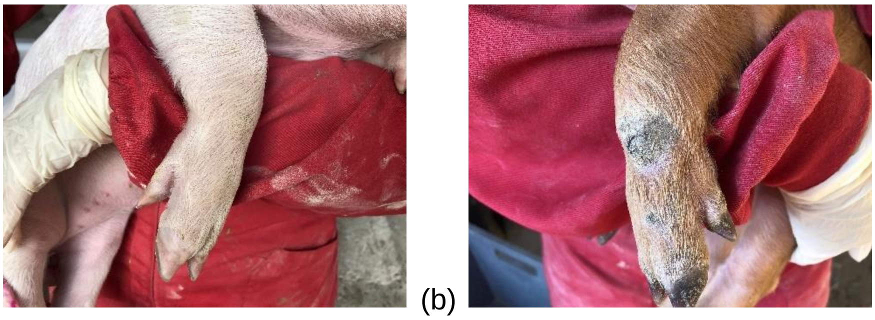
(a) (b)


Figure 5.2 Examples of the assessment of the skin abrasion on piglets' forelegs on D19. **(a)** No skin abrasion on the foreleg (recorded as "0"). **(b)** One skin abrasion on one of the forelegs (recorded as "1").

5.2.7. Statistical analysis

Data were analyzed in Rstudio version 1.2.5033 (R Foundation, Austria). The farrowing pen (i.e. sow) was the experimental unit for reproductive performance, direct behavioral observations, parameters used for the video recordings of the crushing events, and salivary stress biomarkers. The piglet was the experimental unit for growth performance and foreleg abrasion. Statistical significance was set at $P \leq 0.05$, and a tendency was considered when $0.05 < P \leq 0.10$. Data are presented as means with standard error (± SE).

5.2.7.1. Descriptive data

Number of total born/born alive/stillborn/weaned piglets, crating period and equalized litter size between farrowing systems were analyzed with Kruskal-Wallis tests: the above-mentioned variables as the response variable, and farrowing system as the fixed effect.

5.2.7.2. Direct behavioral observations

Behavioral data collected in six sessions on each observation day were summed up for each behavioral category. Proportion of each behavior in each pen was calculated by dividing the amount of each behavior in a pen by the total amount of sample points in one day. Each behavior category was expressed as a proportion of total active behavior. RSC for each observation day was obtained by calculating the average of six RSC sample points on each day. SB and PPE were normally distributed so were analyzed by linear mixed models (LMM). NNC, SC and MYI were log(1+x) transformed and analyzed by LMMs. 84% of MMI and 45% of SEB were 0s, so data were changed to the value of either 1 or 0 (i.e. Yes or No) and analyzed by general linear mixed models (GLMM) with a binomial distribution. RSC was analyzed by a GLMM with a Poisson distribution. All models had the behavior as the response variable, farrowing system, day and their interaction as the fixed effects, litter size as the covariate, and batch and pen as the random effects.

5.2.7.3. Concentration of salivary stress biomarkers in sows

Concentration of CORT and CgA were log transformed to be fitted into LMMs: concentration of CORT or CgA as the response variable, farrowing system, sampling day and their interaction as the fixed effects, basal level (samples collected on 1-day pre-expected farrowing day) as the covariate, and batch and sow as the random effects.

5.2.7.4. Number of crushed piglets per sow and video recordings of the crushing events

Number of crushed piglets per sow was analyzed by a general linear model (GLM) with a Poisson distribution: number of crushed piglets per sow as the response variable, farrowing system, batch, and parity (primiparous *vs.* multiparous) as the fixed effects, and litter size as the covariate.

As for the video recordings of the crushing events, two parameters used to analyze the crushing events, ‘batch’ and ‘parity’, were analyzed by the above-mentioned GLM. For the rest of the parameters (see **Table 5.3**), they were analyzed with several chi-square tests separately to compare the percentage of occurrence between farrowing systems. The parameter, ‘crated or loose’, was compared only between SWAP and JLF15.

5.2.7.5. Growth performance and foreleg abrasion in piglets

Body weight on D3 (BW_3), D19 (BW_{19}), and ADG_{3-19} in the pre-weaning period were analyzed by LMMs: BW_3, BW_{19}, or ADG_{3-19} as the response variable, farrowing system, sex and their interaction as the fixed effects, batch and sow as the random effects, and BW_3 as the covariate (except for the BW_3 model). Foreleg abrasion was analyzed by a GLMM with a binomial distribution: foreleg abrasion (0/1) as the response variable, farrowing system and sex as the fixed effects, batch and sow as the random effects.

5.3. Results

One multiparous FC sow in summer was excluded from the study due to savaging of her newborn piglets, which led to low number of live piglets. One multiparous FC sow in summer and one multiparous JLF15 sow in spring were also excluded from the study due to 1-week delay of farrowing. One multiparous SWAP sow in summer was considered as an extreme outlier due to excessive crushing incidents, which led to eight piglets being crushed, and therefore was also excluded from the study.

Data on behavior, body weight and foreleg abrasion were collected only from the piglets with ear-tags (i.e. the live piglets after the establishment of the litter size). Data about the number of total born/born alive/stillborn/crushed/weaned piglets were collected from all the piglets, including those died before the establishment of the litter size.

In the end, there were 18 sows (three primiparous and 15 multiparous) (and their 183 piglets) in FC, 23 sows (four primiparous and 19 multiparous) (and their 243 piglets) in SWAP, and 23 sows (two primiparous and 21 multiparous) (and their 237 piglets) in JLF15 in the study. **Table 5.4** summarizes the crating period, the litter size after cross-fostering and selected reproductive parameters of sows in FC, SWAP and JLF15.

Table 5.4 Crating period, equalized litter size and selected reproductive parameters of sows by three farrowing systems: the conventional farrowing crate (FC) and two commercially available farrowing pens with temporary crating (SWAP and JLF15).

	FC	**SWAP**	**JLF15**	***P*-value**
Number of sows	18	23	23	-
Crating period (number of days)[1]	31.8 ± 0.5	6.0 ± 0.4	5.3 ± 0.3	< 0.0001
Number of total piglets born per litter	11.2 ± 0.6	11.7 ± 0.5	12.4 ± 0.6	0.29
Number of piglets born alive per litter	10.6 ± 0.6	11.0 ± 0.5	11.3 ± 0.6	0.69
Number of stillborn piglets per litter	0.6 ± 0.2	0.6 ± 0.2	0.8 ± 0.2	0.27
Equalized litter size[2]	10.4 ± 0.5	10.3 ± 0.2	10.2 ± 0.3	0.83
Number of piglets weaned per litter	9.6 ± 0.4	9.0 ± 0.3	9.3 ± 0.3	0.34

[1] Crating period was not different between SWAP and JLF15 (P = 0.28).

[2] Establishment of the litter size (within 72 hours after birth) after cross-fostering.

5.3.1. Direct behavioral observations

Intra-observer reliability test was considered acceptable (Cronbach's α = 0.98). Proportions of exploration and social behaviors of piglets and sows in the three farrowing systems during lactation are presented in **Table 5.5**.

FC piglets performed more SB than SWAP and JLF15 piglets at an early age (D2 and D4), and this higher amount of social interaction between FC piglets tended to continue until weaning. In contrast, SWAP and JLF15 piglets performed more NNC than FC piglets on D2, and SWAP and JLF15 sows performed more MYI than FC sows on D12. Moreover, JLF15 and SWAP piglets tended to perform more SC than FC piglets on D2 and D4, respectively, and JLF15 sows tended to perform more MYI than FC sows on D4. Our results suggested that in general, there was a higher amount of social interaction between sows and piglets in TC during lactation, compared to FC. On D4, 1 day after opening the crate in TC, SWAP and JLF15 sows performed more SEB than FC sows.

Overall, SB was negatively and moderately correlated with NNC (r = -0.36), SC (r = -0.34), and MYI (r = -0.41) (all P < 0.0001), indicating that the more social interactions between littermates, the less social interactions between sows and piglets, and *vice versa*.

Table 5.5 Percentage ((number of behavior/total active behaviors)*100%) of exploration and social interactions of piglets and sows in three farrowing systems during the lactation period (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). RSC is presented in number of piglets. Crates in SWAP and JLF15 were opened on Day 3.

Values with a different letter superscript are significantly different from each other ($P < 0.05$): $^{x, y}$ indicate difference between farrowing systems in the same behavior category on the same day; $^{a, b}$ indicate difference between days in the same behavior category and farrowing system.

Values with a different symbol superscript ($^{+}$, *) correspond to a tendency of difference between farrowing systems in the same behavior category on the same day ($0.05 < P \leq 0.10$).

	Social interaction						Non-social interaction	
	Piglet towards piglet(s)	Piglet towards sow			Sow towards piglet(s)	Sow towards sow	Piglet	Sow
	SB[1]	NNC[2]	SC[2]	RSC[3]	MYI[2]	MMI[4]	PPE[1]	SEB[4]
Day 2								
FC	**40.2 ± 4.3^{x}**	**3.6 ± 0.7^{x}**	11.9 ± 2.4^{+}	1.6 ± 0.3	4.7 ± 1.3	-	30.9 ± 3.4	3.2 ± 1.3
SWAP	**29.9 ± 3.3^{y}**	**9.6 ± 1.6^{y}**	15.8 ± 2.5^{+*}	1.0 ± 0.2	8.8 ± 2.2	-	33.3 ± 2.3	**2.6 ± 1.3^{a}**
JLF15	**30.7 ± 3.6^{y}**	**10.5 ± 2.8^{y}**	20.3 ± 2.7*	1.3 ± 0.2	5.6 ± 1.3	-	**25.9 ± 4.0^{a}**	7.0 ± 3.2

	SB[1]	NNC[2]	SC[2]	RSC[3]	MYI[2]	MMI[4]	PPE[1]	SEB[4]
Day 4								
FC	**41.6 ± 3.4^{x}**	4.8 ± 1.2	12.7 ± 2.1^{+}	1.1 ± 0.2	4.7 ± 1.2^{+}	-	33.4 ± 3.7	**2.8 ± 1.5^{x}**
SWAP	**23.0 ± 2.4^{y}**	7.5 ± 1.2	21.5 ± 3.8*	0.9 ± 0.2	9.2 ± 1.7^{+*}	0.6 ± 0.3	28.2 ± 2.4	**9.9 ± 2.7^{y,b}**
JLF15	**31.5 ± 2.7^{y}**	9.0 ± 1.9	14.0 ± 2.1^{+*}	0.9 ± 0.1	10.3 ± 2.9*	0.4 ± 0.4	**28.2 ± 2.7^{a}**	**6.6 ± 1.7^{y}**
Day 12 (mid-lactation)								
FC	35.1 ± 4.0^{+}	4.6 ± 1.8	16.9 ± 3.2	1.0 ± 0.2	**2.4 ± 0.8^{x}**	-	29.9 ± 3.7	5.6 ± 4.1
SWAP	26.1 ± 1.9*	6.8 ± 0.8	20.4 ± 3.2	0.7 ± 0.2	**8.2 ± 1.2^{y}**	0.6 ± 0.2	32.4 ± 2.2	**5.6 ± 1.3^{b}**
JLF15	26.9 ± 1.6*	8.4 ± 1.3	19.8 ± 1.9	1.0 ± 0.1	**7.4 ± 1.3^{y}**	0.4 ± 0.2	**32.9 ± 2.8^{ab}**	4.2 ± 1.0
Day 23 (late lactation)								
FC	33.0 ± 2.3^{+}	3.6 ± 0.8	17.5 ± 2.5	0.9 ± 0.2	3.1 ± 0.7	-	39.6 ± 1.4	3.2 ± 1.2
SWAP	24.3 ± 1.8*	5.6 ± 0.6	19.6 ± 2.7	1.1 ± 0.2	7.3 ± 1.0	0.2 ± 0.1	35.5 ± 1.8	**7.4 ± 2.1^{ab}**
JLF15	23.7 ± 1.6*	5.6 ± 1.0	19.3 ± 2.6	1.3 ± 0.2	6.3 ± 1.1	0.2 ± 0.1	**39.2 ± 2.1^{b}**	5.8 ± 1.5
Global *P*-value								
Farrowing system	< 0.0001	< 0.0001	0.04	0.87	0.0002	0.16	0.49	0.006
Day	0.06	0.17	0.28	0.20	0.28	0.18	0.003	0.001

Behaviors initiated by the piglets: SB = Social interactions between piglets. / NNC = Piglet initiated naso-naso contact with the sow. / SC = Piglet initiated physical contact (except the snout and the udder) with the sow. / RSC = Piglet resting in physical contact with the sow. / PPE = Piglet locomotor or object play, and exploration of the pen.

Behaviors initiated by the sow: MYI = Sow initiated physical contact with the piglet. / MMI = Mother-mother interactions. / SEB = Sow exploration of the pen.

[1] SB and PPE were normally distributed, so they were analyzed by linear mixed models.

[2] NNC, SC and MYI were log(1+x) transformed and analyzed by linear mixed models.

[3] RSC was analyzed by a general linear mixed model with a passion distribution.

[4] Values of MMI and SEB were changed to 1/0 (i.e. Yes/No) and analyzed by general linear mixed models with a binomial distribution.

5.3.2. Concentration of salivary stress biomarkers in sows

Concentrations of CORT and CgA during lactation are presented in **Table 5.6**. CORT and CgA in FC remained similar throughout the lactation period. However, CORT in SWAP peaked on D2, compared to +1D crating (*P* = 0.02). Additionally, CgA in JLF15 peaked on D4 and remained elevated until D12, compared to -1D crating (*P* = 0.05 and 0.02, respectively).

Table 5.6 Concentration of salivary cortisol (CORT) (µg/dL) and chromogranin A (CgA) (µg/mL) of sows in the three farrowing systems on different sampling days during the lactation period (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). Crates in SWAP and JLF15 were opened on Day 3.

Values with a different letter superscript are significantly different from each other ($P < 0.05$): $^{x, y}$ indicate difference between farrowing systems on the same sampling day; $^{a, b}$ indicate difference between sampling days in the same farrowing system.

	-1D crating[1]	+1D crating[2]	Day 2[3]	Day 4[4]	Day 12 (mid-lactation)	Day 23 (late lactation)	Global *P*-Values Farrowing system Day
CORT, µg/dL							
FC	0.48 ± 0.14	0.49 ± 0.15	**0.35 ± 0.09**^{x}	0.38 ± 0.05	0.66 ± 0.19	0.69 ± 0.29	0.008
SWAP	**0.68 ± 0.16**^{ab}	**0.48 ± 0.11**^{a}	**1.27 ± 0.37**^{y,b}	**0.55 ± 0.08**^{ab}	**0.72 ± 0.11**^{ab}	**0.84 ± 0.18**^{ab}	< 0.0001
JLF15	0.56 ± 0.11	0.52 ± 0.09	**0.64 ± 0.22**^{x}	1.10 ± 0.33	0.75 ± 0.14	0.67 ± 0.11	
CgA, µg/mL							
FC	0.65 ± 0.23	0.73 ± 0.30	0.52 ± 0.12	0.95 ± 0.33	1.18 ± 0.27	0.69 ± 0.18	0.51
SWAP	0.81 ± 0.18	0.62 ± 0.14	0.68 ± 0.18	1.01 ± 0.24	0.81 ± 0.18	0.97 ± 0.23	< 0.0001
JLF15	**0.41 ± 0.10**^{a}	**0.52 ± 0.10**^{ab}	**0.55 ± 0.16**^{ab}	**1.11 ± 0.27**^{b}	**1.16 ± 0.29**^{b}	**0.98 ± 0.26**^{ab}	

5.3.3. Number of crushed piglets per sow and parameters for analyzing the crushing events

Number of crushed piglets per sow between farrowing systems were as follows: 0.3 ± 0.1 in FC, 1.2 ± 0.3 in SWAP, and 0.6 ± 0.2 in JLF15. Crushing rate of SWAP was higher than FC ($P < 0.0001$) and JLF15 ($P = 0.02$), and that of JLF15 was also higher than FC ($P < 0.0001$).

There were in total 49 crushed piglets during the study period. **Table 5.7** lists the details of the parameters used for analyzing these 49 crushing events. Crushing rate in autumn was significantly lower than in the other seasons, including winter ($P < 0.0001$), spring ($P < 0.0001$), and summer ($P = 0.007$). As shown in **Table 5.7**, crushing events occurred similarly before and after opening the crate in SWAP and JLF15 ($P = 0.54$). Additionally, almost two third (63.3%) of the crushing events occurred when the sows used an aid from the pen while changing posture, and the percentage in FC was higher than in SWAP and in JLF15 ($P = 0.05$).

Table 5.7 Parameters used for analyzing all crushing events (*n* = 49) in the three farrowing systems during the study period (from November 2018 to July 2019) (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). These crushing events all led to the death of the piglets, which was confirmed by the surveillance cameras. With the exception of number of crushed piglets, number of live born piglets, and crushing rate in each system, data are presented in percentage where the sum of each parameter in each farrowing system adds up to 100%.

	FC	**SWAP**	**JLF15**	
Number of crushed piglets	6	28	15	
Number of live born piglets	191	252	259	
Crushing rate (%) in each system	3.1	11.1	5.8	
Parameters	**FC**	**SWAP**	**JLF15**	***P*-value**
Batch[1]				< 0.0001
Autumn	0	10.7	26.7	
Winter	66.7	25.0	26.7	
Spring	16.7	21.4	26.7	
Summer	16.7	42.9	20.0	
Parity[1]				0.74
Primiparous	16.7	10.7	6.7	
Multiparous	83.3	89.3	93.3	

Parameters	FC	SWAP	JLF15	*P*-value
Time[2]				0.30
Daytime	33.3	32.1	53.3	
Night	50.0	67.9	40.0	
Unknown	16.7	0	6.7	
Crated/loose[3]				0.54
Crated	100	32.1	46.7	
Loose	-	67.9	53.3	
Day[2]				0.52
Before Day 3	66.7	35.7	46.7	
Day 3[4]	0	17.9	6.7	
After Day 3	33.3	46.4	46.7	
Body part of the sow[2]				0.49
Front	16.7	3.6	6.7	
Middle	33.3	57.1	66.7	
Back	33.3	39.3	20.0	
Unknown	16.7	0	6.7	
Posture change – from posture 1[2]				0.33
Stand	66.7	46.4	33.3	
Sternal/ventral recumbency	0	21.4	6.7	
Sit	16.7	10.7	26.7	
Lie	0	21.4	26.7	
Unknown	16.7	0	6.7	

Parameters	FC	SWAP	JLF15	*P*-value
Posture change – to posture 2[2]				0.46
Stand	0	0	0	
Sternal/ventral recumbency	66.7	50.0	53.3	
Sit	0	0	0	
Lie	16.7	50.0	40.0	
Unknown	16.7	0	6.7	
If the sow used the pen fixture as an aid to change her posture?[2]				0.05
Yes	66.7	28.6	20.0	
No	16.7	71.4	66.7	
Unknown	16.7	0	13.3	

[1] Analyzed by a general linear model with a Poisson distribution: number of crushed piglets per sow as the response variable, farrowing system, batch and parity time as the fixed effects, and litter size as the covariate.

[2,3] Analyzed with chi-square tests: comparing each parameter between [2] FC, SWAP and JLF15; [3] SWAP and JLF15.

[4] Day 3: Opening of the crates in SWAP and JLF15 pens.

5.3.4. Growth performance and prevalence of foreleg abrasion in piglets

Growth performance in piglets is presented in **Table 5.8**. No difference was found between farrowing systems in BW_3 (*P* = 0.71), BW_{19} (*P* = 0.28), and $ADG_{3\text{-}19}$ (*P* = 0.23). BW_3 had an effect on BW_{19} and $ADG_{3\text{-}19}$ (both *P* < 0.0001).

Prevalence of foreleg abrasion on D19 in piglets between farrowing systems was as follows: 66.3 ± 3.6 % (*n* = 175) in FC, 67.5 ± 3.2 % in SWAP (*n* = 209), and 73.5 ± 3.0 % in JLF15 (*n* = 219). No difference was found between farrowing systems in the prevalence of foreleg abrasion (*P* = 0.28).

Table 5.8 Body weight (kg) on Day 3 (BW_3) and 19 (BW_{19}), and average daily gain ($ADG_{3\text{-}19}$) (g/day) of piglets in the three farrowing systems during the lactation period (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating).

	Farrowing system	***n***	**Mean**	**SEM**	***P*-value**
BW_3, kg	FC	183	2.02	0.03	0.71
	SWAP	243	1.88	0.03	
	JLF15	237	1.97	0.03	
BW_{19}, kg	FC	175	5.11	0.08	0.28
	SWAP	209	5.21	0.09	
	JLF15	219	5.15	0.08	
$ADG_{3\text{-}19}$, g/day	FC	175	176.88	4.20	0.23
	SWAP	206	189.49	4.77	
	JLF15	219	179.99	4.38	

5.4. Discussion

In the present study, we compared the behavior, stress physiology and performance of sows and piglets in three farrowing systems, including one conventional farrowing crate system (FC), and two farrowing pens with temporary crating system (TC, i.e. SWAP and JLF15) which are available in the market. The study was conducted on a commercial farm in Spain, in which the results are expected to provide further insight on the feasibility of TC on commercial conditions in warm climates.

In terms of the difference between two TC, the creep area of SWAP is designed near the head of the sow to facilitate a ‘nest-like’ situation. SWAP pen is equipped with a sloping wall, as it is preferred by the sows when they lie down (Damm et al., 2006), to create an environment that is preferred by the sow and protects the piglets. In addition, the design of SWAP is based on a loose housed system where a simple type of confinement – only one wing – is implemented, and the design is rectangular because this is easier for the sows to divide into zones than a square design. On the other hand, JLF15 is based on the traditional crate system where there are two wings but allowing it to open up for the sows to move around. In JLF15, there is no preferred support for the sows but the wings and the rail are the design for piglet protection for the sows to lean against when they lie down. The design of JLF15 is not based on the sows' biological needs and has no preferred lying or dunging areas like SWAP where they can divide in zones.

5.4.1. Mother-young interactions, social interactions between piglets, and exploration in piglets and sows

On D4, one day after the sows were set loose from the temporary crates, SWAP and JLF15 sows were exploring the pens 10-time and six-time more than FC sows respectively. Exploration in SWAP and JLF15 sows was similar due to similar setups in TC (i.e. similar space allowance and access to the nest-building materials). Exploration in TC sows also reached the peak on D4. This finding is in agreement with Chidgey et al. (2016) and Goumon et al. (2018), where exploration is highly motivated due to curiosity when the environment changes (e.g. increased space allowance, presence of newborn piglets) (Wood-Gush and Vestergaard, 1989). In mid-lactation, SWAP and JLF15 sows interacted with the piglets six-time and five-time more than FC sows respectively, which also agrees with the studies of Chidgey et al. (2016) and Singh et al. (2017). As Chidgey et al. (2017) stated, mother-young interactions are determined by the farrowing environment. Due to a larger and open floor space without the restriction of the crate structure in both TC, loose sows can better orient themselves towards piglets. Sow-piglet nose contacts occur frequently when they are in an open space (Portele et al., 2019), and the result of NNC (i.e.

piglet-initiated naso-naso contact with the sow) confirms the findings by Jarvis et al. (2004) and Boulhuis et al. (2018), in which they found that piglets housed in loose house systems had more NNC with their mother sows. Although all the sows were confined on D2, a narrower crate length and width in FC may force the sows to lay under the feed trough which makes it difficult for FC piglets to express NNC.

On the other hand, FC piglets interacted with littermates more than TC piglets on D2 and D4. As we found negative correlations between SB (i.e. social interactions between piglets) *vs.* NNC and MYI (i.e. sow initiated physical contact with the piglet), higher SB in FC might suggest a different time budget in those piglets as they spent more time interacting with their littermates instead of the sow, due to the structure of the crate. Moreover, SB may increase when the space allowance is small, eventually suggesting an inadequate FC pen size for the piglets. As reported by Turner et al. (2000), number of skin lesions increased in pigs housed in low space allowance, indicating an increased aggression within the group; aggression is considered as a SB in the present study.

Regarding PPE (i.e. piglet locomotor or object play, and exploration of the pen), we did not observe any difference between farrowing systems in the present study. However, Singh et al. (2017) found an increased play behavior and a reduced manipulative behavior (i.e. manipulative behavior would be considered as a SB in our study, a negative social interaction) in loose pen piglets. Chaloupková et al. (2007) and Oostindjer et al. (2011) also found an increased play behavior in piglets living in an enriched and enlarged pre-weaning environment. However, in our study, locomotor play, object play, and exploration were not distinguished, so it would be difficult to draw any conclusion on the effect of farrowing systems on play behavior. In addition, apart from an enlarged space, SWAP and JLF15 piglets did not receive regular enrichment (i.e. straw bedding) like in Chaloupková et al. (2007). Oostindjer et al. (2011) also stated that development of foraging related behaviors was positively influenced by early environmental enrichment, but less by sow housing.

5.4.2. Salivary stress biomarkers in sows during lactation

In the present study, we did not find any difference in salivary stress biomarkers, cortisol (CORT) and chromogranin A (CgA), between farrowing systems during lactation, except CORT in SWAP on D2, which was higher than in FC and JLF15 on the same day. This lack of significant differences between farrowing systems suggests that both temporary confinement (no difference between -1D and +1D crating) and removal of confinement (no difference between D2 and D4) did not elevate the stress level (i.e. similar adrenal reactivity) in sows in SWAP and JLF15. Similarly, Goumon et al. (2018) did not find the effect of removal of confinement after 24h in CORT. Level of CORT seems inconclusive in sows in early lactation as some studies found no difference between farrowing crate and farrowing pens (Cronin et al., 1992; Biensen et al., 1996), whereas other studies found a higher (Oliviero et al., 2008) or lower (Hales et al., 2016) level of CORT in crated sows. As CORT is known to be released quickly within 30 minutes after a stressor is introduced, the fact that we did not see a change in CORT after temporary confinement or removal of confinement could be due to a short-lasting effect (Goumon et al., 2018). A higher CORT in SWAP sows on D2 may be linked to the sow's inability to avoid piglets' call for nursing (a higher frequency of NNC in SWAP on D2) due to crating, as shown in the crated sows in Oliviero et al. (2008). It may reflect that nursing is difficult for both sows and piglets when the sow is lying with the udder facing towards the sloping wall, making the space for nursing/suckling crowded.

A peak of CgA in JLF15 sows on D4 and D12 suggested that there was an acute stress response from the SAM (sympathetic-adreno-medullary) axis (Ott et al., 2014) before saliva sampling. Few studies investigated the level of change in CgA after an acute stress was applied in pigs (e.g. immobilization/nose snare, Escribano et al. (2013) and Huang et al. (2017); mixing and feed deprivation, Ott et al. (2014); psychosocial stress (i.e. regrouping or isolation), Escribano et al. (2015); weaning, Ko et al. (2020)), but these stressful events did not apply to our study. CgA is known to be related with psychological stress in humans (Ott et al., 2014) and may be useful to measure stress that is associated with factors of chronic exposure in pigs (e.g. with or without the provision of environmental enrichment) (Casal et al., 2017), which might indicate an ongoing psychological chronic stress in JLF15 sows that cannot be confirmed from the results of this study. Further research which also analyzes different salivary biomarkers, such as IgA and oxytocin, is recommended to better understand the general reactivity of the stress level in sows in FC and TC during lactation.

5.4.3. Crushing in farrowing crates *vs.* farrowing pens with temporary crating system

Sows in TC were set loose from D3 (i.e. the 4th day postpartum), which was a day earlier than Moustsen et al. (2013) recommended, but as Goumon et al. (2018) suggested. In the present study, both TC showed a higher crushing rate than FC during lactation. A higher number of crushed piglets in SWAP is likely to reflect the fact that the crate was wider than both FC and JLF15, meaning that SWAP sows were not as restricted as FC and JLF15 sows. A sloping wall on one side in SWAP could also block the piglets to escape from the sows if the piglets were resting at the wall side. On the other hand, in FC and JLF15, there was relatively more space on both sides of the sows. Crushing rate in TC was similar before and after D3, which was different from Chidgey et al. (2015) and King et al. (2019), where both studies reported an increased crushing rate after crate opening. One of the reasons for this could be due to a relatively low number of animals involved in the study (64 sows in the present study; 732 sows in Chidgey et al., 2015; 168 sows in King et al., 2019).

Additionally, different from most of the studies which used hyper-prolific sows with lower birth weight piglets, our study used a rustic breed with an average of 10 to 11 piglets born alive with a relatively high birth weight. As Melišová et al. (2011) stated, piglets in better body condition can afford to stay close the sow without being crushed, which may be the case in our study.

In the present study, piglet crushing mostly occurred in FC in winter and in SWAP in summer, even though the percentages were very low. However, most of the crushing events in FC happened even when the sows used the crate as a support to change their posture. Heat sources for piglets in the farrowing systems generally include the heating mat, the lamp and sow's udder. Lack of space in FC may result in crowding (Rangstrup-Christensen et al., 2018) in winter, where piglets occupied the heating mat under the lamp and rested next to sow's udder, making the sow difficult to change her posture without overlaying the piglets, even using the pen fixture (i.e. crate in this case) as a support. On the contrary, piglets in SWAP and JLF15 were able to rest in the creep area with the heating mats and the lamp in winter where the sow had no access to, possibly reducing the chance of being overlaid by the sow. On the other hand, due to incorrect management, the temperature in the creep area in summer might have been too high for piglets, which made them use the creep area for defecating and urinating, and rest outside with the sow, and thus increased the risk of being crushed (Marchant et al., 2001). It is possible that there were more litters in SWAP resting outside of the creep area than in JLF15, as the percentage of crushing in summer in SWAP is twice more than in JLF15, and thus resulting in a higher percentage in SWAP than in JLF15 in average even after the crate opening. Although we did not find any difference in RSC between farrowing systems on the same observation day, it could be that we only counted the piglets that were in actual physical contact with the sow. Therefore, unless crowding in piglets occurred and most of the piglets were in physical contact with the sow, the numbers we collected could not reflect the crowding situation well. It is thus indispensable to adjust the temperature of the creep area regularly to encourage piglets resting inside to avoid being crushed.

5.4.4. Growth performance and foreleg abrasion in piglets

Unlike previous studies (Pedersen et al., 2011; Melišová et al., 2014), we did not find any effect of the farrowing system on weight gain in piglets, even though there was a 211 g (from D3 to D19) of difference between FC and SWAP numerically. Similar growth performance may suggest an undisturbed suckling and nursing behaviors in a short- and long-term with regard to crate removal (Goumon et al., 2018), but the amount of creep feed intake may also contribute to pre-weaning weight gain (Oostindjer et al., 2010), which is a parameter we did not measure in the present study.

Prevalence of foreleg abrasion in piglets in the present study was between 66 and 73%, which was relatively high, compared to Mouttotou et al. (1999) (36%, highly associated with part-concrete, part-round-mesh flooring) in the UK, Hoy et al. (1999) (54-84%) in Germany, and Johansen et al. (2004) (46%, cast iron slats) in Denmark. Cushioning and minimizing friction with mineral oil impregnated-neoprene sponge at the suckling flooring area were reported to greatly reduce leg injuries in piglets (Phillips et al., 1995). More research focusing on optimal flooring design for indoor farrowing systems to avoid the development of foreleg abrasion is needed.

5.5. Conclusions

Farrowing pens with temporary crating system enhanced sow-piglet interactions and sow explorative behavior. Neither the farrowing system *per se* nor the opening of the temporary crates altered sows' salivary stress biomarkers. During summer, crushing rate was higher in temporary crated sows than in crates, emphasizing the importance of a correct management of the piglets' creep area. Average daily gain in piglets during lactation was similar across farrowing systems. Farrowing pens with temporary crating system are feasible to house crossbred Duroc sows and piglets on commercial farms in the Mediterranean region. Knowledge-exchange strategies on sow and piglets management around farrowing should be further enhanced to ensure the suitability of temporary crating systems under commercial conditions in Spain and elsewhere.

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CHAPTER 6.

Pilot study:
Welfare and performance of post-weaning sows and piglets previously housed in farrowing pens with temporary crating on a Spanish commercial farm

(First Draft)

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Highlights

- Conventional farrowing crate (FC) and two temporary crating systems (SWAP and JLF15) were tested.
- Level of aggression in post-weaning piglets was similar between farrowing systems.
- Salivary stress biomarkers after weaning did not increase in SWAP piglets.
- Sows vocalized the most on the weaning day and gradually decreased overtime.
- Level of salivary cortisol in FC sows tended to increase after weaning.

Abstract

Four batches of crossbred Duroc sows (*n* = 68) and piglets (*n* = 674) were followed from lactation to 5 days after weaning in a commercial farm between 2018 and 2019 (one batch per season). They were kept in three different farrowing systems during lactation: one conventional system with a farrowing crate (FC, five pens per batch), and two farrowing pens with temporary crating (SWAP and JLF15, six pens of each per batch). The aim of the present study was to study the effect of farrowing systems on weaning adaptability in sows and piglets, using welfare and performance variables. Direct behavioral observation and saliva sampling for stress biomarkers (cortisol, CORT; and chromogranin A, CgA) in sows and piglets, and lesion scoring and growth performance in piglets were conducted. At weaning (on Day (D) 24), sows were moved to group pens (FC: four; SWAP: five; and JLF15:

five pens in total) and piglets were moved to nursery pens (FC: four; SWAP: six; and JLF15: six pens in total), keeping animals from the same farrowing system together. Behaviors were observed live on D24, D25, and D26. Aggression-related skin lesions were scored, and saliva samples were collected on D23, D25, and D26. Body weight was recorded on D23 and D29. Agonistic behaviors in SWAP piglets increased from D24 to D25 ($P < 0.05$). Although there was no difference between farrowing systems, the number of skin lesions in all the piglets first increased on D25 and then decreased on D26 ($P < 0.05$). CORT in FC and JLF15 piglets increased from D23 to D25 ($P < 0.05$), and the increase in JLF15 lasted until D26 ($P < 0.05$). On the other hand, CORT in SWAP piglets remained similar around weaning. CgA in FC piglets increased from D25 to D26, and in JLF15 piglets from D23 to D25, but that in SWAP piglets decreased from D25 to D26 (all $P < 0.05$). Within the 5-day-period post-weaning, FC piglets gained more weight than SWAP and JLF15 piglets ($P < 0.05$). All the sows followed a similar trend in vocalization around weaning, which peaked on D24 and decreased overtime ($P < 0.05$). CORT in FC sows tended to increase from D23 to D25 and tended to last until D26 ($P < 0.10$). Our results suggested that temporary crating does not affect aggression in piglets after weaning, but do seem to mitigate weaning stress in both sows and piglets, especially the SWAP system. Frequent vocalization in sows after weaning may represent a close bonding between sows and piglets during lactation, regardless of the farrowing systems.

Keywords: aggression, farrowing system, stress biomarker, temporary crating, vocalization, weaning

6.1. Introduction

In modern pig farming, farrowing crate is used to reduce the risk of piglet mortality caused by sow crushing (Chidgey et al., 2016). To date, approximately 95% of the sows are housed in the farrowing crates during farrowing and lactation in the European Union (EU) (Johnson and Marchant-Forde, 2009). However, farrowing crate jeopardizes the welfare of the sows (Baxter et al., 2018). Farrowing crate limits the behavioral repertoire of body movements and restricts the expression of the natural behaviors like nest-building and mother-young interactions (Baxter et al., 2018). Along with the growing societal trend of eliminating the farrowing crate policies in several EU countries, and the well-received European citizen initiative 'End the Cage Age' launched in 2018, there are many alternative farrowing systems being studied and implemented lately. Farrowing pen with temporary crating (TC) is one of them. It allows the producers to crate the sows temporarily for few days when the piglets are newly born and vulnerable, to prevent piglet crushing; and to set loose the sows for the rest of the lactation period, to ensure freedom of body movements of the sows.

While there is increasing research on welfare assessment of the alternative farrowing systems in sows and piglets during lactation, few studies followed these animals after weaning. Weaning in pig production is usually performed abruptly which makes it one of the most stressful events in a pig's life in commercial farms (Campbell et al., 2013). Yet, several studies have found benefits of enriched early environment to mitigate weaning stress in piglets (Godyń et al., 2019), including pre-weaning socialization (Camerlink et al., 2018; Salazar et al., 2018; Ko et al., 2020) and environmental enrichment (Martin et al., 2015; Yang et al., 2018; Ko et al., 2020). However, little research has focused on how farrowing systems that facilitate the mother-young interactions plays a role on coping with weaning stress. TC have shown to facilitate the mother-young interactions (Chidgey et al., 2016; Ko et al., 2021), and as Telkänranta and Edwards (2018) stated, sow is 'the most important social figure in the early life of a pig' for piglets, which underlines the importance of the social experiences with the sow during suckling.

This paper is a follow-up study of Chapter 5, in which we compared the welfare and performance of sows and piglets in three farrowing systems, including one conventional system with a farrowing crate (FC) and two commercially available TC, during lactation. On the other hand, this paper focuses on the same group of sows and piglets in post-weaning, until 5 days (D) after weaning.

We hypothesized that piglets raised in the early environment which allows more mother-young interactions, would better cope with abrupt weaning stress, due to previously learnt social skills from the mother, more robust body weight, larger farrowing pen size to play in, and the nesting material to manipulate with (and possibly earlier exposure/consumption of solid food, i.e. the nesting material). We also hypothesized that sows that can interact with the piglets during lactation, would have more stress after abrupt weaning due to a stronger bonding with the piglets. The aim of the study was to study the effect of farrowing systems on behavior, aggression-related skin lesions, salivary stress, and performance in post-weaning sows and piglets from FC compared to two different TC.

6.2. Materials and Methods

6.2.1. Housing and experimental design

The study took place in a farrow-to-finish commercial farm in Girona, Spain. During lactation, three farrowing systems were used, one FC and two commercially available TC, including Sow Welfare and Piglet protection pen (SWAP) and JLF15 (both produced by Jyden; Sæby, Denmark). Regarding the distribution and technical details of the three farrowing systems used in the study, see the **Figure 5.1** and **Table 5.1** in Chapter 5.

In each batch, there were five FC pens, six SWAP pens, and six JLF15 pens during lactation. In total, four batches of sows (*n* = 68) and piglets (*n* = 674) were followed in the study from lactation to 5D after weaning in four seasons between 2018 and 2019: fall (November), winter (February), spring (May) and summer (July).

Weaning occurred on D24. Sows were removed from the farrowing pens first and were moved to the group pens. Then piglets in the farrowing pens were moved to the nursery. Pigs from the same farrowing system were grouped together, and the surplus pigs that were mixed with those from different farrowing systems after weaning, were removed from the study. Due to different availability of the pens for sows and piglets, and the production cycle of the sows (i.e. some were culled after weaning), the number of animals per pen was not the same in the four batches (as specified in **Figures 6.1**). The group pen size for the weaning sows was 2.2 m x 3.5 m and was installed with one feeder and one drinker. The nursery pens of the fall batch were 2.4 m x 2.53 m (installed with two feeders and three drinkers per pen) and 1.2 m x 2.55 m (installed with one feeder and two drinkers per pen). The nursery pens of the rest of the batches were 2.4 m x 2.8 m (installed with two feeders and four drinkers per pen).

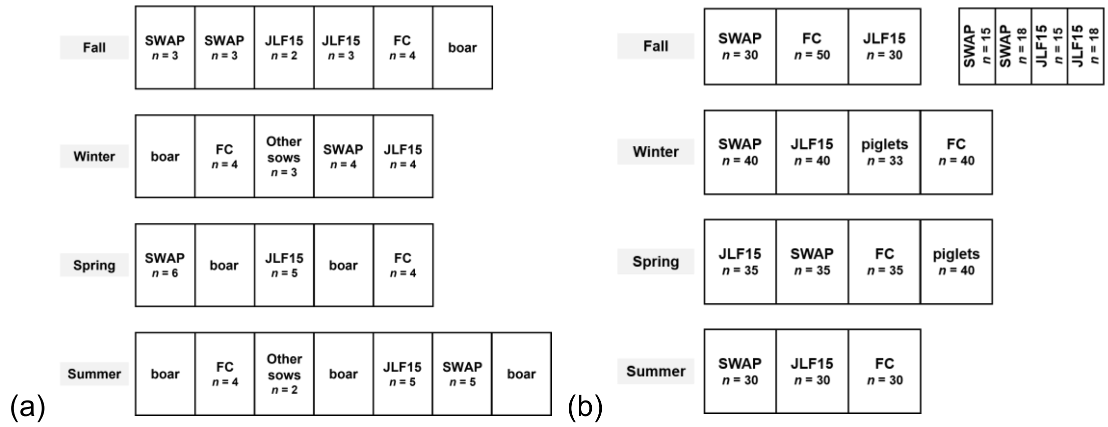

Figure 6.1 Distribution of the **(a)** sows and **(b)** piglets after weaning in four seasons. (FC: animals that were housed in the conventional farrowing pens with a farrowing crate before weaning; SWAP (Sow Welfare And Piglet protection) and JLF15: animals that were housed in two types of farrowing pens with temporary crating before weaning.) *n* indicates the number of the sows or piglets in one pen.

6.2.2. Animals and management

Sows in the group pens and piglets in the nursery pens had *ad libitum* feed and water access. Sows had home-mixed feed which was barley- and soybean-based. Piglets had commercial nursery feed (Nuscience; Ghent, Belgium) and were supplemented with complementary liquid feed (Re-hydralab, Labiana; Terrassa, Spain) during the first 5 days after weaning.

The group pens for the sows after weaning were in a semi-open building which was dependent on natural lighting and ventilation. The nursery for the weaning piglets was an indoor building, in which the lighting was on from 07:00 to 18:00 and the room temperature was programmed at 25 ± 2°C.

The study of the sows ended on 2D after weaning, and the piglets ended on 5D after weaning. Sows and piglets returned to their production cycle of the farm after the study. On the 3rd and 4th days after weaning, sows were inseminated. On the 6th day after weaning, the nursery feed for piglets changed.

6.2.3. Direct behavioral observation in sows and piglets after weaning

Direct behavioral observation was conducted on D24 (the day of weaning), D25 (1D post-weaning), and D26 (2D post-weaning) by one observer. It was conducted hourly between 14:00 and 17:00 on each observation day, making it three sessions per day. Behaviors were recorded by using 30-second scan-sampling for 3 minutes per pen. Each session started observing the sows in the group pens and then the piglets in the nursery. Behavior categories for the piglets and the sows after weaning are listed in **Table 6.1** and **6.2**, respectively.

Table 6.1 Behavior categories for post-weaning piglets recorded through direct observations using scan sampling.

Behavior	Description
Aggression	Any physical interaction that indicates social conflict with brute force involving two or more piglets, including head knocking, pushing and fighting. Fighting, a chain of agonistic interactions by at least two animals; the number of the event is recorded according to the number of animals involved.
Biting	Piglet orally in contact with another piglet, including nibbling, chewing, sucking and biting. Biting during fighting is excluded.
Belly-nosing	Repetitively nosing with a rhythmic pattern towards another piglet's abdomen with its snout.
Other social interaction	Any physical interaction with minimal or moderate force involving two or more piglets with no reaction from the recipient(s), including sniffing, nudging, mounting and chasing.
Locomotor play behavior	Any locomotor play behaviors including scampering, pivoting, head tossing, flopping, hopping, rolling or gamboling (see Martin et al., 2015 for each definition).
Object play and exploratory behavior	Object play and exploratory behaviors including sniffing or manipulating pen features, enrichment objects or other items; feed and water are excluded.

Table 6.2 Behavior categories for post-weaning sows recorded through direct observations using scan sampling.

Behavior	**Description**
Aggression	Any physical interaction that indicates social conflict with brute force involving two or more animals, including head knocking, pushing and fighting. Fighting, a chain of agonistic interactions by at least two animals; the number of the event is recorded according to the number of animals involved.
Biting	Sow orally in contact with another animal, including nibbling, chewing and biting. Biting during fighting is excluded.
Other social interaction	Any physical interaction with minimal or moderate force involving two or more animals with no avoidance response from the recipient(s), including sniffing, nudging and mounting. Oral contact is excluded.
Pen investigation	Sow sniffing or manipulating pen features.
Object investigation	Sow sniffing or manipulating the enrichment object.
Vocalization	Sow produces a certain type of high-pitched call. Normal grunting, vocalization during fighting or being bitten is excluded.
Locomotion	Any locomotor behavior not listed above, for example walking and pacing.

6.2.4. Pre-selection of the piglets for lesion scoring and saliva collection

Of each litter, six piglets were selected: the heaviest, the middle, and the lightest of body weight on D3 of male and female. To assess the intensity of aggression in piglets after weaning, and to study the effect of weaning stress in sows and piglets, three sampling days were determined: D23 (1D pre-weaning), D25 (1D post-weaning), and D26 (2D post-weaning).

6.2.4.1. Skin lesion scoring in piglets around weaning

Number of skin lesions was scored as suggested by Turner et al. (2006) by one observer. Piglet’s body was divided into six parts: the left and the right sides of front (i.e. from head to front leg), middle (i.e. the trunk), and rear (i.e. hind leg to rump). In each body part, only fresh and unbroken linear lesions were scored.

6.2.4.2. Saliva collection and stress biomarkers analysis in sows and piglets around weaning

Saliva samples were collected to determine two salivary stress biomarkers, cortisol (CORT) and chromogranin A (CgA). Saliva samples were collected by inserting the cotton swab from the Salivette® tube (Sarstedt, Aktiengesellschaft & Co., Nümbrecht, Germany) to the pig’s mouth for 1 minute. Saliva samples of the sows were collected between 09:00 and 10:00, and those of the piglets were collected between 10:30 and 14:00. Saliva samples from the SWAP and JLF15 sows on D23 were collected by introducing the cotton swab attached on a long stick to the farrowing pen, which was previously habituated by the sows, without the sampler entering the pen. Samples were immediately centrifuged (Heraeus™ Labofuge™ 200 Centrifuge, Thermo Fisher Scientific GmbH, Dreieich, Germany) for 10 min at 3000 rpm and stored at −20°C until analysis. CORT was detected by automated chemiluminescence immunoassays and CgA was detected by time-resolved immunofluorometry assays. For the rest of the detailed procedure about the lab analysis, it can be found in Chapter 5.

6.2.5. Weighing in piglets

To calculate the average daily gain (ADG) in each individual piglet, two weighing points were scheduled: one on D23 (1D pre-weaning) and the other one on D29 (5D post-weaning). Body weight on D3 (i.e. the initial weight after litter stabilization) was obtained and it is used to fit in the statistical analysis in the present study only.

6.2.6. Statistical analysis

Data were analyzed in RStudio version 1.2.5033 (R Foundation, Austria). The experimental unit for direct behavioral observation is the pen, and for growth performance, number of skin lesions, and salivary stress biomarkers is the individual animal (i.e. the sow or the piglet). Statistical significance was accepted when $P \leq 0.05$, and tendency was considered when $0.05 < P \leq 0.10$. Data are presented as means with the standard error (± SE).

6.2.6.1. Behavior

Behavioral data collected in three sessions on each observation day were summed up and distributed to each behavioral category. Proportion of each behavior in each pen was calculated by dividing the amount of each behavior in a pen by the total amount of sample points in one day. Each behavior category was expressed as a proportion of total active behavior.

6.2.6.1.1. Piglet's behaviors after weaning

Other social interaction was normally distributed, so it was analyzed in a linear mixed model (LMM). Aggression and Object play and exploration were log(1+x) transformed and analyzed in LMMs. In the behaviors of Biting, Belly-nosing, and Locomotor play, 30%, 95%, and 93.3% were 0s respectively, so data were changed to the value of either 1 or 0 (i.e. Yes or No) and analyzed in general linear mixed models (GLMM) with a binomial distribution. All models had the behavior as the response variable, farrowing system and day as the fixed effects, stocking density (i.e. number of animals per pen) as the covariate, and batch and nursery pen as the random factors.

6.2.6.1.2. Sow's behavior after weaning

Pen investigation was normally distributed, so it was analyzed in an LMM. Aggression and Other social interaction were log(1+x) transformed and analyzed in LMMs. 84.4% of Biting, 68.9% of Object investigation and 62.2% of Locomotion were 0s, so data were changed to the value of either 1 or 0 (i.e. Yes or No) and analyzed in GLMMs with a binomial distribution. Vocalization was analyzed in a GLMM with a Poisson distribution. All models had the behavior as the response variable, farrowing system and day as the fixed effects, stocking density as the covariate, and batch and pen as the random factors.

6.2.6.2. Body weight and average daily gain in piglets around weaning

Body weight on 1D pre- ($BW_{1D\ pre\text{-}weaning}$) and 5D post-weaning ($BW_{5D\ post\text{-}weaning}$), and ADG around weaning were analyzed in linear mixed models (LMMs): $BW_{1D\ pre\text{-}weaning}$, $BW_{5D\ post\text{-}weaning}$, or ADG as the response variable, and farrowing system and sex as the fixed effects. In the $BW_{1D\ pre\text{-}weaning}$ model, body weight on D3 (BW_3) was included as the covariate, and batch and sow were the random factors. In the $BW_{5D\ post\text{-}weaning}$ and ADG models, BW_3 and the stocking density in each nursery pen were included as the covariate, and batch and nursery pen were the random factors.

6.2.6.3. Number of aggression-associated skin lesions in piglets around weaning

The total number of skin lesions was summed by individual due to low number of lesions in each body part. Number of skin lesions was not normally distributed after square root transformation. A GLMM with a Poisson distribution was used to analyze the untransformed data: number of skin lesions as the response variable, farrowing system, day, sex, BW_3 (H/M/L), and stocking density as the fixed effects, and batch, individual piglet, and nursery pen as the random factors.

6.2.6.4. Salivary stress biomarkers in piglets and sows around weaning

Samples taken on 1D pre-weaning were considered as the basal level. Salivary stress biomarkers, including CORT and CgA, were log-transformed and analyzed in LMMs.

For piglet's models: concentration of CORT or CgA as the response variable, farrowing system and day as the fixed effects, the basal level as the covariate, and batch, individual piglet, and nursery pen as the random factors. For sow's models: concentration of CORT or CgA as the response variable, farrowing system and day as the fixed effects, the basal level as the covariate, and batch and individual sow as the random factors.

6.3. Results

We present the results by piglets and sows. Two JLF15 sows in the winter batch, one JLF15 sow in the spring batch, one FC sow in the summer batch, and two SWAP sows in the summer batch were culled after weaning and therefore were excluded from the analysis.

All culled sows were multiparous. Information regarding the crating period (in days), average litter size, and the reproductive parameters of the sows in each farrowing system can be found in Chapter 5.

6.3.1. Piglet

6.3.1.1. Post-weaning behavior

The proportion of each active behavior observed in piglets after weaning by three farrowing systems is presented in **Table 6.3**. Overall, we did not find any difference between farrowing systems in the post-weaning behaviors.

Within each farrowing system, aggression in SWAP piglets increased from the day of weaning to 1D post-weaning and then decreased on 2D post-weaning, whereas that in FC and JLF15 piglets neither increased nor decreased. Object play and exploration in SWAP piglets decreased from the day of weaning to 1D post-weaning and then increased on 2D post-weaning, while no changes were observed in neither FC nor JLF15 piglets. In terms of other social interactions, FC and SWAP piglets followed the same trend, in which they decreased from the day of weaning to 2D post-weaning, but JLF15 piglets remained similar around weaning.

Table 6.3 Proportion (number of behavior/total active behaviors) of active behaviors in piglets in the post-weaning period in three farrowing systems (FC, *n* = 4: conventional farrowing crate; SWAP, *n* = 6, and JLF15, *n* = 6: farrowing pens with temporary crating). Values with a different superscript ([a, b, c]) correspond to a significant difference ($P < 0.05$) between observation days in the same behavior category and farrowing system. *n* indicates the number of pens. 'NC' indicates 'not calculable'.

	Aggression[2]	Biting[3] (Yes/No)	Belly-nosing[3] (Yes/No)	Other social interaction[1]	Locomotor play[3] (Yes/No)	Object play and exploration[2]
Day of weaning (D24)						
FC	0.05 ± 0.03	0.50 ± 0.29	0.00 ± 0.00	**0.44 ± 0.09[a]**	0.00 ± 0.00	0.49 ± 0.09
SWAP	**0.04 ± 0.01[a]**	0.67 ± 0.21	0.00 ± 0.00	**0.37 ± 0.04[a]**	0.00 ± 0.00	**0.57 ± 0.03[a]**
JLF15	0.09 ± 0.04	0.33 ± 0.21	0.00 ± 0.00	0.34 ± 0.08	0.17 ± 0.17	0.55 ± 0.06
1D post-weaning (D25)						
FC	0.20 ± 0.10	0.75 ± 0.25	0.00 ± 0.00	**0.41 ± 0.08[ab]**	0.00 ± 0.00	0.34 ± 0.08
SWAP	**0.22 ± 0.08[b]**	0.83 ± 0.17	0.17 ± 0.17	**0.32 ± 0.05[ab]**	0.00 ± 0.00	**0.36 ± 0.07[b]**
JLF15	0.20 ± 0.08	1.00 ± 0.00	0.00 ± 0.00	0.26 ± 0.05	0.00 ± 0.00	0.47 ± 0.07

	Aggression[2]	Biting[3] (Yes/No)	Belly-nosing[3] (Yes/No)	Other social interaction[1]	Locomotor play[3] (Yes/No)	Object play and exploration[2]
2D post-weaning (D26)						
FC	0.09 ± 0.04	0.75 ± 0.25	0.25 ± 0.25	**0.28 ± 0.05[b]**	0.25 ± 0.25	0.48 ± 0.06
SWAP	**0.10 ± 0.03[ab]**	0.83 ± 0.17	0.00 ± 0.00	**0.22 ± 0.05[b]**	0.17 ± 0.17	**0.55 ± 0.09[a]**
JLF15	0.11 ± 0.02	0.83 ± 0.17	0.00 ± 0.00	0.24 ± 0.05	0.00 ± 0.00	0.57 ± 0.07
Global *P*-value	0.76	0.70	NC	0.84	1.00	0.60

[1]Other social interaction was normally distributed so it was analyzed in a linear mixed model.

[2]Aggression and Object play and exploration were log(1+x) transformed and analyzed in linear mixed models.

[3]Values of Biting, Belly-nosing and Locomotor play were changed to 1/0 (i.e. Yes/No) and analyzed in general linear mixed models with a binomial distribution.

6.3.1.2. Body weight (BW) and average daily gain (ADG) around weaning

Table 6.4 presents the BWs in 1D pre- and 5D post-weaning, and the ADG around weaning by three farrowing systems. There was no difference in $BW_{1D\ pre\text{-}weaning}$ and $BW_{5D\ post\text{-}weaning}$ between three farrowing systems (*P* = 0.10 and 0.08, respectively). However, ADG around weaning was significantly different between farrowing systems: FC was higher than SWAP (*P* = 0.02) and JLF15 (*P* = 0.006).

Table 6.4 Body weight (BW) (kg) on D23 (1D pre-weaning) and D29 (5D post-weaning), and average daily gain (ADG) (g/day) after weaning of piglets in three farrowing systems (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). Values with a different superscript ($^{x, y}$) correspond to a significant difference (*P* < 0.05) between farrowing systems in the same category. *n* indicates the number of piglets.

	Farrowing system	*n*	Mean	SEM	*P*-value
$BW_{1D\ pre\text{-}weaning}$, kg	FC	147	5.73	0.10	0.10
	SWAP	162	5.96	0.12	
	JLF15	166	6.28	0.10	
$BW_{5D\ post\text{-}weaning}$, kg	FC	147	6.39	0.12	0.08
	SWAP	162	6.44	0.12	
	JLF15	166	6.75	0.11	
ADG, g/day	FC	147	110.41^{x}	8.42	0.0004
	SWAP	162	80.23^{y}	8.78	
	JLF15	166	77.94^{y}	6.47	

6.3.1.3. Aggression-associated skin lesions around weaning

Table 6.5 presents the number of skin lesions counted in pre- and post-weaning periods by three farrowing systems. No difference in number of skin lesions was observed between farrowing systems ($P = 0.15$). Regardless of the farrowing systems, there is a trendline in the number of skin lesions overtime, which first increases after weaning (between 1D pre- and 1D post-weaning, all farrowing systems $P < 0.0001$), and then decreases a day after (between 1D and 2D post-weaning, all farrowing systems $P < 0.0001$).

Table 6.5 Number of skin lesions of piglets counted on D23 (1D pre-weaning), D25 (1D post-weaning), and D26 (2D post-weaning) in three farrowing systems (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). Values with a different superscript ($^{a,\ b,\ c}$) correspond to a significant difference ($P < 0.05$) between sampling days in the same farrowing system. *n* indicates the number of piglets.

Farrowing system	*n*	1D pre-weaning	1D post-weaning	2D post-weaning
FC	97	0.78 ± 0.17^a	7.93 ± 0.92^b	5.36 ± 0.68^c
SWAP	118	1.36 ± 0.24^a	7.28 ± 0.77^b	5.05 ± 0.63^c
JLF15	116	1.07 ± 0.21^a	7.44 ± 0.96^b	5.66 ± 0.72^c

6.3.1.4. Salivary stress biomarkers post-weaning

Table 6.6 presents the concentration of CORT and CgA in piglets in pre- and post-weaning periods by three farrowing systems. No difference in CORT and CgA was observed between farrowing systems (P = 0.11 and 0.69, respectively).

CORT in both FC and JLF15 increased from 1D pre- to 1D post-weaning, and the increase lasted for 2 days in JLF15, whereas that in SWAP remained at the similar level. CgA in FC increased from 1D post- to 2D post-weaning, and that in JLF15 increased from 1D pre- to 1D post-weaning. However, CgA in SWAP, it decreased from 1D post- to 2D post-weaning.

Table 6.6 Concentration of salivary cortisol (CORT) and chromogranin A (CgA) of piglets collected on D23 (1D pre-weaning), D25 (1D post-weaning), and D26 (2D post-weaning) in three farrowing systems (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). Values with a different superscript ($^{a, b, c}$) correspond to a significant difference (P < 0.05) between sampling days in the same farrowing system. n indicates the number of piglets.

Farrowing system	*n*	1D pre-weaning	1D post-weaning	2D post-weaning
CORT, µg/dL				
FC	40	0.97 ± 0.10^{a}	1.60 ± 0.30^{b}	1.38 ± 0.19^{ab}
SWAP	47	0.89 ± 0.13	1.17 ± 0.24	1.27 ± 0.21
JLF15	48	0.87 ± 0.12^{a}	1.59 ± 0.20^{b}	1.64 ± 0.21^{b}

Farrowing system	*n*	1D pre-weaning	1D post-weaning	2D post-weaning
CgA, µg/mL				
FC	44	0.51 ± 0.05[ab]	0.56 ± 0.09[b]	0.84 ± 0.20[a]
SWAP	55	0.83 ± 0.14[a]	0.73 ± 0.09[a]	0.57 ± 0.07[b]
JLF15	52	0.48 ± 0.07[a]	0.83 ± 0.19[ab]	0.75 ± 0.12[b]

6.3.2. Sows

6.3.2.1. Post-weaning behavior

The proportion of each active behavior observed in sows after weaning by three farrowing systems is presented in **Table 6.7**. Except the tendency in vocalization (P = 0.07), there was no difference between farrowing systems in post-weaning behaviors. In terms of vocalization, despite there was no significant difference between farrowing systems, the trend of the vocalization counts after weaning overtime was similar in all farrowing systems. Sows vocalized the most on the day of weaning, and then rapidly decreased on 1D post- and 2D post-weaning.

Table 6.7 Proportion (number of behavior/total active behaviors) of active behaviors in sows in the post-weaning period in three farrowing systems (FC, $n = 4$: conventional farrowing crate; SWAP, $n = 5$, and JLF15, $n = 4$: farrowing pens with temporary crating). Values with a different superscript ($^{a, b, c}$) correspond to a significant difference ($P < 0.05$) between sampling days in the same farrowing system. n indicates the number of pens.

	Aggression[2]	Biting[3] (Yes/No)	Other social interaction[2]	Pen investigation[1]	Object investigation[3] (Yes/No)	Locomotion[3] (Yes/No)	Vocalization[4] (average counts)
Day of weaning (D24)							
FC	0.02 ± 0.01	0.25 ± 0.25	0.22 ± 0.08	0.42 ± 0.04	0.50 ± 0.29	0.50 ± 0.29	**25.50 ± 9.54^{a}**
SWAP	0.11 ± 0.04	0.33 ± 0.21	0.24 ± 0.06	0.34 ± 0.07	0.80 ± 0.20	0.60 ± 0.24	**52.80 ± 6.45^{a}**
JLF15	0.17 ± 0.05	0.00 ± 0.00	0.37 ± 0.08	0.32 ± 0.06	0.25 ± 0.25	0.25 ± 0.25	**19.25 ± 7.58^{a}**
1D post-weaning (D25)							
FC	0.10 ± 0.08	0.25 ± 0.25	0.23 ± 0.10	0.35 ± 0.14	0.25 ± 0.25	0.50 ± 0.29	**6.00 ± 3.34^{b}**
SWAP	0.03 ± 0.03	0.17 ± 0.17	0.24 ± 0.11	0.46 ± 0.14	0.40 ± 0.24	0.40 ± 0.24	**19.80 ± 8.21^{b}**
JLF15	0.13 ± 0.01	0.25 ± 0.25	0.30 ± 0.17	0.43 ± 0.15	0.25 ± 0.25	0.25 ± 0.25	**7.75 ± 6.12^{b}**

	Aggression[2]	Biting[3] (Yes/No)	Other social interaction[2]	Pen investigation[1]	Object investigation[3] (Yes/No)	Locomotion[3] (Yes/No)	Vocalization[4] (average counts)
2D post-weaning (D26)							
FC	0.12 ± 0.04	0.00 ± 0.00	0.24 ± 0.07	0.33 ± 0.14	0.25 ± 0.25	0.50 ± 0.29	**5.25 ± 5.25[b]**
SWAP	0.10 ± 0.05	0.00 ± 0.00	0.31 ± 0.11	0.27 ± 0.09	0.00 ± 0.00	0.20 ± 0.20	**3.60 ± 3.60[c]**
JLF15	0.07 ± 0.06	0.00 ± 0.00	0.19 ± 0.12	0.49 ± 0.22	0.00 ± 0.00	0.00 ± 0.00	**3.75 ± 3.75[c]**
Global *P*-Value	0.74	0.96	0.93	0.95	0.65	0.74	0.07

[1] Pen investigation was normally distributed so it was analyzed in a linear mixed model.

[2] Aggression and Other social interaction were log(1+x) transformed and analyzed in linear mixed models.

[3] Values of Biting, Object investigation and Locomotion were changed to 1/0 (i.e. Yes/No) and analyzed in general linear mixed models with a binomial distribution.

[4] Vocalization was analyzed in a general linear mixed model with a Poisson distribution.

6.3.2.2. Salivary stress biomarkers post-weaning

Table 6.8 presents the concentration of CORT and CgA in sows in pre- and post-weaning periods by three farrowing systems. No difference in CORT and CgA was observed between farrowing systems (*P* = 0.74 and 0.16, respectively).

Level of CORT in SWAP and JLF15 did not change around weaning, whereas that of CORT in FC tended to increase from 1D pre- to 1D post-weaning, and the increase tended to last for 2 days (1D pre- *vs.* 1D post-: *P* = 0.06; 1D pre- *vs.* 2D post-: *P* = 0.09).

Table 6.8 Concentration of salivary cortisol (CORT) and chromogranin A (CgA) of sows collected on D23 (1D pre-weaning), D25 (1D post-weaning), and D26 (2D post-weaning) in three farrowing systems (FC: conventional farrowing crate; SWAP and JLF15: farrowing pens with temporary crating). *n* indicates the number of sows.

Farrowing system	*n*	1D pre-weaning	1D post-weaning	2D post-weaning
CORT, µg/dL				
FC	13	0.71 ± 0.34	1.70 ± 0.52	1.46 ± 0.36
SWAP	18	0.88 ± 0.21	1.28 ± 0.27	1.63 ± 0.40
JLF15	20	1.15 ± 0.51	1.20 ± 0.28	1.57 ± 0.39
CgA, µg/mL				
FC	14	0.56 ± 0.09	1.17 ± 0.30	1.08 ± 0.23
SWAP	18	0.92 ± 0.24	1.36 ± 0.38	1.35 ± 0.32
JLF15	20	1.37 ± 0.53	1.22 ± 0.35	0.60 ± 0.20

6.4. Discussion

This paper studies the effect of farrowing systems (i.e. early environment) on the weaning adaptability in sows and piglets in a commercial farm. It is a follow-up study of Chapter 5 in the post-weaning period, meaning the same group of animals were followed. Sows and piglets were no longer housed in litters but regrouped in weaning facilities. As the first (published) pilot study involving farrowing pens with temporary crating in Spain, it is interesting to follow these sows and piglets from lactation to few days after weaning, and how they adapt to weaning challenges in commercial conditions.

6.4.1. Piglets

A significantly higher ADG after weaning in FC than in SWAP and JLF15 piglets may be due to compensatory growth (Metcalfe and Monaghan, 2001) for the suckling period. As described by Hornick et al. (2000), compensatory growth is a phenomenon that animals with restricted weight gain previously accelerate their growth rate higher than normal in the following period. In Chapter 5, although ADG during lactation did not differ between farrowing systems, SWAP was 211 g (from D3 to D19) higher numerically than FC. Moreover, BWs recorded on D23 (1D pre-weaning) and D29 (5D post-weaning) also showed a global tendency of having heavier piglets in JLF15 and in SWAP than in FC, respectively, which may suggest a catch-up growth we observed in FC piglets after weaning.

Similar numbers of skin lesions around weaning between farrowing systems indicated that the level of aggression within a group after regrouping was similar, regardless of farrowing systems. The result agrees with Chaloupková et al. (2007) and Verdon et al. (2016), where they found that piglets raised in FC were as aggressive as (e.g. frequency of aggression and fights, fighting duration, and number of skin lesions) those raised in farrowing pens but a single litter after weaning. Early exposure to non-littermates before weaning may play a more important role to reduce aggression after regrouping, especially at weaning (D'Eath, 2005; Chaloupková et al., 2007; Salazar et al., 2018; Ko et al., 2020).

SWAP piglets showed an insignificant increase of CORT and a decrease of CgA post-weaning, suggesting that weaning, known as a stressful event in pig production (Escribano et al., 2019), did not activate the HPA (Hypothalamic-Pituitary-Adrenal) and the SAM (Sympathetic-Adrenal-Medullary) axes in SWAP piglets. We did not expect to see the difference in salivary stress biomarkers between SWAP and JLF15 as both systems are TC. However, some of the differences in pen features between SWAP and JLF15 may explain it. Firstly, SWAP pens have a slightly larger space allowance for sows and piglets than JLF15. Secondly, the flooring of SWAP pens can retain the nest-building materials (hay in this case) on the floor for piglets to manipulate with during the suckling period. Lastly, a metal-barred gate is installed between the adjacent SWAP pens, allowing the piglets to perform nose contacts with non-littermates already before weaning. All in all, an insignificant or lower weaning stress response in SWAP piglets may be due to a larger and a more enriched (both physically and socially) early environment in SWAP pens (physical enrichment: (environmental enrichment) Yang et al., 2018, (space allowance) Lange et al., 2020; social enrichment: (nose contacts) Camerlink and Turner, 2013, (early social play) Horback, 2014, (early socialization) Ko et al., 2020). However, we acknowledge that in Chapter 5, we did not find difference in social interactions between piglets (defined as SB in the paper), exploration in piglets (defined as PPE in the paper), and piglet-initiated mother-young interactions (defined as NNC and SC) between SWAP and JLF15 during the suckling period. A better weaning adaptability in SWAP piglets therefore deserves a deeper understanding by different approaches, and certainly more studies comparing the welfare and performance in sows and piglets in different TC are needed.

6.4.2. Sows

According to an anecdotal report from the farmer, sows in this farm commonly produce high-pitched calls after weaning for few days when they were moved from the farrowing pens to the group pens. In this present study, we did not find any difference in this type of vocalization between farrowing systems, but a similar trend in the change of vocalization counts across farrowing systems. Vocalization is a way of communication with the conspecifics in many animals, including farm animals, and recording vocalization is an easy and non-invasive way to assess the well-being of an individual when a certain call is well-studied (Manteuffel et al., 2004). As Manteuffel et al. (2004) reviewed, louder, longer, and high-pitched calls (e.g. squeals and screams) in pigs are related to the state of the excitement. Additionally, Xin et al. (1989) found that high frequency and long duration of calls can imply more severe stress in pigs, although it was not physiologically validated. We did not find studies about vocalization in sows related to separation from the piglets, so it is difficult to draw any conclusions from the vocalization result. However, it is known that a close bonding between the sow and the piglets is established already in early lactation, with piglets recognizing the odor and the vocalization from its mother by 3 days of age (Horrell and Hodgson, 1992). We therefore suspect the relation between this high-pitched call with the separation from the piglets. Again, more research in weaning sows is required to understand this specific high-pitched call which lasts until at least 2 days after weaning.

In the present study, we hypothesized that a closer bonding between the sow and the piglets in TC due to frequent mother-young interactions may lead to an additional increase of stress in sows and piglets after weaning, compared with those in FC. The insignificant increase of CORT and CgA in sows after weaning could be because of several reasons that may mask the stress of separation from the piglets. Regardless of farrowing systems, sows from the same batch were kept in the same gestation pen before being assigned to different farrowing systems, which would not induce much aggression at regrouping after weaning as they already recognized each other. Having a 'super-dominant' boar (Marchant-Forde and Marchant-Forde, 2005) in the adjacent pen would also help to minimize aggression and salivary stress at regrouping, as suggested in many studies (Grandin and Bruning, 1991; Marchant-Forde and Marchant-Forde, 2005; Séguin et al., 2006). It is also true that the regrouping procedure varied in different batches due to different availability of the group pens, for instance, the stocking density and the distribution of the boars in the adjacent pens. Further research to confirm the stronger mother-young bonding during lactation and its impact on the separation after weaning in loose pen sows and piglets is therefore necessary.

6.4.3. Limitations of the present study

Due to two main limitations, we acknowledge that the low sample size and commercial settings where the control over different variables are limited, and thus the results of the present study are ought to be interpreted with caution.

6.5. Conclusion

In the present study, we observed an increased aggression in SWAP piglets after weaning, even though the number of skin lesions did not reflect on it. Changes of number of skin lesions in all the piglets followed a similar trend around weaning. Salivary CORT and

CgA in FC and JLF15 piglets all increased after weaning, but those in SWAP piglets remained similar (i.e. CORT) or decreased (i.e. CgA) after weaning. Average daily gain after weaning was higher in FC than in SWAP and JLF15 piglets, which can be due to compensatory growth for the suckling period. All the sows vocalized the most on the day of weaning, and then rapidly decreased overtime. Salivary CORT in FC sows tended to increase and last for 2 days after weaning.

Based on the results collected from this pilot study, the farrowing pens with temporary crating which permit more mother-young interactions, did not seem to reduce aggression in piglets after weaning. However, both sows and piglets in farrowing pens with temporary crating, especially SWAP, did seem to show a lower weaning stress response than those from FC and JLF15. An increased high-pitched calls in all the sows after weaning may indicate the stress of the separation from the piglets, regardless of the farrowing systems, but more research in sow vocalization after weaning should be studied. Due to a growing popularity of using the alternative farrowing systems, more research to study the effect of the farrowing/early environment, which promotes close contacts between the mother and the young, on a pig’s life-long adaptability towards social challenges (e.g. weaning or regrouping) is needed.

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CHAPTER 7.

GENERAL DISCUSSION

7.1. Introduction

The general objective of this thesis was to investigate the effects of alternative housing conditions during lactation on the welfare and performance of sows and piglets in intensive production systems. The housing conditions applied in this thesis were alternative to the current conventional indoor farrowing systems, with the aim of fulfilling the pigs' biological needs. We modified the current conventional indoor farrowing systems to improve sow comfort and to facilitate the expression of the natural behaviors of a pig in these stages (i.e. farrowing and lactating stages for sows, and suckling stage for piglets). This thesis consists of two study trials: Trial 1 (Chapter 3 and 4) focused on modifying the housing conditions of piglets to facilitate social interactions with non-littermates as well as exploratory and play behaviors, and the welfare implications throughout their lives; Trial 2 (Chapter 5 and 6) focused on modifying the housing conditions of sows to facilitate mother-young interactions, and the welfare implications for sows and piglets until shortly after weaning (see **Figure 7.1** and **Table 7.1** for the framework of the thesis). In this Chapter, the key modifications to the current conventional indoor farrowing system are shown first. The rationales behind the modifications and the welfare implications of the two study trials are discussed. Lastly, practical recommendations for the current conventional indoor farrowing system, suggestions for future research, and limitations of this thesis are discussed.

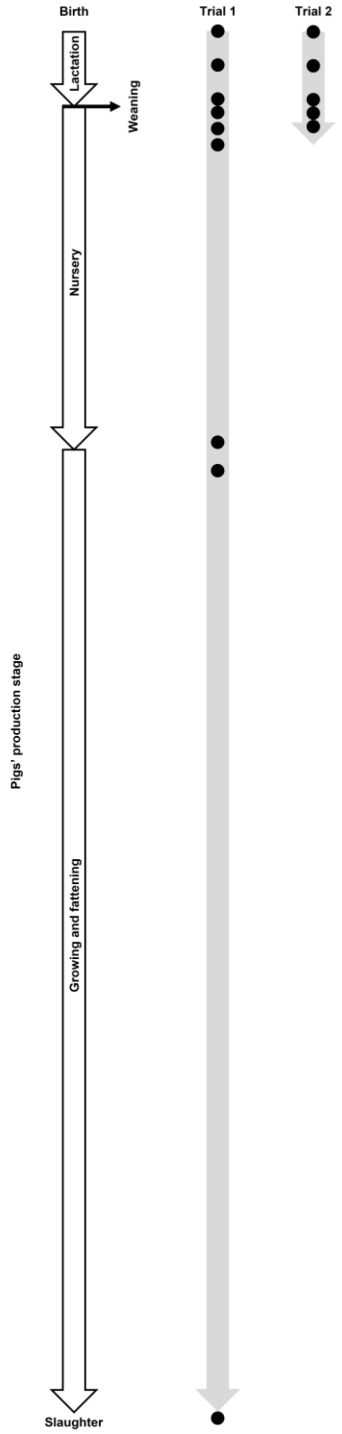

Figure 7.1 Two study trials included in this PhD thesis. The white arrows indicate pig production stages from birth to slaughter. The two grey arrows indicate the timeline of the study period of each trial. The black dots in the grey arrows indicate the days for data collection and sampling during the trial.

Table 7.1 Framework of the two study trials included in this PhD thesis.

	Trial 1	**Trial 2**
Chapters in this thesis	3, 4	5, 6
Study subject	Piglets	Sows and piglets
Study period	From birth to slaughter	(Sow) From entry to the farrowing unit to 2 days after weaning (Piglet) From birth to 5 days after weaning
Modifications of the housing conditions during lactation[1]	Early socialization and environmental enrichment *vs.* conventional crate	Farrowing pens with temporary crating *vs.* conventional crate
Facilitation of the expression of the natural behaviors during lactation	Social interactions with non-littermates as well as exploratory and play behaviors	Freedom of movement and mother-young interactions

[1] Details on the modifications of Trial 1 and 2 are described in Chapter 7 section 7.2.

7.2. Key modifications to the current conventional indoor farrowing system in this thesis

In Trial 1, early socialization and environmental enrichment were provided to the piglets of the treatment group (ENR *vs.* control treatment group, CON). Six enrichment objects (two objects for each type; three types in total, see **Table 3.1**) were installed in each ENR pen from piglets' birth onwards. Barriers of the two neighboring pens were removed to allow two ENR litters of the piglets to socialize (i.e. co-mingle) from 14 days of age. The modifications of Trial 1 (see **Figure 7.2**) lasted until weaning.

Figure 7.2 Setup of Trial 1. The left picture is the setup of the control treatment group (CON), which is a typical conventional indoor farrowing system without modification. The right picture is the setup of the enriched treatment group (ENR), in which six enrichment objects were provided in each ENR pen from birth, and the barriers between two neighboring ENR pens were removed from 14 days of age.

In Trial 2, three types of farrowing systems were tested, including one conventional farrowing crate (FC) and two commercially available farrowing pens with temporary crating (TC, which were SWAP and JLF15, respectively) (see **Figure 7.3**). Sows in TC were crated for 5 to 6 days during the peripartum and were loose for the rest of the period, whereas those in FC were crated from entry to weaning. Farrowing pens of TC were 1.4 to 1.5-time larger than that of FC, and nest-building materials were given in TC. Compared with FC, sows in TC could turn and move around when being loose, and both sows and piglets had a larger space and had access to nest-building materials.

Figure 7.3 Three types of farrowing systems tested in Trial 2. The pictures from left to right are: the typical conventional indoor farrowing crate system with permanent crating (FC), and the two commercially available farrowing pens with temporary crating (TC), which are SWAP and JLF15, respectively. TC sows were crated for 5 to 6 days during the peripartum and were set loose for the rest of the period until weaning. Nest-building materials were provided in TC pens.

7.3. Welfare implications for sows and piglets from farrowing to post-weaning

Both Trial 1 and 2 were conducted on commercial farms and hence the obtained results are expected to reflect the real-world situation better than those collected from experimental farms. Pigs in Trial 1 were studied from birth to slaughter, whereas those in Trial 2 were studied from birth to 5-day post-weaning in piglets, and from entry to the farrowing unit to 2-day post-weaning in sows. In the following two sections, the results obtained from both trials are discussed considering the following phases: around farrowing, during lactation/suckling, after weaning, and growing/fattening until slaughter.

7.3.1. Sows around farrowing and early lactation

As Trial 1 only studied the piglets, in this section, we focus on the salivary stress biomarker results of sows from Trial 2. Sows in farrowing pens with temporary crating were crated temporarily from 1 day before expected farrowing to 3 days after farrowing, whereas sows in farrowing crates were crated from entry to the farrowing unit to weaning. Our results showed that there was no significant difference in the concentration of CORT (salivary cortisol) and CgA (salivary chromogranin A) at crating (i.e. 1 day before and 1 day after crating) and at crate removal (i.e. 1 day before and 1 day after crate removal) between SWAP and JLF15, as also shown in Goumon et al. (2018) after crate removal. This indicated that temporary crating did not activate a stress response in sows in both the hypothalamic-pituitary-adrenal (HPA) (using CORT as the biomarker) and the sympathetic-adreno-medullar (SAM) (using CgA as the biomarker) axes. Although it could be that we did not capture the acute stress response of crating, because CORT and CgA are often released within 30 minutes after the stress is induced (Escribano et al., 2014 and 2015; Goumon et al., 2018), we could argue that the stress response due to temporary crating did not last for more than one day.

SWAP sows showed a higher level of CORT when the piglets were at 2 days of age, compared with FC and JLF15 sows. CORT level in sows around early lactation between farrowing crates and farrowing pens seems inconsistent in the literature, where some studies found no difference (Cronin et al., 1992; Biensen et al., 1996), some studies found a higher (Oliviero et al., 2008) or a lower (Hales et al., 2016) concentration in crated sows. However, a higher CORT level in SWAP sows may be due to the location of the crate. A higher frequency of piglet-initiated naso-naso contacts towards the sow at 2 days of age in SWAP than in FC and JLF15, may indicate the piglets' calls for nursing, but the inability to avoid the piglets' calls in crated SWAP sows could produce stress, as found in the crate sows in Oliviero et al., 2008. Moreover, a higher salivary stress response in SWAP sows may reflect that a sloping wall on one side of the crate can make the space for nursing crowded when the sow's udder is facing towards the sloping wall, which may increase the piglets' calls due to the disturbed nursing bout (Appleby et al., 2001). To optimize the pen design, farm practice and management of farrowing pens with temporary crating, it will be worth investigating the short-term stress response in sows around farrowing and early lactation.

7.3.2. Lactating sows and suckling piglets

Trial 1 focused on creating a physically and socially enriched early environment for the piglets, while Trial 2 focused on providing freedom of movement for the sows, and a larger space to facilitate more mother-young social interactions. Both trials improved the current conventional indoor farrowing system by adding or modifying some elements of the environment, aiming to facilitate the ease of movement and the natural behaviors of a pig during these stages.

In Trial 1, during suckling, ENR piglets performed more exploration and object play behaviors than CON piglets. One explanation can be that a larger farrowing pen size after socialization in ENR may have stimulated more exploration of the pen (Chaloupková et al., 2007). Additionally, a higher percentage of these behaviors in ENR piglets indicated that enrichment objects could meet the biological needs of exploration and foraging in their early ages, which agrees with Martin et al. (2015) and Yang et al. (2018). On the other hand, number of skin lesions increased in ENR piglets after socialization, suggested a higher degree of agonistic interactions than in CON piglets. Even though the increase was in contrast to Salazar et al. (2018), where the authors found that skin lesions of piglets socialized at 14 days of age after socialization did not increase, it was expected and agrees with most studies (e.g. Camerlink et al., 2018 and Kerschaver et al., 2021). As new penmates (i.e. non-littermates) were introduced to a litter, it induced agonistic interactions due to the establishment of new dominance hierarchy, even when piglets are still young (Pitts et al., 2000). Another explanation can be the transition from play fight to actual fight (Šilerová et al., 2010), as more penmates means more individuals to play with. Finally, we did not find difference in growth performance during the suckling period between ENR and CON piglets, which agrees with Hessel et al. (2006), Camerlink et al. (2018), Salazar et al. (2018) and Kerschaver et al. (2021), indicating that the modifications of the early environment did not have a negative impact on piglets' performance. Concerns regarding a potential reduction in weight gain like cross-suckling between sows (van Nieuwamerongen et al., 2014) or increased activity of piglets in enriched environment (Verdon et al., 2016) are therefore excluded. To mimic (semi-)natural conditions and to facilitate the natural behaviors of piglets during lactation, the housing interventions of early socialization and environmental enrichment in Trial 1, stimulated exploration and play behaviors, as well as social behaviors related to aggression, but did not affect the growth performance in piglets.

In Trial 2, farrowing pens with temporary crating encouraged sow-piglet interactions. Piglets in SWAP and JLF15 initiated more naso-naso contacts with sows at an early age, and sows in both systems also initiated more mother-young interactions with piglets in mid-lactation, compared with those in FC. Even though sows in all the systems were crated in early lactation, a smaller crate length and width in FC may have forced the sows to lay under the feed trough, which can limit either the sows or the piglets to initiate the interactions with each other. Nose contact is one of the main affiliative behaviors in pigs (Camerlink and Turner, 2013) and has been known to facilitate sow-piglet bonding (Portele et al., 2019). Camerlink and Turner (2013) mentioned that social nosing may enhance group cohesion due to the stimulation of oxytocin release and the reduction of tension, which can improve growth performance in pigs (Camerlink et al., 2012). Moreover, Oostindjer et al. (2014) found that piglets raised in loose pens with increased sow interactions facilitated more play behaviors and less damaging behaviors (i.e. belly nosing and manipulative behavior) after weaning, which indicated a better ability to cope with weaning stress. Different from the previous studies (Pedersen et al., 2011; Melišová et al., 2014), which found a higher piglet performance in loose pens than in farrowing crates, a higher frequency of mother-young interactions in SWAP and JLF15 in our study was not reflected on piglets' weight gain, compared with FC piglets. Similar performance during lactation between farrowing systems may indicate an undisturbed nursing/suckling behaviors shortly after crate removal and until the end of the lactation period (Goumon et al., 2018). Oostindjer et al. (2010) and (2011) also found that the suckling frequency remained similar regardless of the farrowing systems (i.e. enriched or barren *vs.* confined or loose sows). Another parameter which can contribute to piglets' growth performance and as important as milk intake is creep feed intake, but it was not measured in Trial 2. However, Oostindjer et al. (2014) stated that to stimulate solid feed intake in piglets during lactation, it is essential that sow and piglets should eat together from the same location in a pen. Apart from this, piglets should be able to observe the sow while she is eating, and similar flavor of the feed to the sow's one should be provided to the piglets (Oostindjer et al., 2014), in which these feeding conditions were not met in Trial 2, and thus creep feed intake might not have a significant effect between farrowing systems in our case.

On the other hand, FC piglets were observed to interact more with their littermates at an early age, suggesting a different time budget compared with SWAP and JLF15 piglets. As the space allowance in FC was smaller than SWAP and JLF15, a higher frequency of social interactions between piglets may occur. Moreover, a smaller crate structure in FC, as mentioned earlier, can also restrict piglets' interactions towards sows.

Regarding exploration in sows, one day after crate removal, SWAP and JLF15 sows were observed to explore the pens more than FC sows. Because of an increased space allowance, presence of the newborn piglets, and the remaining shredded newspaper used around farrowing, exploration was highly motivated. Regarding exploration and play behaviors in piglets, we did not observe any difference between farrowing systems. As we did not distinguish between exploration, object play, or locomotor play, it would be difficult to draw the conclusion on the frequency of each play behavior in these farrowing systems. However, Beattie et al. (1996) concluded that the effect of environmental enrichment was more significant than that of floor space allowance in widening the behavioral repertoire of pigs. This could be the case in our study as SWAP and JLF15 piglets were raised in larger farrowing pens than FC piglets, but piglets did not receive regular enrichment stimulation from the environment during the suckling period in any of the three farrowing systems.

In terms of piglet crushing in Trial 2, SWAP had the highest crushing rate, which was followed by JLF15, and FC having the lowest. As stated in Chidgey et al. (2015), sows are able to perform various postures and movements after crate opening, and piglets are less protected especially from the dangerous and sudden change of postures and movements of the sows, which can increase the risk of piglet crushing. Additionally, a higher crushing rate in SWAP than in JLF15 may be due to a wider crate structure and a lesser free space along the sloping wall in SWAP pens. A wider crate allows the sows to perform a wider repertoire of postures and a sloping wall right next to one side of the crate, may give the piglets a lesser chance to escape from being crushed. Despite TC showed a higher crushing rate than FC, crushing rate was similar before and after crate opening, which was different from Chidgey et al. (2015) and King et al. (2019). This may be because of a smaller number of sample size, as well as a different breed with heavier birth weight piglets (i.e. more robust body condition) and a smaller litter size used in Trial 2.

We also found that different seasons showed different crushing rates, with fall having the lowest crushing rate across the farrowing systems, compared with other three seasons. Due to a changing micro-climate condition in farrowing pens in four seasons, sows and piglets used the pens differently. Crushing occurred more frequently in FC in winter and in SWAP in summer. This could be due to a different use of space in piglets in different seasons. Insufficient space and warmth in FC in winter may lead to piglet crowding (Rangstrup-Christensen et al., 2018) close to the sows, in order to seek for additional body heat from the sows, which not only increased the risk of piglet crushing, but also reflected on the higher percentage of sow using a support from the pen fixture but still crushed the piglets, as we found in FC. Oppositely, improper management of the temperature of the creep area in TC resulted in overheating in summer, which made the piglets use the creep area for urination and defecation, and rest at the common space with the sows (See **Figure 7.4**), and thus increased the risk of being crushed (Marchant et al., 2001). Piglets resting at the open space due to overheated creep area in the summer in TC may additionally explain a two-time higher crushing rate during summer in SWAP than in JLF15 after crate opening, as there might be more litters of SWAP lying outside. However, because we did not measure the temperature of the creep area, further investigation to study whether there are any pen features in SWAP that can lead to more piglet crushing than in JLF15 when the sow is loose may be necessary. Correct management and regular inspection of the temperature of the creep area are therefore essential to avoid piglet crushing and to maintain pen hygiene.

Figure 7.4 SWAP (the left) and JLF15 (the right) piglets using the creep area as a toilet during summer.

In summary, sows and piglets behave differently in different farrowing environments. Providing enrichment objects and non-littermates for piglets facilitates exploration and play behaviors, and providing a temporary-crating setting facilitates exploration in sows and mother-young interactions in both sows and piglets. The lack of difference in weight gain of piglets between treatments in both trials suggests that modifying the current conventional indoor farrowing environment does not have an impact on piglet growth. Creating an alternative environment during lactation based on the biological needs of pigs, does broaden their behavioral repertoire, although the environment should also consider some piglet protection features to safeguard the welfare of piglets in terms of crushing. Enriching an early environment which is biologically relevant to pigs, not only improves their welfare but also benefits their later lives (examples like Camerlink et al., 2018 and Kinane et al., 2021; reviewed by Godyń et al., 2019), for instance, being more resilient to the weaning challenge, which is going to be discussed in the following section.

7.3.3. After weaning

Both trials studied the effect of lactation housing conditions on the weaning adaptability in pigs. Trial 1 focused on the piglets and Trial 2 focused on both the sows and the piglets. We studied how they adapted to the challenge of weaning by means of direct behavioral observation, counting aggression-related skin lesions, analyzing salivary stress biomarkers, and growth performance around weaning.

In terms of post-weaning behaviors in Trial 1, we observed that CON piglets performed more negative social behaviors (i.e. agonistic interactions) than ENR piglets, and ENR piglets performed more other active behaviors (i.e. active behaviors not specified in the ethogram of **Table 3.2**) than CON piglets. Several studies have shown that allowing socialization with non-littermates in the pre-weaning period can assist the piglets to develop a variety of social skills (Weng et al., 1998; Kanaan et al., 2012; van Nieuwamerongen et al., 2017), which can largely decrease aggression in a new regrouping event (Hessel et al., 2006; Li and Wang, 2011), such as weaning. Although it was not specifically measured, feeding behavior could be another active behavior more frequent in ENR piglets than in CON piglets, as previous studies found that piglets reared in an enriched lactation environment showed a better growth rate after weaning (Hessel et al., 2006; Kutzer et al., 2009).

In terms of post-weaning behaviors in sows in Trial 2, we did not observe any difference between farrowing systems. However, vocalization, which was a specific type of high-pitched vocal call in this study, by all the sows followed a similar trend, which peaked on the day of weaning and rapidly decreased overtime (with a 5-time reduction in FC and JLF15, and a 15-time reduction in SWAP, from the day of weaning to 2-day post-weaning). To the best of our knowledge, there is no previous literature regarding sow vocalization after weaning. However, this pattern was interestingly similar to the vocalization of the post-weaning piglets (with a 5-time reduction from the day of weaning to 4-day post-weaning), as recorded in Weary and Fraser (1997). Louder, longer, and high-pitched vocal calls, such as squeals and screams, are usually strongly related to the state of excitement of the sender (as reviewed by Manteuffel et al., 2004) or implying a severe stress (Xin et al., 1989) in pigs. As the bonding between sow and piglets is established in an early stage by recognizing the sow's odor and vocalization (Horrell and Hodgson, 1992), the association between this high-pitched vocal call and the separation from the piglets is suspected. Different farrowing system did not affect the vocalization of sow in Trial 2, as vocalization might be more related to other aspects, for example, the duration of the lactation period. Weary and Fraser (1997) reported that piglets weaned at younger ages (i.e. 3 weeks) produced 1.2- or 1.6-time more and 57 Hz-higher frequency of vocal calls than those weaned at later ages (i.e. 4 or 5 weeks). Yet, further investigation on this specific high-pitched call produced after weaning by sows is warranted to confirm the suspicion because the motivation of vocalization produced by post-weaning sows or piglets might be different.

In Trial 1, the increase of aggression-related skin lesions after weaning was higher in CON piglets, compared to ENR piglets. Through early socialization with non-littermates in the pre-weaning period, ENR piglets were able to rapidly establish the dominance hierarchy in a new group in few fights due to improved social experience (D'Eath, 2005), which was also found in several studies (Hessel et al., 2006; Kanaan et al., 2008; Parratt et al., 2006; Morgan et al., 2014; Camerlink et al., 2018; Salazar et al., 2018). On the other hand, number of skin lesions after weaning did not differ between farrowing systems in Trial 2. This was in line with Chaloupková et al. (2007) and Verdon et al. (2016), where piglets raised in loose pens and in single litters were as aggressive post-weaning as those raised in farrowing crates. Early socialization with non-littermates before weaning may still be needed to assist piglets to improve social recognition and to be equipped with necessary social skills after weaning (D'Eath, 2005; Chaloupková et al., 2007; Salazar et al., 2018).

Two major brain networks are usually activated when an individual is experiencing stress: the HPA (Hypothalamic-Pituitary-Adrenal) and the SAM (Sympathetic-Adrenal-Medullary) axes (Godoy et al., 2018), in which CORT and CgA are the two common salivary biomarkers for detecting the activation of the two axes, respectively (Martínez-Miró et al., 2016). In Trial 1, both CORT and CgA in CON piglets increased significantly after weaning, whereas those in ENR piglets did not increase. CORT and CgA in ENR on the 3rd day of weaning was lower compared with the basal level (i.e. 1 day before weaning) but the increase of CORT in CON lasted for 2 days after weaning. Given the same period of time, the trendlines of CORT and CgA indicated that, after 2 days of weaning, CON piglets were still suffering from weaning stress, whereas ENR piglets were already recovering, suggesting a better weaning adaptability in ENR piglets. The results are consistent with those of Salazar et al. (2018) and Yang et al. (2018), who found that enriched piglets (i.e.

socialized with non-littermates and enriched with substrate during lactation, respectively) showed a smaller weaning stress response, compared to those raised in conventional farrowing crate systems. A lasting stress response in CON may be due to a more intense involvement of aggression during the post-weaning period, as there was higher increase of aggression-related skin lesions in CON than in ENR after weaning (also found in Salazar et al., 2018).

On the other hand, in Trial 2, we hypothesized that a more frequent mother-young interactions in TC may lead to an increased weaning stress response in sows and piglets, due to the separation of a closer sow-piglet bonding compared to FC (Newberry and Swanson, 2008). This was however not the case in both sows and piglets in Trial 2. Among the three farrowing systems in Trial 2, CORT and CgA in FC and JLF15 piglets increased after weaning, while CORT did not increase and CgA decreased in SWAP piglets, indicating that weaning activated neither the HPA nor the SAM stress axes in SWAP piglets. A higher post-weaning stress in FC than in SWAP piglets agrees with previous studies (Hillmann et al., 2013; Lange et al., 2020; Oostindjer et al., 2011; Verdon et al., 2016), where piglets raised in a physically and/or socially enriched early environment can better adapt to weaning challenges, compared to those in conventional individual farrowing crate/pen systems, as also discovered in Trial 1. Although we did not expect to see a different stress response between SWAP and JLF15 piglets, as they are both TC, there are some differences in terms of pen features between the two systems, which may create a slightly different early environment and hence affect the adaptability to weaning in piglets. Compared to JLF15, SWAP has a slightly larger farrowing pen, no fixed-side crate blocking the contact with the creep area (See **Figure 7.5**), more chances to access to the enrichment material (i.e. hay) retained on the floor due to a bigger cover of solid plastic flooring, and the ability to perform social nosing behaviors with the neighbor sow and non-littermates from the adjacent pen through a metal-barred gate installed between (see **Figure 7.6**). These pen features that JLF15 does not have, may stimulate SWAP piglets to perform additional exploration and social behaviors with the neighbor sow as well as non-littermates during lactation, and the facilitation of these natural behaviors is known to mitigate the weaning stress, as suggested by several studies (Camerlink and Turner, 2013; Horback, 2014; Lange et al., 2020; Salazar et al., 2018; Yang et al., 2018), even though the behavior results did not reflect the difference between SWAP and JLF15. More refined and specified behavioral categories and the observation of the space preference of the sow and the piglets would be needed to assess the difference of the mother-young bonding between SWAP and JLF15. Additionally, a thorough understanding of the better weaning adaptability in SWAP piglets through different approaches is thus warranted.

Figure 7.5 Different distance for the sow to access to the creep area in SWAP (left) and JLF15 (right) systems.

Figure 7.6 A metal-barred gate installed between the adjacent SWAP pens.

In the case of sows, the effect of farrowing system was not significant in salivary stress biomarkers after weaning. CORT and CgA did not change in any of the sows in Trial 2. The stress due to separation from the piglets as we hypothesized may either not be induced or be masked by other bigger stressors. The insignificant difference in sows between farrowing systems could be that they were from the same batch and from the same gestation pen, and were familiar with the weaning process (85% of the sows were multiparous in the study).

Housing the sows in a familiar environment with familiar penmates would not induce much aggression as they recognized each other (McLeman et al., 2005; Gieling et al., 2011). Moreover, housing some dominant boars (Gonyou, 2007; Marchant-Forde and Marchant-Forde, 2005) in the adjacent pens may reduce agonistic interactions, as suggested in Grandin and Bruning (1991), Séguin et al. (2006), and Marchant-Forde and Marchant-Forde (2005).

In Trial 1, we observed a stable short-term weight gain in ENR pigs after two regrouping events, one after weaning (4-day-period), and the other one from nursery pens to fattening pens (10-day-period). A higher post-weaning average daily gain (ADG) in ENR than in CON piglets was in line with the performance results (within 1-week-period) of other studies (Weary et al., 2002; Hessel et al., 2006). Facilitated exploration and play behaviors, and increased social experience during the suckling period, are likely to assist ENR pigs to better cope with the regrouping stress than CON pigs, due to equipped improved social skills and stress coping capabilities in their early ages (Brunson et al., 2003; Hillmann et al., 2003), which further reflected on their stable weight gain. Additionally, a higher frequency of pen and object exploration in ENR than in CON piglets during the suckling period, may have stimulated chewing on the enrichment objects (Oostindjer et al., 2010), which can lead to a faster adaptation to solid feed. However, in Trial 2, FC piglets gained more weight than

SWAP and JLF15 piglets after weaning. The body weight recorded on different days suggested that it may be because of the compensatory growth (Metcalfe and Monaghan, 2001) for the suckling period in FC piglets. Compensatory growth was first called by Bohman (1955), and it is a physiological process that an animal with retarded weight gain catches up its growth performance in the following period, which can be a growth rate higher than normal circumstances (Hornick et al., 2000). Despite there was no difference in pre-weaning ADG between farrowing systems, the ADG of SWAP piglets was numerically higher than that of FC piglets, and the body weight recorded around weaning (i.e. before and after weaning) showed a tendency of having heavier piglets in SWAP and JLF15 than in FC, which may indicate a compensatory growth in FC piglets after weaning.

Creating an early environment which can broaden the behavioral repertoire of the piglets, to facilitate exploration, play and social behaviors, for example, supports them to be prepared for the unexpected situations and to quickly resolve social conflicts in the future (Spînka et al., 2001; Yang et al., 2018). Piglets from a complex early environment showed a shorter latency for novel feed (Oostindjer et al., 2010), were less involved in agonistic interactions after regrouping with unfamiliar individuals (Beattie et al., 2000; Camerlink et al., 2018), had a lower cortisol level after weaning (De Jonge et al., 1996), and consumed more feed which led to a greater weight gain after weaning (Weary et al., 2002). These benefits confirm that an enriching early environment is fundamental on piglets' development of behavioral patterns and stress regulation system (Telkänranta and Edwards, 2018). Although we did not find the conclusive benefits of mother-young interactions facilitated by the TC environment after weaning in Trial 2, it may be due to several uncontrollable factors from the experimenter at a commercial farm in the post-weaning period: different availability of the nursery buildings, nursery pens for the piglets, and group pens for the sows, different stocking density, different distribution of the boars in the adjacent pens, and the loss of culled sows after weaning during the four batches of the study period. Further research to investigate the effect of maternal behavior and sow-piglet interactions on the weaning or regrouping adaptability with less uncontrollable factors is therefore warranted.

7.4. Long-term effect of lactation housing conditions

In the present thesis, only Trial 1 studied the long-term effect of lactation housing conditions. In terms of ear biting lesions, two treatment groups did not differ on D69 during nursery and on carcasses. Based on previous studies, it seems that damaging behavior like ear biting is more closely associated with the complexity of the current housing conditions (Petersen et al., 1995; van de Weerd et al., 2006; Telkänranta et al., 2014). However, as a recent review suggested, a thorough investigation on the risk factors of developing ear biting behavior in pigs is needed (Prunier et al., 2020).

Another long-term effect of lactation housing conditions we studied in Trial 1 was the possession of the social skills until the moment of being slaughtered. During pre-slaughter transportation and regrouping, meaning the journey from fattening pens at the farm to the lairage at the slaughterhouse, the skin lesions on the carcasses seemed to suggest that CON pigs were involved in more reciprocal fighting (i.e. more skin lesions at the head and the front) whereas ENR pigs received more unilateral bullying (i.e. more skin lesions at the back) (Turner et al., 2006). As pigs from the two treatment groups were not distinguished in this regrouping event, and the basal level of the skin lesions were not collected, the long-term effect of lactation housing conditions on the social skills could not be fully examined. However, the skin lesions on the carcasses obtained from Trial 1 do provide an insight on the life-long social skills in pigs, especially the agonistic interactions when two treatment groups were mixed together, where CON pigs were possibly the aggressors and ENR pigs the receivers of aggression. Previous studies have shown that socialization in the early environment (Camerlink et al., 2018) or repeated regrouping and repenning events (van Putten and Buré, 1997) can increase the social skills in pigs. Nevertheless, more studies focusing on the long-term or life-long effect of lactation housing conditions on their social skills will be needed to decrease aggression at regrouping.

Although we did not study the long-term effect of lactation housing conditions in Trial 2, Chaloupková et al. (2007) found that pigs raised in enriched farrowing pens were less aggressive than pigs raised in farrowing crates or enriched farrowing crates during the fattening stage in food competitions. This study showed that even though the nursery environment was the same between treatment groups for several months, the effect of lactation housing conditions can still influence the agonistic behaviors in pigs during fattening. Li et al. (2012) also agreed that pigs reared in a complex early environment (i.e. group-farrowing system) developed better social behavioral patterns and were more stress resistant towards social and environmental challenges (i.e. mixing and change to the fattening unit) later in their lives, and these benefits consequently improve their performance in the adulthood. As alternative farrowing systems (e.g. loose pens or farrowing pens with temporary crating) are being implemented in many countries in the European Union, it is worth to investigate how the lactation housing conditions shape the behaviors of the pigs in a longer-term.

Table 7.2 summarizes the key findings and welfare implications for sows and piglets in different periods after some modifications of the housing conditions during lactation were applied in this thesis.

Table 7.2 Summary of the key findings and welfare implications for sows and piglets in different periods obtained from this PhD thesis.

	Trial 1	**Trial 2**
Modifications of the housing conditions during lactation[1]	Early socialization and environmental enrichment (ENR) *vs.* conventional crate (CON)	Farrowing pens with temporary crating (TC: SWAP, JLF15) *vs.* conventional crate (FC)
Sows around farrowing and early lactation	-	- no stress response due to temporary crating, including crating and crate removal - high cortisol level in SWAP sows on D2 may be due to disturbed nursing events
Lactation/suckling period	- ↑exploration and object play in ENR - ↑skin lesions after socialization in ENR - no impact on performance in ENR	- different activity time budget between FC and TC piglets:↑mother-young interactions in TC; ↑social behaviors between littermates in FC - ↑exploration after crate removal in TC sows - ↑piglet crushing rate in TC - no impact on performance in TC piglets

	Trial 1	Trial 2
Post-weaning period	- ↑agonistic interactions and skin lesions in CON - ↑and slower recovery from weaning stress response in CON - ↑ short-term weight gain in ENR - implication of better social skills and adaptation to weaning in ENR	- ↑high-pitched vocal calls in all sows, separation from the piglets? - no stress response in SWAP piglets, suggesting a better adaptation to weaning - ↑weight gain in FC piglets, may be due to compensatory growth
Long-term impact (i.e. nursery, fattening, until slaughter)	- no difference in ear-biting lesions - body part of the most skin lesions observed on the carcasses: CON (front) and ENR (back), may indicate CON (aggressor) and ENR (receiver of aggression)?	-

[1] Details on the modifications of Trial 1 and 2 are described in Chapter 7 section 7.2.

7.5. Recommendations for current conventional indoor farrowing system

Based on the results of Trial 1 and 2, creating a physically and socially enriched indoor lactation environment, different from the current conventional one, broadens the behavioral repertoire of sows and piglets. During lactation, ENR piglets in Trial 1 were showing more exploration and object play behaviors than CON, while TC sows and piglets in Trial 2 both initiated more mother-young interactions than FC. The modifications to the current conventional indoor farrowing systems in ENR, contributed to a better adaptability to weaning and regrouping challenges later in their lives, by showing lesser agonistic interactions, a lower stress response and a higher short-term weight gain after regrouping. In Trial 2, on the other hand, although similar frequency of exploration during lactation and similar increase of aggression-related skin lesions after weaning were observed in piglets across the farrowing systems, SWAP piglets showed a lower salivary stress response after weaning. Even though both SWAP and JLF15 are TC, the modifications to the current conventional indoor farrowing systems in SWAP, seemed to contribute to a better adaptability to weaning. To help mitigating aggression at weaning, social interactions with non-littermates in the early stage may be needed (D’Eath, 2005; Chaloupková et al., 2007; Salazar et al., 2018; Ko et al., 2020).

The findings obtained from Trial 1 and 2, allow us to give recommendations for current conventional indoor farrowing system. To facilitate exploration, play and social behaviors in piglets in their early lives, we recommend providing suitable enrichment objects for piglets and early socialization with non-littermates. To facilitate mother-young interactions in sows and piglets, we recommend providing a larger crate, a larger farrowing pen, and opening the crate few days postpartum, after the piglets are accustomed to the location of the creep area. Combining proper staff training for the practice and the management of TC, periodical checks to replace soiled or damaged enrichment objects, examination of litters' health and aggression after socialization, and inspection of the risk of piglet crushing after crate removal are recommended.

7.6. Suggestions for further research

Creating an adequate early environment for piglets is crucial. Early environment plays an important role on piglet's behavioral development (including social skills), cognitive flexibility, and endocrine stress regulation system (Telkänranta and Edwards, 2018), which not only enhances pig's welfare but also benefits the farmers regarding handling and management. In addition, the development of some unwanted and abnormal behaviors commonly seen on commercial farms like tail biting, belly nosing, and increased aggression in pigs are reported to be associated with their early-life environment, which can be reduced after interventions are made (Telkänranta and Edwards, 2018). As described by Telkänranta and Edwards (2018), little attention to the long-term effect of early environment in pigs has been given by the researchers so far. More research is therefore needed to understand this long-term effect to improve pig's behavior and welfare from their early lives.

In terms of the enrichment materials, although the Council Directive 2008/120/EC states that 'pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities,' which applies to piglets, it lists the examples of the materials but does not specify the materials that are allowed or recommended for piglets (Vanheukelom et al., 2011). Studies to investigate suitable enrichment materials for piglets and especially in commercial conditions which are low-cost and easy-to-be-implemented are necessary.

Many studies have found positive outcomes, such as reduced aggression and stress after weaning, when piglets were previously socialized before weaning (Wattanakul et al., 1997; D'Eath, 2005; Hessel et al., 2006; Kutzer et al., 2009; Camerlink et al., 2018; Salazar et al., 2018). However, some downsides of early socialization like disease transmission, increased competition for udder access, reduced weight gain, and increased aggression with non-littermates and other sows may occur, which are the concerns addressed by the farmers (Camerlink and Turner, 2017). Depending on the design of the farrowing system, the practice of early socialization in piglets may vary, from mixing only between two or more litters until weaning, to intermittent mixing (i.e. mixing for few hours per day until weaning). Research on the optimal strategy for early socialization (examples like Ji et al. (2021) and Kerschaver et al. (2021)) in different farrowing systems is therefore necessary.

Farrowing pen with temporary crating is one of the alternatives to farrowing crate. Along with the societal movement of eliminating the farrowing crates, several countries will permit only a short period of sow confinement or complete non-confinement in the near future (e.g. New Zealand in 2025; Austria in 2033; Germany in 2035; European Union (legislative proposal) in 2023 and (with ambition) in 2027). During the transition phase, studies to investigate how the multiparous sows with previous parturition experience in farrowing crates adapt to alternative farrowing systems may be needed. This may effectively help the farmers to better assist the sows with the unforeseen circumstances. Furthermore, there is currently a variety of farrowing pens with temporary crating on the market. Pen size, flooring, crate structure, location of the creep, and piglet protection features, etc., however, vary between these designs and may alter sow's and piglets' behaviors. To the best of the author's knowledge, few studies have compared the welfare and performance of sows and piglets in different farrowing pens with temporary crating. To ensure the welfare and performance of the sows (e.g. freedom of movement and nest-building) and the piglets (e.g.

reduced mortality due to crushing and increased positive behaviors), understanding how sows and piglets behave in different designs is necessary. Research on the short- (i.e. post-weaning) and long-term effects on this type of early environment in pigs is also required, considering the increasing interest of using farrowing pens with temporary crating.

Saliva samples can be collected from pigs less invasively, compared with blood samples, and are being studied widely. As mentioned in Chapter 3, a comparative study between different salivary stress biomarkers is needed to better explain the physiology in pigs before and after the stress is induced. Salivary oxytocin in pigs is receiving attention recently to be a potential biomarker related to stress (transport stress: López-Arjona et al., 2020a; farrowing stress: López-Arjona et al., 2020b), and social behavior and positive human-animal interactions (Lürzel et al., 2020). Further research on the level of oxytocin during lactation in different farrowing systems, to compare with the frequency of mother-young interactions, piglet growth performance, and sow milk production or quality, will shed more light on the importance of maternal behaviors during lactation, and sow as a significant role in piglets' development of social behaviors.

Finally, despite many factors are out of researcher's control with regard to experimental design, it is indispensable to conduct more behavioral and welfare research on commercial farms. As management, environment, and training of farm staff can differ significantly between the research settings and the commercial settings, carrying out trials in real situations may translate the benefits directly into commercial farms.

7.7. Limitation of this thesis

In Trial 1, we did not record specifically which enrichment object was used the most by the piglets, as three types of enrichment objects (see **Table 3.1**) all had different characteristics. Hemp rope was easily destructible by eating or chewing from the piglets, which made it the most frequently renewed object among the three types. A handmade toy was also suspended like the hemp rope, but because it was made of plastic, it was relatively more robust than the hemp rope. One of the rubber chew toys was chained on the floor. Unlike the rest of the enrichment objects, which were all suspended, the rubber chew toy chained on the floor facilitated slightly different exploration and foraging behaviors in piglets. Suspended object facilitated chewing, sniffing, or biting, whereas chained object facilitated chewing, rooting, or nudging in piglets (Godyń et al., 2019; Mkwanazi et al., 2019). Moreover, it was reported in Blackshaw et al. (1997) and Trickett et al. (2009) that enrichment materials provided on the floor are not favored by the pigs, as opposed to those at the pigs' eye level, because they are soiled quickly and thus gets less attractive easily to pigs. From this study, we cannot conclude and recommend the most 'popular' enrichment object and location for piglets raised in the conventional farrowing crate.

All pigs from Trial 1 went through three major regrouping events: from farrowing pen to nursery pen (weaning), from nursery pen to fattening pen, and from fattening pen to lairage at pre-slaughter. To investigate whether there is a long-term effect of pre-weaning socialization and environmental enrichment in the early life on the adaptability to regrouping, it would have been more convenient to carry out lesion scoring and saliva sampling at three sampling points (i.e. 1 day before, 1 day after, and 2 days after regrouping) in each regrouping event. Change of lesion score indicates the level of aggression within a group and that of salivary stress biomarkers indicates the level of stress response before and after regrouping. Future experiments are recommended to consider more sampling points to generate a more robust result.

Although there is a prediction model in pigs which estimates the days needed to reach the slaughter weight (López-Vergé et al., 2018), more weighing points in the fattening stage would have assisted the model to better calculate the growth curve. To investigate the life-long growth performance in pigs, some key weighing points are suggested in each stage, not only to generate a more powerful result but also to ensure the welfare of the experimental animals by avoiding unnecessary handling stress. However, it is also true that weighing causes unnecessary stress to the animals. Combing other parameter like feed intake would also give more insight on growth performance and feed efficiency in pigs when comparing different housing conditions, which also applies to Trial 2.

Low number of animals in Trial 2 is also the limitation, which gives a weak statistical power to interpret the results and to evaluate the parameters like seasonal effect or pre-weaning mortality. A small sample size involved in the study may as well does not reflect adequately the commercial conditions. As farrowing pens with temporary crating are becoming a trend in the European Union, more research on the effect of this system on adapting to weaning stress in piglets is necessary.

Another limitation of Trial 2 is that more welfare indicators could have been included to assess a more complete overview of the welfare of sows and piglets in different farrowing systems. For instance, teat and shoulder lesions in sows, and leg lesions in piglets due to sow stepping. Considering more welfare indicators would help to shed more light on the improvement to design a better farrowing system.

Lastly, SWAP system is designed to encourage the sows to separate the lying and dunging areas. It is one of the limitations of the study that we did not observe whether it was true and apart from SWAP system, how the sows in JLF15 system used their space. Future investigation on space preference of sows in farrowing pens can be considered to help maintaining pen cleanliness and help avoiding piglet crushing. More research using farrowing pens with temporary crating in hot climate countries would also assist to select appropriate alternative farrowing systems for the warmer region.

7.8. References

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CHAPTER 8.

CONCLUSIONS

1.1. Socialization and environmental enrichment during the lactation period facilitated exploratory and object play behaviors in the pre-weaning period, and reduced aggression and stress response in the post-weaning period.

1.2. Socialization and environmental enrichment during the lactation period did not affect the incidence of abnormal behavior (i.e. ear biting) in the later stages of the pigs' lives.

1.3. Skin lesions on the carcasses indicated that socialization and environmental enrichment during the lactation period affected agonistic interactions at pre-slaughter mixing. This suggests a life-long impact of socialization and environmental enrichment during the lactation period on their social skills from their early lives.

1.4. Pigs raised with socialization and environmental enrichment during the lactation period continued their weight gain shortly after two regrouping events. An improved short-term growth performance suggests a better ability to cope with regrouping. Pigs raised with socialization and environmental enrichment during the lactation period also tended to be slaughtered earlier, which may suggest a life-long benefit of a higher growth rate.

2.1. Farrowing pens with temporary crating system facilitated sow-piglet interactions and exploration in sows. Compared with the same sampling points of the sows in conventional crates, the facilities and the practice of temporary crating, including sow confinement and crate opening, did not produce a stress response in the sows in farrowing pens with temporary crating systems.

2.2. Growth performance and prevalence of foreleg abrasion during the lactation period in piglets were similar between farrowing systems.

2.3. Crushing rate was 1.9- and 3.6-times higher in farrowing pens with temporary crating system, compared with the farrowing crate. Fall had the lowest crushing rate compared to the rest of the seasons in all farrowing systems. Whether the sows were crated or not, in temporary crating systems, did not affect the crushing rate. The percentage of sows using a support from the pen fixtures while changing posture but still crushed the piglet was higher in the farrowing crate, compared to farrowing pens with temporary crating system.

2.4. The aggression level in piglets during the post-weaning period was similar between farrowing systems. However, SWAP (i.e. one of the two farrowing pens with temporary crating system) piglets showed a lower stress response after weaning compared to the rest of the farrowing systems.