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Trough half empty – pregnant sows are fed under half of their *ad libitum* intake

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Abstract

Pregnant (dry) sows are fed a rationed amount of feed to maintain healthy weight and production but this does not satisfy their hunger. This study measured the extent of feed restriction compared to sows' desired intake. Forty-seven Large White x Landrace sows were housed in small groups with straw bedding and individual feeding stalls. Following three days on a standard ration of 2.5 kg, they were offered 10 kg a day of commercial dry sow feed for three days, split into four 2.5 kg meals a day which enabled individual intakes to be measured. This quantity was effectively *ad libitum* (maximum daily intake 9.4 kg). Mean (± s.e.) intake per day over the three *ad libitum* days was 5.67 (± 0.24) kg, compared to the 2.5 kg standard ration. The ration thus provides less than half (44.1%) of sows' desired intake. Behaviour on their third rationed day was compared with behaviour on the third day of *ad libitum.* Eating rate and the display of hunger-related behaviours, particularly following the morning feed, was greater under ration feeding; sows spent more time in the food stall and less in the straw bed, and more time active rather than resting. During ration-feeding sows also chewed and nosed more at straw bedding and pen equipment and used the drinker more after their morning meal than when they were fed *ad libitum*. Eating rate on the last rationed day was positively correlated with feed intake on each of the *ad libitum* days. Despite an EU requirement for fibre to be added to diets to ameliorate this problem, and the provision of straw bedding, hunger resulting from food restriction remains a welfare concern for dry sows.

Keywords: Animal welfare, behaviour, eating, hunger, quantitative restriction, sows.

Short title: Quantifying feed restriction in dry sows

Introduction

Breeding sows (*Sus scrofa*) are feed restricted during pregnancy (Lawrence et al 1988; Meunier-Salaün et al 2001; D'Eath et al 2009, 2018). Becoming overly fat during gestation can negatively affect the sow's physical health and cause locomotory problems. Gestation diets are formulated and rationed to meet the nutritional needs of the sow and her growing piglets, with adjustments to diets/ration allocation based on factors including parity, body condition and stage of pregnancy (Ball et al 2008). Rationing thus maintains good sow health and piglet production (de Leeuw et al 2008). However, since diet formulations are typically relatively nutrient and energy dense, the food quantity provided is not enough to satiate the sow, resulting in behavioural and physiological signs of hunger (Meunier-Salaün et al 2001; D'Eath et al 2009, 2018).

Pregnant sow rations are generally provided daily as 2-3 kg of concentrate food in one meal (or sometimes two meals) that is rapidly consumed in around 20 minutes (Petherick & Blackshaw 1989; Terlouw et al 1991; Meunier-Salaün et al 2001). This does not allow for the expression of normal appetitive or consummatory eating behaviours and does not satiate the sow, leading to behavioural stereotypies that reflect hunger and unfulfilled motivation to eat (Meunier-Salaün & Bolhuis 2015). Sows under quantitative feed restriction display more activity, more foraging and more redirected oral behaviours, including manipulation of pen equipment and substrate, sham chewing, teeth grinding and an increase in drinking (Appleby & Lawrence 1987; Terlouw et al. 1991; De Leeuw & Ekkel 2004; D'Eath et al. 2009, 2018). Group relationships seem also to be affected; Marchant et al. (1995) identified inter-sow aggression as a major welfare concern in group gestation housing that can also reduce productivity, and attributed its prevalence to feed restriction in addition to mixing of sow groups.

One starting point for quantifying the extent of hunger in dry sows is to identify the mismatch between the quantity of feed provided in a standard ration and the sow's desired *ad libitum* intake of the same type of feed. Whittemore et al (1977) mentioned that sows would eat three times their ration, and this was supported a decade later by Petherick and Blackshaw (1989), who found that sows fed *ad libitum* during early pregnancy in their study ate 6.1 kg compared to a rationed amount of 2 kg (suggesting their ration restricted them to 33% of *ad libitum*). The work of Lawrence et al (1988), using boars as a model for sows to avoid the issue of pregnancy is frequently cited (e.g. De Leeuw et al 2008; D'Eath et al 2009; Meunier-Salaun & Bolhuis 2015). A diet was formulated and then rationed to provide 1.3 times the calculated maintenance requirements (as recommended for pregnant sows) was found to be 60% of *ad libitum*. As sows have a slightly lower maintenance requirement than boars, Lawrence et al estimated that their ration was at around 70% of *ad libitum*. These estimates, that a commercial ration provides between 33% and 70% of the desired *ad libitum* intake, are both variable and 30 years old.

Through intensive breeding programmes the modern domestic sow has changed considerably over the last 30 years, being 50% heavier (Moustsen et al 2011) and producing litter sizes that have increased by as much as 45% in some countries (e.g. Denmark: 11.2 born alive in 1996 compared to 16.3 in 2016; Danish Pig Research Centre and SEGES Annual Reports 1999 and 2017). At the same time the genetic growth potential of piglets/growing/finishing pigs has increased (Ball et al 2008), with a knock-on effect for the growth potential of the adult sows. This mismatch between potential and actual growth contributes to the need to feed restrict adult sows, a problem which has also been recognized in broiler chickens and their parents (Cooper & Wrathall 2010; Dawkins & Layton 2012). This genetic selection for increased production and reproduction has impacted on the sows' metabolic energy demands. Resting metabolic rate has been shown, in humans, to correlate with hunger levels (Caudwell et al 2013).

This study aimed 1) To provide an estimate of the extent of feed restriction of modern commercial sows during gestation by measuring their *ad libitum* food intake over a three-day period. To facilitate the recording of individual intakes in a group-housing situation, we offered sows four times their usual ration over four separate meals, as a proxy for true *ad libitum* feeding. 2) To characterise behavioural differences between sows when they were ration fed or *ad libitum* fed.

Methods

Ethical considerations

The experiment underwent ethical review and was approved by SRUC's Animal Experiments Committee.

Experimental animals

Sows were sourced from and tested at Scotland's Rural College (SRUC) Research Pig Unit near Edinburgh, UK. The herd has high health-status, and the pigs were housed in enriched indoor environments. Fourteen groups (n = 47) of Large White/Landrace dry sows in five batches participated in the study over a five-week period. Sows were tested in the same groups they are housed in for gestation to avoid social disruption, and had contact with sows in other groups through gate bars. Gestation groups ranged in size from one to six sows (mean ± s.d. = 3.4 ± 1.4). Sows in the earliest (< 30 days post-insemination) and latest (< 18 days pre-farrowing) stages of pregnancy were excluded from the study to avoid potential stress at these particularly sensitive times. Twenty-one sows tested were in the 'early' stage of pregnancy (days 31 - 52), 16 in the 'mid' stage (days 60 - 81), and 10 in the 'late' stage (days 88 - 95). Batches were identified to represent a range of parities (parity 1 n = 10; parity 2 n = 9; parity 3 n = 4; parity 4 n = 0; parity 5 n = 6; parity 6 n = 7; parity 7 n = 5; parity 8 n = 3; parity 9 n = 3). Mean (± s.d.) weight at the start of the study was 259.7 ± 58.7 kg, ranging from 167 kg to 372 kg.

Housing

The experiment took place in a roofed but unheated room (11.5 m × 7.9 m) containing three pens (6.7 m long and either 3.8 m or 4.0 m wide), each designed for 6 dry sows (Figure 1). The room was naturally ventilated with airflow passage enabled by a series of vertical openings in two walls. Data collection took place between 24th July and 25th August 2017, when the mean (± s.d.) maximum 24 hour temperature in the room was 19.3 ± 1.3 °C and the mean minimum was 13.6 ± 1.2 °C. Each pen had a straw-bedded area (2.5 m long), surrounded by blockwork walls 1.35 m high and 0.21 m thick, the rear portion (1.23 m) of which was covered by a wooden roof made from plywood sheeting 15 mm thick, positioned 1.45 m above the floor. Each pen also had a dunging passage which was down a step making it 0.15 m lower than the rest of the pen (2.35 m long, equipped with 2 nipple drinkers), and 6 individual feeding stalls (1.85 m long, 0.5 m wide).

Timeline

Following farm standard practices, sows were fed a single allocation of their respective daily ration at 0715h on a daily basis. For this experiment, selected sows were allowed their normal feed allowance on the Friday, then at approximately 1100h they were weighed individually in a weigh crate, condition scored and herded from their original pens in the dry sow house to the experimental room. Condition scoring was conducted according to a 1-5 scale from Emaciated to Over fat, where 3 is considered normal (Muirhead & Alexander 1997, Carr 1998). Once sows were in their experimental pens, feed stalls were opened and sows were left to acclimatise to the experimental room over the weekend, where they were fed their normal ration from pre-weighed plastic bags at 0800h each day by farm staff, and health-checked. On Monday, sows received their normal ration at 0800h as per the weekend (2.5 kg for all but three older, larger sows who were on 3 kg). On Tuesday to Thursday sows were offered their ration of 2.5 kg at 0800h, 1000h, 1230h and 1500h (total offered = 10 kg over 4 meals). These three additional meals were provided as a proxy for *ad libitum* feeding (food constantly available to consume as and when desired). The period of *ad libitum* feeding was constrained to three days to avoid health problems associated with adiposity and weight gain that may arise from long-term *ad libitum* feeding throughout pregnancy. Prolonged *ad libitum* feeding may also have increased their appetites beyond that of standard commercial rationed sows. On Friday the sows were given their normal feed ration at 0800h, and were weighed, condition scored and moved back to the dry sow house at approximately 1030h. The next batch of sows was then weighed and moved to the experimental room to start the trial.

Feeding

The composition of food, for example its energy density and fibre content affect the quantity that sows will consume (Brouns et al 1995; D'Eath et al 2018). In this study, sows were fed on their usual diet which was a standard pelleted dry sow diet sourced from a major animal feed manufacturer (Premier sow nuts + toxoguard, Harbro Ltd, Aberdeenshire, UK). It constituted the following (g/kg): Barley (ground) 400, Wheat (ground) 300, Wheatfeed (bulk) 164, Soya (bean) meal 40, Extracted rape seed meal 35, Sugar cane molasses 30, Calcium carbonate 14, Vegetable fat 5, Monocalcium phosphate 3, sodium chloride 3, toxoguard 1 , l-lysine 0.4.

A sample of feed was analysed at SRUC's laboratories (https://www.sruc.ac.uk/info/120148/analytical_services/649/animal_feed_testing). Analytical constituents are as follows: Dry matter 859 g/kg, all others are expressed as g/kg of dry matter. Ash 63.2, Crude protein 172, Crude fat (Acid Hydrolysed Ether Extract) 37.9, Starch 371, Sugar 33, Calcium 11.6, Phosphate 6.2. Three estimates of Fibre content were obtained: Crude Fibre 50.6, Neutral Detergent Fibre 206 and Acid Detergent Fibre 82.6. Additional analysis reported by the feed manufacturer : Lysine 0.58%, Methionine 0.25%; Minerals: Sodium 0.1%, Calcium 0.95%, Phosphorus 0.65%, Copper 22.7 mg/kg and Selenium 0.4 mg/kg.

Eating was monitored, and bullying and stealing attempts blocked by shutting the offending sow out of the feeder they were attempting to access. Where possible, sows were not shut in for the duration of their meal, so as not to influence their intake, but feeders were closed after sows had finished and left. When a sow left the feeder prematurely due to a distraction or a bully, she could return if she was nosing repetitively at the feeder gate. On *ad libitum* days, at each of the 4 scheduled meals, food was added to the food troughs with feeder gates open, and sows were allowed to enter the feeders. Often, not all sows entered the feeders. Considerable latency to begin eating was common, so sows were allowed considerable time to begin feeding. The feeder gates were closed as each sow left her feeder, until all of the sows which had visited a feeder for that meal had finished eating. Sows which had not yet fed could enter their feeder up until the moment where all the sows which had already eaten during that meal had finished and their feeders had been closed. After that moment those sows which had not yet fed were considered to have missed that meal. In practice, those sows did not attempt to gain access after this moment (while refusals were being collected and weighed). Refusals were removed from troughs using a vacuum cleaner and weighed after each meal.

Behaviour observations

Digital "Gamet Professional" Sony effio bullet cameras (Gamut, Open 24 seven Ltd, Bristol, UK) were installed in front of the feeding stalls and above each pen from the ceiling using Manfrotto adjustable bracket arms and clamps (Manfrotto UK Ltd, Leicestershire, UK). Video footage from these cameras was recorded and analysed using GeoVision software (GeoVisionUK, Herts, UK) on a PC.

Eating time was determined from video recordings of the feed stalls. Eating was deemed to start as the sow moved her nose in to the trough and started to eat. The end of eating was signalled by the researcher on the feed stall when the sow had eaten the last of the pellets. When refusals were left, eating time was deemed over when the sow had exited the feeder and turned her head. Eating rate was calculated as kilograms consumed per minute, and measured Monday through to Thursday to observe the change over the course of the week.

Video recordings for the third rationed day (Monday) and the third *ad libitum* day (Thursday) were utilized to collect animal location, posture, and behaviour for each sow (using the ethogram in Table 1), allowing for a standard acclimation period for the statistical comparison of rationed and *ad libitum* treatments. Behavioural observations were made by scan interval sampling at five-minute intervals over 30 minutes, at four times of day (pre-feed, post-feed, 0930 - 1000h and 1430 - 1500h; 28 scans on each observation day). Experimental personnel were not present during video recordings to avoid disturbing the animals. Pre-feed was defined as the thirty minutes before the researcher disturbed the sows for their morning feed. Post-feed was defined as the thirty minutes after the researcher had left the room following the morning feed. The ceiling positioned camera was used for these observations, which meant that sows could be 'out of sight' in the covered portion at the rear of the straw-bedded lying area. Scan sampling was used due to time constraints (the first author's stipend covered a fixed period), but is useful to identify the main patterns of behaviour. A more detailed behavioural study of sow oral behaviour around feeding using the videos collected has since been carried out and is in preparation for publication.

Statistical analyses

Genstat 16th Edition (VSN International 2015) was used. Estimated means ± standard error (s.e.) from modelling rather than raw data means are reported throughout. A one-sample t-test was used to test for a change in weight and one sample Wilcoxon test was used to test for a change in condition score of sows (change was calculated first, then the column of differences was used for the one-sample test, so in effect these were paired tests). Effects of parity and pregnancy stage on sow weight, body condition score and changes in these following *ad libitum* feeding were tested using Linear Mixed Models (Genstat REML). The three sows in the study whose standard ration was 3kg were excluded from these analyses, but included in analysis of behavioural observations. Using the three days of *ad libitum* data only, the effect of day and meal on feed intake and eating rate at each meal was modelled using Linear Mixed Models with Day, Meal and Day*Meal as fixed effects, and Batch/((Pen/Sow_ID)*(Day/Meal)) as the random effect. In Genstat, the / symbol indicates nesting, so Meal was nested within Day, and Sow ID nested within Pen, while the interaction of these was nested within batch. Parity and Stage of Pregnancy (early, mid or late) were also added to Day and Meal as fixed effects in separate models, but were left out of the main results reported as they had no significant effect. The eating rate on the last rationed day (Monday) and the last *ad libitum* day (Thursday) were compared using Linear Mixed Models, and correlations (Pearson's) between eating rate on the last rationed day and subsequent total feed intake for each *ad libitum* feeding day were estimated. Behavioural data (also from those two days) were analysed by treating the presence or absence of each behaviour at each of the 5 minute scans within the four 30 minute observation times as 1/0 data, and analysing this with Generalized mixed models (GLMM), fitting a binomial function with logit transformation, and with feeding treatment*time and parity as main effects and Batch/Pen/Sow ID as the random effects (i.e. Sow ID was nested within pen, and Pen was nested within Batch). Time in this model refers to the four observations times: pre-feed, post-feed, 0930 – 1000h and 1430 – 1500h and is referred to as the effect of 'time' or 'observation time' throughout the results and later discussion. Related behaviours were grouped where necessary to run the models. Post-hoc Least Significant Differences (LSD) are reported to explain the direction of effect. LSD tests are based on logit transformed data, but data shown in table 2 were back-transformed to the original scale (proportions of scan observations at which this behaviour occurred ranging from 0-1), and then multiplied by 100 and presented as percentages for ease of interpretation.

Results

Sow weight and body condition score

Later parity sows were heavier than younger sows ($F_{7,35} = 42.02$, $p < 0.001$; e.g. Parity 1 mean ± s.e. = 227.1 ± 10.6 kg; Parity 9+ 311.8 ± 13.0 kg), and later pregnancy sows were heavier than sows in early pregnancy ($F_{2,37} = 12.59$, $p < 0.001$; Early 236.6 ± 9.2, Mid 291.3 ± 5.9 and Late 304.4 ± 7.8). There were significant effects of stage of pregnancy and parity on condition score on entry to the experiment. Late pregnant sows had higher body condition scores ($F_{2,37} = 6.20$, $p < 0.005$; Early 2.9 ± 0.2, Mid 3.6 ± 0.1, Late 4.0 ± 0.2). The effect of parity was significant ($F_{7,37} = 2.42$, $p = 0.038$), but not systematic, with the highest and lowest BCS occurring in parity 8 and 7 respectively. Three days of *ad libitum* feeding significantly increased sow weight by 7.9 ± 4.9 kg (mean ± s.d.; one-sample $t_{48} = 11.18$, $p < 0.001$). Body condition scores (BCS) were also more likely to have slightly increased for some sows (median 3.5 before, median 3.5 after; 29 sows remained the same, 14 had increased BCS while 4 reduced; $W_{18} = 43.0$, $p < 0.030$).

Ad libitum feed intake and eating rate

On the *ad libitum* diet sows consumed 1.42 ± 0.99 kg (mean ± s.d.) of feed at each of the 12 meals they were offered over the three *ad libitum* days, or 5.67 (± 0.24) kg per day. Their standard ration (2.5 kg) is 44.1% of this amount. Focussing on the third day only, sows consumed 1.31 ± 0.94 kg in each of 4 meals, totalling 5.22 (± 1.48) kg. The standard ration is 47.9% of this, resulting in a similar estimate of the extent of restriction. Only seven sows ate all of the food they were offered (10 kg) on the first day, one did on the second day and none on the third day, suggesting that our approach achieved a fair estimate of unrestricted intake for almost all of the sows. As indicated by the standard deviations, there was considerable variation between sows in food consumption. A total of 30 kg was offered over the three days, but total feed intake ranged from 10.6 to 28.2 kg.

Feed intake over the three *ad libitum* days showed significant effects of day ($F_{2,6.9} = 233.02$, $p < 0.001$), meal ($F_{3,35.9} = 30.13$, $p < 0.001$) and a day*meal interaction ($F_{6,35.9} = 4.61$, $p = 0.001$; Figure 2). LSD tests showed that all 3 days were different, and that sows ate the most on the first day (binge), followed by a lower intake on the second day (recover), with an intermediate level of intake on the third day (stabilise). Within days, there was generally a decline in intake over meals. LSD tests showed that on the first day on *ad libitum*, feed intake was lower in the last meal than in the other three, while on the second day the third meal was smaller than the first two, and on the third day the last two meals were smaller than the first two.

Eating rate was greater on the first *ad libitum* day than the second and third days ($F_{2,7.9} = 14.56$, $p = 0.002$; Figure 3; LSD $p < 0.05$), and also declined over meals ($F_{3,34.1} = 18.63$, $p < 0.001$), except on the second day (day*meal interaction $F_{6,36.4} = 3.49$, $p = 0.008$; Figure 2). LSD tests showed that feeding rate declined by the last meal compared to the previous three on the first day and compared to the first two meals on the third day. Adding parity or stage of pregnancy to these models of intake or eating rate revealed no significant effects.

Eating rate was greater on the observed rationed day (Monday; 0.137 ± 0.07 kg/min) than on the last *ad libitum* day (Meal 1, Thursday; 0.117 ± 0.07 kg/min; $F_{1,45} = 45.4$, $p < 0.001$). Finally, eating rate on the observed rationed day (Monday) showed a moderately positive correlation with the total feed intake on all of the *ad libitum* days (First *ad libitum* day $r = 0.48$, $p < 0.001$; Second $r = 0.37$, $p = 0.010$; Third $r = 0.37$, $p = 0.011$). Feed intake and eating rate are both potential indicators of hunger/eating motivation, so we would expect them to be broadly in agreement.

Behaviour – location

Sows were observed to occupy the space within the pen differently when they were ration fed vs having ad libitum access. Feeding treatment was a significant main effect for the number of observations at all locations (Table 2; Figure 4). There were also significant effects of time and of time*treatment interactions. During *Ad libitum* feeding sows spent the majority of their time in the straw-covered bedding area, being observed there a mean of 84 – 84.5% of the time, which was significantly more than during rationing at all four observation times. During ration feeding, sows still spent the majority of their time in the bedding area, but were observed in the food stall significantly more (pre-feed, post-feed and 0930 - 1000h) and adjacent dunging area significantly more (pre-feed, post-feed and 1430 – 1500h) than when they were *ad libitum* fed. Observations of rationed sows in the food stall and dunging area significantly declined over the day, as they significantly increased their time in the straw-covered bedding area (Table 2).

Behaviour – posture

Treatment, time and the interaction of treatment and time were significant for all body postures (Table 2; Figure 5). During ration feeding, the sows spent most of their time in the morning being active (standing and walking for 43-75% of the time). They stood significantly more than during *ad libitum* feeding at all three morning observations, and walked significantly more during the pre and post-feed observation. During ration feeding, sows lay laterally more during the afternoon (1430 – 1500h) observation than *ad libitum* sows did at that time. Generally though, *Ad libitum* feeding resulted in a considerable reduction in activity, with sows spending under 15% of their time standing and walking, and predominantly lying down (lying lateral was significantly greater during morning observation periods when sows were *ad libitum* compared to when they were ration fed). The proportion of time spent in different postures by sows during *Ad libitum* feeding also showed less variation across the four observation times (as shown by the superscripted letters in Table 2 which show fewer posture differences with time of day).

Behaviour – drinking, oral and nasal behaviours

Treatment and time were significant for many of the behaviours although there were fewer significant time by treatment interactions (Table 2; Figure 6). Ration fed sows showed a significant increase in chewing and nosing behaviours after feeding which continued into the next observation time at 0930-1000h, but had declined by the afternoon (1430 – 1500h). They were not observed to drink pre-feeding, but used the drinkers post-feeding, and drank significantly more post-feed and at 0930 - 1000h than during those times on *ad libitum* feeding. *Ad libitum* sows drank more evenly over the four observation times. *Ad libitum* feeding resulted in much lower levels of chewing and nosing behaviours, and use of the drinkers was more evenly spread over the day.

Parity and Stage of pregnancy generally had no effect on posture, location or behaviour, so were removed from the models in the results reported above. There were some exceptions to this: when parity was added into the model, it had a significant effect on the proportion of observations of walking ($F_{7,27}$ = 2.48; p = 0.042; Estimated back-transformed means parity 1 = 26.9%; 2 = 35.0%; 3 = 1.2%; 5 = 1.0%; 6 = 0.6%, 7 = 1.2%, 8 = 1.6%, 9 = 0.8%). From these estimated means it is evident that sows of parity 1 and 2 walked considerably more than older sows. When pregnancy stage was added to models, it also had a significant effect on the proportion of observations of walking, with early pregnant sows walking more ($F_{2,74}$ = 5.47, p = 0.006; Estimated back-transformed means early = 27.6%, mid = 11.3%, late = 10.9%) and on lateral lying ($F_{2,8}$ = 5.67, p = 0.030; early = 1.2%, mid = 2.1%, late = 0.2%).

Discussion

Feed intake

On average the sows consumed 5.67 kg/day of food over the three days of the study, or 5.22 kg/day on the last study day when presented with excess. As the standard commercial ration of dry sows is 2.5 kg, sows were found to be on average restricted to less than half (44-48%) of their desired food intake. This figure demonstrates that the current level of restriction (ration as a % of *ad libitum*) lies between the 70% figure of Lawrence et al (1988) and the 33% figure of Petherick and Blackshaw (1989).

There was considerable variation in intake during the *ad libitum* period, which highlights the welfare implications of providing a blanket diet for every sow, since some seem to have greater appetites than others. We do not know the cause of this inter-individual variation, and this presents a complication for the formulation of diets and ration quantities sufficient to satiate sows.

Behavioural changes

On their restricted diet, sows ate 2.5 kg at a rate of 0.137 kg/min, totalling their average meal time at 18 minutes. With *ad libitum* feeding, consumption rate dropped to 0.117 kg/minute, sows spending an average of 52 minutes eating over the day. It is possible that this had a positive impact on the way to fulfilling motivation to eat (D'Eath et al 2009).

Our behavioural results show that when sows were released from restriction and given *ad libitum* food they spent more time in the bedding area, less time in the food stalls, more time lying laterally and ventrally, less time standing and walking, and drank more evenly over the day rather than mainly after the morning meal. These behavioural changes are in agreement with research detailing the behavioural indicators of hunger in sows (Terlouw et al 1991; de Leeuw & Ekkel 2004; D'Eath et al 2009). In particular, greater levels of activity are a well known behavioural response to feed restriction across a range of species, so the reduction in standing and walking seen with *ad libitum* feeding here is consistent with that.

Another well known behavioural response to food restriction is increased foraging (and re-directed foraging). The observed significant reduction in sows chewing straw, chewing nothing distinguishable, and nosing straw, floor and equipment following the release of restriction is in agreement with reports that quantitative restriction results in an increase in foraging or re-directed foraging oral or nasal behaviours in sows (Appleby & Lawrence 1987, De Leeuw & Ekkel 2004; Bergström 2011). Chewing straw was not eradicated under the *ad libitum* diet, as there seems to be an inherent exploratory component to the expression of this behaviour. Due to time constraints, scan sampling was used to quantify behaviour. The fine detail of oral behaviours at the feeder immediately pre- and post- the morning meal is currently being investigated in greater detail. Although this was not quantified as part of the behavioural observations, ration fed sows were sometimes seen bellowing or screaming, salivating and pawing at the trough pre-meal time, and anecdotally these behaviours appeared to be less prevalent under *ad libitum* feeding.

Methodological limitations

Ad libitum feed intake is a simple quantitative measure of the extent of hunger in food restricted sows. It is only one possible measure though, having a number of shortcomings, and results should be interpreted alongside additional behavioural and physiological measures which are complementary (Miller et al 1955; D'Eath et al 2009). For example, operant tests of motivation to eat (e.g. Souza da Silva et al 2013, reviewed in D'Eath et al 2018), compensatory feeding, willingness to consume food of differing energy density (Bergström 2011), changes in endocrine and neuroendocrine indicators of food consumption/energy state (e.g. Ghrelin, Insulin; Jensen et al 2015). One disadvantage of our approach is the risk of a rebound effect, where sows initially over-eat in response to *ad libitum* food. By providing *ad libitum* food for three days, we saw a fall in intake from day 1 to 2, and a rise to intermediate levels (Figure 2), suggesting a pattern of binge, recover, stabilise. For that reason we present two estimates of restriction: based on overall *ad libitum* intake over 3 days, or on day 3 only.

Another alternative measure of hunger is eating rate, and it was interesting that we found an association between eating rate on the last rationed day, and food consumption on each of the *ad libitum* days, suggesting these measures of hunger / eating motivation are broadly in agreement here. Eating rate can vary between individuals, with the level of competition, feeding schedule that the animals are used to, or with the type of food (D'Eath et al 2009). However, individual differences between sows in their natural eating rate cannot explain the association we found, since fast- and slow-eating sows could logically have eaten similar amounts under *ad libitum* conditions.

Animal Welfare Implications

Sows were provided with a standard commercial dry sow ration from a major UK feed supplier. Our results show that when dry sows are restricted to the recommended amount of this food, they receive just under half their desired (*ad libitum*) intake. *Ad libitum* feeding also resulted in a reduction in activity and foraging behaviours particularly following the morning feed, which may be an indicator that sows have greater satiety and a reduction in signs or behavioural indicators of hunger.

However, *ad libitum* feeding over a prolonged period would not lead to a good welfare outcome for these sows either. Dawkins (2008) argued that good welfare means that animals should be healthy and have what they want. Results of the present study suggest that dry sows cannot have both. Elsewhere (D'Eath et al 2018) we have argued that there is evidence that using dietary fibre, and in particular soluble and fermentable fibres, may lead to satiety benefits for dry sows. EU regulations (Council Directive 2008/120/EC) require that "Member States shall ensure that all dry pregnant sows and gilts, in order to satisfy their hunger and given the need to chew, are given a sufficient quantity of bulky or high-fibre food as well as high-energy food". However, EU regulations do not specify the type and quantity of fibre to be provided, meaning that in the UK at least, the provision of (insoluble fibre) straw bedding in some farms is often perceived as sufficient to satisfy this requirement. Many sows are kept in slattedfloor systems where straw bedding is not provided, which means that low levels of (mainly insoluble) fibre in their diet is their only source of fibre, and the regulation applies equally to them.

We also found considerable variability in the *ad libitum* intake of the sows in our study, suggesting that a 'one size fits all' ration is likely to affect the welfare of different sows differently. More attention to the known differences in energy and nutritional requirements due to sows' age, weight, parity, stage of pregnancy and/or expected litter size could improve the allocation of appropriate diets and rations (particularly in electronic sow feeder systems which facilitate individual sow feeding). However, there may still be individual differences in the experience of hunger and welfare which result from variation in metabolism and personality.

It is hoped that this report highlights the welfare challenge that still face breeding sows after decades of research, and the need for feed companies and the pig industry as a whole to take seriously their obligation under UK and EU law (Council Directive 2008/120/EC) to provide diets that can satisfy the hunger experienced by pregnant sows, while also avoiding the negative welfare consequences of over-feeding.

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Table 1. Ethogram of sow behaviours. Location, posture and behaviour were scan sampled and recorded for each sow at five-minute intervals for two hours over the course of the last ration-fed day (Monday) and third *ad lib* fed day (Thursday). *Sitting was rare so was combined with lying ventral for analysis. †Nosing straw, floor and equipment were combined as 'All nosing' for some analyses. **Chewing straw, equipment and 'Chewing' were combined as 'All Chewing' for some analyses.

Category	***Name***	***Description***
Location	Bedding area	Location categories defined by where the sow's head was.
	Dunging area	
	Food stall	
	Out of sight	Sow's location is not visible
Posture	Walking	Locomotion with limbs in both extension and flexion.
	Standing	All four hooves are on the ground with limbs extended.
	Sitting*	Sow is in an upright position, with fore legs straight and back legs bent such that her weight is supported on the hindquarters.
	Lying ventral*	Sow lying resting on sternum with head raised or rested.
	Lying lateral	Sow lying on either side with her shoulder on the floor.
	Out of sight	Posture cannot be determined because the sow is partly or completely out of sight.
Behaviour	Drinking	Sow holding the water-dispensing nipple in her mouth
	Nosing straw†	Snout in contact with or moving straw.
	Nosing floor†	Snout in contact with floor or moving faeces covering the floor.
	Nosing equipment†	Snout in contact with or manipulating pen bars or feeding trough.
	Chewing straw**	Chewing movements made whilst straw is in the sow's mouth.
	Chewing equipment**	Chewing movements made with pen bars or feeding trough in the sow's mouth.
	Chewing**	Sow chewing on nothing distinguishable.
	Still	Sow not chewing, nosing or drinking.

Table 2. Percentage of time spent by sows in each location, posture and behaviour by feeding treatment (Rationed or *Ad libitum*) and time of observation (pre-feed, post feed, 0930-1000h, 1430-1500h). Data are back-transformed estimated means from GLMM analysis with binary data (modelled as each behaviour occurring or not at each scan sample observation point, then logit transformed). F statistics and p values are given for time and treatment main effects, and the interaction of treatment and time. Of the behaviours listed in Table 1, Chewing equipment was too rare to analyse. Post hoc LSD tests were used to determine where differences lie between groups. Differences between time periods in behaviour for sows during rationed feed are indicated by superscripted capital letters, for sows during *ad libitum* feeding with superscripted lower case letters. Time periods which share a letter do not differ in that behaviour at $p < 0.05$, and an asterisk indicates that there was a difference between rationed and *ad libitum* at that time point.

		Rationed				*Ad Lib*				Treatment		Time		Interaction	
	Code	Pre feed	Post feed	0930-1000h	1430-1500h	Pre feed	Post feed	0930-1000h	1430-1500h	F	*P*	F	*P*	F	*P*
Location	Bedding area	47.2*^{A}	62.9*^{B}	76.2*^{C}	92.9*^{D}	84.0^{a}	84.0^{a}	84.0^{a}	84.5^{a}	87.5	<0.001	25.1	<0.001	26.2	<0.001
	Dunging area	30.0*^{A}	21.6*^{B}	12.7^{C}	5.9*^{D}	10.5^{ab}	8.3^{a}	9.9^{a}	15.0^{b}	33.5	<0.001	8.5	<0.001	19.6	<0.001
	Food stall	15.9*^{A}	10.4*^{B}	7.7*^{B}	0.9^{C}	3.7^{a}	5.5^{a}	4.1^{a}	0.5^{b}	41.3	<0.001	22.1	<0.001	2.6	0.048
Posture	Walking	6.4*^{A}	5.5*^{A}	2.2^{B}	0.3^{C}	1.4^{a}	1.4^{a}	1.1^{a}	1.4^{a}	24.1	<0.001	2.7	0.035	2.7	0.038
	Standing	51.2*^{A}	70.7*^{B}	42.9*^{A}	5.6^{C}	8.1^{a}	12.2^{ab}	14.4^{b}	8.3^{a}	257.6	<0.001	39.0	<0.001	30.2	<0.001
	Lying ventrally or sitting	34.1*^{A}	20.3*^{B}	35.4^{A}	22.8*^{B}	44.0^{a}	43.7^{a}	34.1^{b}	31.8^{b}	27.8	<0.001	7.0	0.001	7.8	<0.001
	Lying laterally	3.1*^{A}	0.8*^{B}	13.3*^{C}	62.7*^{D}	40.1^{a}	26.9^{b}	38.5^{a}	49.7^{c}	8.1	0.004	67.5	<0.001	57.9	<0.001
Behaviour	Drinking	0.0^{AB}	4.2*^{B}	4.8*^{B}	0.2*^{A}	1.2^{ab}	0.3^{b}	1.8^{ab}	2.4^{a}	12.4	<0.001	0.46	0.711	4.7	0.003
	All Nosing	11.3*^{A}	35.4*^{B}	25.2*^{C}	3.3^{D}	3.6^{b}	6.5^{ab}	8.2^{a}	4.1^{b}	123.7	<0.001	30.9	<0.001	8.4	<0.001
	Nosing straw	6.0*^{A}	26.2*^{B}	19.7*^{C}	2.5^{D}	0.5^{a}	5.4^{b}	5.7^{b}	1.8^{a}	85.3	<0.001	34.9	<0.001	3.1	0.027
	Nosing floor	2.3^{A}	2.5*^{A}	2.2^{A}	0.6^{B}	1.6^{a}	0.6^{a}	1.2^{a}	0.8^{a}	7.0	0.008	2.2	0.088	1.5	0.205
	Nosing equipment	1.7^{B}	3.7*^{A}	1.5^{B}	0.0^{AB}	0.9	0.2^{ab}	0.6^{a}	1.1^{ab}	12.6^{b}	0.001	1.4	0.218	1.2	0.315
	All Chewing	2.8^{A}	12.9*^{B}	10.2*^{B}	1.7^{A}	1.4^{ab}	3.4^{a}	2.2^{ab}	0.6^{b}	41.6	<0.001	15.2	<0.001	0.63	0.594
	Chewing	0.6^{AB}	0.8^{A}	0.1^{C}	0.2^{BC}	0.2^{a}	0.5^{a}	0.2^{a}	0.1^{a}	5.1	0.024	4.7	0.003	1.0	0.386
	Chew Straw	1.3^{A}	10.1*^{B}	9.2*^{B}	1.0^{A}	0.8^{ab}	2.1^{a}	1.3^{ab}	0.3^{b}	49.1	<0.001	15.3	<0.001	1.2	0.312
	Still	77.1^{A}	46.9*^{B}	45.5*^{C}	81.9^{A}	81.6^{a}	70.0^{b}	65.6^{b}	80.4^{a}	57.9	<0.001	60.7	<0.001	12.8	<0.001

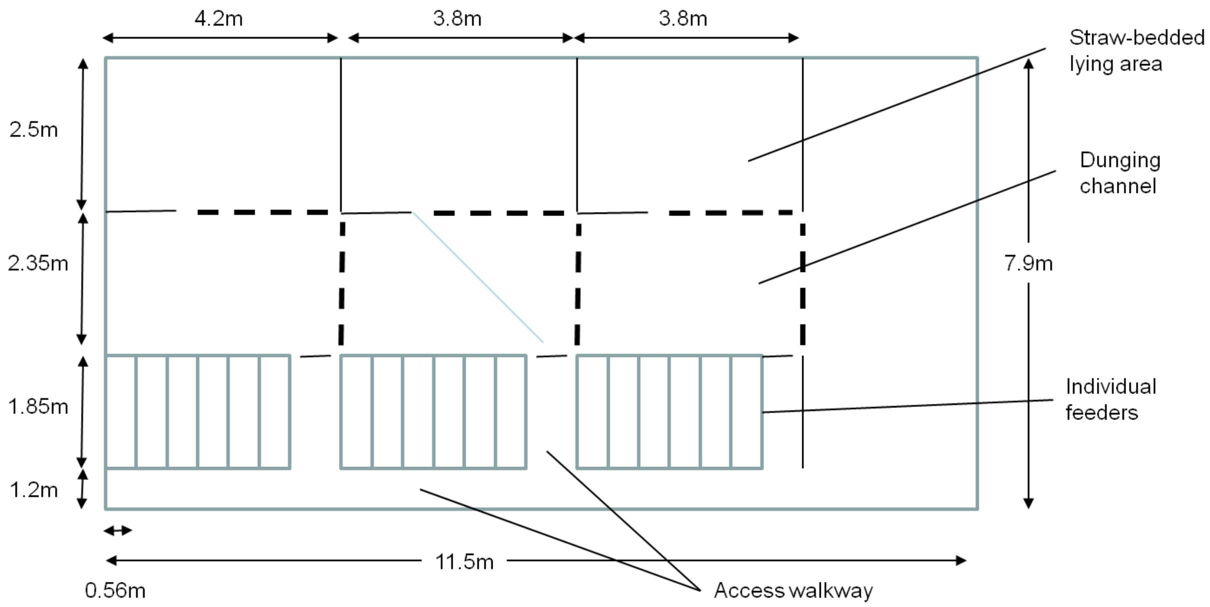

Figure 1: Floor plan of the sow accommodation. Dotted lines indicate gates. There is one gate per pen, and its two extreme positions are shown- the usual position (vertical on the diagram) where the gate is used to separate the pens, but also the cleaning position (horizontal on the diagram) to shut the sows into the bedded area for cleaning out. The feeders were constructed from metal bars, and the bedded areas were constructed from concrete blocks, the rear portion of which was covered with a wooden roof. The room had two solid walls (left and bottom of the diagram), and two walls had openings allowing for airflow (top and right of the diagram).

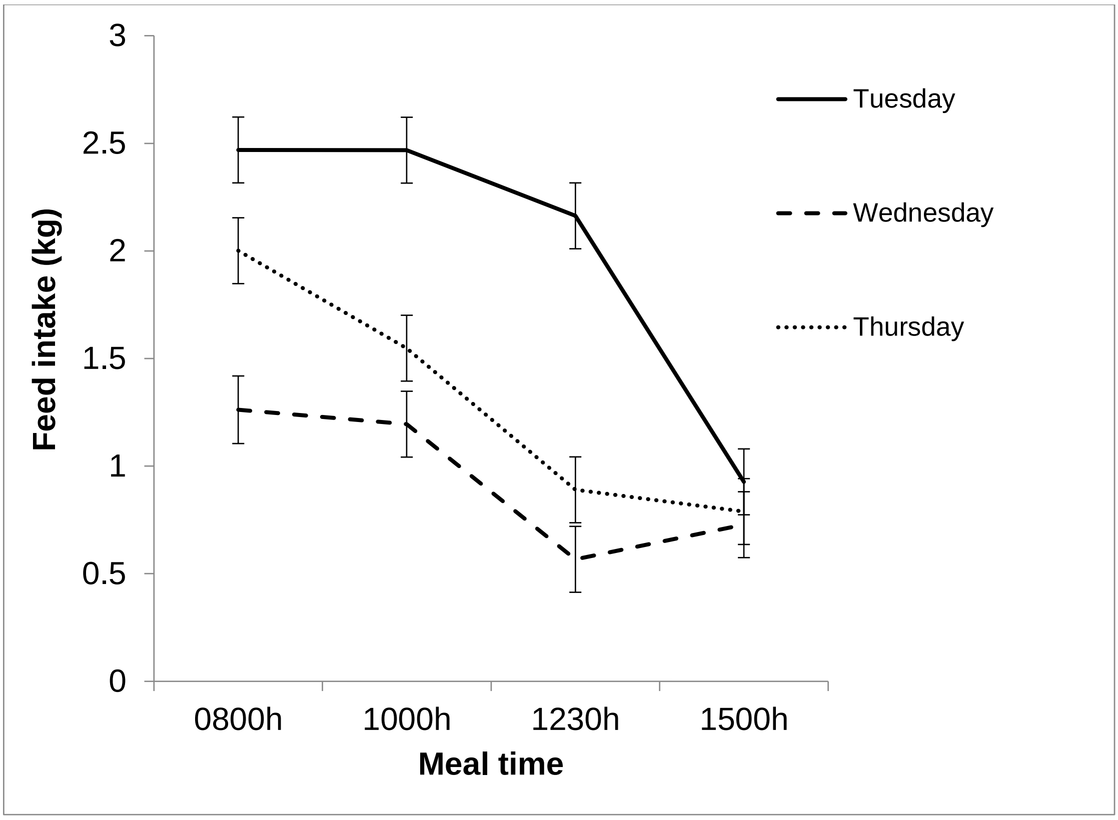

Figure 2: Mean feed intake (± s.e. kg) at each meal in sows offered four 2.5kg meals (referred to as *ad libitum* feeding in this paper) for three days. At each time point, differences between days were all significant at $p<0.05$ except between Tuesday and Thursday at 0800h, between Wednesday and Thursday at 1000h and 1230h, and there were not differences between days at 1500h.

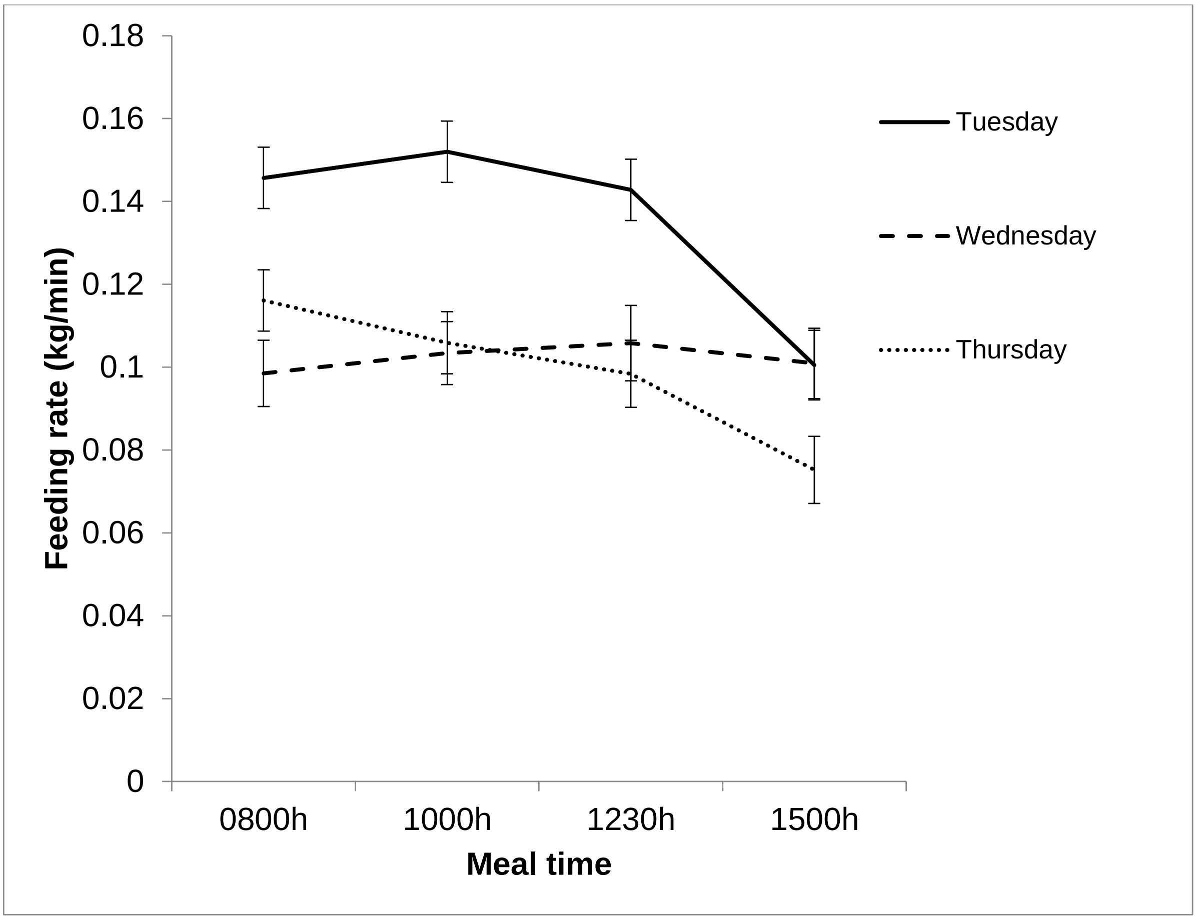

Figure 3: Mean feeding rate (± s.e. kg/min) at each meal in sows offered four 2.5 kg meals (referred to as *ad libitum* feeding in this paper) for three days. Feeding rate on Tuesday and Thursday were significantly different at $p<0.05$ at each time point. Feeding rate on Tuesday and Wednesday were significantly different at each time except 1500h. Wednesday and Thursday were only different at 1500h.

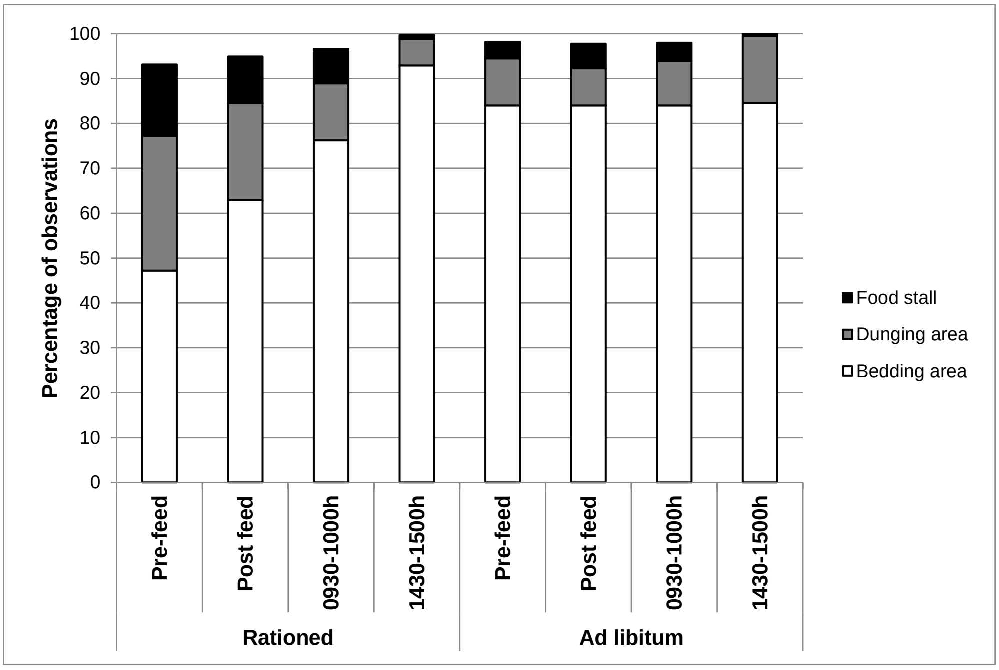

Figure 4: Pen locations occupied by sows (% of scan samples; food stall, dunging area, bedding area) by treatment (Rationed or *Ad libitum*) and observation period (pre-feed, post feed, 0930-1000h, 1430-1500h). Totals do not sum to 100% since out of sight observations are not shown. Statistical significance of the effects of treatment, time and treatment*time, and where pairwise differences lie are shown in Table 2.

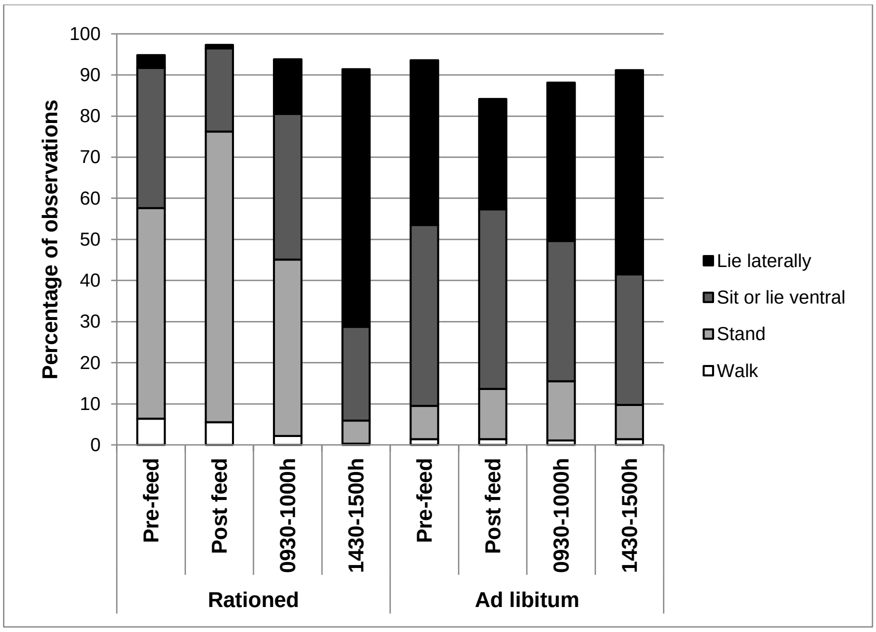

Figure 5: Body postures of sows (% of scan samples; walking, standing, sitting or lying ventrally, or lying laterally) by treatment (Rationed or *Ad libitum*) and observation period (pre-feed, post feed, 0930-1000h, 1430-1500h). Totals do not sum to 100% since out of sight observations are not shown. Statistical significance of the effects of treatment, time and treatment*time, and where pairwise differences lie are shown in Table 2.

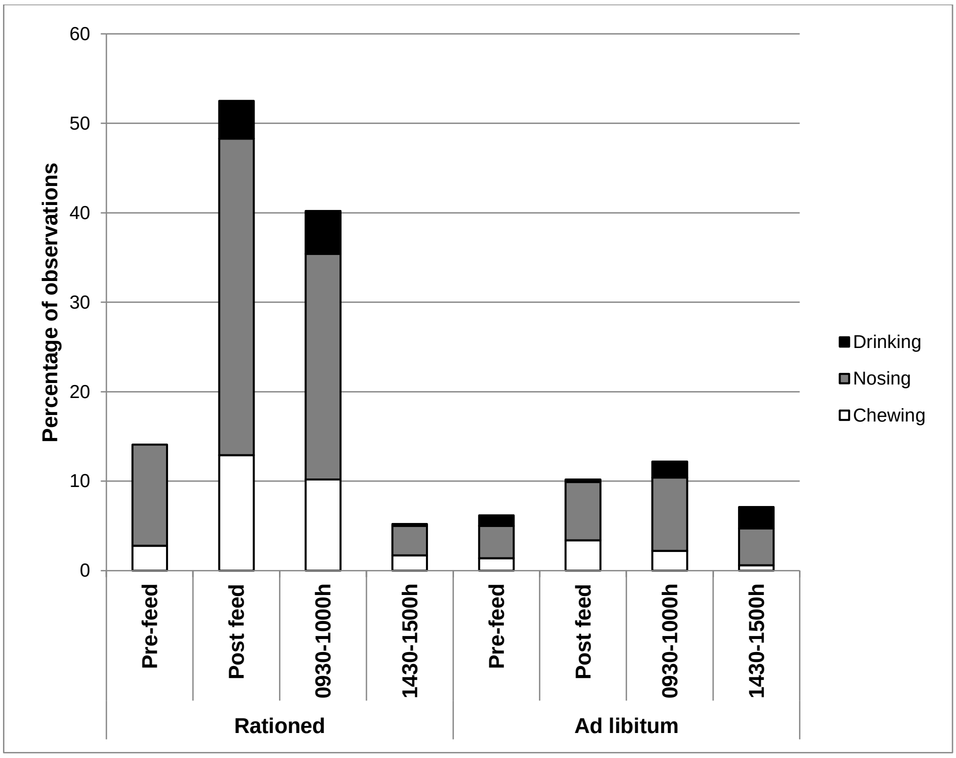

Figure 6: Oral behaviours performed by sows (% of scan samples; drinking, nosing (combines nosing straw, floor or equipment) or chewing (combines chewing straw, equipment and nothing)) by treatment (Rationed or *Ad libitum*) and observation period (pre-feed, post feed, 0930-1000h, 1430-1500h) on the percentage of time spent. Data shown are the percentage of scan sample observations. Time spent performing other behaviours (or remaining still) or being out of sight not shown. Statistical significance of the effects of treatment, time and treatment*time, and where pairwise differences lie are shown in Table 2.