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Pig welfare in farrowing housing systems: linking scientific approaches and stakeholders' expectations

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Orientadora: Profª. Drª. Maria José Hötzel

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Profª. Drª. Maria José Hötzel
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RESUMO

Opiniões sobre bem-estar animal variam entre as diferentes partes interessadas; o público mostra mais preocupação com a naturalidade e os estados afetivos dos animais, enquanto membros da indústria tendem a priorizar o funcionamento biológico. Dois estudos brasileiros, realizados pela autora desta dissertação, sobre sistemas de maternidade de suínos mostraram que o uso de gaiolas de maternidade não é aprovado pelo público. A licença social (i.e., permissão da sociedade para o funcionamento dos sistemas de produção animal) da produção animal pode ser comprometida quando as preocupações do público não são levadas em consideração pela indústria. A suinocultura se beneficiaria, portanto, da adoção de sistemas de maternidade alternativos com base em evidências científicas e abordando as preocupações sobre bem-estar de suínos de todas as partes interessadas. Esta dissertação tem como objetivo utilizar uma revisão sistemática para identificar como o bem-estar de porcas e leitões tem sido avaliado nos estudos empíricos sobre sistemas de maternidade e resumir seus principais resultados. No total, 708 artigos foram identificados por meio de pesquisas bibliográficas no Scopus e Web of Science. As publicações somente foram incluídas se fossem artigos de pesquisa empírica revisados por pares investigando o efeito do alojamento de maternidade em pelo menos um parâmetro de bem-estar animal de porcas e/ou leitões. Após a triagem dos critérios de inclusão, 56 publicações foram retidas. Os resultados sobre bem-estar animal foram categorizados com base na natureza do parâmetro investigado: comportamental, fisiológico, de desempenho e de saúde. Estudos comparando gaiolas de maternidade e baias de maternidade solta foram a maioria (n=20), seguidos pelos estudos comparando gaiolas e alojamentos em grupo (n=10). Parâmetros comportamentais foram os mais utilizados para avaliar o bem-estar de porcas (77%), seguidos por saúde (44%), desempenho (41%) e parâmetros fisiológicos (41%). A maioria dos estudos sobre bem-estar de leitões avaliou parâmetros de desempenho (70%) e parâmetros comportamentais (pré-desmame 57%; pós-desmame 34%), 30% investigaram parâmetros de saúde e 16% parâmetros fisiológicos. Nenhum estudo investigou os impactos dos sistemas de maternidade nos indicadores emocionais de bem-estar animal. Além disso, muitas características variaram entre os estudos selecionados para a revisão (por exemplo, o confinamento temporário de porcas após o parto e o fornecimento de cama), o que dificulta concluir sobre os efeitos dos sistemas de maternidade sobre o bem-estar dos animais. Em geral, a maioria dos parâmetros de bem-estar de porcas teve resultados positivos nos sistemas de alojamento alternativos em comparação às gaiolas de maternidade. A falta de estudos comparando os sistemas de maternidade alternativos não permite concluir sobre o bem-estar animal nos diferentes sistemas alternativos. A maioria dos parâmetros utilizados para avaliar o bem-estar dos leitões teve resultados conflitantes ou não encontrou nenhuma diferença entre os alojamentos de maternidade. Os resultados desta revisão mostram que os sistemas de maternidade alternativos promovem melhor bem-estar animal comparado às gaiolas de maternidade. Entretanto, ainda existem lacunas de conhecimento que precisam ser abordadas para guiar a indústria de suínos no desenvolvimento e adoção de alternativas sustentáveis para os sistemas de maternidade. A adoção de sistemas alternativos que não atendam às expectativas do público, dos produtores e às necessidades dos animais podem se mostrar insustentáveis no longo prazo resultando em perdas econômicas para a indústria.

Palavras-chave: porca, leitão, bem-estar animal, gaiolas de maternidade.

ABSTRACT

Opinions on animal welfare vary among different stakeholders; the public shows more concern for the naturalness and animals' affective states, while animal production stakeholders tend to prioritize biological functioning. Two Brazilian studies, carried out by the author of this dissertation, on farrowing housing systems showed that the use of farrowing crates is not approved by the public. The social license (i.e., society's permission for the functioning of animal production systems) of animal production can be compromised when public concerns are not considered by the industry. The pig industry would therefore benefit from adopting alternative farrowing systems based on scientific evidence and addressing all stakeholders' concerns about pig welfare. This dissertation aims to use a systematic review to identify how sow and piglet welfare have been assessed by empirical studies on farrowing housing systems and summarize their main results. In total, 708 articles were identified via literature searches in Scopus and Web of Science. Publications were only included if they were peer-reviewed empirical research articles investigating the effect of farrowing housing on at least one parameter of sows' and/or piglets' welfare. After screening for inclusion criteria, 56 publications were retained. The results on animal welfare were categorized based on the nature of the parameter investigated: behavioural, physiological, performance and health. Studies comparing farrowing crates and loose farrowing pens were the majority (n=20), followed by studies comparing crates and group housing (n=10). Behavioural parameters were the most used to assess the welfare of sows (77%), followed by health (44%), performance (41%) and physiological parameters (41%). Most studies on piglet welfare evaluated performance (70%) and behavioural parameters (pre-weaning 57%; post-weaning 34%), 30% investigated health parameters and 16% physiological parameters. No study investigated the impacts of farrowing systems on emotional indicators of animal welfare. In addition, many characteristics varied among the studies selected for the review (e.g., temporary crating of sows after farrowing and provision of bedding), which makes it difficult to conclude on the effects of farrowing systems on animal welfare. Overall, most sow welfare parameters had positive results in alternative housing systems compared to farrowing crates. The lack of studies comparing alternative farrowing systems does not allow conclusions about animal welfare in the different alternative systems. Most parameters used to assess piglet welfare had conflicting results or found no difference among farrowing systems. The results of this review show that alternative farrowing systems promote better animal welfare compared to farrowing crates. However, there are still knowledge gaps that need to be addressed to guide the pig industry in the development and adoption of sustainable alternatives to farrowing housing systems. The adoption of alternative systems that do not meet the expectations of the public, producers and the needs of animals may prove unsustainable in the long term, resulting in economic losses for the pig industry's supply chain.

Keywords: sow, piglet, animal welfare, farrowing crates, social license.

RESUMO EXPANDIDO

Introdução

A maioria das porcas e leitões criados comercialmente em todo o mundo são alojados em gaiolas de maternidade (ABCS, 2014; BAXTER, E.; EDWARDS, 2016; USDA, 2015). Nesse alojamento a porca é restringida dentro de uma baia por barras de metal, de forma que ela pode ficar em pé e se deitar, mas não pode se virar ou andar. Os leitões podem circular na baia ao redor da porca e têm acesso a uma área com uma fonte de calor chamada de escamoteador, mas não podem socializar com leitões de outras leitegadas. As porcas são alojadas em gaiolas de maternidade desde alguns dias antes do parto até o desmame dos leitões, que é feito entre 21 e 28 dias de idade. Embora apenas a Noruega, a Suécia e a Suíça tenham proibido o uso de gaiolas de maternidade (BAXTER, E.; EDWARDS, 2016), muitos outros países começaram a discutir a eliminação gradual de seu uso (Alemanha: COMPASSION IN WORLD FARMING, 2020; Reino Unido: GUARDIAN, 2021; Nova Zelândia: NEWSHUB, 2020; União Europeia: PIG PROGRESS, 2021). Estas discussões têm sido instigadas por iniciativas do público, como a "End the Cage Age" (www.endthecageage.eu, acessado em 19 de julho de 2022), que estão de acordo com estudos recentes que identificaram elevada rejeição pública ao alojamento de porcas e leitões em gaiolas de maternidade (SONNTAG et al., 2019; VANDRESEN; HÖTZEL, 2021b, 2021a). À medida que o uso de gaiolas de maternidade se mostra eticamente insustentável, tornam-se necessários sistemas de maternidade alternativos para substituir as gaiolas e atender as preocupações da sociedade.

A principal alternativa para substituir as celas de parição são as baias de maternidade solta, nas quais a porca fica solta com os leitões dentro da baia. As baias de maternidade solta variam em tamanho e design, e muitos modelos diferentes estão atualmente disponíveis no mercado (por exemplo, PigSAFE, Danish Free Farrower, Comfort Pen). Outra opção são os sistemas de lactação em grupo, onde várias porcas em lactação e suas ninhadas podem ser alojadas juntas (sistema de multi-aleitamento), ou as ninhadas podem ser alojadas em baias diferentes com uma área comum para as porcas socializarem sem os seus leitões (sistema de fuga) (VAN NIEUWAMERONGEN et al., 2014). A lactação em grupo é altamente relevante para a discussão sobre o alojamento de parição, pois permite interações sociais entre as porcas, o que foi apontado como uma importante preocupação do público em relação ao bem-estar de suínos (SATO; HÖTZEL; VON KEYSERLINGK, 2017; VANDRESEN; HÖTZEL, 2021b). A maternidade ao ar livre foi o sistema mais positivamente avaliado pelo público quando comparado com as gaiolas de maternidade e as baias de maternidade solta (VANDRESEN; HÖTZEL, 2021a), principalmente por estar mais próximo do ambiente natural dos animais (LASSEN; SANDØE; FORKMAN, 2006). Nesse sistema, as porcas e os leitões são alojados em um piquete de pastagem com cabanas individuais onde a porca pode construir um ninho para parir.

Pesquisas científicas sobre bem-estar animal começaram devido às preocupações éticas da sociedade em relação à qualidade de vida dos animais (FRASER, et al., 1997). Fraser et al. (1997) sugerem que o bem-estar animal pode ser definido com base em três classes de preocupações éticas em relação à qualidade de vida dos animais: funcionamento biológico (preocupações com o funcionamento 'normal' dos sistemas biológicos dos animais), estados afetivos (preocupações com os sentimentos e emoções dos animais) e vida natural (preocupações com a capacidade dos animais de viver de acordo com sua natureza). As opiniões sobre o bem-estar animal variam entre as diferentes partes interessadas; o público está preocupado principalmente com a naturalidade e os estados afetivos dos animais, enquanto os atores da produção animal tendem a priorizar o funcionamento biológico (ALBERNAZ-

SILVA; OLMOS ANTILLON; HÖTZEL, 2021; TUYTTENS et al., 2010). A suinocultura, portanto, se beneficiaria da adoção de sistemas de maternidade alternativos, desenhados com base em evidências científicas que abordem as preocupações de todas as partes interessadas sobre o bem-estar de suínos, uma vez que os sistemas de maternidade alternativos que não atenderem a essas demandas podem se mostrar insustentáveis no longo prazo (semelhante ao caso das gaiolas enriquecidas para galinhas poedeiras; CAO et al., 2021; DOYON et al., 2016; GAUTRON et al., 2021).

Objetivo

Analisar quais parâmetros são investigados nos estudos empíricos sobre bem-estar de porcas e leitões nos sistemas de maternidade, e resumir os resultados e conclusões sobre cada parâmetro avaliado.

Metodologia

As buscas bibliográficas foram realizadas nas plataformas Web of Science (WoS) (https://www.webofknowledge.com/) e Scopus (https://www.scopus.com/), bases de dados que juntas abrangem uma ampla gama de estudos em bem-estar animal. Os códigos de busca foram desenvolvidos com base na metodologia PICO (RICHARDSON et al., 1995), que consiste em definir a população alvo (porcas e leitões), a intervenção (sistemas de maternidade) e o resultado (bem-estar animal). As buscas bibliográficas foram concluídas em 18 de novembro de 2021. As condições para inclusão na revisão eram ser um artigo de pesquisa empírica revisado por pares que investigasse o efeito do alojamento de maternidade em pelo menos um parâmetro de bem-estar de porcas e/ou leitões. Os estudos também deveriam comparar pelo menos dois sistemas de maternidade para serem considerados na revisão. Foram coletados dados sobre o ano de publicação, país do estudo, idioma, sistemas de maternidade investigados, se o estudo utilizou confinamento temporário e por quanto tempo, e se investigou o bem-estar da porca, do leitão ou de ambos. Também foram coletados dados sobre quais parâmetros foram utilizados para avaliar bem-estar animal e quais foram os principais resultados e conclusões sobre cada parâmetro. Os parâmetros utilizados para avaliar bem-estar animal foram categorizados com base na natureza do parâmetro investigado: comportamental, fisiológico, de desempenho e de saúde. Também foram coletadas informações sobre o alojamento de gestação utilizado, quantos dias antes da data prevista do parto as porcas foram transferidas para o alojamento de maternidade, idade de desmame dos leitões e se foi fornecida cama ou enriquecimento no sistema de maternidade.

Resultados

Das 708 publicações identificadas após a remoção de duplicatas, 599 foram excluídas na primeira triagem e 53 na segunda triagem por não atenderem aos critérios de elegibilidade. Cerca de metade das publicações (48%) avaliaram o bem-estar de porcas e leitões, enquanto 30% investigaram apenas o bem-estar dos leitões e 21% apenas o bem-estar das porcas. A maioria dos estudos alojaram porcas em sistemas de gestação coletiva (43%), e 39% dos estudos forneceu material de cama, sendo a palha o material mais utilizado. O momento de transição das porcas do alojamento de gestação para o alojamento de maternidade variou de 2 a 19 dias antes da data prevista do parto, os períodos mais utilizados foram entre 4 e 7 dias. A idade de desmame dos leitões variou de 21 a 50 dias, sendo 28 dias a idade de desmame mais comum (27%).

Os estudos que comparam gaiolas de maternidade e baias de maternidade solta foram a maioria (36%), seguidos por estudos que compararam gaiolas de maternidade e maternidade em grupo (18%). Os parâmetros comportamentais foram os mais utilizados para avaliar o bem-

estar de porcas (77%), seguido por parâmetros de saúde (44%), de desempenho (41%) e fisiológicos (41%). A maioria dos estudos que avaliaram o bem-estar de leitões investigou desempenho (70%) e parâmetros comportamentais (pré-desmame 57%; pós-desmame 34%), 30% investigaram parâmetros de saúde e 16% parâmetros fisiológicos.

Os resultados da maioria dos parâmetros utilizados para avaliar bem-estar animal indicaram que os sistemas de maternidade alternativos melhoram o bem-estar das porcas em comparação com as gaiolas de maternidade. Por exemplo, porcas ocuparam menos tempo em comportamentos estereotipados, tiveram níveis mais baixos de cortisol e melhores interações sociais com seus leitões em sistemas alternativos em comparação com as gaiolas. O único parâmetro que indicou piora no bem-estar da porca em sistemas alternativos em relação às gaiolas de maternidade foi a frequência de lesões de pele; as porcas nas gaiolas tiveram menos lesões de pele do que nos outros sistemas de maternidade. No entanto, lesões de úbere e teto foram menos frequentes em sistemas de maternidade alternativos do que nas gaiolas. Considerando os parâmetros de bem-estar de leitões, os estudos encontraram mais vantagens do que desvantagens em alojar leitões em sistemas de maternidade alternativos do que em gaiolas de maternidade. No entanto, muitos estudos tiveram resultados conflitantes ou não encontraram diferença para o bem-estar de leitões entre os tipos de alojamento investigados. Em relação aos parâmetros de desempenho de leitões, mais estudos encontraram que os sistemas de maternidade alternativos têm efeitos positivos do que negativos em comparação com as gaiolas de maternidade. Muitos estudos sobre o bem-estar de leitões investigaram mortalidade pré-desmame e a maioria não encontrou diferença entre a gaiola de maternidade e os sistemas de alojamento alternativos nesse parâmetro. Nenhum estudo investigou os estados afetivos de porcas ou leitões nos diferentes sistemas de maternidade.

Discussão

O bem-estar dos animais é um valor intrínseco que só pode ser determinado por suas próprias experiências. Portanto, pesquisadores utilizam parâmetros mensuráveis como indicadores para avaliar bem-estar animal (HEMSWORTH et al., 2015). Esta revisão identificou que a maioria dos estudos sobre o bem-estar de porcas em sistemas de maternidade investigou parâmetros de comportamento, seguido por saúde, desempenho e parâmetros fisiológicos. A maioria dos estudos sobre o bem-estar de leitões em sistemas de parição investigou parâmetros de performance, seguido por comportamento pré e pós-desmame, saúde e parâmetros fisiológicos.

O parâmetro comportamental mais utilizados para avaliar o bem-estar das porcas foi postura e alterações posturais. Com base no comportamento natural da espécie, porcas mudam frequentemente de postura para checar seus leitões após o parto (BAXTER; EDWARDS, 2018). No entanto, as porcas não podem mudar de postura nas gaiolas de maternidade porque não são capazes de se virar dentro da gaiola. Esta restrição de movimento pode comprometer as habilidades maternas da porca, portanto, frequências mais baixas de mudanças de postura nas gaiolas de maternidade podem indicar incapacidade das porcas de cuidar de seus leitões. Os estudos que utilizam comportamento para avaliar bem-estar animal em sistemas de maternidade devem avaliar a liberdade das porcas de se movimentar e realizar os comportamentos naturais de sua espécie, como construção de ninhos e interações sociais com outras porcas e seus leitões (BAXTER; EDWARDS, 2018). Para que isso seja possível, os sistemas de maternidade alternativos precisam fornecer espaço, substrato e enriquecimento social suficientes para permitir que os animais realizem esses comportamentos.

Embora as medidas fisiológicas sejam comumente utilizadas para avaliar bem-estar animal (MORMÈDE et al., 2007), os parâmetros fisiológicos foram os menos utilizados para avaliar o bem-estar de porcas e leitões na literatura revisada. O cortisol em amostras de sangue,

saliva e pelo foi o parâmetro fisiológico mais investigado. A concentração de cortisol é uma medida útil para identificar respostas fisiológicas ao estresse. No entanto, os níveis de cortisol não fornecem informações sobre as condições envolvidas na ativação dessa resposta e suas consequências comportamentais ou emocionais para os animais (RALPH; TILBROOK, 2016). Além disso, os níveis de cortisol podem ser influenciados por múltiplos aspectos não relacionados ao bem-estar animal. Por exemplo, as concentrações plasmáticas de cortisol podem variar entre espécies e indivíduos, e podem ser influenciadas pelo consumo de alimentos e pela temperatura e umidade do ambiente (MORMÈDE et al., 2007). Portanto, a avaliação do bem-estar animal por meio dos níveis de cortisol precisa ser utilizada e interpretada com cautela, e sua associação com parâmetros comportamentais e emocionais de bem-estar animal deve ser incentivada.

Muitos parâmetros de saúde foram utilizados para avaliar o bem-estar de porcas e leitões em sistemas de maternidade, como lesões de pele, claudicação e necessidade de tratamento médico. No entanto, o bem-estar animal nem sempre se reflete na saúde dos animais, pois animais com boa saúde física também podem ter um bem-estar ruim (VEISSIER et al., 2008). Portanto, o desenvolvimento de sistemas de maternidade para melhorar o bem-estar animal não deve se basear apenas em indicadores de saúde animal.

Alguns dos parâmetros de desempenho investigados na literatura revisada incluíram o escore de condição corporal da porca e o peso corporal do leitão, o que pode refletir o bem-estar animal, uma vez que animais estressados ou doentes podem apresentar perda de peso (RAULT et al., 2014). No entanto, muitos dos parâmetros de desempenho avaliados não estavam relacionados com bem-estar animal (por exemplo, desempenho reprodutivo e eficiência de conversão alimentar). O aumento na mortalidade pré-desmame de leitões é uma das principais preocupações em relação à adoção de sistemas de maternidade alternativos. No entanto, muitos estudos não encontraram diferença na mortalidade de leitões entre gaiolas e sistemas alternativos. Além disso, diversas outras práticas relacionadas com risco de mortalidade de leitões continuam a ser utilizadas na indústria de produção de suínos. Por exemplo, a seleção genética para hiperprolificidade é uma prática muito comum para aumentar o número de leitões desmamados por porca mas está associada com maior risco de mortalidade pré-desmame devido ao menor peso e vitalidade dos leitões ao nascimento (FOXCROFT et al., 2006). Baxter e Edwards, (2018) também argumentam que não está claro como a morte dos leitões logo após o nascimento influencia o seu bem-estar, enquanto o uso de gaiolas para minimizar a perda de leitões devido ao maior risco de mortalidade de leitões em grandes ninhadas é uma questão de preocupação ética (BAXTER; EDWARDS, 2018; VANDRESEN; HÖTZEL, 2021a).

As alternativas para substituir as gaiolas de maternidade precisam atender às preocupações do público e promover melhor bem-estar animal para serem sustentáveis. A adoção de sistemas de maternidade alternativos que não atendam a essas demandas podem estar associadas a custos econômicos e estratégicos no longo prazo. Portanto, a suinocultura precisa de evidências baseadas em pesquisas das ciências naturais e sociais sobre o bem-estar animal em sistemas de maternidade. Apesar da grande quantidade de estudos sobre bem-estar de porcas e leitões em sistemas de maternidade, a inconsistência nos modelos de alojamento e nas práticas de manejo animal utilizadas comprometeu a avaliação dos sistemas de maternidade. Por exemplo, as baias de maternidade solta variaram no espaço disponível para as porcas, os sistemas de maternidade em grupo alojaram porcas em grupos de tamanhos diferentes, e alguns estudos sobre maternidade ao ar livre utilizaram sistemas semiextensivos. Esta variedade dentro da mesma categoria de alojamento de maternidade pode ter influenciado os resultados dos estudos, comprometendo a avaliação dos efeitos dos sistemas de maternidade no bem-estar de porcas e leitões.

Antes de tomar decisões sobre qual sistema deve substituir as gaiolas de maternidade, são necessárias mais pesquisas sobre como os diferentes modelos de alojamento e práticas de manejo nos sistemas de maternidade podem influenciar o bem-estar animal. As opiniões dos agricultores e do público sobre os sistemas de maternidade são conhecidas, mas também é necessário investigar como as porcas e os leitões se sentem e quais são as suas preferências em relação a esses sistemas. Portanto, lacunas de conhecimento na avaliação do bem-estar animal em sistemas de maternidade devem ser abordadas para permitir tirar conclusões sobre como os sistemas de maternidade influenciam o bem-estar de porcas e leitões.

Conclusão

Os resultados desta revisão sistemática mostram que os sistemas de maternidade alternativos promovem melhor bem-estar animal comparado às gaiolas de maternidade, o que está de acordo com estudos de opinião pública que indicam que as gaiolas de maternidade são socialmente insustentáveis. Entretanto, ainda existem lacunas de conhecimento que precisam ser abordadas para guiar a indústria de suínos no desenvolvimento e adoção de alternativas sustentáveis para os sistemas de maternidade. A adoção de sistemas alternativos que não atendam às expectativas do público, dos produtores e às necessidades dos animais podem se mostrar insustentáveis no longo prazo resultando em perdas econômicas para a indústria.

FIGURE LIST

TABLE LIST

SUMMARY

1 INTRODUCTION

1.1 FARROWING CRATES AS A THREAT TO THE PIG INDUSTRY SOCIAL LICENSE

Animal welfare is a socially driven concept, as scientific research on animal welfare began due to the social ethical concerns regarding the quality of life of animals (FRASER, et al., 1997). Fraser, et al., (1997) suggest that animal welfare can be categorized based on three classes of ethical concerns that can arise regarding animals' quality of life: biological functioning (concerns regarding the 'normal' functioning of animals' biological systems), affective states (concerns regarding the feelings and emotions of animals), and natural living (concerns regarding the ability of animals to live according to their nature).

Confined housing is a pillar of intensive animal production (FRASER, 2008), yet one of the most rejected practices in livestock systems (CLARK et al., 2016). Although animal confinement has been criticized since the initial discussions about the quality of life of animals reared in intensive farm systems (BRAMBELL, 1965; HARRISON, 1964), most commercial pig farms house sows in individual crates during their reproductive life. Gestation and farrowing crates confine the sow in a way that she can stand up and lie down but cannot turn around or walk. Gestation crates are used in intensive pig production systems to house sows during gestation (approximately 114 days), whereas farrowing crates are used to house sows from around a week before farrowing until piglets are weaned (most usually imposed between 21 and 35 days after birth). In the farrowing crate, the piglets can circulate around the sow's crate in a pen of around 4 m^2. The main justification to use farrowing crates is to prevent the sow from crushing piglets, which is done by physically restricting her movements (DRIVER, 2019; EDWARDS, 2002). Piglet crushing, which is considered a main cause of piglet preweaning mortality, occurs when the sow lies over her piglets (DAMM; FORKMAN; PEDERSEN, 2005), and is most common in the first week after farrowing (e.g., 84% preweaning live born deaths occurred 7 days after farrowing, KILBRIDE et al., 2012). The proponents of the farrowing crates argue that the crates are necessary to prevent piglet crushing and that the change to alternative systems would result in the death of many piglets, which would be economically unviable for pig producers and detrimental to piglets' welfare (DRIVER, 2021; NAWAC, 2016). A meta-analysis study concluded that the relative risk of pre-weaning mortality is 14% lower in farrowing crates than in loose farrowing pens (GLENCORSE et al., 2019), which is the main alternative to replace the crates in intensive pig production systems.

However, some studies have questioned the efficiency and need of farrowing crates to prevent piglet crushing, since it has been shown that neonatal piglet mortality is associated with several factors besides housing, namely farrowing management, birth weight, and litter size (GLENCORSE et al., 2019; O'REILLY et al., 2006).

The implications of confinement housing for animal welfare and food production have been a growing matter of debate among researchers, citizens, and policymakers over the years. Attitudes towards animal welfare not always translate into purchasing behaviour, which is widely discussed in the "attitude-behaviour gap" literature (HARVEY; HUBBARD, 2013; VERMEIR; VERBEKE, 2006). However, these attitudes may cause moral discomfort, which may be expressed in ways other than purchasing behaviour (TONSOR; WOLF, 2010). For example, public rejection of farm animal confinement may influence consumers to pay more for products from systems that provide a higher level of animal welfare (CLARK et al., 2017), influence voting behaviour in support of legislation that protects animals (TONSOR; WOLF; OLYNK, 2009), or support private regulations and animal welfare auditing programs to suppliers (GRANDIN, 2014). Society's permission for animal production systems to operate is referred to as social license (HAMPTON; JONES; MCGREEVY, 2020). The pig production social licence can be compromised when public concerns regarding systems or practices are not taken into account by industry and policy makers. Thus, identifying and understanding societal attitudes towards farm animal welfare is key to achieve socially sustainable livestock production (VON KEYSERLINGK; HÖTZEL, 2015). In the case of gestation crates, several studies have shown public concern regarding this housing system (RYAN; FRASER; WEARY, 2015; YUNES, M.; KEYSERLINGK; HÖTZEL, 2018) and many countries and some of the largest food companies in the world have banned their use (VON KEYSERLINGK; HÖTZEL, 2015). In contrast, it is estimated that around 90% of sows and their piglets are housed in farrowing crates in Brazil, United States, and most European Union countries (Brazil: ABCS, 2014; EU: BAXTER; EDWARDS, 2016; US: USDA, 2015), even though citizens from these countries disapprove animal confinement (Brazil: YUNES, M. C.; VON KEYSERLINGK; HÖTZEL, 2017; EU: EUROBAROMETER, 2007; US: SATO; HÖTZEL; VON KEYSERLINGK, 2017). Sweden, Switzerland, and Norway are the only countries where the use of farrowing crates is currently prohibited. One factor that may explain the industry's lack of urgency to change the status quo of farrowing crates may be the lack of research showing empirical evidence of the societal opinion on that matter.

The few studies that investigated public opinion on the use of farrowing crates showed public opposition (Germany: SONNTAG et al., 2019; Brazil: VANDRESEN; HÖTZEL, 2021b). More specifically, SONNTAG et al., (2019) identified that most participants in a survey with around 1,300 German citizens did not agree that limiting sows' movements is acceptable to prevent piglets from being crushed by the sow. Similarly, Vandresen and Hötzel, (2021b) identified overall negative attitudes towards the conventional farrowing crates in two surveys with around 2,000 Brazilian citizens. Participants in this study agreed that farrowing housing systems need to prevent piglet mortality by crushing but not at the cost of depriving the sow's freedom to move and perform natural behaviours. Furthermore, Brazilian citizens considered that sow welfare should be a priority in farrowing housing systems, including the effects of housing to sows' affective states. This study also found a positive association between perceived sows' and piglets' quality of life and attitudes towards farrowing crates, indicating the importance of animals' quality of life for societal support for livestock housing systems. The main issues regarding farrowing housing systems mentioned by participants on Vandresen and Hötzel, (2021b) were sows' restriction of movement and the perception of loss of naturalness of animals living in farrowing crates, which resonates with other studies on public opinion towards livestock systems (HÖTZEL; VANDRESEN, 2022; YUNES, et al., 2021). These studies suggest that using housing that is perceived by the public as detrimental to animal welfare may compromise livestock systems' social license to operate. In the case of pig production systems, the financial, technical, and political efforts made by the pig industry to maintain its social license by transitioning to group gestation housing may be undermined by the reticence to move away from farrowing crates.

1.2 SCIENTIFIC APPROACHES TO ACHIEVE SOCIALLY SUSTAINABLE FARROWING SYSTEMS

In the 2020 decade political debates about phasing out the use of farrowing crates emerged in many countries (Germany: COMPASSION IN WORLD FARMING, 2020; United Kingdom: GUARDIAN, 2021; New Zealand: NEWSHUB, 2020; European Union: PIG PROGRESS, 2021). However, some countries still have not started to consider alternatives to the farrowing crates. One example is Brazil, an important pork producer and exporter (FAO, 2019), where the federal government recently published the Normative Ruling n. 113 (BRASIL, 2020) establishing several management changes aiming at improving pig welfare. These

changes include the replacement of gestation crates with group gestation by 2045, but this same document states that the use of farrowing crates will continue to be permitted. Similarly, regulations that prohibit the use of cages to house some farm animals (e.g., laying hens, veal calves, and gestation sows) allow the use of farrowing crates in the United States (USA, 2018). Despite the lack of action of these countries towards change in farrowing housing systems, recent social movements like the End the Cage Age (www.endthecageage.eu, accessed on 19 July 2022), and research studies that identified high public rejection to housing sows in farrowing crates (SONNTAG et al., 2019; VANDRESEN; HÖTZEL, 2021b, 2021a) highlight that farrowing crates are socially unsustainable and alternative farrowing systems that are in line with societal concerns are increasingly necessary.

The main indoor alternative to replace the farrowing crates are loose farrowing pens, in which the sow is loose with the piglets inside the pen. Loose farrowing pens vary in size and design, and many different models are currently available on the market (e.g., PigSAFE, Danish Free Farrower, Comfort Pen). Some loose farrowing systems keep the sow confined in a crate for a few days around farrowing (i.e., temporary crating) to prevent piglet crushing, which mainly occurs on the first days after farrowing (HALES et al., 2015). Temporary crating is an essential component of hinged farrowing crates, which have similar design and dimensions as the conventional farrowing crates but the crate opens to allow sows to be free inside the pen. Another alternative to the crates is the group lactation system, where multiple lactating sows and their litters can be housed in the same group (i.e., multi-suckling system), or the litters can be housed in different pens with a common area for the sows to socialize without their piglets (i.e., get-away system) (VAN NIEUWAMERONGEN et al., 2014). Group lactation is highly relevant for the discussion on farrowing housing given that it allows social interactions among sows, which was pointed as an important public concern regarding pig welfare (SONNTAG et al., 2019; VANDRESEN; HÖTZEL, 2021b, 2021a). Outdoor farrowing was the most positively evaluated by the public when compared to farrowing crates and loose farrowing pens (VANDRESEN; HÖTZEL, 2021a), mainly because it is closest to the natural environment of the animals (LASSEN; SANDØE; FORKMAN, 2006) as sows and piglets are housed on a pasture paddock with individual huts where the sow can build a nest for farrowing.

Alternative housing systems recommended to solve animal welfare problems need to address the social concerns originating from the demand for change (VON KEYSERLINGK; HÖTZEL, 2015; WEARY, D.M.; VENTURA; VON KEYSERLINGK, 2016). In the case of

farrowing housing systems, there are multiple alternative housing systems that could replace farrowing crates. However, little is known about to what extent these alternative farrowing systems accommodate public concerns regarding sows' and piglets' welfare. One study investigated Brazilian citizens' attitudes towards three options of farrowing accommodation: farrowing crates, loose farrowing pens, and outdoor farrowing systems (VANDRESEN; HÖTZEL, 2021a). The assessment of the different farrowing housing systems was overwhelmingly based on concern about the welfare of the sows, which participants rated as most negative in farrowing crates and most positive in the outdoor housing. Moreover, the preference for the loose pens over the farrowing crates was maintained even when participants were faced with the dilemma that providing more space for sows could incur some piglet mortality by crushing. These findings corroborate and expand previous findings (SONNTAG et al., 2019; VANDRESEN; HÖTZEL, 2021b), indicating that farrowing crates do not have societal support and that the use of piglet mortality cannot be used as justification to maintain this system. Public opposition to housing that prevents animals from moving freely and the clear preference for outdoor systems shown in this and other studies, e.g., (CENTNER, 2010; SATO; HÖTZEL; VON KEYSERLINGK, 2017), call for reflection on the steps to be taken to replace farrowing crates. Public concern for the welfare of the sow indicates that moving towards sow-friendly housing systems would be better suited to societal expectations about farrowing housing systems.

Views about animal welfare vary among different stakeholders; the public is mainly concerned about naturalness and animals' affective states, while animal production stakeholders tend to prioritize biological functioning (ALBERNAZ-SILVA; OLMOS ANTILLON; HÖTZEL, 2021; TUYTTENS et al., 2010). For example, one main concern of pig industry stakeholders regarding farrowing housing systems is the potential increase of piglet mortality by crushing in loose systems (DRIVER, 2021; NAWAC, 2016), while recent studies identified that the public is mainly concerned about the sows' freedom to move (VANDRESEN; HÖTZEL, 2021b, 2021a). The pig industry would benefit from adopting alternative farrowing systems based on scientific evidence that addresses all stakeholders' concerns about pig welfare, given that alternative farrowing systems that do not do so may prove to be socially unsustainable in the long term (similarly to the enriched cages for laying hens; CAO et al., 2021; DOYON et al., 2016; GAUTRON et al., 2021).

This systematic review aimed to investigate how empirical studies on farrowing housing systems assess sow and piglet welfare and summarise its main findings. I hope with

this review to identify research gaps that need to be addressed to guide the change to alternative farrowing housing systems and assess whether the published literature provides enough knowledge to address all stakeholders' concerns regarding pig welfare.

1.3 OBJECTIVE

Analyse which parameters are investigated in empirical studies on the welfare of sows and piglets in farrowing systems, and to summarize the results and conclusions on each parameter evaluated.

2 METHODS

2.1 LITERATURE SEARCH

Search codes were developed based on the PICO methodology (RICHARDSON et al., 1995), which consists of defining the target population (sows and piglets in farrowing housing systems), intervention (farrowing housing systems), and outcome (animal welfare) of the review. The search codes were optimized by the repeated combination of keywords and Boolean operators. The final Boolean phrase used for the literature search was:

(pig* OR sow* OR gilt*) AND (farrow* OR lactat*) AND (design* OR hous* OR system* OR outdoor* OR pen* OR crate* OR cage* OR group* OR loose) AND (welfare OR well-being OR wellbeing)

Literature searches were conducted on Web of Science (WoS) (https://www.webofknowledge.com/) and Scopus (https://www.scopus.com/), databases that together cover a wide range of studies published on animal welfare journals. Literature searches were completed on November 18, 2021.

2.2 ELIGIBILITY CRITERIA

Conditions to be included in the review were to be a peer-reviewed empirical research article that investigated the effect of farrowing housing on at least one outcome of sow and/or piglet welfare. Studies had to compare at least two farrowing housing systems to be considered in the review. Publications were excluded if they investigated different aspects of the same housing system (e.g., type of floor and heating source). Studies on the effect of enrichment within the same housing system were excluded (e.g., farrowing crates with or without straw provision), but studies that compared different housing systems were included (e.g., farrowing crates without straw provision and farrowing pens with straw provision). The provision of enrichment was taken into consideration in the interpretation of the results. Lastly, articles that investigated the effects of farrowing housing only on piglet crushing or had piglet crushing as the main objective of the study (e.g., effect of sow laying behaviour on piglet crushing in different farrowing systems) were not included. Piglet crushing was well addressed in other reviews (e.g. GLENCORSE *et al.*, 2019) and is not in the aim of the present study. Articles were not filtered by language or year of publication. Articles in languages other than English,

Portuguese, and Spanish (proficient language of the author and her supervisor) were interpreted using online translation tools. The title and abstract of all articles were scanned on the first screening to investigate if they fit in the criteria mentioned above. The full text of the papers was read on the second screening to investigate if they matched the aims of the review. Inclusion and exclusion criteria were developed and agreed among three researchers.

2.3 DATA EXTRACTION

Data on year of publication, country of the study, language, farrowing housing systems investigated, whether it included temporary crating and for how long, and whether it investigated sow welfare, piglet welfare, or both were extracted from each paper. Data were also collected on which parameters were used to assess animal welfare and what were the main results and conclusions on each parameter. The parameters used to assess animal welfare were categorized based on the nature of the outcome investigated: behavioural, physiological, performance, and health. Information was also collected on the gestation housing used prior to the farrowing period, how many days before the expected farrowing date sows were moved to the farrowing housing, piglets' weaning age, and whether bedding or enrichment was provided.

3 RESULTS

A flow chart summarizing the identification and selection of publications for the review is presented on Figure 1. Of the 708 publications identified after duplicates removal, 599 were excluded on the first screening and 53 were excluded on the second screening for not meeting the eligibility criteria, totalizing a final sample of 56 studies. Specified reasons for exclusion are detailed on the Appendix A (Tables A1 and A2). The year of publication of the studies selected to the review ranged from 1991 to 2021, with a substantial increase in the number of publications over the last three years: an average of 2 ± 1 publication per year from 1990 to 2018 and an average of 9 ± 1 publication per year from 2019 to 2021. All publications were in English (n = 56), and studies were predominantly from Australia (18%) and Germany (13%) (Table X). Around half of the publications (48%) assessed sow and piglet welfare, while 30% investigated only piglet welfare and 21% only sow welfare.

Half of the studies (50%) selected for the review did not provide information on gestation housing. Many studies housed sows in group gestation housings (43%), two studies housed sows in gestation pens and two studies housed sows in gestation stalls. The time sows were moved from the gestation housing to the farrowing housing ranged from 2 to 19 days prior to the expected farrowing date, with the most used time periods being from 4 to 7 days. Piglets' weaning age ranged from 21 to up to 50 days, and 28 days was the most common age of weaning (27%). Bedding was provided in 39% of the studies, with straw being the most used material. Besides bedding, some type of enrichment (e.g., rope and a plastic roll) was provided in 12 studies.

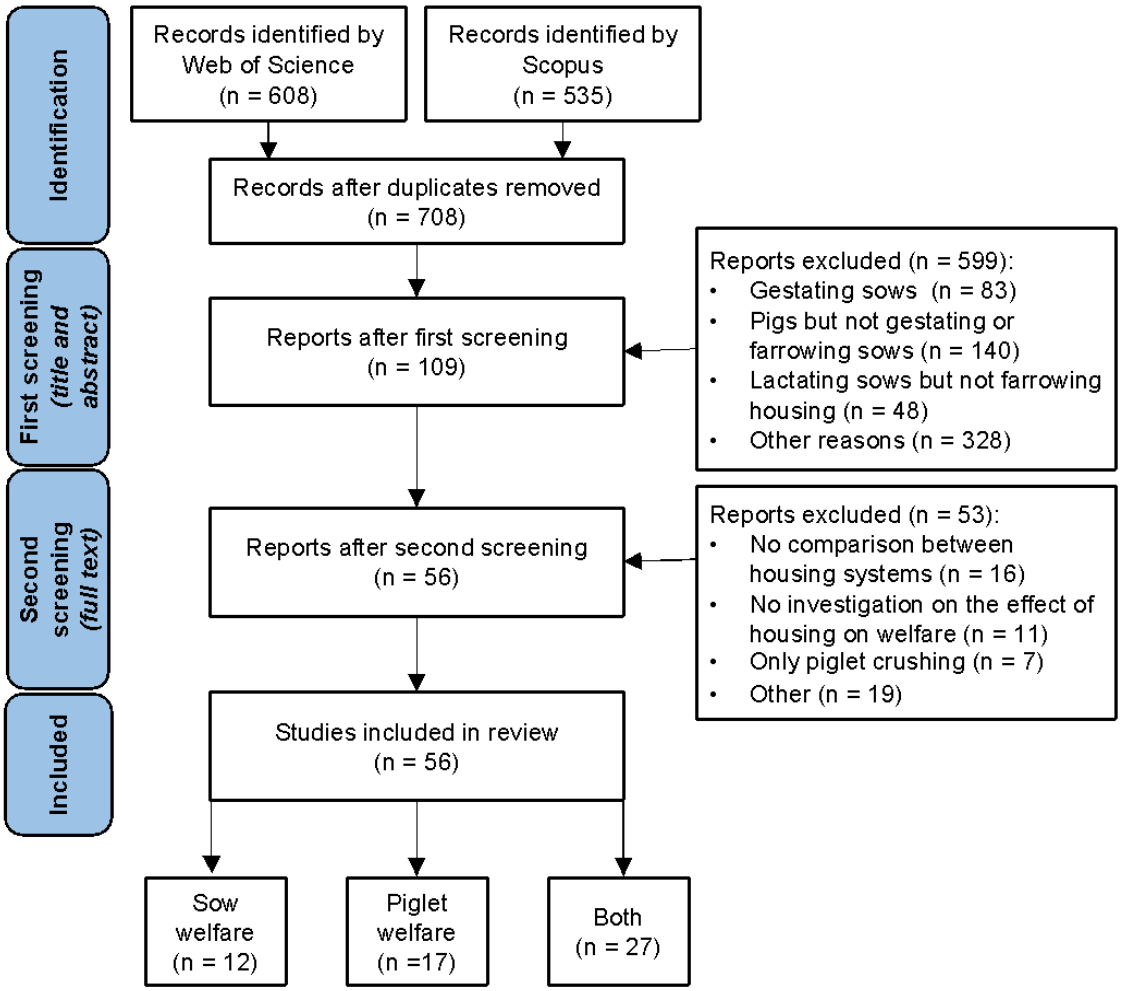

Figure 1. Flow chart depicting the number of publications obtained from each database and the exclusion of publications over the first and second screenings. Studies included in the review (n = 56) were categorized based on whether they investigated only sow welfare parameters (n = 12), only piglet welfare parameters (n = 17), or both (n = 27).

3.1 CHARACTERIZATION OF STUDIES

Studies comparing farrowing crates and loose farrowing pens were the majority (36%), followed by studies comparing crates and group housing (18%) (Table 1). Figures illustrating the design of the housing systems investigated in the reviewed literature are provided in the appendix C. Behavioural outcomes were the most used to assess sow welfare (77%), followed by health (44%), performance (41%) and physiological outcomes (41%). Most studies assessing piglet welfare addressed performance (70%) and behavioural parameters (pre-weaning 57%; post-weaning 34%), 30% investigated health and 16% physiological parameters. Specific

parameters measured in each category are shown in the Appendix B (Tables B1 and B2). The following session presents the relevant results and conclusions of each study as described by the authors.

Table 1. Number of studies selected to the systematic review according to the control and treatment housing systems investigated, and whether they investigated sow or piglet welfare.

Control	Treatment	Sow	Piglet	Total
Farrowing crates	Loose farrowing pen	16	15	20
	Group housing	5	9	10
	Outdoor farrowing	3	4	5
	Loose farrowing pen and Group housing	1	3	3
	Open hinged farrowing crate and Loose farrowing pen	2	2	2
	Ellipsoid-farrowing crate and Farrowing pen	-	2	2
Closed hinged farrowing crate	Open hinged farrowing crate	8	7	9
Loose farrowing pen	Group housing	1	2	2
	Loose farrowing pen (different models)	2	-	2
	Open hinged farrowing crate	1	-	1
Total		**39**	**44**	**56**

3.2 SOW WELFARE IN FARROWING SYSTEMS

3.2.1 Farrowing crates vs Loose farrowing pens

Of the 16 studies that compared farrowing crates and loose farrowing pens, most investigated behaviour (n=13), followed by physiological parameters (n=8), performance (n=5), and health (n=4). The summary of the main results on sow behaviour are shown in Table 2. Although most studies found that nursing was longer and more frequent in the pens, one study found that nursing was longer in the crates by the third day post-partum, which could be due to the higher number of nursing events terminated by sows in the loose pens (HALES et al., 2016). In contrast to most studies on stereotypical behaviours (Table 2), one study found that sows in loose pens rooted the floor more frequently than in farrowing crates on the first week post-farrowing (CHIDGEY et al., 2016). The authors argue that rooting could be a result of increased exploratory behaviour that may have been stimulated by sows' new surroundings,

since it became more frequent on the day after sows were released from temporary crating. It is important to note that this study did not provide bedding or enrichment in any farrowing housing system. When bedding material was provided in both housing systems, substrate-directed behaviours were more frequent in gilts housed in loose farrowing pens than in gilts housed in crates (JARVIS, S et al., 2002, 2004, 2006). One study that provided straw bedding only in the loose farrowing pens found that sows in pens spent a considerable amount of time in straw-directed behaviour, while sows housed in farrowing crates without straw bedding showed increased amounts of floor- and fixture-directed behaviours around the same period (LAWRENCE, et al., 1994).

Regarding health parameters, Singh et al., (2017) found that sows housed in loose farrowing pens had more skin injuries than sows housed in farrowing crates; however, Wiechers et al., (2021) identified that skin lesions decreased equally during the farrowing period in both housing systems. Regardless of litter size, udder abrasion in sows housed in loose pens was reduced compared to sows housed in farrowing crates (KOBEK-KJELDAGER et al., 2020).

Sows and gilts housed in loose farrowing pens had lower cortisol concentrations compared to sows in farrowing crates during the pre-parturient period (LAWRENCE, A. B. et al., 1994) and lactation (BIENSEN; VON BORELL; FORD, 1996; CRONIN et al., 1991) regardless of straw provision (JARVIS, et al., 2002). Similarly, sows housed in farrowing crates had higher cortisol response to a corticotropin-releasing hormone stimulation test (CRH), suggesting changes in the HPA axis consistent with chronic stress (JARVIS, et al., 2006). In contrast, Hales et al., (2016) found that sows that farrowed free had higher salivary cortisol on the farrowing day and first day post-partum compared to sows that farrowed in crates. The authors suggest that the time that sows were housed in the farrowing system before farrowing may have influenced the results. Two studies found no effect of farrowing housing on sows' cortisol levels (plasma: JARVIS, et al., 2004; hair: WIECHERS et al., 2021).

One study found that gilts in crates had elevated adrenocorticotropic hormone (ACTH) levels on the second hour after the first piglet was born compared to gilts in pens (JARVIS, et al., 2004). However, there was no effect of housing on ACTH levels in other studies (CRONIN et al., 1991; JARVIS, et al., 2002) neither on ACTH response to a CRH stimulation test, suggesting that housing sows in crates has no effect on HPA axis responsiveness at the pituitary level (JARVIS, et al., 2006). On the week before farrowing, the concentration of progesterone was lower for sows housed in pens compared to sows housed in crates (BIENSEN; VON

BORELL; FORD, 1996). Sows housed in loose pens showed increased oestradiol concentration on the week before farrowing, while sows in farrowing crates showed constant levels of oestradiol (BIENSEN; VON BORELL; FORD, 1996). Housing sows in farrowing crates or loose farrowing pens had no effect on oxytocin and prolactin levels (JARVIS, et al., 2004; LAWRENCE, et al., 1994).

No studies found significant effects of housing on sows' performance parameters, including piglets weaned per litter (BIENSEN; VON BORELL; FORD, 1996; HALES et al., 2016; LAWRENCE, et al., 1994; ZHANG et al., 2020). However, there were benefits of housing sows in loose pens to piglet survival, as one study concluded that allowing sows to move freely before farrowing is a key factor to shortening farrowing duration and reducing perinatal morality (OLIVIERO et al., 2010).

Table 2. Main results of the studies that investigated sow behaviour in loose farrowing pens (LP), group housing (GH), and outdoor farrowing systems (OF) compared to farrowing crates. Studies are identified based on their citation ID number provided in the supplementary material.

Behaviour	Treatment	Citation ID	Results
Posture and Posture changes	LP	28, 11, 12	Sows spent less time lying down and siting.
		47, 44, 42	Gilts with bedding spent less time sitting and more time standing and walking than gilts in crates regardless of bedding.
		29	Sows with temporary crating of 4 days spent more time standing and rooting the floor and less time lying.
		55, 52	No effect of farrowing housing on sow posture.
	GH	20	Sows spent less time lying and more time walking, standing, and investigating the pen.
		49	No effect of housing on sows' body movements after separation from their piglets.
	OF	43, 36, 34	Sows spent more time lying, standing, and walking, and sows in crates spent more time sitting or kneeling down.
Activity and exploration	LP	55, 11, 12	Sows housed in loose farrowing pens were more active and spent more time exploring the environment.
		29	Sows were more active when released from temporary crating 4 days after farrowing.
		54	No effect of housing on time gilts spent in movement during the pre-parturient phase.
	GH	20	Sows in group housing spent more time investigating the pen.
		22	Sow activity varied according to mixing strategies.
	OF	43	Sows were more active (e.g., rooting, feeding, standing, and walking).
		36, 34	Sows' frequency and time at the feeders was lower in both winter and summer periods.
Nursing	LP	11	Sows housed in loose farrowing pens spent more time nursing their piglets.
		28	Sows that farrowed loose nursed their piglets more frequently on the second day post-partum. Sows that were crated right after farrowing nursed less frequently on the first day post-partum than sows kept loose during all lactation.
		28	Nursing duration was lower for sows housed in loose farrowing pens on the third day post-partum.
	GH	20	Sows had less successful nursing bouts, spent less time nursing successfully, terminated more nursing bouts and had longer inter-nursing intervals.
	OF	36	Nursing was more frequent in semi-outdoor pens, but total time nursing did not differ between housing systems.
		34	Sows in semi-outdoor pens spent more time nursing during the day.
Stereotypical behaviours	LP	12	Stereotypical behaviours were less frequently, and sows spent less time performing sham chewing and biting the pen.
		11	No effect of housing on stereotypical behaviours.
	OF	43	Sows spent less time vacuum chewing.
Social behaviours	LP	29, 44, 11	Sows spent more time socializing with their piglets and performed more piglet-directed behaviours.
		29	Sows interacted more with their neighbour sows. This sow-directed behaviour was more frequent once penned sows were released from temporary crating 4 days post-partum.
		44	Gilts were less reactive to piglets and had lower tendency to show abnormal maternal behaviours.
		42	No effect of housing in the time gilts spent in piglet-directed behaviour.
	GH	20	Sows spent more time interacting with their piglets in multi-suckling systems
Farrowing duration	LP	52, 37	Sows showed a reduced interval between piglet births and reduced total farrowing duration.
		44	No effect of housing on farrowing duration
Maternal responsiveness test	LP	50, 26	No effect of housing on maternal responsiveness
	GH	49	

3.2.2 Farrowing crates vs Group housing

Most of the studies comparing farrowing crates with group housing systems (n=5) investigated behaviour (n=3), performance (n=3) and health (n=3), while physiological parameters were the least investigated (n=2). One study investigated different times for mixing sows in group farrowing systems and found that sows were less active on the first week after mixing when they were housed in a multi-suckling system continuously compared to when they were housed in a get-away system for only 7 hours a day; the authors suggested that this result can be associated with the lower frequency of aggressive interactions observed in the multi-suckling system (GREENWOOD et al., 2019).

Sows in group housing had more skin lesions on the second day after mixing at 7 and 14 days post-farrowing than sows in crates (VERDON; MORRISON; RAULT, 2020). Similarly, primiparous group-housed sows had more skin lesions than primiparous crated sows (HULTÉN et al., 1995); the authors suggest that the skin lesions can be a result of agonistic interactions due to the low social rank of primiparous sows. In the group housing system, primiparous sows had lower back-fat thickness compared to multiparous sows, suggesting that primiparous sows also had lower access to food due to their lower social ranking (HULTÉN et al., 1995). Interestingly, mixing strategies may influence sows' skin lesions: sows mixed with their litters in a multi-suckling system on day 21 of lactation had less skin injuries after mixing compared to when only sows were mixed in a get-away system for 7 hours a day starting on the same lactation day, or when sows were mixed after weaning and after artificial insemination (GREENWOOD et al., 2019). Group-housed sows had less teat and udder skin injuries and more preweaning atrophy of the mammary glands than sows housed in farrowing crates; frequency of mastitis did not differ between the two housing systems (HULTÉN et al., 1995). There was no difference in the frequency of locomotor disorders among sows housed in farrowing crates and group housing; hoof overgrowth was common in the two housing systems (HULTÉN et al., 1995).

No effect of group housing was observed on sow performance besides a shorter interval between weaning to first standing heat and bigger subsequent litters than sows in crates (GREENWOOD et al., 2019; VERDON; MORRISON; RAULT, 2020). There was no effect of housing on sows' plasma and salivary cortisol levels (GREENWOOD et al., 2019; VERDON; MORRISON; RAULT, 2020).

3.2.3 Farrowing crates vs Outdoor farrowing systems

All three studies investigating sow welfare in farrowing crates and outdoor farrowing (Table 2) investigated sow behaviour, while only two investigated performance and health. No study investigated physiological parameters of sow welfare in outdoor farrowing systems. Sows housed outdoors performed the complete nest-building repertoire observed in sows in natural conditions, while sows housed in farrowing crates redirected their nesting behaviour to objects or the crate, e.g., attempts to dig the ground, nosing, biting and rooting parts of the crate, feeder or drinker (HÖTZEL; MACHADO FILHO; DALLA COSTA, 2005). Sows housed outdoors spent a long time building a nest on the day before farrowing, and nesting behaviour was also observed in sows housed in farrowing crates but lasted less than half the time spent on the normal nesting behaviour by outdoor sows (HÖTZEL; MACHADO FILHO; DALLA COSTA, 2005). All the sows housed outdoors built a nest where they delivered their piglets (HÖTZEL; MACHADO FILHO; DALLA COSTA, 2005).

There was no difference in respiratory frequency between sows housed in farrowing crates and sows housed in semi-outdoor pens; the authors suggest that the lack of difference was due to the environmental temperatures being around the thermoneutrality zone of sows (22ºC) during all study (OLIVEIRA JÚNIOR et al., 2014). However, Oliveira Júnior et al., (2011) observed that sows in farrowing crates with floor cooling had lower respiratory rates than sows in conventional farrowing crates and semi-outdoor pens, suggesting that the floor cooling system in the crates may be more efficient to keep animals in thermal comfort than semi-outdoor pens in heat-stress conditions.

Back-fat thickness was lower in sows kept in semi-outdoor pens compared to farrowing crates (OLIVEIRA JÚNIOR et al., 2014), but no effect of housing on lactation back-fat loses was found in another study (OLIVEIRA JÚNIOR et al., 2011). Semi-outdoor sows had better lactation energy efficiency than sows housed in conventional farrowing crates (OLIVEIRA JÚNIOR et al., 2011), but there was no effect of housing on milk production, number of piglets weaned or sows' feed consumption (OLIVEIRA JÚNIOR et al., 2011, 2014).

3.2.4 Closed hinged farrowing crate vs Open hinged farrowing crate

The comparison of closed and open hinged farrowing crates was the second most frequent among studies on sow welfare (n=8) and most studies investigated the effect of temporary crating on sow welfare. Behaviour parameters were the most investigated among these studies (n=6), followed by physiological (n=5), health (n=4), and performance parameters (n=3). The main results of these studies are presented in Table 3.

One study with sows housed in hinged crates with multiple temporary crating periods identified that the longer the sows stay in confinement higher the risk of decreased weaning rate (MORGAN et al., 2021). Another study found no difference on the number of piglets weaned among closed hinged crates and hinged crates open on day 4 or 7 post-partum (CEBALLOS et al., 2021). There was also no difference on sows' skin and shoulder lesions, weight, body condition score and lameness for sows housed in farrowing crates during all lactation or with temporary crating of 4 or 7 days (CEBALLOS et al., 2021; CEBALLOS; GOIS; PARSONS, 2020; LAMBERTZ et al., 2015).

Table 3. Main results of the studies that investigated sow behaviour in closed and open hinged farrowing crates. The time in temporary confinement (TC) is indicated in days and the studies' identification number (Citation ID) is shown according to the supplementary material.

Variable	Citation ID	TC (days)	Results
Behaviour			
Posture and	17	no info	Sows spent more time standing and ventrally lying during parturition.
Postural changes	30	7 and 14	Gilts were lying laterally more frequently on crates with 14 days of TC.
	17	no info	Sows had more postural changes during parturition.
	10	4 and 7	
	23	3	There was no effect of housing on postural changes.
Activity and exploration	10	4 and 7	Sows were more active and spent more time standing, exploring, and interacting with their piglets.
	23	3	
Nursing	16	3	Nursing was calmer on day 25 post farrowing, but litter size had more effect on nursing than housing.
	10	4 and 7	Sows in TC of 4 days spent more time nursing on day 4 but there was no difference on other days of the study.
	35	7	Nursing was longer for sows housed in hinged crates with 7 days of TC.
Stereotypical behaviours	17	no info	Sows housed in open hinged crates showed higher frequencies of bar-biting.
	10	4 and 7	Sows in open hinged crates spent more time vacuum chewing on day 3 post-partum, but only sows from TC of 7 days displayed more vacuum chewing than other treatments on day 6 post farrowing.
Farrowing duration	17	no info	There was no effect of housing on farrowing duration.
Physiological			
Cortisol	17	no info	Sows housed in open hinged crates had greater salivary cortisol concentrations on day 3 before parturition.
	3	multiple	Sows' hair cortisol decreased when the restraint periods was shortened.
	23	3	No significant difference was observed in cortisol concentrations.
	10	4 and 7	
IgG from saliva	23	3	The IgG from saliva was higher on the 24 hours post opening the crate compared to sows that continued crated.
Oxytocin and Prolactin	35	7	There was no effect of housing on Oxytocin and Prolactin concentrations.
Health			
Requirement for medical treatment	3	multiple	Sows housed in hinged crates with short temporary crating (from 3 to 10 days) required less medical treatment than sows with longed temporary crating (at least 13 days).
Teat lesions	1	4 and 7	Opening crates on day 4 having fewer teat lesions than sows permanently crated.
	10	4 and 7	Teat lesions were less frequent in systems with 4 and 7 days of temporary crating.

3.2.5 Farrowing crates compared with at least two alternative farrowing housing systems

One study investigated sow welfare in farrowing crates compared to loose farrowing pens and group housing. This study only investigated behaviour and health parameters of sow welfare. Sows in farrowing crates and loose pens had higher odds for lying laterally than standing and sitting compared to sows housed in group pens (NICOLAISEN et al., 2019). Skin injuries were more frequent in sows housed in group pens on days 14 and 34 post-partum compared to sows housed in farrowing crates and loose farrowing pens; no significant difference was found between sows in crates and in pens (NICOLAISEN et al., 2019).

Two studies investigated sow welfare in farrowing crates compared to loose farrowing pens and open hinged farrowing crates. All studies investigated performance and one investigated health and behaviour. Sows housed in loose pens spent more time standing before farrowing and changed posture more frequently post farrowing than sows housed in farrowing crates or open hinged crates (VERHOVSEK; TROXLER; BAUMGARTNER, 2007). Sows in loose pens also performed more head activities on the floor than sows housed in farrowing crates or open hinged crates (VERHOVSEK; TROXLER; BAUMGARTNER, 2007). Sows housed in farrowing crates had higher prevalence of udder and limbs skin lesions than sows housed in the other systems (VERHOVSEK; TROXLER; BAUMGARTNER, 2007). During farrowing, sows housed in the crated systems had longer interval between piglet births and weaned less piglets per litter compared to sows housed in loose farrowing pens (VERHOVSEK; TROXLER; BAUMGARTNER, 2007). One study found no difference on sows' reproductive performance, gestation length, total litter size, or number of live born pigs among the housing systems (MACK et al., 2017).

3.2.6 Studies with loose farrowing pens as control

One study compared sow welfare in loose farrowing pens (the Schmid pen) and open hinged farrowing crates with 8 days of temporary crating. Lying, sitting and postural changes were more frequent in the hinged crate than in the Schmid pen (DAMM et al., 2003). Sows in crates performed more oral/nasal stereotypies than sows in the Schmid pen but no effect of housing was found in the other stereotypical behaviours (DAMM et al., 2003). There was also no effect of housing on nest building behaviours or sows' heart rate, but sows in hinged crates

had higher heart rate on the last hour before farrowing than sows housed in the Schmid pen (DAMM et al., 2003). Housing treatment also did not influence farrowing duration (DAMM et al., 2003).

Two studies compared sow welfare in different models of loose farrowing pens. One study investigated sow health parameters in five different loose farrowing pen designs (Flugel, Knick, SWAP, Trapez, Pro Dromi) (MASCHAT et al., 2020). Although sows' back injuries increased the longer the sows were housed in temporary crating, loose farrowing pen designs had more effect on body lesions than time in confinement (MASCHAT et al., 2020). The risk of lameness also varied among the different pen designs; for example, Pro Dromi pens had higher odds ratios of lameness than Knick, SWAP and Trapez pens (MASCHAT et al., 2020). The other study assessed sows' behaviour based on their previous experience farrowing in a loose pen (KING et al., 2018). Sows that previously farrowed in pens showed a decreased frequency of ventral lying, sitting and posture changes considered dangerous throughout parturition compared to sows that had only farrowed in crates (KING et al., 2018). Sows that previously farrowed in pens also had a higher pre-partum peak nesting intensity, terminated fewer nursing bouts and had longer successful nursing events than sows that had only farrowed in crates (KING et al., 2018). There was no effect of treatments on farrowing duration (KING et al., 2018).

One study investigated sow behaviour and reproductive performance parameters in loose farrowing pens compared to group farrowing systems (WEARY, et al., 2002). Sows in the group housing system nursed less frequently and consumed more food during lactation than sows in loose farrowing pens, but no difference was found in sow body weight (WEARY, et al., 2002). There was no effect of housing on time to return to oestrus after weaning (WEARY, et al., 2002).

3.3 PIGLET WELFARE IN FARROWING SYSTEMS

The main results of the studies comparing farrowing crates with loose farrowing pens, group housing and outdoor farrowing systems are shown in Figure 2, grouped according to the parameters used to assess piglet welfare. The following sections provide more details on the main findings of these studies.

3.3.1 Farrowing crates vs Loose farrowing pens

During the pre-weaning period, piglets in loose pens spent more time active and exploring (BRAJON et al., 2017; CHIDGEY et al., 2016; ZHANG et al., 2020), and less time engaging in aggressive behaviours (LOFTUS et al., 2020; ZHANG et al., 2020) than piglets in farrowing crates. Loose pens also had less fighting at the udder compared to farrowing crates irrespective of litter size (KOBEK-KJELDAGER et al., 2020). One study found that piglets spent more time feeding from the sow in the loose pens than in the crates (LOFTUS et al., 2020), while another study found that piglets in the crates had significantly longer sucking activity than those in loose pens (BLACKSHAW et al., 1994). Piglets in pens showed play behaviours earlier in life, played and socialized more during pre-weaning and spent more time in close proximity to the sow than piglets in crates (JARVIS, et al., 2004; LOFTUS et al., 2020; MARTIN; ISON; BAXTER, 2015; SINGH et al., 2017; ZHANG et al., 2020). However, some studies found less pre-weaning social and play interactions in loose pens than in farrowing crates (BLACKSHAW et al., 1997; BRAJON et al., 2017). After weaning, Hayes et al. (2021) found that more pigs from loose pens were standing or walking and nosing the pen floor or a pen mate compared to pigs from crates. Brajon et al., (2017) found that pigs from loose pens were lying down more and exploring more the environment post-weaning than piglets from crates. Six days after weaning, pigs from loose pens performed belly nosing more often than pigs from farrowing crates (BRAJON et al., 2017).

The housing system influenced piglets' performance in behavioural tests. Piglets from loose farrowing pens were faster than piglets from farrowing crates to approach and physically interact with a novel object and a human hand in novelty tests (HAYES et al., 2021), and spent more time interacting with the novel object (MARTIN; ISON; BAXTER, 2015). In a social isolation test, piglets from loose pens attempted to escape more often and performed high vocalizations more often and for longer than piglets from farrowing crates (BRAJON et al., 2017). Piglets from loose farrowing pens also had more intense escape behaviour when captured by a stockperson and when receiving an iron injection at 3 days of age than piglets from farrowing crates, but no effect of housing was observed on escape behaviour from vaccination at 3 weeks of age (HAYES et al., 2021). There was no effect of housing on piglets' behaviour in a social confrontation test (BRAJON et al., 2017).

Piglets from loose pens had higher skin injury scores than piglets from farrowing crates during the pre-weaning period, but there was no difference on skin injury scores between

housing systems at the days following weaning and mixing with unfamiliar pigs (HAYES et al., 2021). Singh et al., (2017) found that pre-weaning skin injuries increased equally in farrowing crates and in loose farrowing pens with temporary crating of 3 days. Only one study found a significant difference on piglet performance between housing systems, with piglets from loose farrowing pens losing less weight between 21 and 23 days old than piglets from farrowing crates (BRAJON et al., 2017).

3.3.2 Farrowing crates vs Group farrowing systems

Piglets from group housing gained less weight pre-weaning and weighted less at weaning compared to piglets from farrowing crates (SCHREY; KEMPER; FELS, 2019; VERDON; MORRISON; RAULT, 2020). However, after weaning, pigs from group housing systems consumed more food, had higher weight gain and weighted more than pigs from farrowing crates (MESAREC et al., 2020; PAJOR et al., 1999; VAN NIEUWAMERONGEN et al., 2015). Piglet mortality by crushing was higher in multi-suckling systems, but mortality due to other causes was higher in farrowing crates (VAN NIEUWAMERONGEN et al., 2015). In group housing systems, piglet mortality was higher when piglets were mixed earlier (7 days and 10 days post-farrowing) than later (14 days post-farrowing) (VERDON; MORRISON; RAULT, 2020).

Suckling order was less stable in group pens than in farrowing crates, which was associated with the occurrence of cross-suckling (i.e., when piglets suckle from sows that are not their mother) (MESAREC et al., 2020). More specifically, the suckling order progressed similarly in group pens and farrowing crates for the first two weeks post-farrowing, but it became unstable in group pens during the second half of lactation as the occurrence of cross-suckling increased, while suckling order remained stable in farrowing crates (MESAREC et al., 2020). Similarly, one study identified that one-third of the piglets in group-housing were involved in cross-suckling (MESAREC et al., 2020), and time involved in cross-suckling increased over time (VERDON; MORRISON; RAULT, 2019a).

Piglets from multi-suckling systems showed less damaging oral manipulation (e.g., tail biting) than piglets from farrowing crates during pre- and post-weaning (VAN NIEUWAMERONGEN et al., 2015), and spent less time manipulating other piglets when mixed post-weaning (VERDON et al., 2019a). During the post-weaning period, pigs from group

housing performed less aggressive behaviours, fought less frequently, for shorter time, and reached aggressive bouts baseline levels faster than pigs from farrowing crates (FELS et al., 2021; MESAREC et al., 2020; VERDON; MORRISON; RAULT, 2019a). The number of fights with unfamiliar and familiar pigs was similar for pigs from group housing while pigs from crates fought more with unfamiliar individuals (VERDON; MORRISON; RAULT, 2019a). In contrast, one study found that piglets from get-away systems had a higher biting score at the hours following weaning compared to piglets from farrowing crates (PAJOR et al., 1999). No difference was observed on piglet pre-weaning play behaviour between the housing systems (VAN NIEUWAMERONGEN et al., 2015; VERDON; MORRISON; RAULT, 2019a), but at post-weaning pigs from group housing showed more play behaviour than pigs from crates (VAN NIEUWAMERONGEN et al., 2015).

Piglets had more skin injuries in multi-suckling systems than in farrowing crates, but when mixed after weaning pigs from multi-suckling systems had less skin injuries and fewer deep lesions than pigs from farrowing crates (FELS et al., 2021; GREENWOOD et al., 2019; SCHREY; KEMPER; FELS, 2019; VAN NIEUWAMERONGEN et al., 2015). In contrast, one study found that pigs from group pens had more skin lesions and more deep lesions than pigs from farrowing crates at around one month post weaning (VAN NIEUWAMERONGEN et al., 2015).

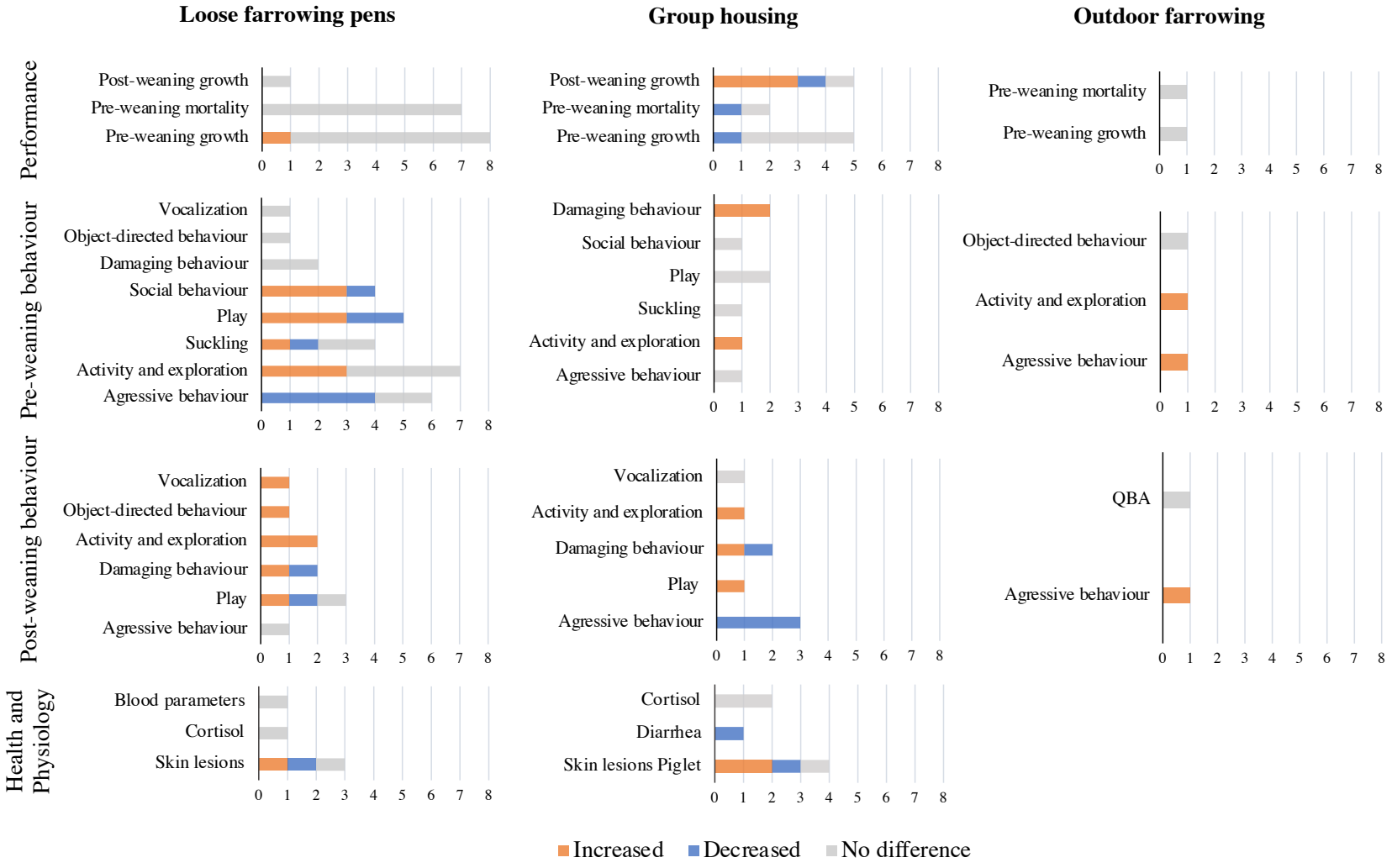

Figure 2. Number of studies that investigated piglet welfare in loose farrowing pens, group housing, and outdoor farrowing systems according to the parameters investigated and its results in comparison to farrowing crates (Increased, Decreased, or No difference).

3.3.3 Farrowing crates vs Outdoor farrowing systems

Outdoor piglets were more active (i.e., standing and moving) than piglets in farrowing crates, and piglet locomotion increased with age in outdoor systems but not in farrowing crates (COX; COOPER, 2001). Agonistic interactions, however, increased with age in farrowing crates but not in outdoor systems, in a way that agonistic interactions were similar in the two housing systems on the first week of life, but were more frequent in farrowing crates by the third week post-partum (COX; COOPER, 2001). After weaning, pigs from outdoor systems were at the food trough more frequently, interacted more with the environment, and engaged in fewer aggressive interactions than pigs from farrowing crates (COX; COOPER, 2001). When piglets were submitted to three behavioural tests after weaning (isolation test, exposure to novel object, and access to food in novel area), piglets from outdoor systems ate more and were scored as more 'calm/passive', whereas piglets from farrowing crates spent more time investigating the environment and were scored as more 'playful/inquisitive' (LAU; PLUSKE; FLEMING, 2015). No effect of housing was observed in the piglet performance parameters (e.g., piglet mortality, litter total weight, piglet weight gain from birth to weaning and mean piglet weight at weaning) (OLIVEIRA JÚNIOR et al., 2011, 2014).

3.3.4 Closed hinged farrowing crate vs Open hinged farrowing crate

Piglet performance was investigated in all studies assessing piglet welfare in closed and open hinged farrowing crates (n=7), followed by pre-weaning behaviour (n=4), health (n=2), physiological parameters (n=2), and post-weaning behaviour (n=1). Most studies involved temporary crating, and the main results are presented bellow with information on the use and time of temporary crating.

Post-weaned piglets from open hinged crates with 4 days of temporary crating reached slaughter weight faster and weighted more at slaughter than piglets from closed hinged crates (KINANE; BUTLER; O'DRISCOLL, 2021). Total mortality and piglet mortality by crushing were higher in open hinged crates than in closed crates (YUN, J et al., 2019). Regarding temporary crating, piglet mortality was higher in hinged crates open at day 4 compared to hinged crates open at day 7 post-partum and closed hinged farrowing crates, the last two systems did not differ from each other in piglet mortality (CEBALLOS et al., 2021). When comparing closed and open hinged crates with multiple temporary crating durations, the

majority of the piglets died on the first 3 to 4 days post-partum when all sows were still restrained in crates (MORGAN et al., 2021). However, some studies found no difference on piglet pre-weaning mortality between closed hinged crates and open hinged crates with temporary crating of 3 days (GOUMON, Sébastien et al., 2018), 4 days (KINANE; BUTLER; O'DRISCOLL, 2021), 7 and 14 days (LAMBERTZ et al., 2015).

Piglets spent more time at the udder and performed less ear and tail biting in hinged crates open at 4 days post-partum than in closed hinged crates (KINANE; BUTLER; O'DRISCOLL, 2021). However, other studies found no difference on piglet activity at the udder or suckling behaviour between closed hinged crates and hinged crates open at 3 days post-partum (GOUMON, et al., 2018; ILLMANN et al., 2019). In behavioural tests at post-weaning, pigs from the open hinged crate with 4 days of temporary crating had higher latency to touch the novel object than piglets from closed hinged crates, but this difference was significant only on the first day of the test (KINANE; BUTLER; O'DRISCOLL, 2021). There was no effect of housing on play, social, fighting and pen-directed behaviours (i.e., rooting, biting, or sniffing the pen) (KINANE; BUTLER; O'DRISCOLL, 2021). Interestingly, Illmann et al., (2019) found that increased litter size increased fighting independently of the housing system.

A study with sows housed in open hinged crates with multiple temporary crating periods identified that piglets from open hinged crates with short temporary crating (3 to 10 days) required fewer medical treatments than piglets from hinged crates with long temporary crating (at least 13 days) (MORGAN et al., 2021). This same study found that piglets' hair cortisol levels increased according with sow's hair cortisol levels, which increased with longer restraint periods (MORGAN et al., 2021). There was no difference on piglets' faecal cortisol concentrations or hoof scores between open hinged crates with 4 days of temporary crating and closed hinged crates (KINANE; BUTLER; O'DRISCOLL, 2021).

3.3.5 Farrowing crates compared with at least two alternative farrowing systems

Three studies compared piglet welfare in farrowing crates, loose farrowing pens and group housing systems. Two of these studies investigated health and performance, while one investigated pre-weaning behaviour. The two studies that investigated piglet performance had conflicting results. One study found that piglets from loose pens and group housing systems

had higher average daily weight gain during the rearing and fattening periods respectively (LANGE et al., 2021), but the other study found no effect of housing on piglets post-weaning weight (GENTZ et al., 2019). Regarding health parameters, piglets from farrowing crates had more intact tails compared to piglets from group pens, and skin lesions were more frequent in farrowing crates on the first week after farrowing (LANGE et al., 2021). However, by the sixth week post-partum piglets from group pens had more skin lesions, and by week 18 there was no effect of housing (LANGE et al., 2021). Cross-suckling was a frequent pre-weaning behaviour in group housing systems, but only a few piglets were engaged in this behaviour (NICOLAISEN et al., 2019).

Two studies investigated piglet welfare in farrowing crates, loose farrowing pens and open hinged farrowing crates. Piglet performance was investigated in both studies, while one study also investigated pre-weaning behaviour. Piglet weight and daily weight gain were higher and piglet mortality was lower during the first two weeks post-partum in farrowing crates and open hinged crates with temporary crating of 15 days than in loose pens, but no difference was observed among the housing systems on the following two weeks (MACK et al., 2017). Piglet mortality by crushing was higher in open hinged crates without temporary crating and loose farrowing pens than in farrowing crates, but piglet mortality by starvation was the lowest in loose farrowing pens among the three housing systems (VERHOVSEK; TROXLER; BAUMGARTNER, 2007). When tested in a social test, piglets from loose pens spent more time touching non-aggressively an unknown piglet and spent the less time far away from an unknown piglet compared to piglets from the crated systems, which did not differ from each other (MACK et al., 2017).

Two studies assessed piglet welfare in farrowing crates, loose farrowing pens and ellipsoid-farrowing crates where the sow can turn around inside the crate. Both studies investigated post-weaning behaviour, while one study also investigated health, pre-weaning behaviour, performance and physiological parameters. Piglets housed in farrowing crates vocalized more, had shorter latency to move, and longer duration of locomotion than piglets housed in Ellipsoid-farrowing crates and loose farrowing pens (CHALOUPKOVA et al., 2007b). In a food competition test at 3 and 6 months old, pigs from loose pens were less aggressive than pigs from Ellipsoid-farrowing crates and conventional farrowing crates (CHALOUPKOVÁ et al., 2007a). The pH of the meat from pigs reared in Ellipsoid-farrowing crates was lower than the meat of pigs reared in loose farrowing pens (CHALOUPKOVA et al., 2007b). Housing had no effect on piglets performance in isolation tests at pre- and post-

weaning, or in the human approach test at post-weaning (CHALOUPKOVA et al., 2007b). During the post-weaning period, housing also had no effect on agonistic behaviours, number of skin lesions and proportion of abnormally ended fights (CHALOUPKOVÁ et al., 2007a). Housing systems did not influence piglets' saliva cortisol concentrations one hour before, immediately after, and one hour after transport of animals to the slaughterhouse at 26 weeks of age (CHALOUPKOVA et al., 2007b).

3.3.6 Loose farrowing pens vs Group farrowing systems

Two studies compared piglet welfare in loose farrowing pens and group farrowing systems. Both studies investigated pre- and post-weaning behaviours, while one study also investigated piglet performance. In a group housing where sows remained in individual pens and piglets were able to circulate between the pens, piglets spent substantial time in pens of other litters but were rarely seen cross-suckling during successful nursing (WEARY et al., 2002). Piglets housed in the group housing system ate more creep feed before and after weaning, but gained less weight than piglets from crates (WEARY et al., 2002). However, group housed piglets gained more weight after weaning in a way that piglets average body weight did not differ between housing systems when piglets were 42 days old (WEARY et al., 2002). Although there were agonistic interactions when piglets were mixed at 14 days old, group-housed piglets engaged in less aggressive interactions compared to piglets from loose farrowing pens when mixed after weaning (WEARY et al., 2002). One study found no difference between group housing and loose farrowing pens in the frequency of playing, fighting or biting behaviour among piglets during the pre- and post-weaning periods (ŠILEROVÁ et al., 2010).

4 DISCUSSION

Animal welfare is defined by the World Organization for Animal Health (WOAH) as animals' physical and mental states in relation to the conditions in which they live and die (WOAH, 2022). The welfare of animals is an intrinsic value that can be only determined by their own experiences. Therefore, researchers have developed scientific approaches to determine measurable parameters to be able to assess animal welfare (HEMSWORTH et al., 2015). This review identified that most studies on sow welfare in farrowing housing systems investigated animal behaviour, followed by health, performance, and physiological parameters. Most studies on piglet welfare in farrowing systems investigated performance, followed by behaviour pre- and post-weaning, health, and physiological parameters.

4.1 SCIENTIFIC ASSESSMENT OF ANIMAL WELFARE IN FARROWING SYSTEMS

The behaviour parameters most used to assess sow welfare in the reviewed literature were posture, posture changes and activity. Sow's posture is an important parameter to assess the risk of piglet mortality given that most piglet crushing events occur when sows change postures (WEARY et al., 1996). However, how the frequency of postures adopted by sows can inform about their own welfare is unclear. Based on the natural behaviour of the species, sows frequently change postures to check on their piglets after farrowing (BAXTER; EDWARDS, 2018). However, sows cannot change postures in farrowing crates because they are not able to turn around inside the crate. This restriction of movement may compromise sows' maternal abilities, thus lower frequencies of posture changes in farrowing crates may indicate the inability of sows to care for their offspring. Higher sow activity can indicate positive animal welfare because it may reflect that sows can fulfil their motivation to explore (LOFTUS et al., 2020), which is not possible in farrowing crates because the sow is restricted in a way that she can only stand up and lay down. Studies using behaviour to assess animal welfare in farrowing housing systems should assess sows' freedom to move and to perform natural behaviours, like nesting building and socially interact with other sows and their piglets (BAXTER; EDWARDS, 2018). For it to be possible, alternative farrowing systems need to provide enough space, substrate, and social enrichment to allow animals to perform these behaviours.

Although physiological measures are commonly used to assess animal welfare (MORMÈDE et al., 2007), physiological parameters were the least used to assess sow and piglet

welfare in the reviewed literature. Cortisol in blood, saliva and hair samples was the physiological parameter most investigated. Cortisol is released when the hypothalamic-pituitary-adrenal (HPA) axis is activated, which happens when individuals are exposed to aversive situations. Therefore, cortisol concentration is a useful measure to indicate animals' physiological responses to stress. However, cortisol levels do not provide information about the conditions involved in the activation of the HPA axis and its behavioural or emotional consequences (RALPH; TILBROOK, 2016). For example, increased levels of plasma cortisol can indicate that the animal is experiencing fear or is expecting a reward (RALPH; TILBROOK, 2016). Moreover, cortisol levels can be influenced by multiple aspects not related to animal welfare. For example, plasma cortisol concentrations can vary among species and individuals, and can be influenced by feeding behaviour and environment temperature and humidity (MORMÈDE et al., 2007). Saliva and hair samples can be collected via non-invasive methods, but the collection of blood samples is invasive and can be distressful to animals influencing the cortisol levels in the collected sample (MORMÈDE et al., 2007). Therefore, the assessment of animal welfare via measures of cortisol needs to be used and interpretated with caution, and its association with behavioural and emotional parameters of animal welfare is encouraged.

Many health parameters were used to assess sow and piglet welfare in farrowing housing systems, like skin lesions, lameness, and requirement for medical treatment. Animal health is an important component of animal welfare, as sick animals have their welfare compromised (BROOM; CORKE, 2002). For farmers and veterinarians, the main responsible for the care of animals, health is considered the main component of animal welfare (VANHONACKER et al., 2008). However, animals' health does not always reflect animal welfare because animals in good physical health can also be in distress and experiencing poor welfare (VEISSIER et al., 2008). Therefore, the development of farrowing housing systems to improve animal welfare should not be based only on indicators of animal health.

Animal performance does not reflect animal welfare given that improved animal welfare can be associated with lower production efficiency and poor animal welfare may not compromise animal performance (ZHAO et al., 2014). However, many studies in this review investigated production performance parameters. Some of the performance parameters investigated in the reviewed literature included sow body condition score and piglet body weight, which could reflect animal welfare given that distressed or sick animals may show

weight loss (RAULT et al., 2014). However, many of the performance parameters evaluated were not related to animal welfare (e.g., reproduction performance and feed conversion efficiency). Many of the studies on piglet welfare in farrowing housing systems investigated piglet mortality. However, piglet pre-weaning mortality may be a matter of ethical debate rather than an animal welfare issue. Baxter and Edwards, (2018) argue that it is not clear how the death of piglets soon after birth influences their welfare. Meanwhile, the systematic genetic selection for hyperprolificity to increase the number of piglets weaned per sow and the use of farrowing crates to minimize piglet loss due to the risk of increased piglet mortality in large litters is a matter of ethical concern (BAXTER; EDWARDS, 2018; FOXCROFT et al., 2006; VANDRESEN; HÖTZEL, 2021a).

4.2 SOW WELFARE IN FARROWING HOUSING SYSTEMS

The results of most parameters used to assess animal welfare indicated that alternative farrowing housing systems enhance sow welfare in comparison to farrowing crates. For example, sows performed less stereotypical behaviours, had lower cortisol levels, and had better social interactions with their piglets in alternative systems compared to the crates. However, it is not possible to identify which of the alternatives would be the most beneficial to sow welfare because most studies only compared alternative farrowing systems with farrowing crates. The few studies that compared alternative systems found that different housing models had different effects on animal welfare. For example, Maschat et al., (2020) found that sow lameness scores varied among different loose farrowing pen models. Moving forward, it is important for the pig industry to have more information about sow welfare in the different alternative farrowing housing systems to help on the decision-making about which housing system or housing design would be the best fit to replace the farrowing crates.

The only animal welfare parameter that indicated lower animal welfare in alternative systems compared to farrowing crates was the frequency of skin lesions; sows in crates had fewer skin lesions than in the other housing systems. However, udder and teat lesions were less frequent in alternative farrowing systems compared to the crates. This may be related to the higher number of nursing events terminated by the sow in the alternative systems compared to the farrowing crates (HALES et al., 2016), which may compromise the nursing of piglets. However, many studies on nursing and suckling behaviours found that nursing was longer, and sows had better maternal interactions with their piglets in alternative systems than in farrowing

crates (LOFTUS et al., 2020; OLIVEIRA JÚNIOR et al., 2014; SINGH et al., 2017). Moreover, some studies suggest that skin lesions can be reduced with the provision of enrichment materials (KO et al., 2020; VANHEUKELOM; DRIESSEN; GEERS, 2012). Thus, sows' overall body lesions can be prevented by the use of alternative farrowing housing systems associated with enrichment provision. Indeed, the association of space provision and substrate provision may be necessary to attend sow's and piglets' necessities (JARVIS et al., 2001, 2002).

Many studies found no significant differences on the welfare parameters investigated between open and closed hinged farrowing crates, which may be due to the use of temporary crating in open hinged crates. Although in open hinged crates with temporary crating the sows stay in confinement for a shorter period of time than in the closed hinged crates, temporary crating occurs around farrowing when the sow is highly motivated to build a nest and take care of her offspring (BAXTER; EDWARDS, 2018). Thus, sow confinement at this moment is highly stressful even though it lasts for a short period of time (JARVIS, S et al., 2004). This study did not focus on reviewing studies using of temporary crating, but its influence on sow welfare needs to be taken into account when developing alternative farrowing housing systems to enhance animal welfare.

Although half of the studies selected for this review did not provide information about the gestation housing used prior to the farrowing period, almost all studies that provided this information used group gestation pens. In group gestation systems, sows are housed in pens with space to walk and interact with other sows. Sows may struggle when moved from group gestation to farrowing housing systems that do not provide the same space allowance and social enrichment as the gestation housing system. For example, gilts housed in loose pens during gestation had more skin injuries and showed continued discomfort post-farrowing in farrowing crates compared to gilts housed in gestation stalls (BOYLE et al., 2000). Similarly, sows housed in group pens during gestation were more restless during parturition and early lactation when housed in farrowing crates compared to sows that were housed in gestation stalls (BOYLE et al., 2002). A study on rats found that animals showed depression-like behaviours when they experienced environmental enrichment loss (VANHEUKELOM; DRIESSEN; GEERS, 2012). Studies on sows' affective states are needed to better understand how the transition from group gestation systems to farrowing housing systems can influence sow welfare. Sows' previous experience in farrowing housing systems may also influence their welfare. One study identified that sows that previously farrowed in loose pens adapted better to the loose system than sows

that had only farrowed in crates (KING et al., 2018). It suggests that the benefits of alternative loose farrowing systems to sow welfare may improve with time as sows gain experience in those systems. However, it may be necessary to consistently house sows loose to guarantee their adaptation to the new housing systems (KING et al., 2018).

Overall, alternative farrowing systems that provide sows freedom to move and perform natural behaviours have positive effects to sow welfare compared to farrowing crates. Alternative systems that do not do so, or that continue to use sow confinement, may prove to be unsustainable in the long term because they do not improve sow welfare and are not in line with social expectations towards farrowing housing systems (VANDRESEN; HÖTZEL, 2021b, 2021a).

4.3 PIGLET WELFARE IN FARROWING HOUSING SYSTEMS

Performance parameters were the most evaluated in studies of piglet welfare in farrowing housing systems. Although performance is not a direct indicator of animal welfare, improved performance can contribute to the adoption of systems that promote animal welfare due to its importance for the animal production industry (FISHER et al., 2019). The reviewed studies found more positive than negative effects on piglet performance in alternative farrowing systems compared to farrowing crates. These results indicate that the adoption of alternative farrowing systems would not compromise piglet production and may even improve animals' performance in comparison to the farrowing crates. Considering the animal welfare parameters investigated, more studies found advantages than disadvantages of housing piglets in alternative housing systems than in crates. However, many studies had conflicting results or found no effect of housing to piglet welfare. Moreover, as in the case of sows, no studies investigated piglets' affective states in the different farrowing housing systems. Multiple studies have been done on the effects of housing systems during farm animals' early life (e.g., DE HAAS et al., 2014; GAILLARD et al., 2014; VAN DE WEERD et al., 2005). Neural development and brain functions can be influenced by early life stress (BRAUN et al., 1999), and can result in long-term negative effects like decreased animal performance and increased development of abnormal behaviours (NAPOLITANO; DE ROSA; SEVI, 2008). Research on how the different farrowing housing systems can influence piglets' neural development and how it can influence their life in the long term are needed to better understand how farrowing housing systems influence piglet welfare. Overall, alternative farrowing housing systems enhanced piglet

welfare in comparison to farrowing crates, but more studies are necessary to clarify how the different farrowing housing systems can influence piglet welfare.

Many studies on piglet welfare investigated piglet mortality. Although some studies have found increased piglet crushing in alternative farrowing systems (GLENCORSE et al., 2019; HALES et al., 2014), most of the studies selected for this review found no effect of housing on piglet mortality. The varying results regarding piglet crushing in farrowing systems may reflect the variation in the degree of maturity of cage- free farrowing systems in different countries and studies, and may suggest that farmers' experience with alternative farrowing systems may improve piglet survival. Schuck-Paim et al. (2021), for example, showed that the cumulative mortality in cage-free aviaries decreased over the years of experience with the housing system, while mortality in caged systems did not change, resulting in no differences in mortality between caged and cage-free aviaries in recent years. Importantly, multiple aspects of farrowing systems other than housing are risk factors that can be targeted to reduce piglet mortality. For example, it has been shown that many aspects of farrowing management influence piglet survival (EDWARDS, 2002; PEDERSEN et al., 2011; SCHILD et al., 2020). Also to be considered are large litters and the associated variation in piglet birth weight and the greater risk of piglet mortality in smaller piglets (BAXTER; SCHMITT; PEDERSEN, 2020). The pig industry has advocated for systematic genetic selection for hyperprolificity to increase the number of piglets weaned per sow, despite awareness of the risk of increased piglet mortality in large litters (FOXCROFT et al., 2006), indicating that individual piglet survival has been a relatively low priority in the production context.

4.4 SUSTAINABILITY OF ALTERNATIVE FARROWING HOUSING SYSTEMS

The farrowing crate was the housing system most used as control in the reviewed studies, and the loose farrowing pen was the alternative farrowing system most investigated. One main advantage of the loose farrowing pen is that it facilitates individual animal management as sows are individually housed with their litters in pens. However, loose pens do not provide outdoor access and no sow-sow interactions are allowed. Outdoor access and social interactions between sows were pointed as highly valued by the public (VANDRESEN; HÖTZEL, 2021b, 2021a). Moreover, many studies on loose farrowing pens and open hinged crates temporarily confined the sow after farrowing. Confining sows in crates deprives them of

fulfilling the motivation to perform maternal behaviours such as nesting and caring for their new-born piglets, which not only causes stress (JARVIS et al., 2001) but also deprives sows of some of the few opportunities they have of experiencing positive emotions in commercial farms. Consumers value outdoor systems in part because they see animals as “happy” in these systems (LASSEN; SANDØE; FORKMAN, 2006; SATO; HÖTZEL; VON KEYSERLINGK, 2017; VANDRESEN; HÖTZEL, 2021a). Philosophers and scientists increasingly discuss the importance of positive emotions in the context of farm animal welfare and try to devise ways to incorporate environmental features that allow positive emotions in intensive livestock production systems (BRACKE; HOPSTER, 2006; LAWRENCE; VIGORS; SANDØE, 2019). Looking into the future, the transition away from farrowing crates must seek to incorporate aspects that add positive emotions, rather than simply focusing on avoiding suffering. Half-way solutions may cost a great amount in time and financial investment with questionable returns to farmers, given that many studies indicate that they may not settle the issue for consumers (RYAN; FRASER; WEARY, 2015; VANDRESEN; HÖTZEL, 2021a; YUNES, M.; KEYSERLINGK; HÖTZEL, 2018). In addition, farmers would also benefit from the development of farrowing housing systems that meet the needs of the animals and address the concerns of the public, due to the economic risk associated with adopting unsustainable husbandry systems.

Group farrowing was the second housing system most compared with farrowing crates in the reviewed literature. In group housing systems, social interactions are improved and animals have higher space allowance than in farrowing crates and loose pens. However, the different designs of group farrowing systems may have different consequences to animal welfare. For example, one study added doors between loose pens for piglets to circulate among multiple pens (WEARY et al., 2002). Although this housing systems is easier to adopt than multi-suckling pens and the social interactions between litters had positive effects to piglet welfare (WEARY et al., 2002), the sow is still socially restricted. The same can be considered for piglets in get-away systems, where the sows can socialize in a common area, but piglets cannot socially interact with other litters (VAN NIEUWAMERONGEN et al., 2014). Socialization with non-littermates had positive effects to piglet welfare as it reduced piglet aggression pre- and post-weaning (FELS et al., 2021; MESAREC et al., 2020; VERDON; MORRISON; RAULT, 2019a). Socially complex group housing systems may be more beneficial to animal welfare, like multi-suckling systems where both sows and piglets are housed in the same group pen (VAN NIEUWAMERONGEN et al., 2014). Moreover, sows’

aggressive behaviours, a main animal welfare concern related to group housing, were reduced in multi-suckling systems compared to get-away systems (GREENWOOD et al., 2019). Overall, group housing systems improve animal welfare compared to farrowing crates, but within these systems the multi-suckling pens seem to be more in line with the public expectations considering the social enrichment it provides for animals and may better for farmers to adopt, due to the reduced aggression among sows.

Outdoor farrowing housing systems have high public acceptance compared to farrowing crates and loose farrowing pens (VANDRESEN; HÖTZEL, 2021a). Moreover, German citizens positively evaluated outdoor pig production systems even when informed about possible associated noise and odour emissions (SONNTAG et al., 2019). In the United Kingdom, almost half of the farrowing systems are outdoors (BAXTER; EDWARDS, 2016). However, only a few of the reviewed studies investigated animal welfare in outdoor farrowing housing systems. The benefits of outdoor farrowing systems to animal welfare are mainly related to the naturalness of the system, as animals are allowed to perform a wide range of natural behaviours, which is highly valued by the public (LASSEN; SANDØE; FORKMAN, 2006). However, climatic conditions may be an obstacle to maintain sows and piglets outdoors. Pigs thermoneutrality zone is around 22ºC and climatic conditions may be challenging in both higher and lower temperatures (OLIVEIRA JÚNIOR et al., 2014). As one of the reviewed studies indicated, indoor floor cooling systems were more effective in alleviating sow's heat stress than outdoor access (OLIVEIRA JÚNIOR et al., 2011). It may be possible to associate indoor and outdoor facilities to keep sows in thermal comfort while still allowing outdoor access to maintain the naturalness of the system.

4.5 KNOWLEDGE GAPS AND LIMITATIONS TO THE DRAWING OF CONCLUSIONS

Alternatives to replace the farrowing crates need to address the public concerns and promote increased animal welfare to be sustainable. Adopting alternative farrowing housing systems that fail to do so may be associated with economical and strategical costs in the long term. Therefore, the pig industry needs research-based evidence from the natural and social sciences on animal welfare in farrowing systems. Despite the large number of studies on the welfare of sows and piglets in farrowing systems, the inconsistency in housing models and in animal management practices used among studies compromises the evaluation of the farrowing

housing systems. For example, loose farrowing pens varied in the space available for sows, group farrowing systems housed sows in groups of different sizes and some studies on outdoor farrowing used semi-outdoor systems. This variety within the same farrowing housing category may have influenced the results of the studies, compromising the assessment of the effects of farrowing systems on sows' and piglets' welfare.

Provision of substrate also varied among studies and between housing systems investigated in the same study, which compromises the fair comparison between the housing systems considering that access to substrate can influence animal welfare (JARVIS, et al., 2004). The different temporary crating periods used among studies may also have influenced the results due to the influence of time in confinement on sow's welfare (MORGAN et al., 2021). The time that sows were moved from the group housing to the farrowing housing system also varied among studies, and no explanation was provided about how this time was defined. Some studies have been done on technologies to identify when sows are close to farrow to allow sows to be moved to the farrowing housing closer to the actual farrowing date (OCZAK; MASCHAT; BAUMGARTNER, 2020; PASTELL et al., 2016). The use of these tools can be beneficial to animal welfare because it would reduce the time that sows stay in the farrowing system unnecessarily. Moreover, some studies have been done on the effect of confinement around farrowing (e.g., GOUMON et al., 2018; MASCHAT et al., 2020), but no investigation has been done on the effect of time in confinement prior to the farrowing date. More research is necessary to understand when is the best moment to move sows from the gestation housing to the farrowing housing, and what are the implications of different time periods to sow welfare.

5 CONCLUSION

This study systematically reviewed the literature on sow and piglet welfare in farrowing housing systems. Behaviour, health, performance and physiological parameters were used in the literature as measures of animal welfare. Most sow welfare parameters had positive results in alternative housing systems compared to farrowing crates, which was the housing system most used as a control across studies. However, many studies on sow welfare have evaluated behaviours that are not directly related to animal welfare. Studies on the welfare of piglets in farrowing housing systems focused on the assessment of performance parameters. Among studies evaluating piglet welfare parameters, most had conflicting results or found no difference between farrowing systems. No study investigated the effect of different farrowing systems on the affective states of sows or piglets. The reviewed literature shows that farrowing crates are detrimental to sow and piglet welfare, which is in line with studies on public opinion that indicate that farrowing crates are socially unsustainable. However, research gaps need to be addressed before making decisions on the adoption of alternative farrowing housing systems, like the effects of housing to animals' affective states and how management practices within the alternative housing systems can influence animal welfare.

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SUPPLEMENTARY MATERIAL

Citation ID of the reviewed studies

1	(CEBALLOS *et al.*, 2021)	**20**	(VERDON; MORRISON; RAULT, 2019b)	**39**	(VERHOVSEK; TROXLER; BAUMGARTNER, 2007)
2	(KINANE; BUTLER; O'DRISCOLL, 2021)	**21**	(GENTZ *et al.*, 2019)	**40**	(CHALOUPKOVÁ *et al.*, 2007)
3	(MORGAN *et al.*, 2021)	**22**	(GREENWOOD *et al.*, 2019)	**41**	(CHALOUPKOVA *et al.*, 2007)
4	(FELS *et al.*, 2021)	**23**	(GOUMON, S *et al.*, 2018)	**42**	(JARVIS, Susan *et al.*, 2006)
5	(WIECHERS *et al.*, 2021)	**24**	(KING *et al.*, 2018)	**43**	(HÖTZEL; MACHADO FILHO; DALLA COSTA, 2005a)
6	(LANGE *et al.*, 2021)	**25**	(MACK *et al.*, 2017)	**44**	(JARVIS, S *et al.*, 2004)
7	(HAYES *et al.*, 2021)	**26**	(SINGH *et al.*, 2017)	**45**	(DAMM *et al.*, 2003)
8	(MESAREC *et al.*, 2020)	**27**	(BRAJON *et al.*, 2017)	**46**	(WEARY, D M *et al.*, 2002)
9	(MASCHAT *et al.*, 2020)	**28**	(HALES *et al.*, 2016)	**47**	(JARVIS, S *et al.*, 2002)
10	(CEBALLOS; GOIS; PARSONS, 2020)	**29**	(CHIDGEY *et al.*, 2016)	**48**	(COX; COOPER, 2001)
11	(LOFTUS *et al.*, 2020)	**30**	(LAMBERTZ *et al.*, 2015)	**49**	(PAJOR *et al.*, 1999)
12	(ZHANG *et al.*, 2020)	**31**	(LAU; PLUSKE; FLEMING, 2015)	**50**	(HARRIS; GONYOU, 1998)
13	(VERDON; MORRISON; RAULT, 2020)	**32**	(MARTIN; ISON; BAXTER, 2015)	**51**	(BLACKSHAW *et al.*, 1997)
14	(KOBEK-KJELDAGER *et al.*, 2020)	**33**	(VAN NIEUWAMERONGEN *et al.*, 2015)	**52**	(BIENSEN; VON BORELL; FORD, 1996)
15	(NICOLAISEN *et al.*, 2019)	**34**	(OLIVEIRA JÚNIOR *et al.*, 2014)	**53**	(HULTÉN *et al.*, 1995)
16	(ILLMANN *et al.*, 2019)	**35**	(YUN, Jinhyeon *et al.*, 2013)	**54**	(LAWRENCE, A. B. *et al.*, 1994)
17	(YUN, J *et al.*, 2019)	**36**	(OLIVEIRA JÚNIOR *et al.*, 2011)	**55**	(BLACKSHAW *et al.*, 1994)
18	(VERDON; MORRISON; RAULT, 2019a)	**37**	(OLIVIERO *et al.*, 2010)	**56**	(CRONIN *et al.*, 1991)
19	(SCHREY; KEMPER; FELS, 2018)	**38**			

APPENDIX A - REASONS FOR EXCLUSION OF STUDIES

Table A1. Detailed reasons for exclusion of publications on the first screening

Reasons for exclusion	n	%
Pigs but not farrowing sows/piglets	140	23%
About gestating sows	83	14%
Review paper	49	8%
Lactating sows but not about the farrowing housing	48	8%
New technologies	47	8%
Preweaned piglets but not about the farrowing housing	44	7%
Not about pigs	35	6%
Aspects of the farrowing housing (e.g. heat source, floor type)	34	6%
Nutrition	25	4%
Piglet crushing	24	4%
Enrichment for sows	17	3%
Reproduction	16	3%
Public opinion	11	2%
Enrichment for piglets	10	2%
Economic aspects	7	1%
Characterization of farrowing housing in countries	6	1%
Guidelines document	1	0%
Products of pig production	1	0%
Report paper	1	0%
Total	**599**	

Table A2. Detailed reasons for exclusion of publications on the second screening

Reasons for exclusion	n	%
Does not compare farrowing housing systems	16	30%
No investigation on the effect of housing on pig welfare	11	21%
Focused on piglet crushing	7	13%
Aspects of the farrowing housing (e.g. heat source, floor type)	4	8%
Compares crate vs crate	3	6%
Enrichment for piglets	3	6%
Lying behaviour focused on piglet crushing	2	4%
Lying/posture behaviour	2	4%
No investigation on housing	2	4%
Data bases from multiple farms	1	2%
New technologies	1	2%
Performance measures	1	2%
Total	**53**	

APPENDIX B - ANIMAL WELFARE PARAMETERS INVESTIGATED

Table B1. Number (n) and percentage (%) of publications among the reviewed literature investigating sow welfare (n = 39) according to welfare outcomes. Welfare outcomes were categorized based on the nature of the parameter investigated. Percentages of categories were calculated based on the total number of publications identified in the systematic review (n = 56). Percentages of sow welfare outcomes were calculated based on the number of publications in their respective category.

	n	**%**
Behaviour	**30**	**77%**
Posture and posture changes	25	83%
Activity and exploration	13	43%
Nursing	12	40%
Object-directed behaviours	7	23%
Farrowing duration	7	23%
Social behaviour	6	20%
Stereotypies	6	20%
Position and location	4	13%
Aggression	4	13%
Nesting behaviour	3	10%
Maternal responsiveness test	3	10%
Vocalization	2	7%
Play behaviour	1	3%
Mounting	1	3%
Performance	**16**	**41%**
Weaning rate	8	50%
Weight	5	31%
Back fat thickness	5	31%
Reproduction performance	6	38%
Feed conversion efficiency	4	25%
Milk production	1	6%
Lactation energy efficiency	1	6%
Health	**17**	**44%**
Skin and shoulder lesions	11	65%
Teat and udder lesions	6	35%
Lameness	5	29%
Temperature	3	18%
Respiratory rate	2	12%
Body condition score	2	12%
Faecal consistency	1	6%
Heart rate	1	6%

Physiological	**16**	**41%**
Cortisol	14	88%
Adrenocorticotropic hormone (ACTH)	4	25%
Oxytocin	2	13%
Prolactin	2	13%
Heart rate	1	6%
Progesterone	1	6%
Estradiol	1	6%
IgA saliva	1	6%

Table B2. Number (n) and percentage (%) of publications among the reviewed literature investigating piglet welfare (n = 44) according to welfare outcomes. Welfare outcomes were categorized based on the nature of the parameter investigated. Percentages of categories were calculated based on the total number of publications identified in the systematic review (n = 56) and percentages of piglet welfare outcomes were calculated based on the number of publications in their respective category.

	n	**%**
Performance	**31**	**70%**
Pre-weaning growth	22	71%
Pre-weaning mortality	20	65%
Post-weaning growth	10	32%
Post-weaning feed conversion efficiency	4	13%
Meat quality	1	3%
Behaviour pre-weaning	**25**	**57%**
Aggressive and agonistic behaviours	12	48%
Activity and exploration	11	44%
Suckling	11	44%
Play behaviour	10	40%
Behavioural tests	8	32%
Social behaviour	7	28%
Damaging behaviours	7	28%
Position and location	4	16%
Object-directed behaviours	3	12%
Cross-suckling	3	12%
Response to painful procedure	1	4%
Vocalization	1	4%
Behaviour post-weaning	**15**	**34%**
Behavioural tests	10	67%
Aggressive and agonistic behaviours	8	53%
Play behaviour	6	40%
Damaging behaviours	6	40%

Activity and exploration	4	27%
Object-directed behaviours	2	13%
Vocalization	2	13%
Response to vocal call of sow	1	7%
Social behaviour	1	7%
Mounting	1	7%
Qualitative Behaviour Assessment	1	7%
Food competition test	1	7%
Cognitive test	1	7%
Health	**14**	**32%**
Skin lesions	10	71%
Tail lesion	2	14%
Hoof scores	1	7%
Faecal consistency	1	7%
Requirement for medical treatment	1	7%
Physiological	**7**	**16%**
Cortisol	6	86%
Blood parameters (neutrophil, lymphocyte, haptoglobin, IgG, IgM)	2	29%

APPENDIX C – FIGURES ILLUSTRATING FARROWING HOUSING SYSTEMS

Figures from reviewed studies illustrating the farrowing housing systems investigated.

Loose farrowing pens

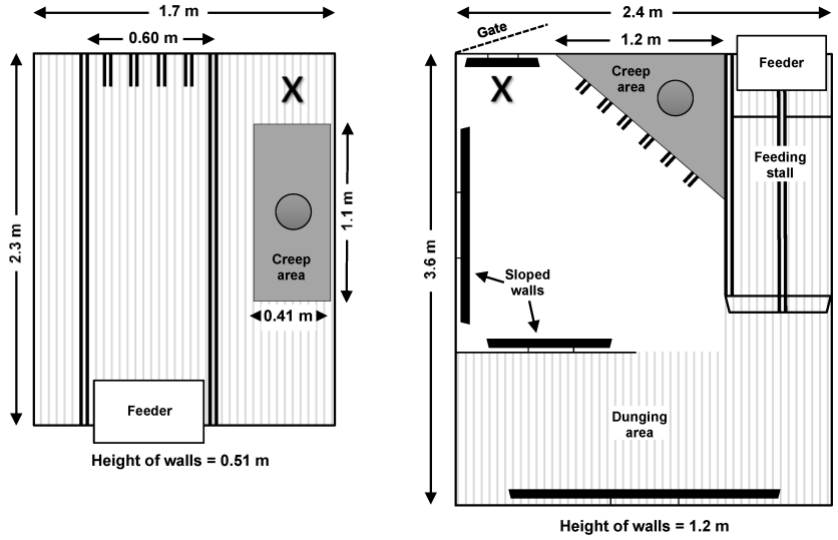

Figure S1. Layout and dimensions of (a) farrowing crate and (b) loose farrowing pen used by Hayes et al., (2021).

Group housing (multi-suckling system)

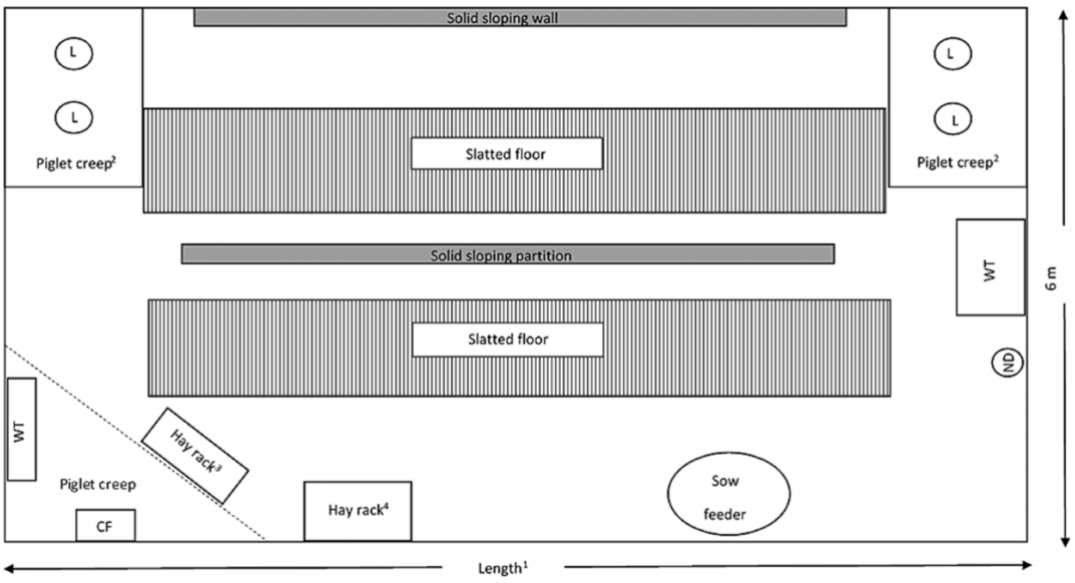

Figure S2. Layout of group lactation pens used by Verdon et al., (2020). CF, creep feed; WT, water trough; L, heat lamp; ND, nipple drinker.

Group housing (get-away system)

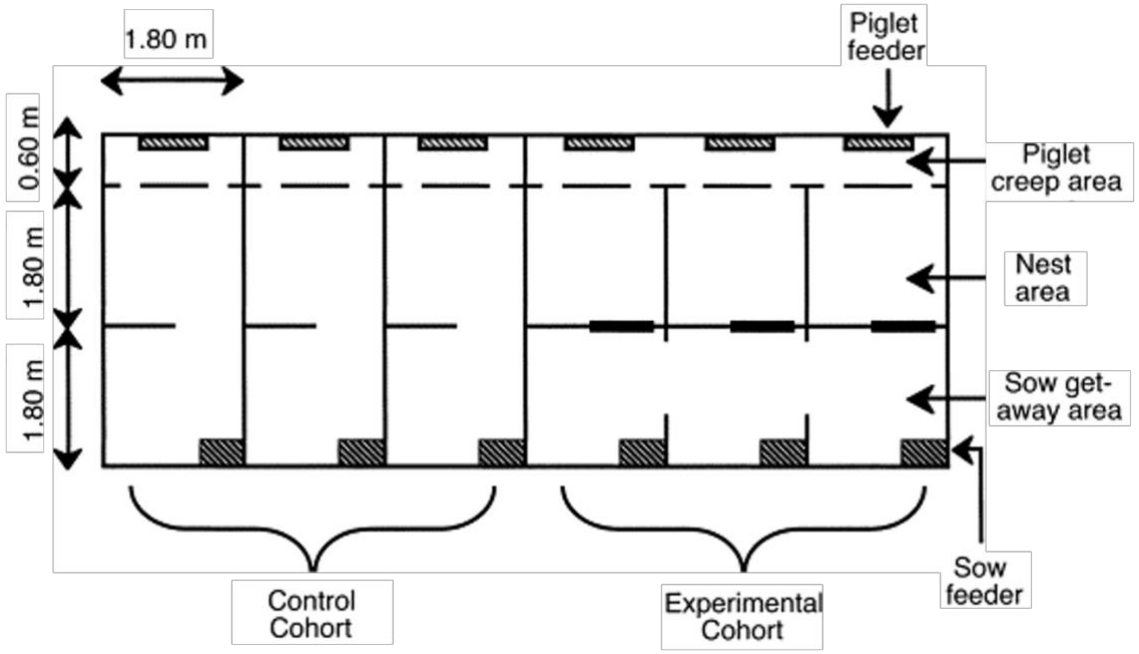

Figure S3. Floor plan for six pens in the experimental room showing housing for an experimental cohort of three sows and a control cohort. All piglets had access to a heated creep area adjacent to the nest area they shared with the sow. In experimental cohorts, piglets could move between pens, and the three sows could access a communal get-away area by crossing a piglet-proof barrier. In control cohorts, each sow and litter had a separate pen, and piglets could follow the sow wherever she went. Source: Weary et al., 2002

Open and closed hinged farrowing crates

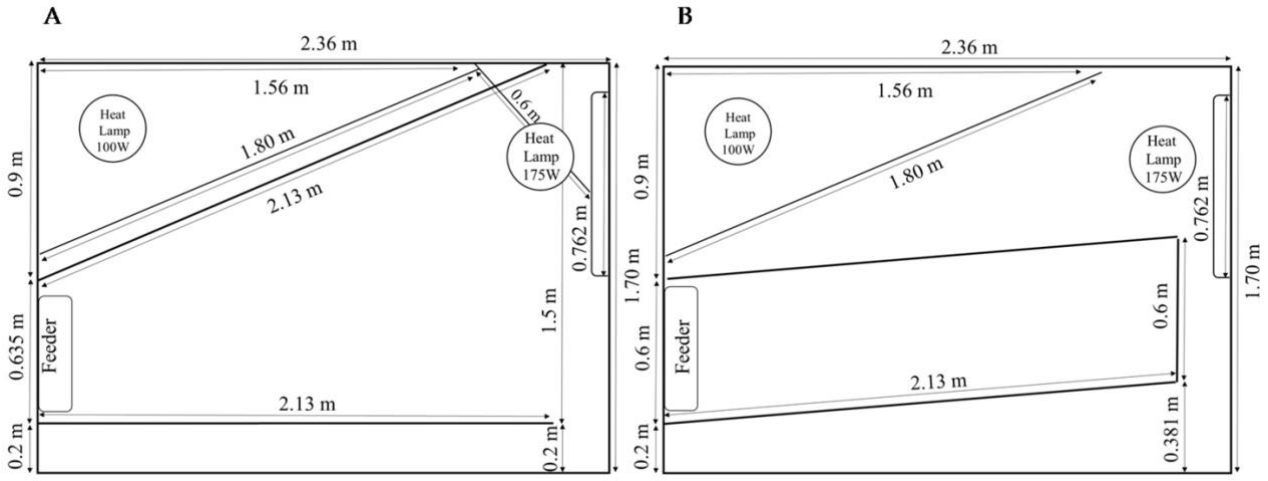

Figure S4. Schematic of pen equipped with a hinged farrowing crate used by Ceballos et al., (2021). (A) Open. (B). Closed.

Outdoor farrowing system

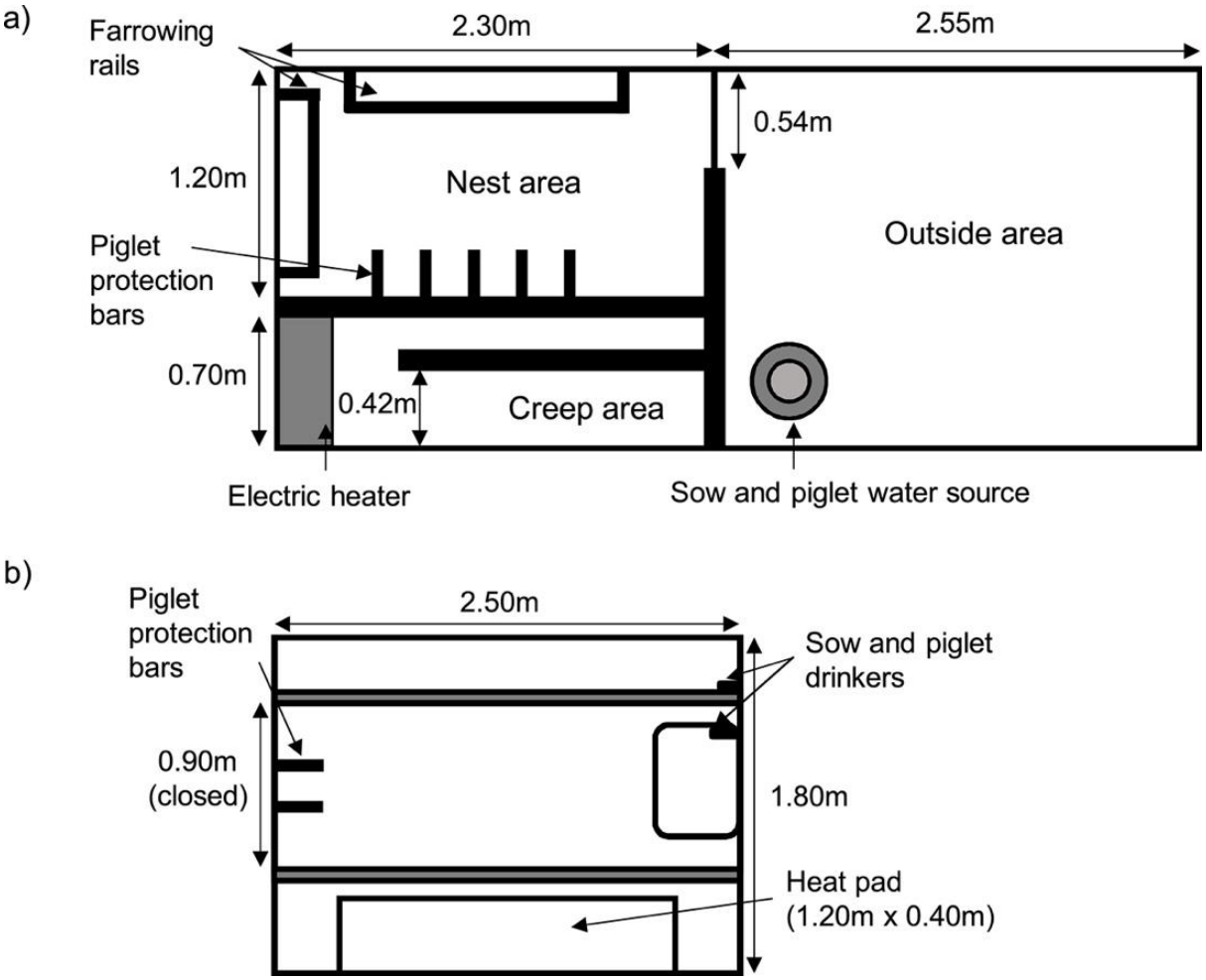

Figure S5. Sow farrowing pen layouts illustrating dimensions for (a) the straw-based pen with outside run and (b) the 360 °Freedom Farrower from King et al., (2018).