THE FEEDING BEHAVIOUR OF SOWS AND ITS RELATIONSHIP TO SOW WELFARE AND REPRODUCTION

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Executive Summary

The productivity of group gestation housing systems may be limited by poor performance of the most subordinate animals. Feeding sows by dropping food directly onto the pen floor (i.e. floor-feeding) is one of the cheapest and simplest method of feed delivery. However, floor-feeding systems are criticised on the basis that they create a competitive environment that results in uneven distribution of feed. When fed from the floor, dominant sows monopolise the feeding area while the lowest ranking (i.e., submissive) sows may sacrifice the opportunity to feed in an attempt to avoid receiving aggression. As a result, submissive sows in floor-feeding systems have reduced intake and exhibit lower weight gain throughout gestation, and may experience increased stereotypies, reproductive failure and incidence of culling.

Current advice on feeding regimes for floor-fed gestating sows is largely based on speculation rather than scientific evidence. Although floor-feeding sows once per day is common, feeding sows their daily allocation over multiple feed drops per day may satiate dominant sows in the early drops and create more opportunities for subordinate sows to feed in later bouts. Alternatively, feeding sows over multiple bouts may lead to multiple peaks in aggression and consequently increase risks to subordinate animals, in contrast to one feeding bout and one peak in aggression.

This study examined the feeding behaviour of sows, fed over multiple feed drops, and how this relates to sow welfare and reproduction. Over four time replicates, 275 sows were randomly mixed into groups of 10 (floor space of 1.8 m²/sow) within 7 days of insemination for both their first and second gestations (200 sows per gestation with 126 sows observed in both gestations). Sows were marked with individually identifiable symbols prior to mixing, and during gestation were floor fed a daily allowance of 2.5 kg/sow/day over four feed drops per day (0730, 0900, 1100, 1500 h). From video recordings, observations on the feeding and aggressive behaviours of individual sows were conducted after each feed drop at days 2, 9 and 51 post-mixing. For the observations of feeding behaviour, the identity of sows that were performing behaviours related to feeding (head down, rooting the ground/feed, chewing) was recorded using instantaneous point sampling at 30 s intervals over four 5-minute time blocks (a total of 20 minutes) following each feed drop. Due to the concentrated
distribution of feed over a specific area in floor-feeding systems, feeding sows were also recorded as being located directly under the feed hopper (i.e. high food availability; HF), on the cement flooring but not directly under the feed hopper (i.e. reduced food availability; RF) or on the slats at the back of the pen (i.e. scarce to no food availability, NF). Observations of aggression delivered and received by individual sows were made for 30 minutes post-feed delivery. Using the aggression data obtained at day 2, sows were classified as dominant (delivered more aggression than received), subdominant (received more aggression than delivered) or submissive (delivered little or no aggression). Also obtained were the number of fresh skin injuries and plasma cortisol concentrations for individual sows at days 2, 9, and 51 after mixing, live weight gain from days 2 to 100 post-mixing, litter size (born alive, total born, and stillborn piglets) and farrowing rate.

Time spent feeding directly under the feed hoppers declined from 5-10 minutes post-feed delivery, which corresponded with an increase in the time feeding on the surrounding cement flooring. This suggests that, when fed their daily allocation over four drops per day, sows consume the majority of feed within 5-10 minutes of delivery. From approximately 10 minutes post-feed delivery onwards, sows continue to display appetitive feeding/foraging behaviours (e.g., rooting the ground), despite the fact that there is little or no food remaining, suggesting an un-satiated motivation to feed.

The feeding behaviour of dominant, subdominant and submissive sows was generally consistent over the two gestations. Sows classified as dominant spent the most time feeding directly under the feed hoppers and the least time feeding in areas of reduced on no feed availability. Subdominant sows fed most frequently from areas of reduced feed availability (i.e., in the feeding area but not in the area directly below feed hoppers). Submissive sows performed feeding related behaviour (e.g., rooting the pen floor) on the slatted area of the pen more often than subdominant and dominant sows, and spent the least time feeding in the areas of high and reduced feed availability. The relationships between aggression classification and feeding behaviour did not change over feed drops or days. Thus, despite the fact that aggression declines over subsequent feed drops, dominant sows continue to monopolise the feeding area. In addition to restrictions on the quantity of food provided to gestating sows, floor feeding systems place considerable spatio-temporal restrictions on the availability of feed. This system forces low ranking sows to risk receiving aggression by feeding in close proximity to high ranking sows, or alternatively avoiding feeding. While it is
difficult to reduce temporal restrictions on food availability to floor-fed gestating sows, spatial restrictions may be minimised by increasing the spread of feed onto the ground (e.g., by increasing the number of feed hoppers per pen) thereby increasing accessibility for low ranking sows.

Sows that fed directly under the feed hopper spent less time feeding on the slatted area at the back of the pen, delivered more aggression, gained more weight and were heavier toward the end of gestation. Sow intake was not recorded in the present study and is inferred through observations of feeding behaviour in areas of the pen associated with high, reduced or no feed availability. The relationships between sow feeding behaviour and weight gain offer support for this presumption. There are some indications that sows with the highest feed intake have larger litter sizes and higher farrowing rates, but more research with larger animal numbers is required to confirm this. Sows that frequently fed on the cement floor (where there was reduced feed availability) had lower cortisol concentrations, but received more aggression. One possible explanation for this result is that both defending and avoiding the area of high feed availability is associated with more stress than risking the receipt of aggression by feeding opportunistically. Some subordinate sows (i.e., any sow that is not dominant) may be more willing to risk receiving aggression for feed than others. Feeding behaviour in gestation 1 did not affect the welfare and productivity of sows in gestation 2. Ethical considerations relating to the price, in terms of fear, stress and injury, competitive feeding systems require submissive sows to pay in order to get access to food are required when feeding systems for group-housed are being implemented.

Care is required in interpreting the results of this study because it was observational and correlations, rather than experimental and comparative, making causality difficult, if not impossible, to determine. Therefore, controlled comparisons of floor-feeding regimes are required if such questions are to be answered. Many questions remain regarding whether the high levels of competition and resulting variation in feed intake observed in floor-feeding systems are an inherent consequence of the feeding system itself, or can be minimised through effective management of feeding regimes in these systems. For example, reducing the time between feed drops may better promote satiety in sows, while increasing the number of feed droppers per pen may improve accessibility for subordinate sows. Other possibilities to improve sow satiety is to restrictively feed sows a low-fibre diet with
supplemented *ad libitum* access to roughage or foraging materials, or feed a low energy diet in high quantities. These require further research.
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1. Introduction

The feeding system is the most important behaviour system for survival (Koene, 2006). Natural feeding behaviour consists of two phases, the appetitive and the consumatory phase. The appetitive phase involves searching and the localisation of food, whereas the consumatory phase describes handling, manipulating, tasting and actual consumption (Koene, 2006). Animals living under natural conditions spend considerable amount of time and energy searching for and consuming food, as well as making decisions about feeding site and diet selection (Price, 2002). For social animals that live in groups, foraging often occurs in direct competition with other group members. Thus, variation in foraging strategies have evolved to ensure that individuals in the same group maintain sufficient intake (Koene, 2006). For example, individuals within a group spatially distribute according to food availability. Agonistic behaviour is partly responsible for regulation of this spatial distribution, as the risk of aggression increases when individuals compete for access to the same restricted resource. Some individuals are more likely to move further from the group and forage un-explored territory, whereas others are more likely to exploit the knowledge of a conspecific that has located a food source.

Koene (2006) describes the process of domestication as a “quantitative process, in which behaviour in its limited form reflects the limited environment of the domesticated animal”. According to Fraser et al. (1995), evolved traits of mammalian social behaviour are broad sets of conditional responses rather than fixed ones, and are often involved in behaviour under artificial (i.e., captive) conditions. For instance, when Stolba and Woodgush (1989) observed intensively reared domesticated pigs under semi-natural conditions, they found that behaviour very closely resembled that of the wild boar. This implies that the essential characteristics of evolutionary adaptive behaviour, such as aggressive and feeding behaviour, are still present and operational in the domesticated animal (Koene, 2006). However, feeding in captivity has become very different from the circumstances under which it has evolved, or even the conditions under which domestication occurred (Koene, 2006).
Common feeding regimes for intensively housed farm animals involve a human caretaker providing, at predictable intervals, a formulated, and often concentrated, diet that has a relatively uniform composition to animals who are living in crowded conditions (Price, 2002). While these diets meet the nutritional requirements of the animal, engagement in the appetitive phase of feeding as well as control over the quality, quantity and availability of food, is lost. High levels of feeding motivation may continue after a meal when the appetitive phase of feeding is not fulfilled, which can lead to the development of oral stereotypies (Lawrence and Terlouw, 1993; Koene, 2006), frustration and aggression (Nielsen et al., 2006).

Pigs show an inelastic demand for food (Ladewig and Matthews, 1996; Nielsen et al., 2006). They will defend access to feed even when fed ad libitum (Brouns and Edwards, 1994). To prolong longevity, gestating sows on commercial pig farms are commonly fed a restricted diet of $1.5 \times$ the level of maintenance (approximately 60% ad libitum intake) (Nielsen et al., 2006). This diet often eaten in one single meal, which lasts around 15-20 minutes (Marchant-Forde, 2009). Observations of sows living in semi-natural conditions have found they spend between 50-75% of their time engaged in feeding behaviour, and particularly those related to the appetitive phase (i.e., foraging, rooting etc.) (Nielsen et al., 2006; Marchant-Forde, 2009). For domestic pigs living on commercial farms, this figure reported to be around 19-24% (Marchant-Forde, 2009). Sows display appetitive (i.e., rooting) behaviour for up to 1 hour after consuming their daily food allowance (Brouns and Edwards, 1994), while stereotypies and other behavioural indicators of hunger (e.g., increased competition for food, willingness to work for food) are observed in feed restricted sows. This suggests that gestating sows are hungry for a considerable period of the day (see review, Verdon et al., 2015a). The effects of chronic hunger may be particularly evident in sows that are pregnant for their first gestation, as these animals are experiencing feed restriction for the first time.

High levels and/or prolonged aggression continue to be a major welfare issue for commercial pig farming. Aggression post-mixing is associated with the formation of dominance relationships and is particularly intense. Due to the consequences of this aggression on sow welfare (see Hemsworth et al., 2015), it is appropriate that research continues to identify aspects of design and animal management that allow
a hierarchy to quickly form. The establishment of a dominance hierarchy, however, does not eliminate aggression between group-housed sows. Sows will continue to deliver aggression over competition for access to, or defense of, a restricted resource; and the restricted resource sows most frequently compete over is food (Baxter, 1983; Csermely and Wood-Gush, 1987). To be clear, food restriction per se does not affect the probability of aggressive behaviour when an encounter between conspecific occurs (Hinde, 1970). However, the probability and duration of encounters is increased due to increased animal activity (associated with the appetitive phase of consumption), and particularly when food is delivered at a specific time and place. Aggressive bouts delivered over competition for food are shorter in duration, but can occur much more frequently than aggression observed post-mixing (Spoolder et al., 2009). When sows have to compete for food, aggression around feeding does not stabilise until at least 28 days following mixing (Barnett, 1997; Arey, 1999; Verdon et al., 2016).

With gestating sows experiencing hunger for a significant period of the day, feeding becomes the major daily event. The type of feeding system affects competition for feed, and consequently the level of aggression at feeding (Spoolder et al., 2009). Dropping feed directly onto the pen floor (i.e., floor feeding) has gained popularity by being the cheapest and simplest method of delivering feed to sows. Floor-feeding systems fulfill some elements of natural feeding behaviour by allowing sows to feed simultaneously (Verdon et al., 2015a). Feeding is socially facilitated in the pig, and so allowing sows to feed simultaneously may reduce some frustration (Marchant-Forde, 2009). However, the resulting competition for access to, or defense of, food results in aggression immediately following feed delivery (e.g. Csermely and Wood-Gush, 1987; Verdon et al., 2015b, 2016) that lasts for approximately 20 minutes (Verdon et al., 2015b), which coincides with when the majority of feed has been consumed (Brouns and Edwards, 1994). Thus, in systems where feed delivery is concentrated in both space and time, some foraging strategies (e.g., high defense of food) may be more successful than others (e.g., forage away from the group).

Dominant sows monopolise the feeding area as long as feed remains present (Csermely and Wood-Gush, 1990; Rault et al., 2015), delivering the most and receiving the least aggression while doing so (Verdon et al., 2016). Csermely and
Woodgush (1990) observed dominant sows standing directly over the area where the majority of feed was delivered, using aggression to prevent subordinate sows from gaining access. Other studies have found that low-ranking sows in floor-feeding systems have reduced intake and exhibit lower weight gain throughout gestation (Edwards, 1992; Verdon et al., 2016). Underweight sows display more stereotypies, experience reproductive failure, and/or delayed return to estrus, have lower embryo survival and are culled more frequently than sows of an appropriate weight (Virolainen et al., 2004; Courboulay, 2007; Hoving et al., 2011). On the other hand, increasing the feed intake of pregnant sows improves farrowing rate (Athorn et al., 2013; Sawyer et al., 2013). Consequently, ensuring all sows maintain a sufficient intake is imperative not only to sow welfare, but also to sow productivity.

Some researchers (see Bench et al., 2013) have advocated for feeding of sows individually (i.e., using an electronic feeding station [ESF] or feeding stalls) to reduce aggression around feeding, while allowing for better control of individual sow intake. However, increased vulva bites are reported when full body feeding stalls (Andersen et al., 1999) and ESF systems (Scott et al., 2009; Olsson et al., 2011) are used to feed sows, suggesting that gaining access to these systems can also lead to competition and aggression (Bench et al., 2013). After reviewing the literature, Verdon et al. (2015a) wrote that it is difficult to derive a conclusive relationship between feeding systems and sow welfare, because ‘research directly comparing aggression, injuries, and intake (i.e., weight gain) between floor-feeding, feeding stall, and ESF systems is lacking’. Similarly, floor-feeding systems are criticised on the basis that they create a competitive environment that results in uneven distribution of feed (e.g., Bench et al., 2013). However, current advice on feeding regimes for floor fed gestating sows is based on speculation rather than scientific evidence. This makes it difficult to conclude that it floor-feeding systems itself, rather than the management of the system, that results in high levels of aggression and variation in sow intake.

When fed from the floor, submissive sows may sacrifice the opportunity to feed in an attempt to avoid receiving aggression (Verdon et al., 2011, 2016). Although feeding sows once per day is common (Brouns & Edwards, 1994; Harris et al., 2006; Remience et al., 2008), feeding sows their daily allocation over multiple feed drops
per day may create more opportunities for subordinate sows to feed in later bouts. A preliminary study conducted by Rault et al. (2015) suggested that, when fed over four feeding drop per day, dominant sows become satiated during the first feeding drop as they are present less frequently in the third drop. Alternatively, feeding sows over multiple bouts may lead to multiple peaks in aggression and consequently increase risks to subordinate animals, in contrast to one feeding bout and one peak in aggression. Verdon et al. (2015b) showed that feeding sows over four bouts per day does not prevent subordinate (i.e., any sow that is not dominant) sows from receiving aggression, although the intensity of aggression received by subordinate females appears to reduce with subsequent feeding bouts. Further, Schneider et al. (2007) reported that increasing feeding frequency from two to six bouts reduced vulva and skin lesions as well as the frequency of culling for lameness and leg injuries in sows, but not gilts. Clearly, more comprehensive research on the implications of floor-feeding regimes on the welfare and productivity of gestating sows is required.

Thus, the welfare and productivity of group gestation housing systems may be limited by poor performance of the most subordinate animals. Competition for feed is of paramount importance for sow production and welfare, and delivering feed over multiple drops may provide subordinate sows with increased feeding opportunities. This study examined the feeding behaviour of sows, fed over multiple feed drops, and how this relates to sow welfare and reproduction.
2. Study 1 - The feeding behaviour of sows floor fed four times per day

2.1 Materials and methods

2.1.1 Ethical note

All animal procedures were conducted with prior institutional ethical approval under the requirement of the New South Wales Prevention of Cruelty to Animals Act (1979) in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organization/Australian Animal Commission *Australian Code of Practice for the Care and Use of Animals for Scientific Purposes* (NHMRC, 2013).

2.1.2 Facilities

This study was conducted between October 2010 and February 2012 in a gestation unit of a large commercial piggery in southern New South Wales, Australia. The 6-m-long and 19-m-wide building was equipped with adjustable blinds. Overhead water sprinklers covered 50% of the slatted floor area of the pens and were activated (3 min on and 15 min off) when the internal temperature exceeded 26°C. The maximum and minimum mean daily ambient temperatures for spring, summer, autumn, and winter of 2011 were 21.3 and 8.5°C, 29.2 and 15.2°C, 21.3 and 7.9°C, and 15.6 and 3.9°C, respectively. Within the unit, 12 pens (3.7 by 4.8 m) were used. Each pen had partially slatted floors (50%) with a solid cement lying/feeding area and a slatted dunging area and was fitted with two overhead feed droppers and one nipple drinker. One video camera with built-in infrared lights was positioned above each pen and recorded from 0700 to 1700 h on the second day of mixing (labelled Day 2) and Days 9 and 51 after mixing. The camera covered most of the pen floor area (14 m²); however, some area in the corners of the pens could not be observed. Importantly, the area of the pen floor where feed was delivered was within the field of view of the camera. This is where most of the sow interactions at feeding occurred.
2.1.3 Animals and Experimental Design

A total of 275 pregnant Large White × Landrace sows (Sus scrofa) were used in this study so that 200 gilts (50 gilts per replicate) in 4 replicates were studied in their first gestation and 200 sows in 4 replicates were studied in their second gestation (200 animals per gestation with 126 animals common to both gestations). Gilts detected in oestrus from 32 weeks of age were transferred from groups of 30 gilts to stalls for insemination. Gilts were twice artificially inseminated (morning/afternoon insemination routine) and, within 7 d of insemination, were randomly mixed into groups of 10 (space allowance of 1.8 m²/gilt) between 0800 and 1300 h. Before mixing, symbols were sprayed on the backs of gilts allowing for individual identification. One week before farrowing, gilts were moved to farrowing stalls where they remained until piglets were weaned at 25 d of age. After piglets were weaned, the parity 1 sows were housed in mating stalls, again twice artificially inseminated (morning/afternoon insemination routine), and within 7 d, were randomly mixed into groups of 10 (space allowance of 1.8 m²/sow). Females were allocated to different groups for their second gestation and remained in these groups for the remainder of the gestation. On average, the maximum number of sows in a group that has been housed together in the first gestation was 2.4 (range 0-4). The same farrowing management as for first gestation was applied. For convenience, in the remainder of this paper, gestating gilts will be referred to as sows. The gestation number of the sow will reflect her parity status: nulliparous or primiparous. During gestation, sows were fed a standard commercial gestation pelleted diet (13.1 MJ/kg DM and 12.8% protein; 31.3 kg per feeder per drop and 2.5 kg per sow per d). Feed was delivered onto the floor in four feed drops (at approximately 0730, 0930, 1100, and 1500 h). Water was supplied ad libitum.

2.1.4 Measures recorded

*Feeding behaviour.* The feeding behaviour of individual sows was recorded using instantaneous point sampling (Martin and Bateson, 2009) with 30 s intervals over four, 5 min time blocks (i.e. a total of 20 min) commencing 30 s after the delivery of each of the four feeding bouts per day, at days 2, 9 and 51 post-mixing (40 possible sample points per sow, per feeding bout, per day). A sow was recorded as feeding if her head was down and she was rooting the ground/feed, or if she was observed to be picking up and chewing food, regardless of the position of her head.
If a sow was feeding, her location in the pen was also recorded as either (1) directly under the feed hopper (i.e., high feed availability, HF), (2) on the cement flooring around the feed hopper (i.e., reduced feed availability, RF) or (3) on the slats at the back at the pen (i.e., scarce or no feed availability, NF). The location of sows that were not performing feeding behaviour was not recorded.

**Aggressive behaviour at feeding.** Aggressive behaviour of individuals was observed using continuous sampling for 30 min after each of 4 daily feed drops on the day after mixing (Day 2) and Days 9 and 51. Aggressive behaviour was defined as bites, presses, and knocks (Samarakone and Gonyou, 2009) and also included fights, which were defined as aggressive interactions involving the same pair of animals and that continued for at least a 5-s duration. The numbers of aggressive acts delivered and received by each individual sow during the observation period were recorded. During fights, a bout criterion interval of 5 s was chosen to separate one bout of aggressive behaviour from another bout (Hemsworth et al., 2013). Only when the full head of the attacking animal and the identifying symbol of the animals delivering and receiving aggression were clearly in the field of view were aggressive interactions recorded. From the observations of aggressive behaviour at feeding at Day 2, sows were classified as “dominant” if they delivered more aggression than they received at Day 2, “subdominant” if they received more aggression than they delivered at Day 2, and “submissive” if they delivered very little or no aggression relative to aggression received at Day 2 (that is, the ratio of aggression delivered to aggression delivered + aggression received ≤ 0.05). Aggressive behaviour at Day 2 was used because aggression between group-housed sows that are restrictively fed is most pronounced early after grouping (Barnett et al., 2001). This aggression classification is similar to that devised by Mendl et al. (1992) and used later by Zanella et al. (1998), but these researchers used displacements rather than aggression.

**2.2 Statistical analysis**

Due to removal of unproductive animals, and to ensure each gestation had 200 animals at mixing, a total of 275 animals were selected for the study. Some animals
were observed in the first gestation and not the second, and vice versa, but there were 126 animals common to both gestations.

The number of sows and pens observed at each day in each gestation are reported in Table 1. In the first gestation, a technical malfunction meant there were no day 51 behavioural data for replicate 3, while an operational error meant that the fourth feed drop was not delivered at day 2 of replicate 2 or day 51 of replicate 1. In the second gestation, the same operational error meant that the fourth feed drop was not delivered at days 2 or 51 or replicate 3. At day 51 of gestation 2, one pen in replicate 3 broke a gate and mixed with non-trial pigs, so feed drops 3 and 4 were excluded from analysis for this pen. One gestation 2 sow escaped the pen before any data could be obtained.

**Table 1.** Number of pens recorded per feed drop/day, and total sows recorded per day, in gestation 1 and 2.

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<th>Number of pens recorded</th>
<th>Number of sows recorded</th>
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<td>FD 1</td>
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<td><strong>Gestation 1</strong></td>
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<td>Day 9</td>
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<td>Day 51</td>
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<td><strong>Gestation 2</strong></td>
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<tr>
<td>Day 2</td>
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<td>Day 9</td>
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<td>Day 51</td>
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Part 1 of this report studied changes in the feeding behaviour of dominant (D), subdominant (SD) and submissive (SM) sows (a) over time post feed-delivery, and (b) over four feed drops within a day. The statistical models used are detailed below. The statistical package used for all analysis was SPSS 23.0 (SPSS Inc., Chicago, IL) and the unit of analysis was always the individual gilt/sow.

Generalised linear mixed models (GLMM) with an identity link were developed to relate the number of times (averaged over four feed drops per day) submissive (SM), subdominant (SD) and dominant (D) sows were observed displaying feeding
behaviours over four, 5 min time periods post-feed delivery at day 2, 9 and 51 post-mixing. Separate models were developed for pen locations associated with high (HF), reduced (RF) or no (NF) food availability, and for each gestation. Time period (5, 10, 15, 20 min post feed-delivery), day post-mixing (2, 9, 51) and aggression classification (SM, SD, D), as well as their 2- and 3-way interactions, included in the model as fixed factors.

Data on the feeding behaviour of sows per feed drop within days represented a count of occurrences (i.e., number of observations sows were feeding) in a fixed period of time (i.e., total of 20 minutes post-feed delivery). As such, a GLMM with an underlying Poisson distribution and log link function were developed to relate the total number of times SM, SD and D sows were observed displayed feeding behaviours in each of the four feed drops at days 2, 9 and 51. Separate models were developed for locations associated with high (HF), reduced (RF) or no (NF) food availability and for each gestation. For this analysis, feed drop within a day (1, 2, 3, 4), day post-mixing (2, 9 and 51) and aggression classification (SM, SD, D), as well as their 2- and 3-way interactions, included in the model as fixed factors.

Observations on the same individuals were repeated longitudinally over days, so all models in both sets of analysis accounted for repeated observations of the same sow over time/feed drop and day with a first order auto-regressive correlation structure. Group/pen (nested within replicate) and replicate were included in the model as random blocking factors. The Satterwaite approximation was used to adjust degrees of freedom. When an interaction was not significant it was removed from the model so that significant effects could more reliably interpreted. Where there were significant main or interactive effects (P<0.05) the LSD test determined where estimated marginal means differed.
2.3 Results

2.3.1 Changes in feeding behaviour over time post-feed delivery.

The relationship between sow aggression classification and feeding behaviour over four 5-min time periods post-feed delivery (averaged over four drops delivered per day) at days 2, 9 and 51 are presented in Figs 1 and 2.

There was an aggression classification × time post-feeding interaction for feeding directly under the feed hopper (HF) in both gestations 1 and 2 (gestation 1: $F_{6,1520}=6.9 \ P<0.001$; gestation 2: $F_{6,1736}=12.2 \ P<0.001$). In both gestations, dominant sows spent the most time feeding at the HF location regardless of time. Also in both gestations, submissive sows spent less time feeding at the HF location than subordinate sows in the first 10 minutes post-feed delivery, but not from 10-20 minutes post-feed delivery. Feeding at the HF location declined over time post-feed delivery for all classifications of sow in gestation 1, and for dominant and subdominant sows in gestation 2. However, the time submissive sows spent feeding at the HF location in gestation 2 declined only from 5-10 min post-feed delivery, with no further reductions recorded. Both dominant and subdominant sows spent less time feeding at the HF location at day 51 of gestation 2 than at days 2 and 9, but time feeding at HF was the same for submissive sows regardless of day (aggression classification × day $F_{4,1225}=4.5 \ P<0.001$). Sows spent more time feeding at HF in the first 10-min post-feed delivery at day 9 than days 2 or 51 of gestation 1 (day × time interaction $F_{6,1660}=7.5, \ P<0.001$).

There were significant aggression classification × time interactions for time spent feeding on the cement flooring but not directly under the feed hoppers (RF) in gestations 1 and 2 (gestation 1: $F_{6,1515}=2.5 \ P=0.02$; gestation 2: $F_{6,1621}=4.9 \ P<0.001$).

In both gestations, all classifications of sow increased their time spent feeding in the RF location from 5-min post-feed delivery. In gestation 1, dominant sows fed at the RF location less frequently in the first 10-min post-feed delivery than submissive and subdominant sows, but the three classifications of sow did not differ from 10-20 minutes post-feed delivery. In gestation 2, subdominant sows spent the most time feeding at the RF location in the first 10-min post-feed delivery, followed by
submissive sows with dominant sows spending the least time feeding at RF. From 10-20 min post-feed delivery, however, there was no difference between the submissive and subdominant classifications. Time feeding at the RF location in gestation 1 peaked higher and took longer to decline at day 9 than at days 2 and 51 (day × time $F_{6,1653}=7.3$, $P<0.001$). In gestation 2, sows spent the most time feeding at the RF location at day 9 and the least at day 51 (day $F_{2,1238}=12.2$, $P<0.001$).

The number of times sows were observed performing feeding related behaviours on the slats at the back of the pen (i.e., the NF location) did not interact with day or time post-feed delivery in either gestation ($P>0.05$). Submissive sows spent the most time feeding at the NF location (gestation 1: aggression classification $F_{2,549}=504$, $P=0.005$; gestation 2: aggression classification $F_{2,458}=23.6$, $P<0.001$). While in gestation 1 dominant and subdominant sows spent comparable time at the NF location, in gestation 2 dominant sows were recorded at the NF location less frequently than subdominant sows. In both gestations, feeding at the NF location increased over the first 15-min post-feed delivery before declining from 15-20 min post-feed delivery. However, feeding at NF in gestation 1 peaked at a higher level and took longer to begin declining at day 9 compared to days 2 and 51 (gestation 1: day × time post-feeding $F_{6,1630}=2.5$, $P=0.02$). Sows fed at the NF location more frequently at 51 of gestation 2 than at days 2 and 9 (day $F_{2,1206}=2.9$, $P=0.052$).
Fig 1. Gestation 1: The number of times Dominant (−), Subdominant (---) and Submissive (…) sows were recorded showing feeding behaviour (averaged per feed drop at days 2, 9 and 51) in areas associated with high (HF; 1a, 1b, 1c), reduced (RF; 1d, 1e, 1f) or no (NF, 1g, 1h, 1i) food availability, observed over four, 5-minute time periods.
Fig 2. Gestation 2: The number of times Dominant (•), Subdominant (---) and Submissive (…) sows were recorded showing feeding behaviour (averaged per feed drop at days 2, 9 and 51) in areas associated with high (HF; 1a, 1b, 1c), reduced (RF; 1d, 1e, 1f) or no (NF, 1g, 1h, 1i) food availability, observed over four, 5-minute time periods.
2.3.2 Changes in feeding behaviour over four feed drops per day

Relationships between sow aggression classification and feeding behaviour over four feed drops delivered at days 2, 9 and 51 are presented in Figs 3 and 4.

Regardless of day and feed drop number, dominant sows spent the most time feeding directly under the feed hoppers (i.e., HF location) (gestation 1: aggression classification $F_{2,722}=57.9$, $P<0.001$; gestation 2: aggression classification $\times$ day $F_{4,1224}=2.9$ $P=0.018$) and the least time feeding at locations associated with reduced (RF) feed availability (gestation 1: aggression classification $F_{2,699}=7.6$, $P<0.001$; gestation 2: aggression classification $F_{2,522}=18.4$, $P<0.001$). Subdominant sows spent more time than submissive sows feeding at the HF location in gestation 1 and at day 51 of gestation 2, but not at days 2 and 9 of gestation 2. Subdominant and submissive sows did not differ in time spent feeding at the RF location in both gestations 1 and 2. There was an aggression classification $\times$ feed drop interaction in gestation 2 ($F_{6,1645}=2.5$ $P=0.018$). The time dominant sows spent feeding at HF was lower in the 4th than in the 1st and 2nd feeding drops, but this was not associated with a change in the time submissive and subdominant sows spent feeding at the HF location.

In both gestations 1 and 2, time feeding at the HF location reduced from the feed drops 2 to 4 at days 2 and 51, but not at day 9 (day $\times$ feed drop: gestation 1 $F_{6,1558}=3$ $P=0.006$; gestation 2 $F_{6,1730}=4.4$ $P<0.001$). The same relationship was observed for time feeding at the RF location in gestation 2 (day $\times$ feed drop $F_{6,1710}=4.0$ $P<0.001$). Interpretation of the day $\times$ feed drop effect for time feeding at the RF location in gestation 1 is more complicated. At days 2 and 9, time feeding at RF declined between feed drops 2 to 3, but at day 2 feeding at RF increases again at drop 4 whereas at day 9 it does not. At day 51 of gestation 1 feeding at the RF location declines over the four feed drops.

Submissive sows spent the most time feeding on the slats (NF) at the back of the pen (gestation 1 aggression classification: $F_{2,805}=12.2$ $P<0.001$; gestation 2: aggression classification $F_{2,508}=27.3$ $P<0.001$). Dominant sows spent less time feeding
at the NF location than subdominant sows in gestation 1 (P=0.053) and gestation 2 (P<0.05). In gestation 1, time feeding at NF was higher during feed drop 1 than drops 2, 3 and 4 (feed drop number $F_{3,1116}=15.1$ $P<0.001$) and was higher at day 9 than day 51 ($F_{2,1346}=5.1$ $P=0.006$). In gestation 2, time spent feeding at the NF location declined over the four feed drops at day 2, but at day 9 time feeding at NF was higher in drops 2, 3 and 4 than in drop 1, whereas at day 51 time feeding at NF was consistent (feed drop × day $F_{6,1689}=2.8$ $P=0.01$).
Fig 3. Gestation 1: The number of times Dominant (−), Subdominant (---) and Submissive (...) sows were recorded showing feeding behaviour in areas associated with high (HF; 3a, 3b, 3c), reduced (RF; 3d, 3e, 3f) or no (NF, 3g, 3h, 3i) food availability, when fed over four feed drops at days 2, 9 and 51 post-mixing.
Fig 4. Gestation 2: The number of times Dominant (−), Subdominant (---) and Submissive (...) sows were recorded showing feeding behaviour in areas associated with high (HF; 3a, 3b, 3c), reduced (RF; 3d, 3e, 3f) or no (NF, 3g, 3h, 3i) food availability, when fed over four feed drops at days 2, 9 and 51 post-mixing.
2.4 Discussion

Drop feeding systems distribute feed onto the floor in a reverse cone shape, with the highest volumes of feed directly under the feeder. Thus, sows that spend significantly more time performing feeding behaviours directly under the feeder likely have the highest intake of food per unit of time (Csermely and Wood-gush, 1990). In the present research, sows classified as dominant spent more time feeding directly under the feed hoppers and the least time feeding in areas of reduced on no feed availability. Subdominant sows fed most frequently from areas of presumably reduced feed availability (i.e., around the edges of the area where the majority of feed was delivered), a finding that was also reported by Csermely and Wood-gush (1990). Submissive sows performed feeding related behaviour (e.g., rooting the pen floor) on the slatted area of the pen more often than subdominant and dominant sows. This suggests that submissive sows avoided the feeding area despite being motivated to feed, as it is unlikely that food was present in this area of the pen.

Pigs are a gregarious species, and when housed in groups establish roughly linear, and mostly stable, dominance hierarchies (Verdon and Rault, 2017). Submissive sows actively avoid interactions with those more dominant, and through this avoidance, the dominance hierarchy regulates priority access to resources, such as food (Gonyou, 2001). For example, when fed ad libitum, high ranking sows feed more frequently and alone, whereas low ranking sows wait until other sows leave the feeder before beginning their meal, and then often feed alongside others and until they are displaced (Brouns and Edwards, 1994). In addition to restrictions on the quantity of food provided to gestating sows, floor feeding systems place considerable spatio-temporal restrictions on the availability of feed. Consequently, the space that is available to pigs to feed, and regulate social interactions when feeding, is limited. This forces low ranking sows to risk receiving aggression by feeding in close proximity to high ranking sows, or alternatively avoiding feeding. Csermely and Wood-gush (1990) conducted observations of sows floor-fed twice per day. After both feed drops, subdominant sows moved around the group looking for opportunities to feed between those more highly ranked. These subdominant sows increasingly risked receiving aggression as food began to disappear by moving closer
to the area where feed was most available. However, they did not gain unrestrictive access the area until feed was mostly finished and dominant sows began to leave (Csermely and Wood-gush, 1990).

The feeding strategy adopted by subdominant sows in the present study is comparable to the opportunistic feeding strategy adopted by subordinate sows in the studies conducted by Csermely and Wood-gush (1987, 1990) and described in the previous paragraph. In contrast to the dichotomous classifications of dominant and subordinate utilised by Csermely and Wood-gush (1987, 1990), however, the present study classified sows as submissive, subdominant and dominant. This allowed for important discriminations to be made between (1) sows that deliver aggression (i.e., dominant and subdominant classification) and those that deliver very little or no aggression (i.e., submissive classification); and (2) between subordinate sows that deliver aggression (i.e., subdominant sows) and subordinate sows that deliver little or no aggression (i.e., submissive sows). Using this classification method, the present study identified a cohort of sows with low dominance status that avoid the feeding area and, therefore, may be at risk of undernutrition. Discussions relating to the management and design of feeding systems for group-housed sows would benefit from specific considerations of those that are avoiding the feeding area.

The relationships between aggression classification and feeding behaviour in the present study did not change over feed drops or days post-mixing. These results are comparable to other studies that fed sows once (Brouns and Edwards, 1994) and twice (Csermeley and Wood-gush, 1990) per day. Anecdotal evidence suggests that dominant sows spend more time delivering aggression in defence of food than consuming it (Brouns and Edwards, 1994; Csermely and Wood-gush, 1987, 1990). Previous research has shown that aggression delivered by dominant sows, aggression received by all sows, and skin injuries decline over subsequent drops per day (Schneider et al., 2007; Verdon et al., 2011, 2015b). It has previously been hypothesised that dominant sows become satiated after the first feed drop of the day, providing subdominant and submissive animals with increased opportunity to access food in later feeding bouts (Rault et al., 2015; Verdon et al., 2011, 2015b). However, the results of the present study and others (Csermely and Wood-gush,
show that although aggression declines over subsequent feed drops, dominant sows nonetheless monopolise the feeding area in each feed drop. Thus, under the conditions described in the present study, floor feeding sows multiple times per day does not increase the time submissive sows spent feeding in the later drops.

This study highlights the importance of research into the promotion and/or prolonging of satiety in group-housed sows, particularly for those that are low ranking. Indeed, from approximately 10 minutes post feed-delivery in the present study, and for up to one hour post-feed delivery (Brouns and Edwards, 1994), sows continue to display appetitive behaviours (e.g., rooting the ground), despite the fact that there is little or no food remaining. Commercial kept adult pigs fed ad libitum eat three larger meals, one of which occurs during the night (Nielsen et al., 2006). The size of a meal is dependent on the physical characteristics of the food offered, and is limited by the size of the stomach and controlled by inhibitory signals from gastrointestinal sites to the central nervous system (Nielsen et al., 2006). Thus, temporal aspects of the feeding regime adopted by adult pigs fed ad libitum may be associated with declining feelings of satiety. By contrast, if a meal is not large enough for the positive feedback effects of feed consumption to override the inhibitory feedback from the ingestion of nutrients, feeding motivation will persist (Lawrence and Terlouw, 1993). One strategy to promote satiety and reduce competition in floor fed sows could be to reduce the time between feed drops. For instance, Schneider et al. (2007) found reduced injuries and removal for injury when group-housed sows were floor fed six times (0700, 0730, 0800, 1530, 1600 and 1630 h) rather than twice (0700 and 1530 h) per day, although there were no effects on sow weight or variation in sow weight.

Increasing the frequency of feeding may have negative consequences for pig welfare if meals are not provided in close succession. Gilts individually housed in gestation stalls performed more stereotypies and were more active around feeding when fed twice (0800 and 1430 h) rather than once per day (Roberts et al., 2002), and when fed daily rather than every third day (Douglas et al., 1998). However, feeding frequency did not affect other behavioural indicators of feeding motivation (Roberts et al., 2002) or pre-feeding blood glucose (Douglas et al., 1998). Electronic sow feeder records show that 79% of sows will take their daily food allocation in a single
meal, but 87% of the herd - and particularly young and newly introduced sows - varied in their feeding pattern (Eddison and Roberts, 1995). Douglas et al. (1998) suggested that feeding sows larger meals less frequently increases satiety after the consumption of feed and advocated for decreasing the frequency of feedings as a management practise. Conversely, there are reports of increased occurrence of twisted stomachs and spleens when stall-housed sows are fed on alternating days as a result of very high rate of intake due to excitability, particularly for the sows that were fed last (see Fraser, 2008). In a study on young pigs, Mahnhardt et al. (2014) found that feeding at two fixed times per day (0600 and 1500 h) is preferable to six randomly timed feedings, as indicated by a lower resting heart rate. Thus, in addition to short inter-meal intervals, predictability may also be important. Conclusive recommendations of the management of floor feeding systems cannot be made without controlled comparisons of various floor-feeding regimes.

Brooks (2005) provided a good description of the relationship between diet and feeding motivation of sows. If sows are fed a low density, high bulk diet ad libitum (typical of the wild pig), feeding motivation is driven by the energy requirement of the sow. If sows are fed a typical, commercial, high density diet ad libitum, feeding motivation comes from lack of gut fill. If the sow is restrictively fed a typical, commercial, high-density diet feeding motivation is driven by low gut fill, but, in the absence of sufficient food or edible bedding (for example) cannot be satisfied and as consequence is redirected as stereotypic behaviour (Brooks, 2005). Considering this, satiety may be promoted in restrictively fed sows either by reducing the state of internal hunger, or by allowing a more appropriate expression of foraging behaviour (Lawrence et al., 1993). Scientific evidence has not yet provided specific recommendations to effectively reduce hunger in sows, however. For instance, the evidence that a high-fibre diet will prolong satiety and reduce sow aggression is contradictory (see review Verdon et al., 2015a; Sapkota et al., 2016), and likely depends on the source of fibre used (de Leeuw et al., 2008; Souza da Silva et al., 2012). Feeding sows higher quantities of food (Spoolder et al., 1995; Bergeron et al., 2000; Jensen et al., 2012, 2015), and extending meal length (Bergeron and Gonyou, 1997) reduce stereotypies and activity. Foraging materials (e.g., straw, spent mushroom compost, grass silage, and rice hulls) may allow the feeding motivation of unsatiated sows to be channelled into foraging behaviour (Lawrence and Terlouw, 1993; Spoolder et al., 1995; Boyle et al., 2002) and also
act as a secondary feed source (Jensen et al., 2000). The timely provision of these materials (e.g., before, during or after a meal) may be integral in promoting satiety and the expression of foraging behaviour without creating a new source of competition.

Qualitative, rather than quantitative, food restriction provides the animal with more control over its feeding behaviour, meaning that meals are ended while food is still available, a more normal meal pattern is observed, feeding time is extended and oral stereotypies are strongly reduced (see review Kyriazakis and Tolkamp, 2011). Some suggestions to achieve qualitative restriction include feeding sows a low-fibre diet with supplemented *ad libitum* access to roughage or foraging materials may promote satiety (Verdon et al., 2015a), or feed a low energy high-bulk diet in greater quantities throughout the day. A multifactorial approach to reducing hunger in sows, that utilises dietary manipulations, methods to extending meal length and the provision of substrates that allow for the expression of appetitive behaviours, requires investigation.

The time sows spent feeding directly under the feed hoppers declined from 5-10 minutes post-feed delivery, which corresponded with an increase in the time feeding on the surrounding cement flooring. This suggests that, when fed their daily allocation over four drops per day, sows consume the majority of feed within 5-10 minutes of delivery. When floor-feeding systems deliver the daily allowance over one (Brouns and Edwards, 1994) or two (Csermely and Wood-gush, 1990) drops, the majority of feed is reportedly consumed within 20-30 minutes. Other studies have found that sows fed once per day in lock-in feeding stalls consume nearly 42% of their daily ration within 5-minutes of delivery and 77% (with 5 of the 39 sows studied consuming their entire ration) within 10 minutes of delivery (Bøe and Cronin, 2015). Thus, independent of the housing system used, the feed delivered to gestating sows can be consumed in about 5 minutes, if the food is composed of energy dense low dietary fibre grain products, such as wheat (Nielsen et al., 2006). Both Verdon (2014) and Csermely and Wood-gush (1987) found that aggression declines with time after feed delivery, becoming close to zero by the time all feed is consumed. This high rate of consumption has two primary implications. First, this provides a limited period of time in which interventions (in terms of management, housing etc.) will
effectively reduce competition and aggression around feeding. Second, enrichment is also needed to combat boredom and frustration throughout the day.

Submissive sows left the area of high feed availability more quickly, and spent less time in the area of reduced feed availability, in the second gestation of the present study than the first. Further, at day 9 of gestation 1 the time sows spent feeding in all locations peaked higher and took longer to decline compared to days 2 and 51. Verdon et al. (2016) found that dominant sows received more aggression, and all sows sustained more skin injuries, in gestation 1 than gestation 2. The authors hypothesised that ‘following the experience of group housing in the first gestation, low-ranking sows may have learned to avoid high-ranking sows, whereas the latter sows may be more confident in their fighting ability and respond accordingly’. Thus, the differences between gestations 1 and 2 of the present study may be attributed to the limited social experience of gilts.
3. Study 2 - The relationship between sow feeding behaviour and welfare

3.1 Materials and methods

3.1.1 Ethical note

All animal procedures were conducted with prior institutional ethical approval under the requirement of the New South Wales Prevention of Cruelty to Animals Act (1979) in accordance with the National Health and Medical Research Council/Commonwealth Scientific and Industrial Research Organization/Australian Animal Commission *Australian Code of Practice for the Care and Use of Animals for Scientific Purposes* (NHMRC, 2013).

3.1.2 Facilities

This study was conducted between October 2010 and February 2012 in a gestation unit of a large commercial piggery in southern New South Wales, Australia. The 6-m-long and 19-m-wide building was equipped with adjustable blinds. Overhead water sprinklers covered 50% of the slatted floor area of the pens and were activated (3 min on and 15 min off) when the internal temperature exceeded 26°C. The maximum and minimum mean daily ambient temperatures for spring, summer, autumn, and winter of 2011 were 21.3 and 8.5°C, 29.2 and 15.2°C, 21.3 and 7.9°C, and 15.6 and 3.9°C, respectively. Within the unit, 12 pens (3.7 by 4.8 m) were used. Each pen had partially slatted floors (50%) with a solid cement lying/feeding area and a slatted dunging area and was fitted with two overhead feed droppers and one nipple drinker. One video camera with built-in infrared lights was positioned above each pen and recorded from 0700 to 1700 h on the second day of mixing (labelled Day 2) and Days 9 and 51 after mixing. The camera covered most of the pen floor area (14 m²); however, some area in the corners of the pens could not be observed. Importantly, the area of the pen floor where feed was delivered was within the field of view of the camera. This is where most of the sow interactions at feeding occurred.
3.1.3 Animals and Experimental Design

A total of 275 pregnant Large White × Landrace sows (Sus scrofa) were used in this study so that 200 gilts (50 gilts per replicate) in 4 replicates were studied in their first gestation and 200 sows in 4 replicates were studied in their second gestation (200 animals per gestation with 126 animals common to both gestations). Gilts detected in oestrus from 32 weeks of age were transferred from groups of 30 gilts to stalls for insemination. Gilts were twice artificially inseminated (morning/afternoon insemination routine) and, within 7 d of insemination, were randomly mixed into groups of 10 (space allowance of 1.8 m2/gilt) between 0800 and 1300 h. Before mixing, symbols were sprayed on the backs of gilts allowing for individual identification. One week before farrowing, gilts were moved to farrowing stalls where they remained until piglets were weaned at 25 d of age. After piglets were weaned, the parity 1 sows were housed in mating stalls, again twice artificially inseminated (morning/afternoon insemination routine), and within 7 d, were randomly mixed into groups of 10 (space allowance of 1.8 m2/sow). Females were allocated to different groups for their second gestation and remained in these groups for the remainder of the gestation. On average, the maximum number of sows in a group that has been housed together in the first gestation was 2.4 (range 0-4). The same farrowing management as for first gestation was applied. For convenience, in the remainder of this paper, gestating gilts will be referred to as sows. The gestation number of the sow will reflect her parity status: nulliparous or primiparous. During gestation, sows were fed a standard commercial gestation pelleted diet (13.1 MJ/kg DM and 12.8% protein; 31.3 kg per feeder per drop and 2.5 kg per sow per d). Feed was delivered onto the floor in four feed drops (at approximately 0730, 0930, 1100, and 1500 h). Water was supplied ad libitum.

3.1.4 Measures recorded

Feeding behaviour. The feeding behaviour of individual sows was recorded using instantaneous point sampling (Martin and Bateson, 2009) with 30 s intervals over four, 5 min time blocks (i.e. a total of 20 min) commencing 30 s after the delivery of each of the four feeding bouts per day, at days 2, 9 and 51 post-mixing (40 possible sample points per sow, per feeding bout, per day). A sow was recorded as feeding if her head was down and she was rooting the ground/feed, or if she was
observed to be picking up and chewing food, regardless of the position of her head. If a sow was feeding, her location in the pen was also recorded as either (1) directly under the feed hopper (i.e., high feed availability, HF), (2) on the cement flooring around the feed hopper (i.e., reduced feed availability, RF) or (3) on the slats at the back at the pen (i.e., scarce or no feed availability, NF). The location of sows that were not performing feeding behaviour was not recorded.

**Aggressive behaviour at feeding.** Aggressive behaviour of individuals was observed using continuous sampling for 30 min after each of 4 daily feed drops on the day after mixing (Day 2) and Days 9 and 51. Aggressive behaviour was defined as bites, presses, and knocks (Samarakone and Gonyou, 2009) and included fights, which were defined as aggressive interactions involving the same pair of animals and that continued for at least a 5-s duration. The numbers of aggressive acts delivered and received by each individual sow during the observation period were recorded. During fights, a bout criterion interval of 5 s was chosen to separate one bout of aggressive behaviour from another bout (Hemsworth et al., 2013). Only when the full head of the attacking animal and the identifying symbol of the animals delivering and receiving aggression were clearly in the field of view were aggressive interactions recorded. From the observations of aggressive behaviour at feeding at Day 2, sows were classified as “dominant” if they delivered more aggression than they received at Day 2, “subdominant” if they received more aggression than they delivered at Day 2, and “submissive” if they delivered very little or no aggression relative to aggression received at Day 2 (that is, the ratio of aggression delivered to aggression delivered + aggression received $\leq 0.05$). Aggressive behaviour at Day 2 was used because aggression between group-housed sows that are restrictively fed is most pronounced early after grouping (Barnett et al., 2001). This aggression classification is similar to that devised by Mendl et al. (1992) and used later by Zanella et al. (1998), but these researchers used displacements rather than aggression.

**Cortisol concentrations.** Blood samples were taken by a single team at Days 2, 9, and 51 by venipuncture of the jugular vein while animals were restrained with a snout snare. Sampling commenced at approximately 1200 h and it took an average of 37 min to sample all sows in the replicate (average 7.5 min per pen). A 6-mL
sample was taken in a heparinized tube (BD Vacutainer; Becton, Dickinson and Company, Belliver Industrial Estate, Plymouth, UK). For each animal, a maximum of 2 min from snaring was allowed to obtain the blood sample. This was so that an acute stress response associated with handling and blood sampling could be avoided, which would influence concentrations of plasma cortisol (Broom and Johnson, 1993). Karlen et al. (2007) found no effects of repeatedly sampling different animals within groups on salivary cortisol concentrations. The individual samples were centrifuged for 10 min at 1,912 × g at 4°C, and the plasma was poured off into individual microtubes and stored at -20°C until analysed. During this study, the laboratory that analysed the plasma samples for gestation 1 and for the majority of gestation 2 ceased to operate (Monash University, Melbourne, Australia). Consequently, 92 of 177 samples collected at Day 51 of gestation 2 (replicates 3 and 4) were analysed elsewhere (The University of Western Australia, Perth, Australia). The first laboratory measured plasma cortisol with an extracted RIA (Bocking et al., 1986), using hydrocortisone (H-4001; Sigma Chemical Co., St. Louis, MO) as the standard. The assay used [3H]-cortisol (Amersham Pharmacia Biotech, UK, Buckinghamshire, England) as tracer and a dicholoromethane extraction procedure. The second laboratory measured plasma cortisol using a commercial RIA kit (Cortisol GammaCoat RIA kit CA-1549; DiaSorin Inc., Stillwater, MN). The intra- and interassay CV of the first and second laboratories were 7.81 and 12.06% and 5.13 and 4.85%, respectively.

Skin injuries. The same assessment as described by Karlen et al. (2007) was used to assess skin injuries for individual sows in the morning of each of Days 2, 9, and 51 after mixing. Only skin injuries categorized as being fresh (scratches, abrasions, and cuts) were recorded. Each side of the sow’s body was divided into 21 areas for injury data collection (see Karlen et al., 2007). The number and the type of skin injuries were recorded, and, from these records, the number of fresh injuries was collated for each sow on each observation day.

Live Weight gain. Sows were individually weighed at Days 2 and 100. From this, live weight gain for the gestation was calculated.
Reproductive performance. The reproductive performance data collected allowed for the farrowing rate percent of inseminated sows that farrowed (excluding those removed for injury, illness, or death) to be calculated. Litter size data (number of piglets that were born alive, total number born and stillborn) as well as non-reproductive removals were also collected. Stillborn piglets were judged on the basis that they were fully formed at farrowing, covered in foetal membrane, had fully formed eponychia on their hooves, and were located behind the sow.

3.2 Statistical analysis

Due to removal of unproductive animals, and to ensure each gestation had 200 animals at mixing, a total of 275 animals were selected for the study. Some animals were observed in the first gestation and not the second, and vice versa, but there were 126 animals common to both gestations.

The number of sows and pens observed at each day in each gestation are reported in Table 1 (see Part 1). In gestation 1, 182 sows had complete injury and cortisol data sets (i.e., data collected at days 2, 9, and 51). One gestation 2 sow escaped the pen before any data could be obtained. The numbers of sows with complete data sets for aggressive behaviour, skin injuries, and cortisol in the second gestation were 177, 177, and 176 sows, respectively.

The patterns of correlation between data relating to feeding behaviour (i.e., time feeding in areas of the pen associated with high, reduce or no feed availability), welfare (i.e., aggression delivered and received, injuries and cortisol) and productivity (i.e., weight gain and reproduction) were subjected to a principle component analysis (PCA; Harris, 1985). PCA is a technique that produces new linear variables (called factors, or components) that best represent the underlying correlations between the original variables. This technique reduces data from a large number of correlated variables into a smaller number of uncorrelated variables, called factors or components, without losing information present in the large set of variables.
To aid with interpretation, sets of data relating the sow feeding behaviour, welfare and productivity were separately subjected to PCA. Each PCA was conducted for sows in gestation 1 and 2 separately, and again for the cohort of sows that were common to gestations 1 and 2. This allowed for the immediate (i.e., within gestation) and longer term (i.e., from gestation 1 to gestation 2) implications of feeding behaviour to be examined. There was little variation in the feeding behaviour of D, SD and SM sows over days or feed drops within days, while feed is mostly consumed within 10 minutes of delivery (see Part 1). Thus, for the PCA of data relating to the feeding behaviour of sows, the time sows spent HF, RF and NF in the first 10 minutes post-feed delivery was totalled over the entire gestation. As a result, only sows that had complete feeding behaviour records (i.e., records for days 2, 9 and 51) were utilised in this PCA (gestation 1 n=140; gestation 2 n=177).

Prior to conducting each PCA on the three sets of variables (feeding behaviour, welfare and productivity), the suitability of the data for the analysis was assessed using criteria outlined by Pallant (2013). An inspection of the correlation matrix revealed that the coefficients were all above the required 0.3. Furthermore, the Kaiser-Meyer-Olkin (KMO) value exceeded the recommended value of 0.6, and Bartlett’s Test of Sphericity reached statistical significance. Thus, the factorability of the correlation matrix was supported. A Varimax rotation was conducted and factors extracted from the resulting PCAs on the feeding, welfare and productivity sets of variables.

For each factor (i.e., component) generated in the PCAs of feeding behaviour, productivity and welfare, component scores were calculated for sows using the least squares regression approach. These predict the location of each individual on the factor, producing a score that is comparable to the Z-score matrix (Horback and Parsons, 2016). The relationships between sow feeding behaviour and sow welfare and productivity were assessed by correlations (pearson correlations) between component scores for the factors extracted from the PCA for feeding behaviour, to component scores for the factors extracted from the PCAs for sow welfare and productivity.
Farrowing rate data were binary (0/1). GLMMs with a binomial distribution and logit link (i.e., logistic regression) were fitted to this variable. Logistic regression predicts the probability of a dependent response, rather than the value of the response. Feeding in pen locations associated with high (HF), reduced (RF) or no (NF) food availability (in the first 10-mins post-feed delivery, totalled over the entire gestation) were the predictors included in the model. This analysis was conducted for each gestation separately, and controlled for group/pen (within replicate) as well as replicate as random blocking factors. The significance of predictor terms were evaluated using Wald F statistics (P<0.05).

3.3 Results

3.3.1 Factors/components generated in PCAs

Two factors/components (i.e., PC1 and PC2) were generated from the PCA on feeding behaviour that accounted for 77 and 82% of the variation in data on the feeding behaviour of sows in gestations 1 and 2 respectively, and 76.5% of the variation in data on the feeding behaviour of sows common to gestations 1 and 2 (Table 2). The two factors were labelled based on the strength of item loadings as PC1-Avoidance feeder in gestation 1 and for common sows, PC1-Dominant feeder in gestation 2, and PC2-Oppportunistic feeder in gestations 1 and 2 as well as for the common sows.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gestation 1</th>
<th>Gestation 2</th>
<th>Common sows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PC 1&lt;sup&gt;1&lt;/sup&gt;</td>
<td>PC 2&lt;sup&gt;1&lt;/sup&gt;</td>
<td>PC 1&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>(Sample size)</td>
<td>(140)</td>
<td>(177)</td>
<td>(124)</td>
</tr>
<tr>
<td>High feed availability</td>
<td>-0.80</td>
<td>-0.12</td>
<td>0.85</td>
</tr>
<tr>
<td>Reduced feed availability</td>
<td>0.07</td>
<td>0.99</td>
<td>0.02</td>
</tr>
<tr>
<td>No/low feed availability</td>
<td>0.82</td>
<td>0.00</td>
<td>-0.85</td>
</tr>
<tr>
<td>Variance explained (%)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>43.9</td>
<td>33.5</td>
<td>48.4</td>
</tr>
</tbody>
</table>

<sup>1</sup>Variables that load on the same factor are related, so that PC1 and PC2 represent all underlying relationships among all feeding behaviour variables.
<sup>2</sup>Rotation Sums of Squared Loadings
Item loadings ≥0.3 were considered to have significant weight and were clustered to create factors, as indicated by bold text.

Three factors/component (i.e., PC1, PC2 and PC3) that explained 71 and 61% of the variation in data on the productivity for sows in the first and second gestations, respectively, were generated from the PCA with sow productivity data (Table 3). Based on the loading profiles presented in Table 3, the components/factors generated in the PCA using data on sow productivity in gestation 1 were labelled as PC1-Weight gain, PC2-Piglets weaned, and PC3-Piglets born alive. The components/factors generated in the PCA using data on sow productivity in gestation 2 were labelled PC1-Weight gain, PC2-Piglets born alive, PC3-Piglets weaned.

Table 3. Factors produced using PCA on variables related to sow productivity. Loadings of each of the items on each component of the PCAs on sow productivity for sows in gestations 1 and 2, as well as for sows common to both gestations 1 and 2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gestation 1</th>
<th>Gestation 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>PC 1</td>
</tr>
<tr>
<td>Weight gain</td>
<td>166</td>
<td>0.94</td>
</tr>
<tr>
<td>D100 weight</td>
<td>166</td>
<td>0.95</td>
</tr>
<tr>
<td>Litter size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Born alive</td>
<td>163</td>
<td>0.34</td>
</tr>
<tr>
<td>Mummified</td>
<td>163</td>
<td>0.07</td>
</tr>
<tr>
<td>Stillborn</td>
<td>163</td>
<td>0.06</td>
</tr>
<tr>
<td>Deaths</td>
<td>160</td>
<td>0.02</td>
</tr>
<tr>
<td>Weaned</td>
<td>160</td>
<td>0.12</td>
</tr>
<tr>
<td>Eigenvalue²</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Variance explained (%)²</td>
<td>27.3</td>
<td>24.9</td>
</tr>
</tbody>
</table>

1Variables that load on the same factor are related, so that PC1, PC2 and PC3 represent all underlying relationships among all variables related to sow productivity.
2Rotation Sums of Squared Loadings

Item loadings ≥0.3 were considered to have significant weight and were clustered to create factors, as indicated by bold text.

Three factors/components (PC1, PC2 and PC3) were extracted from the PCA using the variables relating to sow welfare in gestations 1 and 2, which accounted for 47 and 52% of variation, respectively (Table 4). Based on the loading profiles presented in Table 4, the components/factors were labelled as PC1-Aggressiveness, PC2-Stress and PC3-Aggression received in gestation 1 and PC1-Aggressiveness, PC2-Aggression received and PC3-Stress in gestation 2.
Table 4. Factors produced using PCA on variables relating to sow welfare. Loadings of each of the items on each component of the PCAs on sow welfare for sows in gestations 1 and 2, as well as for sows common to both gestations 1 and 2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gestation 1</th>
<th></th>
<th>Gestation 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n PC 1 PC 2 PC 3</td>
<td></td>
<td>n PC 1 PC 2 PC 3</td>
<td></td>
</tr>
<tr>
<td>Aggression delivered</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>200 0.76 -0.12 0.32</td>
<td>199 0.85 -0.14 0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 9</td>
<td>197 0.78 0.06 0.01</td>
<td>196 0.85 -0.18 -0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 51</td>
<td>137 0.67 -0.13 -0.12</td>
<td>177 0.86 -0.14 -0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggression received</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>200 0.06 -0.09 0.74</td>
<td>199 -0.20 0.73 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 9</td>
<td>197 -0.45 0.02 0.48</td>
<td>196 -0.26 0.81 -0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 51</td>
<td>137 -0.45 -0.21 0.28</td>
<td>177 -0.22 0.78 -0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh skin injuries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>200 -0.11 0.09 0.61</td>
<td>200 -0.12 -0.28 -0.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 9</td>
<td>197 -0.49 -0.14 0.25</td>
<td>196 -0.44 0.15 -0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 51</td>
<td>182 -0.37 0.04 0.31</td>
<td>177 -0.31 0.31 -0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma cortisol</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>200 0.06 0.70 0.14</td>
<td>198 -0.17 -0.01 0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 9</td>
<td>196 -0.04 0.73 -0.13</td>
<td>195 0.05 -0.09 0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 51</td>
<td>183 -0.004 0.72 -0.002</td>
<td>177 0.09 0.04 0.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eigenvalue(^2)</td>
<td>2.4 1.6 1.5</td>
<td>2.7 2.1 1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variance explained (%)(^2)</td>
<td>20.2 13.7 12.8</td>
<td>22.5 17.3 11.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Variables that load on the same factor are related, so that PC1, PC2 and PC3 represent the underlying relationships among all variables relating to sow welfare.
2Rotation Sums of Squared Loadings
Item loadings ≥0.5 were considered to have significant weight and were clustered to create factors, as indicated by bold text.

3.3.2 The relationships between sow feeding behaviour and sow productivity and welfare

Pearson correlations between sow component scores for the factors extracted from the PCA on feeding behaviour and component scores for the factors extracted in the PCAs on sow welfare and productivity in gestations 1 and 2 are presented in Tables 5 and 6, respectively.

Sow component scores on the factors/components “Weight gain” and “Sow aggressiveness” were negatively correlated with sow component score on the factor/component “Avoidance feeding” in gestation 1 (Table 5, Figures 5) and positively correlated sow component score on the factor/component “Dominant
feeding” in gestation 2 (Table 6, Figures 6). The strength of the correlations were stronger in gestation 2 than in gestation 1 (Tables 5 and 6).

In gestations 1 and 2, sow component scores on the factor/component “Opportunistic feeder” (i.e., sows that feed on the cement flooring around the areas where the majority of feed is delivered) was negatively correlated with that on the factor/component “Stress”. There was a weak negative correlation between sow component score on the factors/components “Opportunistic feeder” and “Sow aggressiveness”, and a moderate positive correlation between sow component score on the factors/components “Opportunistic feeder” and “Aggression received”.

Table 5. For sows in gestation 1, pearson correlations between sow component score on factors/components named “Avoidance feeder” and “Opportunistic feeder” and component scores on factors/components relating to sow welfare and productivity.

<table>
<thead>
<tr>
<th></th>
<th>Gestation 1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avoidance feeder</td>
<td>Opportunistic feeder</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>r</td>
<td>r</td>
</tr>
<tr>
<td>Productivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1 (Weight gain)</td>
<td>115</td>
<td>-0.23*</td>
<td>0.15</td>
</tr>
<tr>
<td>PC2 (Piglets weaned)</td>
<td>115</td>
<td>-0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>PC3 (Piglets born alive)</td>
<td>115</td>
<td>-0.03</td>
<td>-0.03</td>
</tr>
<tr>
<td>Welfare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1 (Aggressiveness)</td>
<td>133</td>
<td>-0.47**</td>
<td>-0.17</td>
</tr>
<tr>
<td>PC2 (Stress)</td>
<td>133</td>
<td>-0.006</td>
<td>-0.26**</td>
</tr>
<tr>
<td>PC3 (Aggression received)</td>
<td>133</td>
<td>-0.11</td>
<td>-0.19</td>
</tr>
</tbody>
</table>

Significance levels: **, P<0.01; *, P<0.05.
Table 6. For sows in gestation 2, pearson correlations between sow component score on factors/components named “Avoidance feeder” and “Opportunistic feeder” and component scores on factors/components relating to sow welfare and productivity.

<table>
<thead>
<tr>
<th></th>
<th>Gestation 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dominant feeder</td>
<td>Opportunistic feeder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$n$</td>
<td>$r$</td>
<td>$r$</td>
</tr>
<tr>
<td>Productivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1 (Weight gain)</td>
<td>136</td>
<td>0.39**</td>
<td>-0.003</td>
</tr>
<tr>
<td>PC2 (Litter size)</td>
<td>136</td>
<td>0.07</td>
<td>-0.09</td>
</tr>
<tr>
<td>PC3 (Piglets weaned)</td>
<td>136</td>
<td>-0.006</td>
<td>-0.06</td>
</tr>
<tr>
<td>Welfare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC1 (Aggressiveness)</td>
<td>172</td>
<td>0.59**</td>
<td>-0.17*</td>
</tr>
<tr>
<td>PC2 (Aggression received)</td>
<td>172</td>
<td>-0.001</td>
<td>0.41**</td>
</tr>
<tr>
<td>PC 3 (Stress)</td>
<td>172</td>
<td>0.03</td>
<td>-0.23**</td>
</tr>
</tbody>
</table>

Significance levels: **, $P<0.01$; *, $P<0.05$.

Fig. 5. For sows in gestation 1, scatterplots showing the relationships between factor component scores for factors/components named (A) “Avoidance feeder” and “Weight gain”, (B) “Avoidance feeder” and “Aggressiveness”, and (C) “Opportunistic feeder” and “Stress”.

Table 6. For sows in gestation 2, pearson correlations between sow component score on factors/components named “Avoidance feeder” and “Opportunistic feeder” and component scores on factors/components relating to sow welfare and productivity.
Fig. 6. For sows in gestation 2, scatterplots showing the relationships between sow component scores for factors/components named (A) “Dominance feeder” and “Weight gain”, (B) “Dominant feeder” and “Aggressiveness”, (C) “Opportunistic feeder” and “Stress”, (D) “Opportunistic feeder” and “Aggression received” and (E) “Opportunistic feeder” and “Stress”.
Table 7. For sows common to gestations 1 and 2, pearson correlations between sow component score on factors/components named “Avoidance feeder” and “Opportunistic feeder” in gestation 1 and component scores on factors/components relating to sow welfare and productivity in gestation 2.

<table>
<thead>
<tr>
<th></th>
<th>Gestation 1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avoidance feeder</td>
<td>Opportunistic feeder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>r</td>
<td>r</td>
</tr>
<tr>
<td>Productivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight gain</td>
<td>58</td>
<td>-0.17</td>
<td>0.25*</td>
</tr>
<tr>
<td>Litter size</td>
<td>58</td>
<td>-0.01</td>
<td>0.17</td>
</tr>
<tr>
<td>Piglets weaned</td>
<td>58</td>
<td>-0.03</td>
<td>-0.10</td>
</tr>
<tr>
<td>Welfare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggressiveness</td>
<td>80</td>
<td>-0.19</td>
<td>-0.27**</td>
</tr>
<tr>
<td>Aggression received</td>
<td>80</td>
<td>-0.04</td>
<td>0.008</td>
</tr>
<tr>
<td>Stress</td>
<td>80</td>
<td>-0.09</td>
<td>0.19</td>
</tr>
<tr>
<td>Feeding in gestation 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant feeder</td>
<td>80</td>
<td>-0.22*</td>
<td>-0.12</td>
</tr>
<tr>
<td>Opportunistic feeder</td>
<td>80</td>
<td>0.05</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Significance levels: ***, P<0.01; **, P<0.05, *, P<0.06

There were few significant correlations between sow component scores on factors/components extracted from the PCA on feeding behaviour in the first gestation and those on factors extracted from the PCAs on welfare and productivity in the second gestation (Table 7). There were tendencies for component scores on the gestation 1 factor/component “Avoidance feeder” to negatively correlate with that on the gestation 2 factor “Dominant feeder” (P=0.052), and for component score on the gestation 1 factor “Opportunistic feeder” to positively correlate with that on the gestation 2 factor “Weight gain” (P=0.059). However, the only significant correlation (P<0.05) was between component scores on the gestation 1 factor/component “Opportunistic feeder” and that on the gestation 2 factor/component “Aggressiveness”; the more dominant a sow was in the second gestation the less time she spent feeding opportunistically in gestation 1 (Table 7, Figure 7). For sows in gestation 1, scatterplots showing correlations between factor component scores for factors/components named (A) “Avoidance feeder” and “Weight gain”, (B) “Avoidance feeder” and “Aggressiveness”, and (C) “Opportunistic feeder” and “Stress”.
Fig. 7. For sows common to gestations 1 and 2, scatterplots showing the relationships between sow component scores for factors/components named (A) “Avoidance feeder” in gestation 1 and “Dominant feeder” in gestation 2, (B) “Opportunistic feeder” in gestation 1 and “Weight gain” in gestation 2, and (C) “Opportunistic feeder” in gestation 1 and “Aggressiveness” in gestation 2.
In gestation 1, 29 sows of the 192 sows that were not removed for injury, illness or death failed to farrow (85% farrowing rate). The logistic regression found that time sows spent feeding directly under the feed hopper (HF; Wald $F_{1,188}=2.6$, $P=0.11$), on the cement floor around the feed hopper (RF; Wald $F_{1,188}=0.33$, $P=0.57$), or on the slats at the back of the pen (S; Wald $F_{1,188}=0.69$, $P=0.41$) did not affect the farrowing rate of sows in the gestation 1.

In gestation 2, 19 of the 184 sows that were not removed for injury, illness or death failed to farrow (90% farrowing rate). Feeding at the RF location (Wald $F_{1,180}=0.72$, $P=0.40$) and NF location (Wald $F_{1,180}=0.90$, $P=0.34$) were not significant predictors of farrowing rate, but there was a tendency for farrowing rate to increase with time spent feeding in the HF location (Wald $F_{1,180}=2.86$, $P=0.092$). The odds ratio suggests that every 1% increase in farrowing rate is associated with a 3.1% increase in time sows spend feeding at the HF location.

### 3.4 Discussion

Sow intake was not recorded in the present study and is inferred through observations of feeding behaviour in areas of the pen associated with high, reduced or no feed availability. The correlation between sow component scores for the factors labelled “Dominant feeding” and “Weight gain” offer support for this contention. In both gestations 1 and 2, the more time sows spent performing feeding behaviours in areas of the pen associated with high feed availability, and the less time in area of no feed availability, the more weight they gained. These relationships were stronger in the second gestation than in the first. Part 1 of the present research found that dominant sows spend the most time feeding under the feeder and submissive sows spend the most time preforming feeding behaviours on the slats. Brouns and Edwards (1994) also found that low ranking sows gained less weight when floor fed. However, when fed ad libitum there is no relationship between dominance and weight, even though low ranking sows spent less time feeding and were displaced from the feeder more frequently than high-ranking sows (Brouns and Edwards, 1994). When feed is not restricted, subordinate sows may be able to compensate for reduced feeding time by increasing their consumption rate (Lawrence et al., 1993; Brouns and Edwards, 1994), but this is not possible when sows are fed a diet restricted in space and time.
Part 1 of this research showed that sows that deliver little or no aggression (i.e., submissive sows) spend the most time avoiding the feeding area (i.e., “avoidance feeder” strategy, while middle ranking sows (i.e., subdominant sows) feed opportunistically around the area of high feed availability. The present study found that sows that adopted an “avoidance feeder” strategy gained less weight, but those that adopted an “opportunistic feeder” strategy experienced less stress, although they received more aggression in gestation 2. One interpretation of these results is that sows that fed opportunistically were more willing than avoidance feeders to risk receiving aggression from dominant conspecifics in order to gain access to feed.

Characteristics of the individual animal, such as where the animal lies on the continuum of fear and feeding motivation at a specific moment, may determine how much the animal is willing to risk to increase their opportunities to feed. It is likely that the quantitative dietary restrictions imposed on gestating sows means that all sows, independently of aggression classification/hierarchy position, experience feelings of hunger and are highly motivated to feed. Hunger is primarily aroused by internal cues but fear is primarily aroused by external stimuli (Hogan, 2005). When sows have to compete for access to feed, the motivation to minimise harm and avoid aggression is put in direct conflict with the motivation to approach the feeding area (Lawrence et al., 1993). In this case, the length of time an animal spends feeding is not a simple reflection of feeding tendency or motivation to feed, but also an indication of the strength of competing motivations (Lawrence et al., 1993). In other words, the tendency to approach dangerous or potentially dangerous stimuli (in this case, a feeding dominant conspecific) will be inhibited by fear or anxiety at a distance from the stimuli at which the motivation to avoid becomes stronger than the motivation to approach (Janczack, 2010). Hunger is one of the two (the second being thirst) most basic, primitive and unremitting of all motivating forces (Webster, 1995). Thus, the level of fear within the cohort of sows that adopted an avoidance feeder strategy, and the consequences of that fear on animal welfare, should not be underestimated. Part 1 of this research showed that sows that avoided the feeding area were nonetheless present for some time in the areas of high and reduced feed availability (albeit at lower levels to all other sows). However, this research raises ethical questions relating to the price, in terms of
fear, stress and injury, competitive feeding systems require submissive sows to pay in order to get access to food.

Many animal welfare problems related to feeding are multifactorial (see Koene, 2006). In the present study, submissive sows spent the most time avoiding the feeding area, and this research presumes that this is because they were fearful of receiving aggression. The experience of fear per se is assumed to be uncomfortable and therefore detrimental to welfare (Janczack, 2010), but there is no certainty in the stipulation that sows that avoided the feeding area experienced more hunger than other sows. The component score for the factor labelled “Stress” negatively correlated with time spend feeding in the area of reduced feed availability, rather than high or no feed availability. As reviewed by Verdon et al. (2015a) and Kyriazakis and Tolkamp (2011), however, plasma cortisol concentrations are not an appropriate physiological measure of stress associated with hunger. Koene (2006) hypothesised that animals suffer when they are not able to feed as they are designed to do. In some cases, behavioural or physiological indicators of distress are present when highly motivated behaviours (such as feeding) are prevented (Koene, 2006; Fraser, 2008). For instance, oral stereotypies likely reflect a frustrated motivation to feed and generally increase with the level of food restriction in pigs (see Kyriazakis and Tolkamp, 2011). When the environment does not allow for sows to respond to feelings of hunger in a natural way (e.g., foraging, rooting), then the development of stereotypies may be the best indicator of hunger (Fraser, 2008). Thus, an examination of the relationship between the prevalence of oral stereotypies and feeding behaviour may provide an indication of variation in sow hunger within groups.

Plasma cortisol concentrations increase in response to a range of aversive stimuli, and the psychological component of the stressor is the main determinant of the magnitude of the response (Kyriazakis and Tolkamp, 2011). Thus, sows that occupied or avoided the area of high feed availability may have higher cortisol concentrations than those that fed opportunistically, but for different reasons. While the former may be associated with the physical and emotional exertion involved in defending food, the latter may be associated with experience of fear of receiving aggression and frustration at not being able to feed. Indeed, while the
behavioural expression of fear includes the suppression of other behavioural systems and attempts to avoid, terminate or escape exposure to threatening stimuli, fear is also expressed physiologically via activation of the HPA-axis which is indicated by elevated plasma cortisol concentrations (Janczack, 2010). These results appear to contradict those presented by Verdon et al. (2016), who found subdominant sows to have higher stress than dominant, but not submissive, sows at day 2 of gestation 2. Although in this study submissive sows were observed on the slats more often than dominant and subdominant sows, they were also observed in the other feeding areas. The reverse is also true for dominant and subdominant sows. Thus, the analysis conducted by Verdon et al. (2016), which reported on the relationship between aggressive behaviour and stress, is not directly comparable to that conducted in the present research.

Despite the relationships between feeding behaviour and aggressive behaviour, stress and weight gain, there were no strong relationships between feeding behaviour and reproductive productivity either within or between gestations in the present study. When subjected to maternal undernutrition, the body prioritises maintenance of pregnancy and lactation over other bodily functions (Kyriazakis and Tolkamp, 2011). For example, even moderate undernutrition during pregnancy can have negative consequences for the immune system and long-term implications for off-spring health (see Kyriazakis and Tolkamp, 2011). However, previous research has found that underweight sows display more stereotypies, experience reproductive failure, and/or delayed return to oestrus, have lower embryo survival and are culled more frequently than sows of an appropriate weight (Virolainen et al., 2004; Courboulay, 2007; Hoving et al., 2011). There is also evidence that increasing the feed intake of pregnant sows may improve farrowing rate (Athorn et al., 2013; Sawyer et al., 2013). Turner et al. (1999) showed that some sows are more resistant than others are to the effects of cortisol on reproduction, while ovulation rate and litter size may, in part, be determined by genetics (Rothschild et al., 1996; Rathje et al., 1997). The number of piglets born alive in gestation 1 loaded positively onto the same factor as weight gain in gestation 1, and the number of stillborn piglets in gestation 2 loaded negatively onto the same factor as weight gain in gestation 2. However, these loadings were weak (0.34 and 0.40, respectively), and both variables loaded more strongly onto different factors. As such, larger animal numbers may be required to detect significant differences in a
measure such a reproduction, where significant individual variation is expected. An alternative explanation is that subordinate females were able to consume enough food to sustain reproduction, despite having fewer opportunities than dominant females to feed.
4. Outcomes

The main findings are:

1. Dominant sows spent the most time feeding in the location of the pen where the majority of feed was distributed. Subdominant sows spent more time feeding opportunistically, whereas submissive sows spent the most time avoiding aggression and consequently the feeding area.

2. Floor feeding sows multiple times per day did not increase the time submissive sows spent feeding in the later drops.

3. Sows that fed directly under the feed hopper spent less time showing feeding behaviour on the slatted area at the back of the pen, delivered more aggression, gained more weight and ended up heavier.

4. Sows that frequently fed on the cement floor where there was reduced feed availability had lower cortisol concentrations, but received more aggression.

5. There were no strong relationships between feeding behaviour and reproductive productivity either within or between gestations.

6. Submissive sows spent the most time avoiding the feeding area, presumably, because they were fearful of receiving aggression.

5. Application of Research

The interpretations from the main research findings are:

1. Dominant sows spent the most time feeding in the location of the pen where the majority of feed was distributed. Subdominant sows spent more time feeding opportunistically, whereas submissive sows spent the most time avoiding aggression and consequently the feeding area. In addition to the food restriction imposed on gestating sows, floor feeding systems place considerable spatio-temporal restrictions on the availability of feed. Consequently, the space that is available to pigs to feed, and regulate social interactions at feeding, is limited. This system forces low ranking sows to risk receiving aggression by feeding in close proximity to high ranking sows, or
alternatively avoiding feeding. While it is difficult to reduce temporal restrictions on food availability to floor-fed gestating sows, spatial restrictions may be minimised by increasing the spread of feed onto the ground (e.g., by increasing the number of feed hoppers per pen) thereby increasing accessibility for low ranking sows.

2. **Floor feeding sows multiple times per day did not increase the time submissive sows spent feeding in the later drops.** Although aggression declines over subsequent feed drops, dominant sows nonetheless monopolise the feeding area in each feed drop. Many questions remain regarding whether the high levels of competition and resulting variation in sow intake observed in floor-feeding systems are an inherent consequence of the feeding system itself, or can be minimised through effective management of feeding regimes in these systems. A multifactorial approach to reducing hunger in sows, that utilises dietary manipulations, methods to extending meal length and the provision of substrates that allow for the expression of appetitive behaviours, may be required. For example, restrictively feeding sows a low-fibre diet with supplemented *ad libitum* access to roughage or foraging materials may promote satiety. Another alternative is to feed a low energy diet in high quantities. Finally, reducing the time between feed drops may better promote satiety in sows, while increasing the number of feed droppers per pen may improve accessibility for subordinate sows.

3. **Sows that fed directly under the feed hopper spent less time showing feeding behaviour on the slatted area at the back of the pen, delivered more aggression, gained more weight and ended up heavier.**

Sow intake was not recorded in the present study and is inferred through observations of feeding behaviour in areas of the pen associated with high, reduced or no feed availability. The relationships between sow feeding behaviour and weight gain offer support for this presumption. When feed is not restricted, subordinate sows may be able to compensate for reduced feeding time by increasing their consumption rate, but this is not possible when sows are fed a diet restricted in space and time.
4. Sows that frequently fed on the cement floor where there was reduced feed availability had lower cortisol concentrations, but received more aggression. Sows that occupied or avoided the area of high feed availability may have higher cortisol concentrations than those that fed opportunistically for different reasons. The former being associated with the physical and emotional exertion involved in defending food, while the latter associated with experience of fear of receiving aggression and frustration at not being able to feed. These results appear to contradict those presented by Verdon et al. (2016), who found subdominant sows to have higher stress than dominant, but not submissive, sows at day 2 of gestation 2. Although in this study submissive sows were observed on the slats more often than dominant and subdominant sows, they were also observed in the other feeding areas. The reverse is also true for dominant and subdominant sows. Thus, the analysis conducted by Verdon et al. (2016), which reported on the relationship between aggressive behaviour and stress, is not directly comparable to that conducted in the present research.

5. There were no strong relationships between feeding behaviour and reproductive productivity either within or between gestations. In maternal undernutrition maintaining pregnancy and lactation may be prioritised over other bodily functions, such as maintaining the immune system (Kyriazakis and Tolkamp, 2011). However, previous research suggests that underweight sows display more stereotypies, experience reproductive failure, and/or delayed return to oestrus, have lower embryo survival and are culled more frequently than sows of an appropriate weight. On the other hand, there is evidence that increasing the feed intake of pregnant sows may improve farrowing rate. Some sows are more resistant than others are to the effects of cortisol on reproduction, while ovulation rate and litter size may, in part, be determined by genetics. Larger animal numbers may be required to detect significant differences in a measure such a reproduction, where significant individual variation is expected. An alternative explanation is that subordinate females were able to consume enough food to sustain reproduction, despite having fewer opportunities than dominant females to feed.
6. Submissive sows spent the most time avoiding the feeding area, presumably because they were fearful of receiving aggression.

When submissive sows have to compete for access to feed, the motivation to minimise harm and avoid aggression is put in direct conflict with the motivation to approach the feeding area. Hunger is one of the most basic, primitive and unremitting of all motivating forces. Thus, the level of fear within the cohort of sows that adopted an avoidance feeder strategy, and the consequences of that fear on animal welfare, should not be underestimated. However, these animals sustained an adequate level of intake to maintain pregnancy and some growth. While the experience of fear *per se* is assumed to be uncomfortable and therefore detrimental to welfare, there is no certainty in the stipulation that sows that avoided the feeding area experienced more hunger than other sows. An examination of the relationship between the prevalence of oral stereotypies, that likely reflect a frustrated motivation to feed, and feeding behaviour may provide the best indicator of variation in sow hunger. Ethical considerations relating to the price, in terms of fear, stress and injury, competitive feeding systems require submissive sows to pay in order to get access to food are required when feeding systems for group-housed are being implemented.

6. Conclusion

The data presented in this research indicates that sows consume the majority of feed within 10 minutes of delivery, when floor fed four times per day. However, sows will continue to show appetitive behaviours for at least another 10 minutes, suggesting they remain motivated to feed. Observations of the first 10 minutes after feed delivery is recommend when feeding behaviour is being used to generalise an understanding about sow intake.

Dominant sows spent the most time feeding in the location of the pen where the majority of feed was distributed, and delivered the most aggression in defence of this priority resource. Subdominant sows spent more time feeding opportunistically,
consuming what they could from between and around dominant females at the risk of receiving aggression. Submissive sows spent the most time avoiding aggression and consequently the feeding area. These relationships were true regardless of day and feeding bout.

Sows that fed directly under the feed hopper spent less time showing feeding behaviour on the slatted area at the back of the pen, delivered more aggression, gained more weight and ended up heavier. The relationships between feeding behaviour and sow welfare and productivity were stronger in the second gestation than they were for the first, possibly due to differences in the social experience of gilts and sows. There are some indications that sows with the highest intakes gain have larger litter sizes and higher farrowing rates, but more research with larger animal numbers is required to confirm this. Sows that frequently fed on the cement floor where there was reduced feed availability had lower cortisol concentrations, but received more aggression. Some subordinate sows (i.e., any sow that is not dominant) may be more willing to risk receiving aggression to maintain feed intake than others, and this could characterise the difference between the submissive and subdominant classifications. Ethical considerations relating to the price, in terms of fear, stress and injury, competitive feeding systems require submissive sows to pay in order to get access to food are required when feeding systems for group-housed are being designed.

Thus, the hypothesis that feeding sows over multiple drops creates more opportunities for subordinate sows to feed by increasing the satiety of dominant sows in the initial drops is rejected. Controlled comparisons of floor-feeding regimes are required to assess whether the high levels of competition and resulting variation in sow intake observed in floor-feeding systems are an inherent consequence of the feeding system itself, or can be minimised through effective management of feeding regimes in these systems. A multifactorial approach to reducing hunger in sows, that utilises dietary manipulations, methods to extending meal length and the provision of substrates that allow for the expression of appetitive behaviours, may be required.
7. Limitations/Risks

The main limitation when interpreting the results of this research is that assumptions have been made regarding the relationship between feeding behaviour, pen location and consumption. Secondly, these results may, or may not, be directly applicable to different floor-feeding management regimes (i.e., closely spaced feed drops, more or less frequent feed delivery, other interactions between feeding regime and pen design), and this requires investigation. Thirdly, sows that were out of view, drinking, or lying/standing without showing feeding behaviour were not recorded in the present research. Nonetheless, observations were made on 200 animals every 30 s over four feed drops per day, 3 days and 2 gestations, providing a sufficient estimation of sow feeding behaviour. Finally, care is required in interpreting the findings of this study because it was observational and correlational, rather than experimental and comparative, making causality difficult, if not impossible, to determine.

8. Recommendations

Current advice on feeding regimes for floor fed gestating sows is largely based on speculation rather than scientific evidence. This makes it difficult to conclude that it floor-feeding system per se results in high levels of aggression and variation in sow intake, rather than the management of the floor-feeding regime. Further research into the management of floor-feeding systems are required so that advice can be provided to pork producers on the appropriate regime to reduce variation in sow intake, and improve sow welfare and productivity. In particular, the following research is recommended:

1. A controlled experiment, with increased animal numbers, that examines the effects of single versus multiple feed drops per day on the frequency of aggression delivered and received by individual sows, as well as the time sows spend feeding and reproductive performance (litter size, farrowing rate).
2. This study highlights the importance of research into the promotion and/or prolonging of satiety in group-housed sows, particularly for those that are low ranking. A multifactorial approach to reducing hunger in sows, that utilises dietary manipulations, methods to extending meal length and the provision of substrates that allow for the expression of appetitive behaviours, is required.
9. References


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