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Enhancing pig welfare: exploring the effects of early socialisation in commercial pig farming (*Sus scrofa domesticus*)



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## Enhancing pig welfare: exploring the effects of early socialisation in commercial pig farming (*Sus scrofa domesticus*)

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## **Abstract**

*In commercial pig farming, the process of weaning typically occurs between three and five weeks of age. Weaning under conventional circumstances is an abrupt process that involves a sudden separation of piglets from their mother, followed by grouping with unfamiliar conspecifics, dietary changes and relocation into high densities. This abrupt transition induces social and psychological stress, resulting in heightened aggression, abnormal behaviours and health issues among piglets. In recent years, there has been growing interest in on-farm strategies aimed at mitigating these negative effects of weaning. One of these strategies is early socialisation, where piglets are introduced to unfamiliar conspecifics before the weaning period begins. In this way, piglets develop the social skills needed during weaning. This review investigates the impact of early socialisation on various indicators of pig welfare in commercial farming settings. Specifically, we examine its effects on aggression, injuries, stress-related behaviours and physiological markers, fear, positive social interactions, health and performance, before, during and after weaning. The findings of this literature review confirm the positive impact of early socialisation in commercial pig farming. Notable benefits include reductions in aggressive behaviour, injuries, stress-related abnormal behaviours and physiological stress markers, alongside increases in positive social interactions, overall health and performance. Despite these advantages, many farmers remain hesitant to implement alternative housing systems because of concerns about potential economic losses due to reduced growth or increased mortality. Therefore, future research should delve deeper into the effects of implementing early socialisation practices and their implications for economic viability. By bridging the gap between economic interest and animal welfare, we encourage sustainable farming practices that prioritise pig welfare while ensuring economic viability.*

## Plain language summary

Veel mensen hebben het beeld van koeien die grazen in weilanden en varkens die rondlopen in de modder wanneer ze aan de veehouderij denken. Deze beelden zijn echter vaak van dieren die gehouden worden volgens biologische of drie sterren beter leven systemen. In de conventionele veehouderij ziet de realiteit er anders uit, en de afgelopen jaren is er veel kritiek geuit op het welzijn van deze dieren. De meeste dieren worden binnen gehouden, vaak in grote groepen en groeien op onder suboptimale omstandigheden. In Nederland komt bijna 50% van al het geconsumeerde vlees van varkens. Daarom is het welzijn van varkens in de vleesindustrie een grote zorg. De omstandigheden waaronder deze dieren leven veroorzaken veel stress, wat van invloed is op hun groei, voortplanting, gedrag, immuniteit tegen ziektes, en zelfs de kwaliteit van het vlees. Het is de verantwoordelijkheid van de mens om dieren te behandelen met respect en zorg om zo het dierenwelzijn te handhaven. Door de varkens in de veehouderij te laten leven onder suboptimale omstandigheden, schenden wij onze morele verantwoordelijkheid. Is het bijvoorbeeld ethisch verantwoord om zeugen individueel te huisvesten, terwijl het sociale dieren zijn? Is het ethisch verantwoord om vleesvarkens op te laten groeien in een hoge bezettingsgraad met 1m<sup>2</sup> per varken, zonder uitloop naar buiten en ze niet kunnen wegvluchten bij agressie? Het is daarom van groot belang om nieuwe strategieën te ontwikkelen om de stress te verminderen en leef omstandigheden bij deze dieren te verbeteren.

Een van de meest stressvolle situaties in het leven van een varken in de commerciële veehouderij is het spenen. Dit gebeurt al tussen de 3 en 5 weken nadat de varkens zijn geboren. Ze worden abrupt gescheiden van hun moeder, overgezet van melk naar vast voedsel en samengevoegd met grote aantallen onbekende dieren. Dit staat in contrast met hoe het spenen in het wild verloopt. Daar brengt de moeder de biggen al in week 2 bij de rest van de groep, en begint het spenen in week 4. Dit verloopt geleidelijk tot de biggen in week 17 tot 20 volledig gespeend zijn. Zo krijgen ze de kans om langzaam te wennen aan andere omstandigheden. Het is duidelijk dat de leeftijd van spenen in de commerciële veehouderij ver van de natuurlijke situatie afligt, wat veel stress oplevert voor de dieren.

In deze review hebben we onderzocht of vroege socialisatie, een van de strategieën om stress rondom het spenen te verminderen, het welzijn van varkens kan bevorderen. Het idee van vroege socialisatie is om biggen al voor het spenen kennis te laten maken met onbekende biggen, door bijvoorbeeld een deurtje tussen de verblijven te openen. Uit ons onderzoek is gebleken dat vroege socialisatie niet alleen de stress tijdens het spenen vermindert, maar dit ook doet op de lange termijn. Zo vertonen varkens minder agressief gedrag en angst en vertonen ze meer positief gedrag zoals spel. Bovendien blijkt dat vroeg gesocialiseerde dieren beter groeien en minder vatbaar zijn voor ziektes.

Ondanks deze voordelen zijn boeren terughoudend om vroege socialisatie toe te passen vanwege de potentiële kosten die hiermee gepaard zouden kunnen gaan. De angst is dat de gesocialiseerde varkens een verminderde groei en verhoogd sterfte hebben, wat leidt tot kosten. Uit onderzoek blijkt echter dat deze strategie in sommige gevallen economisch voordelig kan zijn voor boeren. Meer onderzoek zal nodig zijn om aan te tonen dat vroege socialisatie op lange termijn kosteneffectief is, voordat boeren grootschalig gebruik zullen maken van deze methode. Veelbelovend is deze strategie wel en hopelijk zien we in de toekomst steeds meer boeren deze methode gebruiken om de dieren een beter leven te geven.

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## Introduction

The agricultural sector faces major challenges in the realms of environmental sustainability and animal welfare (Garnett et al., 2013). Nowadays, there has been an increase in interest and commitment to addressing these challenges. More specifically, in the context of animal welfare, there is an increase in public concern for improving the living conditions of farm animals. Despite efforts to address animal welfare issues in livestock production, a noticeable gap persists between intention and actual on-farm practices, hindering animals from exhibiting natural behaviours. In the Netherlands alone, nearly half of the meat consumed includes pork (Dagevos et al., 2020), making this industry a focal point of concern. The majority of pigs in this sector are housed in indoor systems, characterised by high stocking densities, limited enrichment and suboptimal living conditions. The consequence of these conditions is stress, which impacts performance, reproduction, behaviour, immunity and meat quality (Smulders et al., 2006). Notably, aggression during introductions to unfamiliar individuals emerges as a predominant welfare concern in commercial pig farming (Peden et al., 2018). These challenges underscore the need to develop on-farm strategies that effectively enhance the living conditions for animals.

To gain deeper insight into possible strategies that influence pig welfare, it is essential to establish a clear understanding of what animal welfare is. In this review, we adopt the definition proposed by Ohl and Van der Staay (2012), who state that animal welfare is a dynamic, rather than static, concept. According to their perspective, the welfare of an animal is dynamic, meaning an animal can experience both positive and negative states. This provides the animal to effectively adapt to its environment without surpassing its limits (Ohl and Van der Staay, 2012). According to Ohl and Van der Staay's definition, animal welfare is: *"An individual is in a positive welfare state when it has the freedom adequately to react to: hunger, thirst or incorrect food; thermal and physical discomfort; injuries or diseases; fear and chronic stress, and thus, the freedom to display normal behavioural patterns that allow the animal to adapt to the demands of the prevailing environmental circumstances and enable it to reach a state that it perceives as positive"*. This dynamic welfare concept is based on the adaptive capacity of an individual.

Production pigs endure a multitude of stressors throughout their lives, primarily as conditions that are offered on many commercial pig farms hinder the expression of natural behaviours. There is limited space, restriction of highly motivated behaviours such as nesting and rooting, a lack of socialisation and exposure to painful management practices, including tail docking, vaccinations and castrations shortly after birth (Herskin et al., 2018; Schmid et al., 2021). One of the most severe stressors in the life of a pig is the weaning process. During this phase, piglets are forced to group with unfamiliar individuals, suddenly removed from their mothers, undergo abrupt dietary changes and relocated in extremely high densities (Weary et al., 2008; Albernaz-Gonçalves et al., 2021). In commercial settings, weaning typically occurs between three and five weeks of age (Weary et al., 2008). In contrast, under natural conditions, weaning is a gradual process, starting at four weeks of age until full separation occurs between 17 and 20 weeks of age (Jensen, 1986). Notably, by the second week, the mother initiates the piglets' introduction to the group, allowing them to explore and interact with non-littermates (Jensen and Redbo, 1987). These early positive interactions create a better tolerance to unfamiliar conspecifics and facilitates a smoother integration into their new and larger social group.

Early weaning, as commonly practiced in commercial settings, is associated with social and psychological stress (Weary et al., 2008; Albernaz-Gonçalves et al., 2021). This manifests in heightened aggression and abnormal behaviours, including tail biting, fighting and bullying, leading to skin lesions, pain and difficulty resting (D'Eath, 2002; Widowski et al., 2008). These negative early experiences have a profound impact on the hippocampus, resulting in observable behavioural and cognitive changes, including reduced learning and memory and exhibit increased abnormal and aggressive behaviours (Orgeur et al., 2001; Yuan et al., 2004; Poletto et al., 2006). From a health perspective, the stressors associated with weaning can induce reduced food intake, resulting in weight loss during the first weeks post-weaning (Hötzel et al., 2011; Pluske et al., 2018). Furthermore, weaning stress is linked to increased cortisol levels, affecting immunity, leaving animals more susceptible to pathogens (Moberg and Mench, 2000; Colson et al., 2012). This compromised immunity necessitates the use of antibiotics



to treat disease outbreaks and maintain low mortality rates (Waluszewski et al., 2021). A study conducted in Germany predicted that pigs receive antibiotics during 48.5 days out of their 200-day lifespan (Raasch et al., 2018), with a concentration around the weaning period (Sjölund et al., 2016; Sarrazin et al., 2019; Albernaz-Gonçalves et al., 2021). Notably, weaning stress emerges as the primary risk factor of diarrhoea, the leading cause of antibiotic use in weaners (Sjölund et al., 2016; Pluske et al., 2018; Albernaz- Gonçalves et al., 2021).

This underscores the importance to reform the weaning process not only to enhance pig welfare by reducing aggressive and abnormal behaviours, but also for promoting human wellbeing and diminishing antibiotic use and its associated costs. This aligns with the One Welfare concept, acknowledging the interconnectedness of animal welfare, human wellbeing and the environment (Pinillos et al., 2016). The improvement of pig welfare holds the potential to minimise the overreliance on antibiotics in the livestock industry (Woolhouse et al., 2015), thereby addressing ethical, social and public health concerns related to the growing threat of antibiotic-resistant bacteria (Van Boeckel et al., 2015; Minssen et al., 2020).

The early life experiences of pigs play a pivotal role in the development of gut microbiota and immune system (Zhang, 2014), social skills and the establishment of coping mechanisms for future life challenges (Ko et al., 2020). Therefore, creating optimal early life conditions is crucial for shaping lifelong health (Blavi et al., 2021). Variances in rearing techniques are expected to exert positive or negative influences on the development of these critical components (Schokker et al., 2014). Maternal care and peer interactions play a crucial role in shaping behaviour and brain function (reviewed by Branch and Cirulli, 2014). In the context of conventional commercial farming, peer interactions are typically limited to littermates and the opportunity to interact with peers only occurs after weaning. However, this coincides with the stressors associated with weaning, including separation from the mother, dietary changes and grouping with unfamiliar conspecifics (Weary et al., 2008; Albernaz-Gonçalves et al., 2021). A strategy suggested to mitigate weaning stress and promote peer interactions pre-weaning is through early socialisation. Early socialisation can be achieved by either mixing piglets, not sows, from different adjacent farrowing pens (Morgan et al., 2014; Camerlink et al., 2018), or utilising a multi-suckling system, where multiple sows and their litters are mixed (Van Nieuwamerongen et al., 2015). However, due to the considerable space requirements and higher costs associated with the multi-suckling system, we will primarily focus on early socialisation. This approach is of great interest to farmers as it can be facilitated by creating a passage between neighbouring pens, allowing piglets to interact. Importantly, this method is resource-efficient, required minimal installation, and is both cost-effective and its implementation is usually fast (Salazar et al., 2018).

This review aims to uncover the impact of early socialisation on the welfare of pigs within conventional commercial housing systems in western Europe. In the context of animal welfare, our focus lies on the components that may be influenced by early socialisation, including the freedom to adequately react to injuries and diseases, fear and chronic stress and display normal behavioural patterns needed to adapt to the environment. Furthermore, it is important to note that in this review, our focus is on the welfare of production pigs, excluding the effects on sows. It is hypothesised that piglets subjected to early socialisation are better equipped for the weaning process, increased experience leads to improved social skills during regrouping, resulting in reduced aggression. This, in turn, facilitates a smoother transition and enhances overall growth performance (Blavi et al., 2021). The anticipated decrease in aggressive interactions contribute to a decrease in stress levels (Salazar et al., 2018) as well as improved overall health (Gravaud et al., 2023). Furthermore, it is suggested social skills improve by the enhancement of social play (Prunier et al., 2020). Building on these hypotheses, it is expected to observe several behavioural effects of early socialisation. Firstly, we expect a reduction in aggression, subsequently minimising injuries. Secondly, we expect an increase in positive interactions, such as social play. Thirdly, we predict a decrease in stress, leading to less fear and a reduction in stress-related abnormal behaviours, such as tail and ear biting. Lastly, we expect effects on health. A reduction in stress and increased peer interactions are expected to result in decreased common health issues, such as diarrhoea, along with an enhanced overall immunity.

## Methods

We conducted a bibliographic search using Google Scholar, accessed from February 12, 2024, to March 6, 2024. The search keywords consisted of “pig”, “piglet”, “*Sus scrofa domesticus*” and “porcine” along with “welfare”, terms related to housing systems (“early socialisation”, “pre-weaning socialisation”, “co-mingling”) and various areas of interest (“aggression”, “skin lesions”, “stress”, “ear biting”, “tail biting”, “fear”, “positive social interactions”, “social play”, “health”, “performance”, “survival”, “growth”). The scope of this review was limited to studies conducted on farms in Western Europe, including UK, Norway, Finland, Sweden, Denmark, Germany, the Netherlands, Austria, Switzerland, Belgium, France, Spain. Only studies focussing on conventional commercial housing were utilised. Therefore, only studies who weaned piglets between three and five weeks of age were included. During pre-weaning socialisation, sows had to be crated, as in conventional systems, while allowing piglets from different sows to intermingle. Primary and secondary literature that was either open access or accessible to Utrecht University students were utilised. Additionally, referenced articles were included. While we aimed to avoid studies combining socialisation and enrichment, some were included due to limited availability of research on the effects of early socialisation. These cases are explicitly mentioned for transparency.

## Aggressive interactions and skin lesions

In natural conditions, piglets engage with one another without elevated levels of aggression or injuries (Gundlach, 1968). However, in commercial settings, aggression is a common occurrence due to the regular regrouping of unfamiliar pigs, leading to aggression to establish dominance hierarchies (McGlone, 1985). In commercial farming, aggression stands out as the foremost welfare concern, persisting for decades without finding a satisfactory solution (Marchant-Forde and Marchant-Forde, 2005; Peden et al., 2018). The prevalence of aggression in commercial settings poses severe consequences for pigs, including injuries such as skin lesions, which allows pathogens to enter the body (Turner et al., 2006), lameness (Rydhmer et al., 2006), along with exhaustion (Camerlink et al., 2016) and stress, impacting the immune system (Morrow-Tesch et al., 1994), reproduction (Turner et al., 2005) and overall performance (Coutellier et al., 2007).

Early socialisation has a notable impact on aggressive behaviour, influencing patterns both before, during and after weaning. Immediately following the mixing of litters from adjacent pens, an increase in aggressive behaviour is observed (Camerlink et al., 2018). This heightened aggression can be attributed to the fact that conventionally housed piglets do not encounter unfamiliar peers during this period of their lives. Despite the initial negative effects post-mixing, positive outcomes regarding aggression reduction become evident during and after weaning, a phase when aggression and its consequences are more severe. During the weaning event, piglets subjected to early socialisation exhibit less aggression, such as fighting, biting, mounting and belly-nosing, compared to those raised under conventional circumstances (Morgan et al., 2014). Post-weaning, a significant reduction in pushing and ear-biting behaviour as well as overall aggression rates are observed in early socialised piglets compared to conventionally housed piglets (Camerlink et al., 2018; Mesarec et al., 2020). Even four days after grouping, socialised piglets engage in fewer fights (Fels et al., 2021), and this persists during later-life regroupings. Consistently, biting behaviour decreases in frequency and duration in pigs socialised before weaning (Weary et al., 1999; D’Eath, 2005; Kutzer et al., 2009; Van Nieuwamerongen et al., 2015; Salazar et al., 2018; Camerlink et al. 2018). Socialised entire male pigs display reduced fighting, biting and mounting behaviour, comparable to conventionally housed castrated males (Rydhmer and Andersson et al., 2024). Moreover, socialised pigs exhibit less bullying behaviour, such as unilateral chasing and (attempted) biting, during regrouping situations (D’Eath, 2005). Resident intruder tests, involving the introduction of a smaller conspecific (the intruder) into the pen of the resident (the test subject), provide additional insights into the effect of early socialisation on aggression towards unfamiliar individuals. In these tests, it became evident that socialised pigs take longer to initiate interaction with the intruder. However, once contact is established, they demonstrate a faster attack response towards the intruder (D’Eath, 2005; Camerlink et al., 2018). This suggests that early socialisation may increase aggression, but a quicker attack does not necessarily indicate more severe



aggression. Camerlink et al. (2018) interpret this outcome as an indication that socialised pigs possess enhanced assessment skills. They take more time to evaluate their opponent, and once they determine they can win the confrontation, they initiate a rapid attack, a behaviour that is also observed in pigs with high fighting experience (Camerlink et al., 2017; Camerlink et al., 2018). Contradictory, this initial increase in fighting contributes to an eventual reduction in fighting and its consequences during later-life regroupings

The decrease in aggression observed in socialised piglets may be attributed to their ability to quickly and efficiently resolve aggressive interactions (Camerlink et al., 2019). In socialised pigs, aggression tends to be short-lived, returning to baseline levels once a dominance hierarchy has been established (D'Eath, 2005). The acquired social skills enable these piglets to solve dominance hierarchies more rapidly and effectively during aggressive encounters (D'Eath, 2005, Desire et al., 2015; Camerlink et al., 2018; Salazar et al., 2018). Moreover, the outcomes of aggressive interactions become more distinct, with a clear winner and loser (Fels et al., 2021). This heightened clarity persists into the finishing phase, where socialised pigs demonstrate an increased ability to establish new rank orders after regroupings, suggesting increased adaptability (Fàbrega et al., 2013). This underscores the existence of a critical early-life window during which piglets can develop greater tolerance towards unfamiliar conspecifics, which has benefits for their long-term stability (Desire et al., 2015). Recognising and exploiting on this early-life window presents an opportunity to effectively reduces aggression in pig farming (Prunier et al., 2020).

Aggressive interactions among pigs often result in physical consequences, predominantly manifested as skin lesions. Immediately after mixing piglets from adjacent pens, socialised piglets exhibit higher number of skin lesions compared to conventionally housed conspecifics that were not subjected to mixing (Camerlink et al., 2018). Increased number of lesions can be attributed to the fact that conventionally housed pigs were not subjected to mixing before weaning. After weaning, a consistent and unanimous observation indicates that socialised pigs experience fewer skin lesions after weaning than conventionally housed individuals (D'Eath, 2005; Van Nieuwamerongen et al., 2015; Salazar et al., 2018; Camerlink et al., 2018; Wen et al., 2021; Fels et al., 2021; Gravaus et al., 2023; Rydhmer and Andersson et al., 2024). Findings reveal a significant 19% reduction in skin lesions resulting from aggressive interactions even four weeks post-weaning in socially housed compared to conventionally housed pigs (Camerlink et al., 2018). Moreover, combining socialisation with additional enrichment, a study by Saladrigas-García et al. (2021) reveals a threefold increase in skin lesions in conventionally housed pigs compare to socially and enriched pigs. Additionally, while conventional housed pigs experience a notable rise in skin lesions both pre- and post-weaning, no such increase is observed in socialised pigs, suggesting fewer and less severe instances of aggression at weaning (Schrey et al., 2019). This difference is further emphasised by the less severe nature of skin lesions in early socialised pigs (Gravaud et al., 2023).

Beyond severity, the location of skin lesions provides valuable insights into the behaviour causing injuries. Turner et al. (2006) notes that lesions on the central and anterior parts of the body indicate reciprocal fighting, while lesions resulting from bullying (unilateral fighting or biting while the opponent is fleeing) appear to be located on the posterior body parts (Turner et al. 2006). In socialised pigs, lesions are primarily found on the central and anterior parts, indicative of reciprocal fighting, whereas conventionally housed pigs predominantly exhibit lesions on the posterior part of the body, a result of bullying behaviour (Wen et al., 2021).

While existing studies primarily focus on the impact of early socialisation on aggression and its consequence on skin lesions, little attention has been directed towards exploring its effects on potential consequences other than skin lesions. For instance, lameness, an injury than can arise from aggression, becomes more apparent during the grower and finishing phases when pigs reach a heavier weight (Peden et al., 2019). Given that research on early socialisation predominantly focusses on the periods surrounding weaning, creates a gap in understanding the influence of early socialisation on injuries in later stages of a pigs development. To conclude, in this examination of aggression in pig farming, the impact of early socialisation emerges as an effective method in reducing both the frequency and severity of aggressive interactions among pigs.

## Stress

Stress is a common issue in commercial farming, with weaning and transport identified as particularly stressful situations for pigs (Martínez-Miró et al., 2016). Pigs housed in conventional housing systems exhibit both behavioural and physiological indicators of chronic stress, experiencing a more negative affective state (Douglas et al., 2012; Luo et al., 2020; Luo et al., 2020a). This is evident in the elevated rates of stress-related behaviours and physiological markers observed in commercial settings, such as illustrated by the high prevalence of tail biting behaviour (Valros et al., 2004; Smulders et al., 2008).

The impact of early socialisation on stress becomes apparent when comparing socialised piglets to conventionally housed piglets. Notably, early socialisation has been noted for its potential to alleviate weaning stress (Ko et al., 2020). To delve into behavioural stress markers, specifically abnormal behaviours associated with stress, it is crucial to examine the most common destructive behaviour on commercial farms, tail biting, an issue that is most prevalent during the grower and finisher phase (Sonoda et al., 2013; Valros et al., 2013). Nevertheless, it is crucial to recognise that not all instances of tail-biting serves as a marker of stress. Tail biting behaviour can be categorised into three types: two-stage, sudden-forceful and obsessive tail biting, each associated to a different motivational base (see review by Taylor et al., 2010). Unfortunately, studies often fail to differentiate between types of tail-biting. However, they do typically focus on instances that lead to observable damages. While research on the effects of early socialisation on tail biting is limited, findings indicate no significant difference in the number of pigs engaging in tail biting under socialised and conventional conditions (Klein et al., 2016). However, the socialised group exhibits a higher percentage of intact and longer tails, suggesting a potential decrease in the severity of biting (Klein et al., 2016). Tail-docking, the amputation of (a part of) the tail, is a common practice to mitigate tail biting. However, it is crucial to explore alternative approaches, as tail-docking does not eliminate tail-biting, inflict acute pain by mutilation and does not address the underlying problem (Sutherland and Tucker, 2011). Another damaging behaviour, ear biting, often linked to boredom and frustration (Prunier et al., 2020a), may occur as a redirected oral manipulation behaviour in farms with pigs with short-docked tails (Diana et al., 2019). This redirection towards ears aligns with the observation that the frequency of ear biting is associated with a short-docked morphology (Goossens et al., 2008). While early socialisation does not seem to significantly impact ear biting in terms of visible lesions, it is important to note that the study focused on visible lesions and not biting frequency (Ko et al., 2020), raising the possibility that lesions may have healed before measurement.

Exploring the physiological indicators of stress, we discover the impact of early socialisation on the activation of two stress-associated brain networks: the Sympathetic-Adrenal-Medullary (SAM) and Hypothalamic-Pituitary-Adrenal (HPA) axis (Godoy et al., 2018). Among the physiological markers, cortisol, a well-known stress indicator that is the product of activation of the HPA-axis (Martínez-Miró et al., 2016), undergoes notable effects due to early socialisation. Multiple studies have demonstrated reduced cortisol increases during weaning in socialised piglets compared to conventionally housed piglets (Yang et al., 2018; Salazar et al., 2018; Ko et al., 2020). Moreover, socially housed piglets exhibited no significant increase in cortisol levels before and during weaning, contrasting with the significant rise observed in conventionally housed piglets (Saladrigas-García et al., 2021). This suggests that socialised piglets may not perceive weaning as stress-inducing as conventionally housed piglets do. Post-weaning, cortisol levels tend to remain lower in socialised piglets (Salazar et al., 2018), although uniformity of this effect is not consistent among studies (Gravaud et al., 2023). The lack of a consistent reduction after weaning may be attributed to the overall reduction in stress levels after weaning, since in this phase dominance hierarchies have already been established. Nonetheless, the increase in cortisol levels remained significantly lower in socialised compared to conventionally housed pigs (Gravaud et al., 2023). Notable, variations in cortisol measurement methods, such as the use of hair cortisol in one study as opposed to salivary cortisol in others, may have contributed to the observed differences in findings. Nevertheless, the general agreement remains that early socialisation does not elevate cortisol levels, implying neutral or positive effects on prolonged stress reduction.

Stress markers indicating the activation of the SAM-axis include chromogranin A and  $\alpha$ -amylase (Martínez-Miró et al., 2016). Both stress markers are reduced in the days surrounding weaning in piglets reared in socialised combined with an enriched environment compared to those raised under conventional circumstances (Ko et al., 2020). This does not dismiss the possibility that these effects were induced by enrichment rather than socialisation. However, it does suggest that early socialisation might influence these stress markers in some way. Another marker of stress is the granulocyte/lymphocyte ratio (Sutherland et al., 2012). Cortisol decreases the number of lymphocytes in the blood (Dhabhar et al., 1995), resulting in an expected increase in the granulocyte/lymphocyte ratio under prolonged stressful conditions. As anticipated, this ratio is significantly higher in conventionally housed pigs compared to socialised pigs (Wen et al., 2021). This further underscores the positive impact of early socialisation on reducing weaning stress. Collectively, these findings suggest that early socialisation is an effective method for reducing stress around weaning, potentially extending its benefits beyond this period.

### **Fear**

The influence of early socialisation on fear in pigs remains vastly unexplored, despite the widely acknowledged negative implications of fearfulness for animal welfare (Mota-Rojas et al., 2020). Nonetheless, a couple of studies have delved into this topic, providing valuable insights into how socialisation can potentially reduce fear-related behaviours. Weller et al. (2020) applied a social preference test within a T-maze setup. The maze presented a smaller stimulus pig on one side and a larger one on the other side, each accompanied by food bowls with equal quantities of food. The results indicated that socialised pigs displayed a faster rate to exit the middle section, suggesting an improved capacity to assess the potential threat posed by unfamiliar conspecifics (Weller et al., 2020). Contrary to expectations, these socialised pigs spent more time in the arm of the T-maze containing the larger pig. This unexpected behaviour challenges the original hypothesis that they would favour the smaller pig due to their increased experience with unfamiliar conspecifics and are therefore quicker to assess dominance. It is suggested that early socialisation experiences led to decreased fear of unfamiliar individuals, making them more at ease in the presence of larger pigs (Weller et al., 2020). Another study examined fear in the context of human-animal relationships. Pigs were reared either in conventional housing or enriched housing, including early socialisation between pens and various enrichment materials such as straw and hanging chains. The findings revealed that pigs in the enriched group exhibited reduced fear of humans during the human animal relation test, which involved an unfamiliar observer entering the pen for a three-minute period (Wen et al., 2021). This indicates an enhanced human-animal relationship assisted by the enriched pre-weaning environment. Nevertheless, interpreting these results required caution due to the potential influence of enrichment materials. In conclusion, these recent studies hint at the potential effect of early socialisation to reduce fear not only towards unfamiliar conspecifics but also in the context of human-animal interactions.

### **Positive social interactions**

Positive social interactions play a crucial role in the social lives of pigs (Camerlink et al., 2021). However, existing pig welfare studies tend to emphasise negative social behaviours, overshadowing the fact that pigs experience frequent positive social interaction, possibly exceeding the occurrence of negative ones (Camerlink et al., 2021). These positive interactions include activities such as sleeping and resting in physical contact (Goumon et al., 2020; Camerlink et al., 2022), allogrooming (Camerlink and Turner, 2013), synchronised exploration (Zwicker et al., 2015), social play (Newberry et al., 1988; Brown et al., 2015) and the use of the nose for close-contact communication, known as social nosing (Camerlink et al., 2012; Camerlink and Turner, 2013). Piglets in particular, heavily rely on nose interactions, taking up to 78% of all social interactions (Clouard et al., 2022).

As expected, the impact of early socialisation extends beyond negative social behaviours and positively influences social interactions among pigs. Piglets that were socialised before weaning exhibited increased tendencies to rest together and share home pen areas before weaning compared to conventionally housed pigs (Weary et al., 1999; Weary et al., 2002). Furthermore, socialised pigs

spent more time in rooting activities and interacting positively, while conventionally housed pigs exhibited more oral stimulation of the pen and penmates, along with damaging and aggression-related behaviours (Wen et al., 2021). Additionally, socialised piglets spent more time on exploring objects and their pens in comparison to conventionally housed piglets (Ko et al., 2020; Saladrigas-García et al., 2021).

Social play has gained most interest as a positive social behaviour and is widely utilised as a positive welfare indicator in recent animal welfare research. Therefore, increased play is seen as a sign of good welfare, and reduced play is linked to poor welfare (see review by Ahloy-Dallaire et al., 2018). Consistently, studies confirm that early socialisation positively influences play behaviour, seen by piglets socialised with other litters engage in more play compared to conventionally housed piglets (Weary et al., 1999; Salazar et al., 2018; Wen et al., 2021). However, merely specific components of social play may be effected by early socialisation. It was found that not the overall level of social play, but play fighting varied between socialised and conventionally housed pigs (Weller et al., 2019; Prunier et al., 2020). This suggests that the advantages of social play may be regulated by mechanisms other than socialisation (Prunier et al., 2020). Social play is believed to develop skills essential for future interactions, for example in aggressive contexts. Notably, socialised piglets engaging in more play-fighting displayed a faster response in attacking intruder pigs during resident-intruder tests (Weller et al., 2019), suggesting a correlation between play-fighting and aggressiveness. Early socialised pigs may have gained more experience and were therefore less fearful of the intruder. In summary, early socialisation emerges as an effective method for enhancing positive social interactions in pigs, offering valuable insights into the potential implications for animal welfare.

## Health

Improving pig health is a primary concern for farmers, as increased susceptibility to diseases not only constrains average daily weight gains, but also elevates mortality rates and treatments costs, leading to significant economic losses (Cornelison et al., 2018). Enhancing pig immunity stands out as a key strategy to mitigate disease vulnerability. Early social interactions play a role in facilitating piglet contact and stimulate microbiota exchange, evident in alterations observed in the faecal microbiota of early socialised piglets (Bi et al., 2021; Nowland et al., 2022). While there may not be substantial differences in the microbial colonisation process itself, as abundance remains consistent, there are remarkable changes in the global structure of caecal microbiota (D'Eath, 2005; Saladrigas-García et al., 2021). This implies that early socialisation during the lactational period influences the development of intestinal microbiota. While no changes became apparent during the pre-weaning period, a shift in global structure became evident during the post-weaning period. It is suggested that the effects on the piglets microbiota only manifest during the post-weaning period, because early socialisation enhances the adaptability to stressors, thereby mitigating stress-related intestinal dysfunctions (Saladrigas-García et al., 2021). This clarifies why alterations in microbiota become apparent only after weaning, possibly due to their association with the stress response. As socialised piglets are better equipped to cope with stressors, they experience reduced stress during and after weaning. Consequently, socialised pigs are less susceptible to stress-related intestinal dysfunction, potentially explaining the changes observed in intestinal microbiota. However, direct links are yet to be investigated.

Early socialisation not only impacts overall immunity but also enhances immune responses in various ways. Exposure to a broader range of pathogens during their early life contributes to heightened immunity in piglets (Hervè et al., 2022). This extends to improved immune cell competence and a reduced susceptibility to diseases caused by co-infection (Van Dixhoorn et al., 2016; Wen et al., 2021; Gravaud et al., 2023). Furthermore, socialised piglets exhibit stronger responses to vaccinations, indicating enhanced innate immune competence during weaning (Gravaud et al., 2023). These beneficial effects endure in the long term (Wen et al., 2021), potentially characterised by the reduction of weaning stress in socialised piglets, which in turn, improves their ability to deal with immune challenges (De Groot et al., 2001). To sum up, early socialisation appears to promote immunity in piglets.

## Performance

Farmers hold a great interest in the survival and growth of pigs (Theil et al., 2012), making improvements in survival and growth rates of great economic interest. While no studies specifically focus on the impact of early socialisation on piglet survival, several investigations delve into its effects on growth rate. In the pre-weaning phase, studies indicate no observable differences in the average daily weight gain between socialised and conventionally housed piglets (Hessel et al., 2006; Kutzer et al., 2009; Camerlink et al., 2018; Salazar et al., 2018; Ko et al., 2021). However, post-weaning, a number of research suggests an increased average daily weight gain in socialised piglets compared to conventionally housed piglets (Weary et al., 1999; Hessel et al., 2006; Kutzer et al., 2009; Schrey et al., 2019; Ko et al., 2020; Rydhmer and Andersson, 2024). Furthermore, some studies found indications, results close to significance, that socialised piglets exhibit a faster growth rate than conventionally housed piglets (Kanaan et al., 2012; Schrey et al., 2019; Ko et al., 2021). A faster growth rate in socialised pigs could lead to these animals reaching their targeted market weight sooner. This is evidenced by the study of Ko et al. (2021), which suggested that socialised pigs tended to reach the slaughterhouse 2.8 days earlier than conventionally raised pigs. However, some studies reported no differences in average daily weight gains between the two groups (Salazar et al., 2018; Camerlink et al., 2018). Differences in findings may be attributed to the timing of measurements. Some studies identified only short-term effects before weight gain stabilised and average daily gain did not differ between pigs raised in socialised or conventional conditions. Therefore, only finding effects when zooming in on a specific part of a pigs life. For instance, Schrey et al. (2019) noted an increase in average daily weight gain between day 35 and day 39, with only a trend visible until day 63. Moreover, some studies observed effects only in the week (Rydhmer and Andersson, 2024) or two weeks following weaning (Weary et al., 1999; Kutzer et al., 2009). Nevertheless, nearly all studies demonstrate positive or potentially positive outcomes (as indicated by trends).

Improvements in average daily weight gain align with the increased food consumption observed in socialised piglets (Weary et al., 2002; Salazar et al., 2018; Yang et al., 2018; Ko et al., 2020). Conventionally housed pigs typically consume less food in the days following weaning due to time needed to be invested in aggressive interactions aimed at establishing dominance hierarchies. Reduced voluntary food intake in conventionally housed pigs has been linked to weaning stress (Pluske et al., 2013; Campbell et al., 2013), suggesting that decreased weaning stress, as seen in socialised pigs, may lead to increased food consumption. From an economic perspective, increased food consumption may not seem advantageous. However, when considering feed conversion, studies have shown no differences between socialised and conventionally housed pigs (Rydhmer et al., 2013; Fàbrega et al., 2013), indicating that increased food intake may not have significant economic consequences. Contradictory, the days after weaning, conventional housed pigs exhibit elevated energy demands compared to socially housed pigs (Saladrigas-García et al., 2021). Thus, conventionally housed pigs have higher energy demands despite their reduced food intake. This can be attributed to the fact that socialised pigs cope better during weaning and establish dominance hierarchies more rapidly, thereby reducing the need for aggressive interactions, which consume energy. By minimising the time spent on agonistic interactions, socialised pigs have more time for other activities, including feeding. Creatine plays a crucial role in energy metabolism by facilitating the conversion of adenosine diphosphate (ADP) into adenosine triphosphate (ATP) (Brosnan and Brosnan, 2007). The reduction in creatine levels in early socialised piglets indicates a potentially lower energy expenditure, suggesting enhanced efficiency compared to conventionally housed pigs (Saladrigas-García et al., 2021). Additionally, the adaptation to dry-food intake may be facilitated by reduced stress, contributing to the observed increase in daily weight gain in the socialised group (Saladrigas-García et al., 2021). In summary, with only two studies reporting no effects, and no instances of negative impacts of socialisation on growth rate, the findings underscore the implications for farmers in terms of enhanced growth rates.



## Discussion

In this review, our primary objective was to assess the impact of early socialisation on the welfare of pigs in conventional commercial housing conditions. Our investigation focussed on various behaviours, including aggression, abnormal behaviours, fear responses and positive social interactions, alongside welfare indicators such as injuries, physiological stress markers, overall health and performance. We hypothesised that early socialisation would facilitate a smoother weaning process for pigs, leading to a reduction in aggression and stress levels, while concurrently enhancing health, performance and social skills. Through our extensive literature research, we validated this hypothesis. Consistent with our expectations, this review revealed compelling evidence supporting the benefits of early socialisation. Pigs subjected to early socialisation exhibited reduced aggression, resulting in fewer incidences of injuries such as skin lesions. Moreover, these socialised pigs demonstrated reduced sensitivity to stress and exhibited fewer fear and stress-related abnormal behaviours, such as tail and ear biting. Notably, physiological stress markers showed either lower levels or less increases among socialised pigs compared to conventionally raised pigs. Furthermore, our research revealed an increase overall health, performance and positive social interactions, including social play, among socialised pigs. These findings are graphically represented in figure 1, while table 1 provides an overview of the literature, categorised by the observed positive, negative and neutral effects of implementing early socialisation.

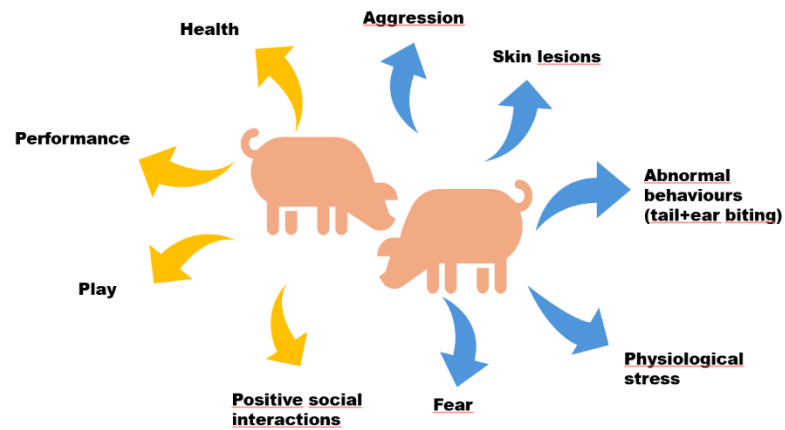


Figure 1. The impacts of early socialisation on various welfare indicators. Blue arrows represent the effects of early socialisation on components resulting in reduced frequency or lower levels/rates compared to conventional systems. Yellow arrows represent the effects of early socialisation on components resulting to increased frequency or higher levels/rates compared to conventional systems.

Table 1. Overview of the literature research categorised into different welfare indicators. Literature is divided by negative, neutral or positive consequences.

Welfare indicator	Negative consequence	No difference	Positive consequence
Aggression			
- Before weaning	Increased aggression (Camerlink et al., 2018)		
- During weaning			Less aggression (Morgan et al., 2014)
- After weaning	Faster attack response (D'Eath, 2005; Camerlink et al., 2018)		Less aggression (Camerlink et al., 2018; Mesarec et al., 2020; Fels et al., 2021; Rydhmer and Andersson et al., 2024)  Less biting behaviour (Weary et al., 1999; D'Eath, 2005; Kutzer et al., 2009; Van Nieuwamerongen et al., 2015; Salazar et al., 2018; Camerlink et al. 2018)



			<p>Less bullying (D'Eath, 2005)</p> <p>Quicker resolving of fights (D'Eath, 2005; Desire et al., 2015; Camerlink et al., 2018; Salazar et al., 2018; Camerlink et al., 2019)</p> <p>More distinct outcomes of fights (Fàbrega et al., 2013; Fels et al., 2021)</p>
<p><b>Skin lesions</b></p> <p>- Before weaning</p> <p>- During weaning</p> <p>- After weaning</p>	<p>Increased skin lesions (Camerlink et al., 2018)</p>		<p>No significant rise in skin lesions between pre- and post-weaning (Schrey et al., 2019)</p> <p>Decreased number of skin lesions (D'Eath, 2005; Van Nieuwamerongen et al., 2015; Salazar et al., 2018; Camerlink et al., 2018; Wen et al., 2021; Fels et al., 2021; Saladrigas-García et al., 2021; Gravaud et al., 2023; Rydhmer and Andersson et al., 2024)</p> <p>Less severe lesions (Gravaud et al., 2023)</p> <p>Lesions from reciprocal fighting instead of unilateral (Wen et al., 2021)</p>
<p><b>Abnormal behaviours</b></p>		<p>Number of pigs engaging in tail biting (Klein et al., 2016)</p> <p>Number of visible lesions (Ko et al., 2020).</p>	<p>Decreased severity of tail biting (Klein et al., 2016).</p>
<p><b>Physiological stress markers</b></p> <p>- Before weaning</p> <p>- During weaning</p>			<p>Reduced cortisol increase (Saladrigas-García et al., 2021)</p>

- After weaning		Cortisol levels (Gravaud et al., 2023)	<p>Reduced cortisol increase (Yang et al., 2018; Salazar et al., 2018; Ko et al., 2020; Saladrigas-García et al., 2021; Gravaud et al., 2023)</p> <p>Reduced chromogranin A and <math>\alpha</math>-amylase (Ko et al., 2020)</p> <p>Reduced granulocyte/lymphocyte ratio (Wen et al., 2021)</p> <p>Lower cortisol levels (Salazar et al., 2018)</p>
Fear			<p>Decreased fear of unfamiliar conspecifics (Weller et al., 2020)</p> <p>Reduced fear of humans/enhanced human-animal relationship (Wen et al., 2021)</p>
Positive social interactions			<p>Increased tendency to rest together and share home pen area (Weary et al., 1999; Weary et al., 2002)</p> <p>More rooting and positive interactions (Wen et al., 2021)</p> <p>More exploring (Ko et al., 2020; Saladrigas-García et al., 2021)</p>
Play			<p>Increased play behaviour (Weary et al., 1999; Salazar et al., 2018; Wen et al., 2021)</p> <p>Increased play fighting (Weller et al., 2019; Prunier et al., 2020)</p>
Health			<p>Changes in faecal microbiota (Bi et al., 2021; Nowland et al., 2022)</p> <p>Changes in caecal microbiota (D'Eath, 2005; Saladrigas-García et al., 2021)</p>

			<p>Increased immune cell competence (Hervè et al., 2022)</p> <p>Reduced susceptibility to diseases (Van Dixhoorn et al., 2016; Wen et al., 2021; Gravaud et al., 2023)</p> <p>Stronger response to vaccinations (Wen et al., 2021; Gravaud et al., 2023)</p> <p>Increased immunity (De Groot et al., 2001)</p>
<p><b>Performance</b></p> <p>- Before weaning</p>		<p>Average daily weight gain (Hessel et al., 2006; Kutzer et al., 2009; Camerlink et al., 2018; Salazar et al., 2018; Ko et al., 2021)</p>	
<p>- After weaning</p>		<p>Average daily weight gain (Salazar et al., 2018; Camerlink et al., 2018)</p>	<p>Increased average daily weight gain (Weary et al., 1999; Hessel et al., 2006; Kutzer et al., 2009; Schrey et al., 2019; Ko et al., 2020; Saladrigas-García et al., 2021; Rydhmer and Andersson, 2024)</p> <p>Faster growth rate (trend)( Kanaan et al., 2012; Schrey et al., 2019; Ko et al., 2021)</p> <p>Tending to reach targeted market weights sooner (Ko et al., 2021)</p> <p>Lower energy demand and expenditure (Saladrigas-García et al., 2021)</p>

This review enhances our understanding of how early socialisation contributes to animal welfare, defined by the freedom of an animal to adequately react to environmental changes and receive a state it perceives as positive. Given the dynamic nature of welfare, animals must demonstrate adaptability. In pig farming, adaptability during crucial phases like weaning is vital. Research indicates that animals with robust coping mechanisms cope better during stressors, characterised by more accurate

behavioural and physiological responses to their environment (Chen, 2019). Early life experiences, while potentially stressful, but within an animals manageable limits, contribute to the development of coping strategies for future stressful periods (Parker and Maestripieri, 2011). In the case of pigs, early socialisation can be regarded as a minor early life stressor, during pre-weaning mixing of unfamiliar conspecifics, preparing them for more significant challenges, like weaning. As observed in this review, socialised pigs exhibited lowered physiological stress levels and fewer stress-related abnormal behaviours, suggesting enhanced stress resilience due to early socialisation. Moreover, reduced fearfulness in pigs further contributes to stress alleviation. This suggests early socialisation has the ability to improve welfare by enhancing the ability to cope with stressful changes in their social environments such as during weaning and later-life regroupings.

Furthermore, animals in positive welfare states should demonstrate adequate reaction to injuries and diseases. Although the definition of welfare acknowledges injuries and diseases as occurrences, they should be effectively dealt with. The findings of this review indicate that socialised pigs experience fewer aggression-induced injuries and possess enhanced immunity. This enhances the animals ability to deal with health challenges, therefore meeting the fourth element of welfare. The fifth element of welfare, animals should perform normal behavioural patterns that help them adapt to environmental circumstances, while reaching a positive mental state. While aggression is considered a normal behaviour, needed to form dominance hierarchies, the demands of the environmental circumstances in commercial farming exceed the animals adaptive capacity, resulting in an escalation of aggressive behaviour. Socialised pigs exhibit reduced aggression, allowing them to express a more normal behavioural pattern that includes positive behaviours, among them social interactions and play. These behaviours are expressed more often in socialised pigs than in conventional housed pigs, indicative of a more positive mental state in socialised pigs (Mellor et al., 2009). This suggests welfare is improved since socialised pigs perform more normal behavioural patterns, which allows them to experience a more positive mental state. Through fostering adaptability, resilience and positive behavioural expressions, early socialisation emerges as a promising strategy to improve animal welfare in commercial farming practices.

While this review and much of the research have concentrated on the welfare of production pigs, it is worth considering the potential effects of early socialisation on sows as well. Despite the importance of understanding the impacts of socialised piglets on sows, this area has largely been understudied. However, a minority of studies have focussed on the effects on sows and have found no differences in number of medical treatments, overall health or aggression towards own and other piglets (Rydhmer and Andersson, 2024). Changes in sow behaviour were observed on the day that barriers were removed. Sows exhibit reduced time lying and increased restlessness, returning to normal within 24 hours (Hessel et al., 2006; Ledergerber et al., 2015). The stress response was visible in increased saliva cortisol levels on the day of barrier removal, but normalised already on the following day, suggesting a mild short-term stress event (Ledergerber et al., 2015). In one study, higher teat damage at weaning was observed in sows of socialised piglets (Camerlink et al., 2018), although this finding is not consistent across studies (Van Kerschaver et al., 2021; Rydhmer and Andersson, 2024). A major concern regarding the implementation of early socialisation on farms is the potential for cross-suckling. However, research indicates that cross-suckling occurs infrequently, with only 2.9% of piglets observed engaging in this behaviour (Morgan et al., 2014; Rydhmer and Andersson, 2024). Thus, while further research on the effects of early socialisation on sows is needed, initial studies suggest no severe consequences. Only a mild, short-term stress response has been observed, necessitating further investigation into its effects. Additionally, the occurrence of teat damage in one of the three studies suggests further examination is necessary to mitigate potential issues during the implementation of early socialisation.

This review not only enhances our comprehension of the impact of early socialisation on pig welfare within commercial farming, but also offers practical insights beneficial for farmers and consumers. However, the implementation of early socialisation in conventional farming practices entails costs. This requires a demonstration that the benefits outweigh the costs, which is a common concern among farmers, making them wary of investing in animal welfare improvements as this usually comes with a

cost (Bornett et al., 2003; Gocsik et al., 2015). Stress in commercial farming can lead to a range of negative consequences, such as reduced appetite, immunity, reproductive capacity and growth, alongside increased susceptibility to infectious diseases and higher mortality rates (Kyriazakis et al., 1998). Our research underscores that early socialisation effectively mitigates these stress-related consequences, presenting a significant advantage for farmers. Yet, the fundamental question remains: do these benefits justify the costs? In a recent study by Peden et al. (2021), various aggression mitigation strategies that are proven to mitigate aggression effectively, including early socialisation, larger group housing and synthetic maternal pheromone exposure (Andersen et al., 2004; Samarakone and Gonyou, 2009; Guy et al., 2009), were evaluated for their economic feasibility. Both larger group housing and exposure to maternal pheromones resulted in an estimated 100% negative effect. Early socialisation emerged as the most cost-effective method, exhibiting neutral or positive effects in 38% of cases (Peden et al., 2021). However, in the remaining 62% there are still associated costs. Nonetheless, the economic range of costs to benefits indicates that early socialisation offers potential economic gains, with net benefits ranging from a maximum cost of €0.45 to a maximum benefit of €0.26 per pig produced (Peden et al., 2021). While early socialisation proves to be the most promising strategy, its implementation still poses financial implications for farmers in the majority of cases. However, it is essential to consider the perspective of the consumers. Studies indicate that consumers are willing to pay higher prices for meat of pigs raised in loose-housed systems, have access to outdoor areas (Tonsor and Wolf, 2011; Denver et al., 2017) or have more space (Denver et al., 2017). This suggests that farmers could potentially compensate their investment by asking higher prices for products derived from animals subjected to improved welfare practices by the implementation of early socialisation. Nonetheless, further research is necessary to ascertain consumer preferences and willingness to pay, thereby providing farmers with the necessary evidence to support the adoption of early socialisation. Furthermore, adoption of early socialisation may prove useful in the aim of the European Union's objective (Council Directive 2008/120/EC of 18 December 2008) to phase out tail-docking. Phasing out tail docking necessitates new measures to prevent tail biting. Early socialisation presents a promising strategy in addressing this need, potentially decreasing expenses of alternative interventions. This approach would ensure that both animal welfare and economic viability are taken into account within the commercial farming sector.

Benefits from early socialisation extend beyond potential financial gains for farmers as they hold the potential to benefit public health. The widespread use of antibiotics in animal agriculture has raised serious concerns regarding the emergence of antibiotic-resistant bacteria, raising ethical, social and public health concerns (Van Boeckel et al., 2015; Minssen et al., 2020). The concern is that the excessive use of antibiotics in the farm industry will accelerate the natural process of resistance (Woolhouse et al., 2015). This escalating issue has prompted global health authorities, such as the World Health Organisation (WHO), to declare a worldwide public health emergency, emphasising the urgent need for strategies to mitigate antibiotic usage. In pig production, post-weaning diarrhoea is a prevalent issue that not only reduces productivity, but also increases mortality, and is therefore the main reason of frequent antibiotic use (Lallès et al., 2007). However, our review reveals that early socialisation can mitigate these health challenges by improving gut microbial health and reducing vulnerability to pathogens. Decreased stress experienced during weaning among socialised pigs correlates with a decrease in diarrhoeal incidences (Tang et al., 2022), highlighting the potential of early socialisation to improve gastrointestinal resilience. Furthermore, early socialisation contributes to reduced aggression among pigs, resulting in fewer skin lesions. This reduction in skin lesions not only improves pig welfare, but also ensures harmful bacteria, such as the disease causing *Staphylococcus hyicus*, cannot gain access through wounds, reducing the need for antibiotic usage (Foster, 2012). While the effectiveness of early socialisation in mitigating antibiotic usage needs further investigation, it presents a promising strategy towards achieving One Welfare objectives (Pinillos et al., 2016). By promoting the health and wellbeing of animals and humans, while ensuring food safety and environmental sustainability, early socialisation may provide a multi-dimensional strategy with implications for public health and animal welfare.

In addition to considerations of pig welfare and human health there may be other implications for meat consumers in particular. Most research has delved into the effects of transportation stress on meat quality, recognising its substantial economic impact by damaging meat quality (Machado et al., 2022; Romero et al., 2022; An et al., 2023). Stress triggers physiological dysfunctions in crucial glands, such as the pituitary, adrenal and thyroid, leading to meat deterioration (An et al., 2023). Moreover, aggression levels, often correlated to stress, also influence meat quality (D'Eath, 2010; Vanheukelom et al., 2012). Despite extensive research on transportation stress, there has been a notable gap in investigating the impact of early life experiences on meat quality. Consequently, drawing conclusions on the efficacy of early socialisation in enhancing meat quality remains challenging. Nevertheless, early socialisation is recognised for its potential to mitigate weaning stress, which could have long term effects on stress-reduction. By reducing stress levels, socialised pigs may exhibit decreased stress responses even during transportation, thereby potentially enhancing meat quality. However, further research is needed to determine the direct relationship between early socialisation and meat quality improvements.

While this review offers valuable insights, it is crucial to acknowledge several limitations that may affect the interpretation of our findings. Firstly, not all topics were investigated extensively, leading to varying weights on different aspects of the research. For instance, while there has been extensive research on the impacts of early socialisation on aggressive behaviour surrounding weaning, other potential effects, such as positive social interactions or long-term outcomes, like antibiotic use, meat quality and economic benefits for farmers, remain relatively understudied. These aspects are crucial for spreading knowledge regarding the implementation of early socialisation as a strategy for improving animal welfare, enhancing production and public health. Moreover, the diverse methodologies employed by different studies present another challenge. Variations in factors such as group sizes, housing designs and weaning age can significantly influence research outcomes. Additionally, difference in measurement timing, ranging from short-term effects on growth rate until long-term evaluations over months, further complicate comparing findings. Furthermore, variations in the timing of socialisation, ranging from one day to 14 days post-partum, may have impacted the results. The efficacy of different socialisation timings remain uncertain. However, despite these methodological differences, it is noteworthy that many studies showed similar outcomes. This consistency suggests that, regardless of methodological differences, the beneficial effects of early socialisation appear robust and consistent across various contexts. Lastly, it is crucial to acknowledge that, while early socialisation can mitigate weaning stress, it does not entirely eliminate it. Weaning involves several stressors other than mixing of unfamiliar individuals, such as the abrupt separation of the mother, the transition in diet, high stocking densities and lack of enrichment. Although early socialisation can help animals to better cope with these stressors, the stressors are still there. Even with the implementation of early socialisation, welfare concerns still remain that need to be addressed. Early socialisation is a promising first step towards enhancing welfare but, ultimately, all common stressors in commercial farming should be minimised to achieve optimal welfare.

Our findings present a promising opportunity for future research to explore the implications of early socialisation. We encourage researchers to explore not only the immediate impacts, but also the long-term consequences of early socialisation, particularly focussing on areas with economic consequences for farmers. Demonstrating that early socialisation not only effectively mitigates weaning stress and aggression, but also yields economic benefits for net production, is essential before it can be implemented on larger scales. We recommend investigations into survival rates, both in the short- and long-term, as well as long-term performance, including various parameters of meat quality. Such studies could shed light on the economic advantages stemming from increased sellable meat and consumers willingness to pay for better-quality products. Furthermore, we encourage researchers to focus on positive welfare indicators. By exploring whether early socialised pigs exhibit a more positive affective state compared to conventionally housed pigs through methods, such as active choice judgement bias tests (Roelofs et al., 2016), we aim to provide a clearer understanding of animal welfare for consumers. Heightened awareness among consumers can in turn promote farmers to enhance welfare practices on their farms. Finally, we promote the development of additional strategies to



complement early socialisation, helping animals in coping with the diversity of stressors inherent in commercial farming practices.

In this literature review, we revealed numerous positive effects associated with the implementation of early socialisation on commercial farms. Despite these findings, the implementation of early socialisation remains uncommon in conventional commercial farming practices (Peden et al., 2018). Farmers express concerns regarding the practicality of mixing piglets, including worries about sow aggression towards unfamiliar piglets, growth reduction, cross-suckling and the perceived high costs associated with pen modifications (Camerlink and Turner, 2017). However, evidence suggests that these concerns may be largely unfounded and associated costs of the implementation of early socialisation are predicted to be minimal (Peden et al., 2021). We promote farmers to consider implementing this strategy on a small scale, by introducing minor modifications, such as installing small doors in existing pens to facilitate piglet interactions pre-weaning. By trialling this approach in a limited number of pens, farmers can assess the benefits against the costs. If positive outcomes are observed, farmers may be more willing to extend these modifications to all pens. Moreover, should farmers find the results unsatisfactory, the doors can simply be kept closed. This flexible approach, in addition to further research on this topic, creates the chance for farmers to make informed decisions based on evidence, ultimately promoting the implementation of early socialisation.

## Conclusion

This study confirms the positive impact of early socialisation in commercial farming. Positive impacts extend across various elements of animal welfare, evidenced through reductions in aggression, skin lesions, stress-related abnormal behaviours and physiological parameters and fear. Furthermore, increased positive social interactions, play, health and performance show the efficacy of implementing early socialisation. Despite the clear advantages of early socialisation, there is resistance to the widespread adoption within conventional housing systems. The reluctance stems from concerns around the perceived risk of economic losses associated with the implementation of alternative housing systems. In light of these challenges, it is crucial that future research prioritises research aiming to enhance animal welfare within economic viability. By delving into strategies that improve animal welfare and do not lead to economic losses, researchers can contribute to aligning the different objectives. Moreover, such investigations hold the potential to yield insights surrounding the implementation of early socialisation, as well as shifting the view on animal welfare and economic sustainability towards mutually reinforcing rather than antagonistic concerns.

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