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The effect of preferential associations on the reproductive performance of group-housed sows

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ABSTRACT

The investigation of social bonds as a measure to improve reproduction in farmed species is an underrepresented research area. This study investigated the effects of preferential associations between group housed sows (average herd size, $n = 59$) on stillborn and crushed piglet numbers. Preferential associations were described as resting within < 1 m of a conspecific in which the proximity was tolerated > 60 s. The study occurred over 63 consecutive days, broken down into three 21-day periods referred to as cycles. The 21-day cycles represent the time between reintegrating events. Seven days per cycle were selected for observations providing 63 h of footage covering the functional areas of the barn. Production data were taken from one farrowing that occurred after a sow had been transferred from the barn to the farrowing house during the study period. For group-level analysis, the sows were categorised as socially prominent or non-socially prominent. Social prominence is defined as an individual that engages in significantly higher levels of interactions than their sub-group conspecifics. The subgroups were determined by our previous work that identified assortment by social connectivity within the same study herd. Each subgroup was defined as a *k*-core, in which the *k*-value represents the level of connectivity of those in the group (i.e., subgroup K1 means sows are connecting with at least one other conspecific). For individual-level analysis, sows were categorised as a sow with stillborn (at least one stillborn piglet) or a sow without stillborn (no stillborn piglets) and as a crushing sow (at least one crushed piglet) or a non-crushing sow (no crushed piglets). Degree centrality was applied to determine the number of interactions that individuals initiated and received. Results showed no overall effects of social prominence on live-born piglets ($p = 0.436$). Socially prominent sows demonstrated a lower mean rate of stillborn than non-socially prominent sows. Sows with stillborn had significantly lower degree centrality than sows without stillborn ($p < 0.05$). The numbers of crushed piglets between socially prominent and non-socially prominent sows were variable with crushing sows demonstrating significantly higher degree centrality than non-crushing sows ($p < 0.05$). Overall, the evidence does not provide a clear relationship between social prominence during gestation and the reproductive outputs of sows. Therefore, further work is required to validate the effects of social position in affiliative networks on the production indices of farmed pigs.

1. Introduction

The formation of social bonds is an indirect strategy for improving welfare, fertility, reproductive processes, and offspring survival. From a socio-biological perspective, affiliation contributes to fitness-enhancing benefits at an individual and group level (Rault, 2019). Species-specific benefits from affiliative interactions may arise due to multiple physiological and social factors, for example, control of parasites (Wascher et al., 2019), maintenance of dominance status (Hodgson et al., 2024), social cohesion (Mendonça et al., 2021), enhanced offspring survival (Silk et al., 2003), or maintenance of dyadic relationships (Gutmann et al., 2015). Social bonds and preferred partners have been documented

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in farmed species including dairy cows (Gutmann et al., 2015; Rocha et al., 2020), pigs (Veit et al., 2024), goats (Górecki et al., 2020), and sheep (KieŁtyka and Górecki, 2015; Ozella et al., 2022). The benefits of engaging in socio-positive behaviours has been shown to enhance production output although the literature is restricted to dairy cows (i.e., Fadul-Pacheco et al., 2021; Marumo et al., 2022), potentially indicative of the relatively small body of work available on social bonds between farmed animals compared to the amount of literature on agonistic behaviours.

Social bonds are generally perceived as strong, stable relationships (i.e., Silk et al., 2003), yet the constructure of enduring ties in farmed pigs is challenging due to mixing practices, large groups, and group compositions of unfamiliar conspecifics. Wild boar form long-lasting relationships determined by kinship and familiarity (Podgórski et al., 2014), however, they are also highly adaptable to changes in the social group (Bieber et al., 2019). Several studies have demonstrated that farmed pigs also have the capacity to form affiliative, preferential, and durable relationships beyond mother-offspring bonds (Durrell et al., 2004; Clouard et al., 2024; Veit et al., 2024). As in wild boar, farmed pigs are also shown to adapt their behavioural strategies to cope with the social environment enabling them to form relationships. These strategies include the formation of affiliative ties between unfamiliar individuals in both growing pigs and sows (Goumon et al., 2020; Horback et al., 2021). With further strategies demonstrated in subgrouping behaviour under free-range and intensive conditions when the establishment of a structured hierarchy is impeded by group size (Rodríguez-Estévez et al., 2010; Kaufholz et al., 2021).

Research has implemented multiple measures including active social behaviours (e.g., nose-nose contacts, nose-body contacts, allogrooming) and spatial proximity (Camerlink et al., 2022; Clouard et al., 2024) to identify affiliative relationships in farmed pigs. Therefore, where the development of affiliative ties is measurable, a relevant avenue of investigation into the effects of socio-positive relationships on reproduction in sows is presented. Further providing an alternative perspective that informs management strategies, which is important when considering that piglet mortality is a significant welfare and economic concern (KilBride et al., 2012; KilBride et al., 2014). Pre-weaning piglet losses are typically between 10 % and 20 % (Muns et al., 2016) and crushing is identified as the leading cause of preweaning mortality (Muns et al., 2016). Piglet mortality is contributed to by many factors; housing (KilBride et al., 2012), management practises (Vasdal et al., 2011), and sow-related traits such as litter size, parity, and individual maternal behaviour (Weber et al., 2007). Current strategies to improve piglet survival rates focus on practical solutions such as sow nutrition, farrowing accommodation, intervention at farrowing, and cross-fostering (Tucker et al., 2021).

Social positioning and sociality are behavioural strategies that can improve reproduction and offspring survival, extending beyond mating opportunities and success. For example, socially prominent individuals in wild animal prosocial behaviour networks achieve greater fecundity and offspring survival than less prominent conspecifics (Silk et al., 2003; Cameron et al., 2009; Ramp et al., 2010; Schülke et al., 2010). However, the consistency of network position is identified as a highly neglected area of research (Krause et al., 2015). This is demonstrated by the underrepresentation of studies that positively correlate network centrality and fitness (i.e., McDonald, 2007, Ryder et al., 2008; Silk et al., 2009). In social network analysis, network centrality refers to multiple individual-level metrics (i.e., degree centrality, betweenness centrality, eigenvector centrality, closeness centrality) that may be selected to investigate network position and fitness with each metric representing different facets of an individual's behaviour within a group. For example, degree centrality relates to the number of directed or undirected social interactions an individual engages. Depending on the context of a network (e.g., behavioural, disease or parasitic transmission, information transference), an individual with a high degree centrality may have an increased fitness (i.e., in a grooming network) or a decreased fitness (i.e., in a disease transference network).

This study aims to increase knowledge of the effects of social bonds and affiliation in farmed pigs. Our previous work revealed the presence of socially prominent sows in the preferential association networks of a sow herd housed under socially dynamic conditions (Jowett and Amory, 2021). This study will further investigate the effect of social prominence in preferential association networks on the reproductive metrics including live-born, stillborn, and crushed piglets. Specifically, we predict that socially prominent sows will have significantly improved production indices than non-socially prominent sows.

2. Methods

2.1. Animals and housing

This study was conducted at Sturgeon's farm, Writtle University College, Chelmsford, Essex, United Kingdom, which supports a sow unit, consisting of a commercial cross Landrace x Large White breed, parities ranging from one to six. During gestation, sows are group housed within the dry barn (Fig. 1) with access to the functional areas including the straw bedded area (20 m x 6.5 m), the passageway (17 m x 3 m), the drinking station (including three nipple drinkers), and the electronic sow feeder station (including two feeders). Sows additionally had *ad libitum* access to straw. Due to the dynamic management system, stocking densities were variable, with approximately 2.32 m^2 space allocation per sow. The sows were fed Delta Renovo TD sow pellets with individual quotas electronically determined by body weight. Sturgeon's farm operates a dynamic production system in which small groups (approximately twelve sows) are reintegrated every third Tuesday post-insemination. The system follows a continuous cycle of production, farrowing week, breeding week, and weaning week. In this study, a cycle refers to the 21-day observation period in the dry barn between reintegration events. For individual identification, each sow was marked with coloured dots, stripes or both on their backs using a livestock marker, corresponding to the ear-tag reference number. Sows observed included cycle 1 ($n = 70$), cycle 2 ($n = 52$), and cycle 3 ($n = 56$). Sows were moved from the dry barn to the farrowing accommodation approximately one week before farrowing. The farrowing crates (Quality Equipment with floating rails) adhere to the standard dimensions (0.85 m x 2.20 m), consisting of fully slatted, plastic flooring and the provision of a heated creep area (1.55 m x 0.6 m).

2.2. Video observations

Observations were recorded using five H.265 4MP Eyeball PoE infrared dome cameras (Genie, WIP4EBVS) from November 2017 to January 2018. Cameras were positioned in the barn to observe sow behaviour in the functional areas, including the straw bedded area, the passageway, the feeding station, and the drinking station. The footage was recorded continuously onto an H.265 eight-channel network video recorder (Genie, WNVR185) fitted with a 3TB hard drive. The DVR was housed in a side room of the barn, accessible without disturbing the sows and connected to a 21.5" LED Hi-Res VGA, DV1 HDMI CCTV monitor (Genie, LM-215). Preferential association data were collected over three consecutive cycles (cycle 1, cycle 2, cycle 3). The hours of observation which reflect the optimum activity times, 08:00–09:00 h, 15:00–16:00 h and 20:00–21:00 h were determined by the prior pilot. The aims of the pilot study were to establish optimum timings for data collection (when the sows were active to observe the initiator and recipient of behaviour), to test the feasibility of the video cameras, and to test the use of the cameras in their positioning within the dry barn. The pilot study occurred in August 2017 and observed the interactions of sows housed within the dry barn ($n = 60$) on preselected days from 07:00 h −23:00 h. In the current study, video observations occurred on seven days of the 21-day cycle including, the day before reintegration, the day of reintegration and continued three consecutive days following reintegration

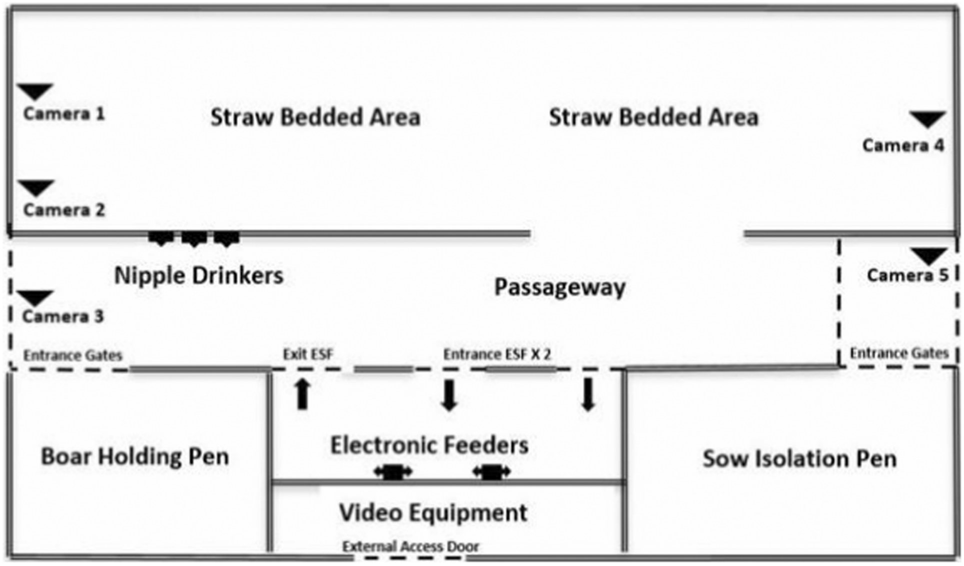

Fig. 1. Schematic of the sow barn (20 m x 13 m) at Sturgeon's Farm, Writtle University College, Chelmsford, Essex, UK, indicating the functional areas and positions of the five cameras. The functional areas include the straw bedded area (20 m x 6.5 m), the sow feeding area (two electronic sow feeders), the drinking station (three nipple drinkers), and the passageway (17 m x 3 m). Copyrights obtained (Jowett and Amory, 2021).

(Oldigs et al., 1992; Moore et al., 1993). The seventh and fourteenth days after reintegration were also selected. Overall, 21 h of video footage for each cycle was included, providing 63 h of behaviours for analysis. The same researcher (SJ) collated the behavioural observations from the video footage using data collection sheets, recording the initiator of behaviour, the recipient of behaviour, and coding the behaviours.

2.3. Reproduction indices

Farm diaries were accessed to obtain production data for 87 sows, these indices included the number of live-born piglets and two of the major causes of piglet mortality, stillbirths and crushing (Edwards and Baxter, 2015). Stillborn piglets were defined as a piglet that dies shortly before or during parturition with no signs of decay (Vanderhaeghe et al., 2013). Crushed piglets were defined as a death due to crushing or smothering by the sow (Galiot et al., 2018). The individual production data were taken from the farrowing event that occurred directly after a sow had been removed from any of the three observed cycles to investigate the effect of social prominence on the indices. Sows were then categorised as sows with stillborn (a sow with at least one stillborn piglet), sows without stillborn (a sow with no stillborn piglets), a crushing sow (a sow that had crushed at least one piglet), and a non-crushing sow (a sow that had crushed no piglets).

2.4. Behavioural measures

Preferential associations were determined when an individual approached and rested by the same sow at least twice. The threshold of interactions was calculated in our previous work (Jowett and Amory, 2021), to discount potentially random interactions. Preferential associations were measured using spatial proximity in which a sow (the initiator) had to approach and then rest (sitting or lying) within < 1 m of the preferred individual (the recipient). The initiator's proximity to the recipient had to be tolerated for at least 60 s without the presence of aggressive behaviour from the recipient. All occurrences of preferential associations in cycle 1, cycle 2, and cycle 3 were captured using video observations during the predetermined periods. The initiator and receiver of each behaviour were recorded to enable directional ties to be identified.

2.5. Social network construction

2.5.1. Classifying the subgroups

Social prominence was quantified by an individual's behaviour at the subgroup level. Subgroups were applied as the formation of subgroups can develop in large group sizes when no clear social hierarchy can be achieved (Horback et al., 2021). We had previously identified an assortment by connectedness (k-core) in the preferential association networks of the same study herd (Jowett and Amory, 2021). Therefore, k-cores have been applied to each network in cycle 1 ($n = 70$), cycle 2 ($n = 52$), and cycle 3 ($n = 56$) to ascertain the subgroup formations. A k-core is a subgraph in which every node has degree k or more connections with other nodes within the subgraph (Borgatti et al., 2018, King et al., 2019) and indicates the number of individuals whom a sow connects with. For example, a higher k value (i.e., K4) represents a connection to more individuals than conspecifics with a lower k value (i.e., K1). However, coreness values do not represent the weight of connections (i.e., indegree centrality and outdegree centrality in a directed network).

2.5.2. Classifying social prominence

Borgatti et al. (2018) define degree centrality as '*the number of ties of a given type that an individual has*'. In directed networks, such as in this study, the direction of ties is also known (i.e., which specific individuals initiate and receive the behaviour). The social network term for initiated behaviour is outdegree centrality and received behaviour is referred to as indegree centrality. In the directed preferential association networks degree centrality refers to the frequency of interactions an individual engaged in, combining indegree centrality (received ties) and outdegree centrality (initiated ties). Degree centrality provides a measure of prominence within the subgroups (Gero et al., 2013), as those that engage in higher levels of interaction are perceived as being more socially active. As such, high degree centrality has been described in previous studies as an indicator of social prominence (Verdolin et al., 2014). Therefore, sows with a significantly higher degree centrality than their k-core conspecifics are classified as socially prominent (Jowett and Amory, 2021). Classifying the sows based on their degree centrality compared to subgroup conspecifics provides a categorical measure of their social position in this study for the purposes of reporting the results on the differences in live-born, stillborn, and crushed piglets. In this study, the term social prominence does not provide a specific degree centrality value but rather categorises individuals based on their overall degree centrality compared to conspecifics as being either socially prominent sows (SPS) or non-socially prominent sows (non-SPS).

2.5.3. Quantifying missing sows

Due to the dynamic nature of the herd, sows were not always consistently present during the 21 h of observation in each cycle. Data were weighted to account for the number of hours sows remained absent from a network with a coefficient applied to the indegree centrality and outdegree centrality of these individuals (for further details see Jowett and Amory, 2021).

2.5.4. Sow with stillborn and sow without stillborn

To extend beyond investigating the effect of social prominence (see 2.5.2.) on production indices as determined by a classification of social position, all sows that were observed in the study were classified as either a sow with stillborn or a sow without stillborn to ascertain differences in degree centrality between these two types of sows.

2.5.5. Crushing sow and non-crushing sow

To extend beyond investigating the effect of social prominence (see 2.5.2.) on production indices as determined by a classification of social position, all sows that were observed in the study were classified as either a crushing sow or a non-crushing sow to ascertain differences in the degree centrality between these two types of sows.

2.6. Social network analysis and statistics

Matrices of the preferential association networks for each production cycle were constructed in Excel and imported into Ucinet 6, version 6.634 (Borgatti et al., 2002). The general network and individual network metrics analysed in Ucinet included indegree centrality and outdegree centrality. Statistical analysis was performed in R.3.4.1 (R Development Core Team, 2017). Data were subsequently tested for normality via histograms and the Shapiro-Wilks test. The data were found to be nonnormally distributed. GLMMs were performed in R.3.4.1 (R Development Core Team, 2017) using the R package lme4, version 1.1–21 (Bates et al., 2015) to test for differences in production metrics (stillborn and crushed piglets) between socially prominent sows (SPS) and non-socially prominent sows (non-SPS) and differences in the degree centrality between crushing sows and non-crushing sows, and between sows with stillborn, and sows without stillborn. The multiple GLMMs were corrected to reduce the risk of type 1 errors with the application of the false discovery rate (FDR). Upon testing, the negative binomial model was found to be the best fit for the probability distribution. For each model, the pig identification number represented the random effects, and fixed effects included social roles (i.e., SPS and non -SPS) or production category (i.e., crushing sows, non-crushing sows, sows with stillborn, sows without stillborn).

2.7. Ethics

This study was approved by the Writtle University College Ethics Committee

3. Results

3.1. Social prominence in the subgroups

Within the subgroups (based on connectedness) of the preferential association networks socially prominent pigs were quantified in cycle 1, cycle 2, and cycle 3 (Table 1). Socially prominent sows had a combined degree centrality (indegree centrality and outdegree centrality) above the 95 % confidence interval range for their subgroup. Individuals were assigned to the subgroups consistent with their level of connectivity, referred to as a coreness value (k). For example, if an individual was interacting with at least one other conspecific they were assigned to the subgroup K1, if they were interacting with at least three other conspecifics they were assigned to the subgroup K3. Cycle 1 identified 21 socially prominent sows (K2: n = 3, K3: n = 9, K4: n = 9), which represented 30 % of the network. Cycle 2 identified 19 socially prominent sows (K1: n = 9, K2: n = 10), representing 37 % of the network. A further 17 socially prominent sows were quantified in cycle 3 (K1: n = 6, K2: n = 11), representing 30 % of the network.

Table 1
Socially prominence sows (SPS) quantified in the subgroups (k-cores) for cycle 1 (n = 70), cycle 2 (n = 52), and cycle 3 (n = 56). SPS demonstrated a degree centrality in the preferential association networks above the 95 % confidence interval of their subgroups. Copyrights obtained (Jowett and Amory, 2021). An individual was assigned to a subgroup based on their level of connectivity. For example, if a sow was interacting with at least three other conspecifics they were assigned to the subgroup K3.

Cycle and k-core	Mean degree ± SD	95 % Confidence Range	Number of SPS
Cycle 1			
K4	20.0 ± 6.0	17.8 – 22.3	9
K3	10.6 ± 4.2	9.1 – 12.2	9
K2	7.0 ± 2.9	5.2 – 8.8	3
Total			**21**
Cycle 2			
K2	8.5 ± 4.2	7.0 – 10.0	10
K1	2.6 ± 1.2	2.1 – 3.0	9
Total			**19**
Cycle 3			
K2	7.9 ± 3.3	6.8 – 8.9	11
K1	2.5 ± 1.0	2.1 – 2.9	6
Total			**17**

3.2. Social prominence and production indices

3.2.1. Live born piglets

The mean live-born numbers remained consistent over all three networks for both socially prominent sows and non-socially prominent sows (Table 2). Despite a significant difference in live-born piglets between socially prominent and non-socially prominent sows in cycle 3 (p = 0.02), there were no overall significant differences revealed in mean live born piglet numbers between socially prominent sows (12.8 ± 3.68 SD) and non-socially prominent sows (12.0 ± 3.57 SD), GLMM,

Table 2
Differences in the mean number ± standard deviation (SD) for live-born, stillborn, and crushed piglets for socially prominent sows (SPS) and non-socially prominent sows (non-SPS) in Cycle 1 (n = 70), Cycle 2 (n = 52), and Cycle 3 (n =56).

Cycle (Number of sows)	Number of SPS	Number of non-SPS	Production variable	SPS	Non-SPS	P-Value
Cycle 1 (n = 70)	21	49	Live-born	12.0 ± 4.2	12.3 ± 3.5	0.61
			Stillborn	1.3 ± 3.3	1.9 ± 2.6	0.08
			Crushed	1.0 ± 1.2	0.4 ± 0.9	0.05
Cycle 2 (n = 52)	19	33	Live-born	13.1 ± 2.7	12.5 ± 3.8	0.30
			Stillborn	0.9 ± 1.6	2.1 ± 2.9	0.08
			Crushed	0.4 ± 0.7	0.8 ± 1.2	0.88
Cycle 3 (n = 56)	17	39	Live-born	13.4 ± 3.9	12.7 ± 3.0	0.02*
			Stillborn	1.3 ± 1.6	2.3 ± 3.6	0.63
			Crushed	0.5 ± 0.9	0.5 ± 1.0	0.33

coef. 0.04, z 0.78, $p = 0.436$.

3.2.2. Stillborn piglets

The impact of being socially prominent on stillbirths was presented in all three networks, socially prominent sows consistently demonstrated lower rates of stillborn than non-socially prominent sows in cycle 1, cycle 2, and cycle 3 (Table 2). In cycle 1 and cycle 2 there was a tendency towards significant differences in the number of stillborn piglets between socially prominent and non-socially prominent sows ($p = 0.08$). All sows were categorised as a sow with stillborn or sows without stillborn to investigate further the effect of degree centrality in the preferential association networks on stillborn rates. Sows with stillborn (15.6 ± 9.62 SD) were revealed to have a significantly lower degree centrality than sows without stillborn piglets (18.9 ± 8.56 SD), GLMM, coef. −0.23, z −2.604, $p < 0.05$ (Fig. 2).

3.2.3. Crushed piglets

There was variation in the mean number of crushed piglets of socially prominent and non-socially prominent sows observed over cycle 1, cycle 2, and cycle 3 (Table 2), with a tendency for more crushed piglets by socially prominent sows in cycle 1 ($p = 0.05$). However, when sows were categorised as a crushing sow or a non-crushing sow to investigate further the effect of degree centrality in the preferential association networks on crushing behaviour, crushing sows (23.6 ± 11.97 SD) were revealed to have a significantly higher degree centrality than non-crushing sows (15.5 ± 10.11 SD), GLMM, coef. 0.46, z 3.037, $p < 0.05$ (Fig. 3).

4. Discussion

The findings indicate a possible association between social prominence and reproduction, sows with a greater number of social relationships had fewer stillbirths and more live-born piglets, although differences in live born were not consistent across the three observed cycles. Previous studies of piglet mortality (e.g., KilBride et al., 2012; King et al., 2019) have investigated the impact of the physical environment and management strategies on piglet mortality. This study provides a more detailed assessment of the potential impact of a positive social environment (i.e., engaging in preferential associations) on the sow as measured by their production indices. Sows with stillborn piglets have a lower degree centrality for preferential associations than those individuals with a full litter of live births. Furthermore, sows with at least one crushed piglet have a higher degree centrality than those who did not crush.

The presence of socially prominent individuals in every observed cycle in the current study presents an opportunity to investigate potential effects of differing social position on reproduction, particularly as the proportion of socially prominent sows identified in all three networks showed a consistent pattern at the group level. Social position is a behavioural mechanism for improving offspring survival (Schneider-Crease et al., 2022), with centrality and sociality as a predictor of individual fitness in affiliative networks (Silk et al., 2009; Cheney et al., 2016). However, these examples relate to primates and although little is known about the relationship between social position in affiliative networks and reproduction in farmed sows, evidence shows that rank can affect offspring parameters. Mendl et al. (1995) reported the influence of maternal dominance rank on the birth-sex ratio, with high-ranking sows producing significantly fewer male piglets than low ranking sows. Further evidence indicates that rank influences an individual's physiological response to the social environment (Tuchscherer et al., 1998), which in turn may impact reproductive performance (von Borell et al., 2007). Compared to growing female pigs, pregnant sows are driven to achieve more stable social conditions (Parent et al., 2012), potentially decreasing stress through a reduction in group aggression and increasing socio-positive behaviours. Therefore, how an individual responds to the social environment through their behavioural interactions which may influence their social position (i.e., prominence) is particularly relevant when considering the instability of the social

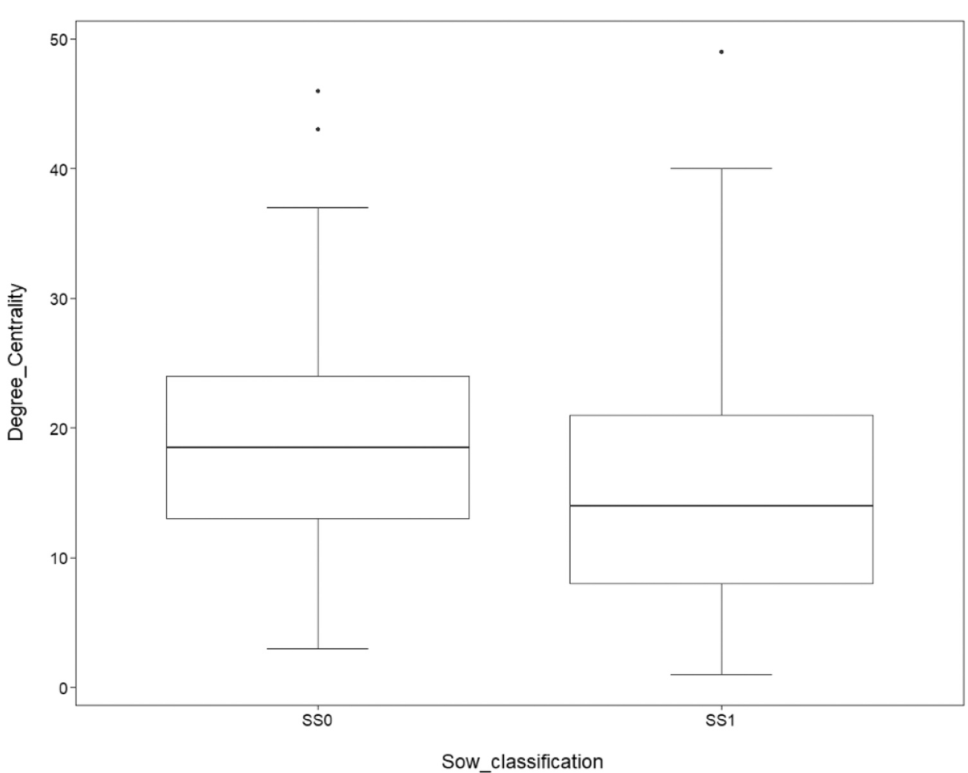

Fig. 2. Distribution of combined indegree centrality and outdegree centrality between individuals classified as sows with stillborn ($n = 51$) and sows without stillborn ($n = 36$) in the preferential association networks. S1 = sows with stillborn. S0 = sows without stillborn.

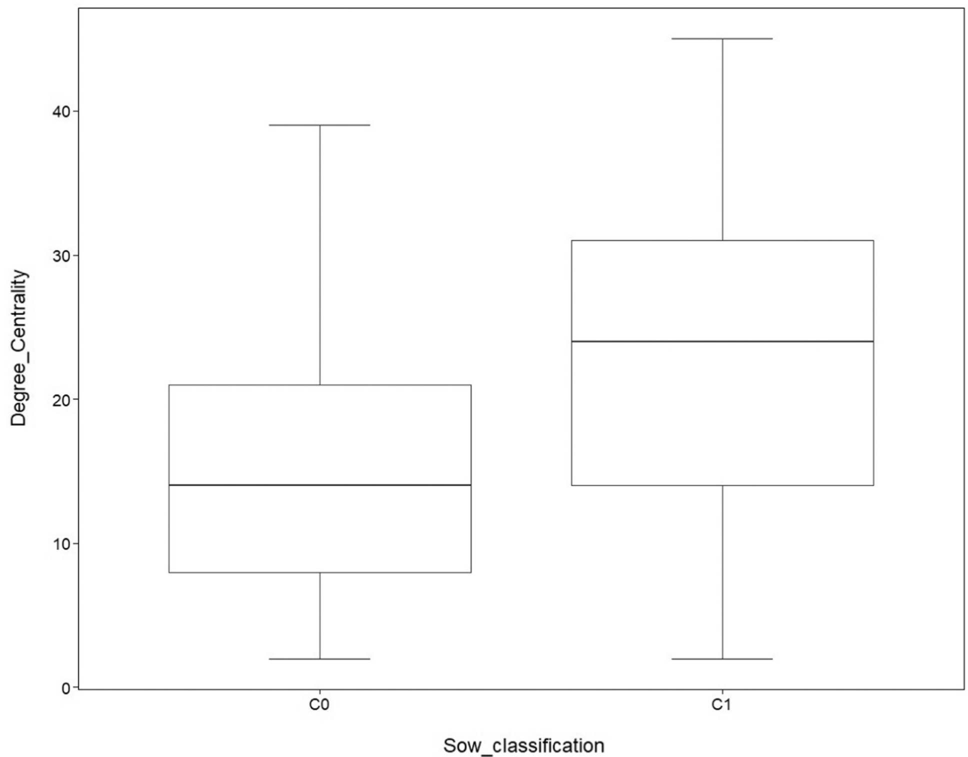

Fig. 3. Distribution of combined indegree centrality and outdegree centrality between individuals classified as crushing sows (n = 27) and non-crushing sows (n = 60) in the preferential association networks. C1 = crushing sows. C0 = non-crushing sows.

structure for gestating sows housed in groups that experience reintegration events.

The current study presents the findings of one farrowing event per sow against her likely changing social position with different cycles. A potential explanation for the differences in stillbirths between socially prominent sows and non-socially prominent sows is changes to the neuroendocrine functions, which has fundamental control of reproductive processes (von Borell, 1995). Rault (2012) provided a detailed account of the beneficial impact of socio-positive behaviours on the physiological mechanisms that support the processes responsible for reproduction. Further discussing how social support impacts the neuroendocrine system by decreasing the activation of the Hypothalamic-Pituitary-Adrenal (HPA) axis and therefore reducing high levels of hormones (i.e., corticotropic-releasing hormone, adrenocorticotropic releasing hormones) and glucocorticoids that may negatively impact reproduction when the homeostatic balance is not maintained. While the regulation of specific neuroendocrine hormones is favourable during gestation, the increased production of other hormones is just as important both during gestation and postpartum.

One such favourable neuroendocrine hormone is the neuropeptide oxytocin which represents a major part of the neuroendocrine system, shown to be essential for successful parturition in mammals by improving uterine function (Luckman et al., 1993). Oxytocin production arising from positive social interactions is also responsible for enhancing physiological state (i.e., reducing blood pressure and heart rate), behavioural state, and an individual's ability to mitigate stress (Rault, 2012). An individual's behavioural state as driven, in part, by oxytocin levels is an important consideration when investigating the production indices of sows housed in unstable groups in which exposure to socially disruptive reintegration will increase stress both acutely and chronically. However, the role of oxytocin as a mitigator of acute stress may be less relevant to reproductive performance than its role in controlling chronic stress (Turner et al., 2002). The evidence demonstrates how positive experiences can contribute towards maintaining equilibrium of the neuroendocrine system during gestation to improve reproductive success as indicated by the fewer stillborn piglets produced by socially prominent sows compared to non-socially prominent sows.

A recent study of sow welfare and offspring immune response demonstrated positive experiences during gestation produced a significant effect on piglet survival (Merlot et al., 2022); sows housed in enriched pens produced fewer stillborn than sows housed in conventional pens. Enriched sows further demonstrated significantly lower overall mortality from birth to 12 hours postpartum. If positive interactions experienced by the sow during gestation enhances reproductive processes this suggests that socially prominent sows, who engage in significantly higher rates of positive interactions than conspecifics may have, in part, improved neuroendocrine function. Further indicating a potential process for applied management strategies (i.e., grouping compositions) that aim to maintain the balance of the neuroendocrine system required for piglet survival by attenuating social stressors through socio-positive interactions.

The investigation into crushing revealed a relationship between degree centrality and piglet mortality. Despite our expectations, with significant differences in degree centrality between crushing sows and non-crushing sows, the findings indicate that prominence in the preferential association networks detrimentally impacts the number of piglet deaths due to crushing. By engaging in the numerous mechanisms of social support (i.e., preferential associations or social buffering), resistance to the social and environmental challenges faced by pigs can be promoted (Kanitz et al., 2014; Reimert et al., 2014; Tuchscherer et al., 2014; Pol et al., 2021). By comparison, reduced resistance brought about by high levels of stress during gestation (which have not been mitigated by engaging in affiliative interactions) can also impact behaviour by increasing the frequency of sow posture changes postpartum (Rutherford et al., 2014), furthering the chance of overlays. However, our findings contrast with those of Rutherford et al. (2014) suggesting another reason for the differences in the number of crushed piglets based on degree centrality. It is possible that the breaking of attachment bonds when transferred from the herd to a farrowing crate might have induced higher stress levels. Even temporary social bonds in female pigs can be enduring (Podgórski et al., 2014), and bond disruption is a contributing factor to changes in behaviour (O'Malley et al., 2022). Despite this, the inconsistencies of the results over all three observed cycles and the differences in crushed piglets between social positions indicate a more precautionary approach is taken.

Research has begun to evaluate the impact of affiliative behaviours on production indices in farmed species, an important consideration when seeking to provide support for positive welfare changes to management strategies. Investigations between social bonds and reproduction in farmed species are currently underrepresented in animal behaviour research, a few recent studies of dairy cows have shown a positive effect of engaging in affiliative relationships on milk yield and milk composition (Fadul-Pacheco et al., 2021; Marumo et al., 2022). Future investigations of the sows' physiology with respect to her changing social relationships and studies of other dynamic group systems are needed for greater understanding of how we can manage these sows to promote reproductive performance and maintain good animal welfare. Future work should also seek to validate measures of affiliative behaviour determined by social position with other aspects of sociality and positive welfare.

5. Conclusions

The predominant findings of this research show that the frequency of stillborn piglets is consistently lower in socially prominent than non-socially prominent sows. The findings also show inconsistencies in the numbers of crushed piglets between the social positions. Although the three cycles were not socially stable, socially prominent individuals were identified in every network. Furthermore, there was similarity in the proportion of socially prominent sows compared to non-prominent sows in each of the cycles. The information gained in this study does not show a clear relationship between social prominence and reproductive outcomes in sows. However, the study does provide support that social networks are strategies for reducing the deleterious effects of commercial practices by shining a light on social structure and individual behaviour as an avenue towards improving welfare and production.

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CRediT authorship contribution statement

Jonathan R Amory: Writing – review & editing, Supervision, Conceptualization. **Zoe E Barker:** Supervision. **Sarah Jowett:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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