Maximising weaner performance: Effects of weight distribution within groups and space allowance

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By

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Executive Summary

Basic pork management practices, which can cost little to implement, have the potential to improve the social environment of the pig, therefore maximising on post-weaning performance. Such management practices include how the pigs are sorted into weaner housing as well as pig flow and the allocation of space. Allocating pigs into body weight groups (light, medium and heavy) is a common way to sort pigs at weaning. One reason for sorting piglets this way is to sometimes feed a different specification diet to lighter pigs; however, and most of the time, it is based on the assumption that lighter piglets will perform better without the potential bullying threat of larger pigs. This, in turn, may reduce both the risk of injury and cause less competition at the feeder, resulting in a greater feed intake and, subsequently greater growth. However, in studies using small group sizes (less than 12 pigs per pen) it is recognised that fights are more frequent and severe between pigs of a similar size and improvements in performance are rarely reported. Therefore, mixing pigs according to body weight at the time of weaning might simply add additional labour costs without improving production, welfare and health outcomes.

In addition to sorting strategies, optimising the pig's environment through appropriate stocking density as a strategy to eliminate unnecessary stress and minimise disease is becoming increasingly important, especially as pork industries worldwide move towards reducing antimicrobial usage. Over-crowding in the nursery has shown to negatively impact on performance and susceptibility to disease, with research from Canada demonstrating that that even a small difference of 0.04 m^2 (i.e., 0.26 m^2 versus 0.3 m^2) can positively influence growth as well as pig posture, feeding and drinking behaviour during the first five weeks after weaning. Therefore, it seems worthwhile examining the effects of further increases in space allowance above what is stipulated in the Model Code of Practice for the Welfare of Animals: Pigs (Third Edition).

The aims of this study were to examine the effects that i) sorting by body weight and ii) maximising space allowance can have on the social environment of weaner pigs as measured by post-weaning performance, aggression and indicators of morbidity and mortality. Labour efficiency was also measure in part one of the study. The study was performed in two parts with the outcomes from part one being applied to part two. In the first part of the study, pigs were either sorted into pens according to body weight (visual assessment: light, medium and heavy) or not sorted, creating homogeneous and heterogeneous pens of pigs. The sorting procedure took longer for farm staff to achieve and at the end of the weaner phase, sorting pigs by body weight did not improve performance and more pigs tended to be removed from the homogeneous pens than the heterogeneous pens for health reasons. Overall, the heavy pigs fought the most and within the heavy weight category, the homogeneous pigs fought more than their heterogeneous counterparts. The opposite was true for the light weight class. However, no significant differences between markers of stress and inflammation were appreciated between homogeneous and heterogeneous pigs during the first two weeks post-weaning.

The results from part two of the study indicated that improvements in growth and body weight can be achieved at the end of the weaner phase by providing more space in the pen (0.4 m^2 vs 0.3 m^2 per pig), and even small improvements in space (0.35 m^2 vs 0.3 m^2 per pig) resulted in an improvement in growth. Pigs with more space also tended to have higher levels of brain-derived neurotrophic factor, a blood marker of cognitive function and stress resilience, and less pigs were removed from the pen for health reasons.

Overall, the results of the current project demonstrated that improvements in post-weaning performance, health and welfare can be achieved by focusing on space allowance rather than sorting pigs by body weight. Although light pigs may still benefit from being housed with similar sized pigs to reduce potential bullying, these benefits are only in the short-term since aggression peaks at 24 hours post-weaning and then reduces. Ultimately, pigs with more space at the end of weaning finished 1.5 kg heavier. The results of this study demonstrate that simple management strategies should not be underestimated in their ability to improve weaner pig performance and health, especially during a time when a large amount of focus is placed on advances in genetic, nutritional and environmental strategies to maximise post-weaning performance.

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1. Introduction

Despite advances in nutritional, genetic and environmental strategies, weaning remains one of the most stressful events in a pig's life. Basic management practices aimed at improving the social environment of the pig should not be overlooked in the potential role they can play in maximising post-weaning performance. Such management practices include how the pigs are sorted into weaner housing as well as pig flow and the allocation of space. To a degree, the latter two might be harder to achieve because shed design and pig flow is often difficult to change on an established system. However, these considerations are important when new sheds are constructed, old facilities renovated or pig flow is reviewed.

The sorting of pigs can be done according to a number of criteria such as litter, sex, body weight, and temperament. Sorting by temperament and litter of origin are often not considered practical options in a large commercial setting. Split-sex social management introduces the option of more specific phase feeding given males grow faster than females; however, the performance of neither sex is affected by gender ratios within the pen (Gonyou 1998, Colson et al., 2006). The sorting of pigs into body weight groups (light, medium and heavy) is one of the more common management practices. One reason for sorting piglets this way is to sometimes feed a different specification diet to lighter pigs, although most of the time, it is based on the assumption that lighter piglets will perform better without the potential bullying threat of larger pigs. This, in turn, may reduce both the risk of injury and cause less competition at the feeder, resulting in a greater feed intake and, subsequently greater growth. Interestingly however, results from earlier studies have concluded that weaner productivity is not negatively affected by within-pen body weight variability (Francis et al.,1996, Bruininx et al., 2001). In this regard, mixing piglets according to body weight at the time of weaning (e.g., into heavy, medium and light categories, and excluding hospital pen pigs) might simply add additional labour costs without improving production and (or) health outcomes. In saying this however, other measurements of pre-pathological state and welfare need to be examined before drawing firm conclusions about the practice of mixing according to body weight at the time of weaning.

In addition to optimising group composition, optimising the pig's environment through appropriate stocking density as a strategy to eliminate unnecessary stress and minimise disease has come to light again with the recent shift towards reducing antibiotic usage in the pork industries worldwide. Australian indoor production systems usually keep weaner pigs in pens from weaning up to 25-30 kg. The Model Code of Practice for the Welfare of Animals: Pigs (Third Edition, 2008) stipulates that a space allowance of 0.3 m^2 per pig is required for such housing, working with an average weight of 30 kg at the end of the nursery period (approximately 10 weeks of age). Over-crowding in the nursery has shown to negatively impact on performance (Wolter et al. 2002; Callahan et al. 2017) and susceptibility to disease (Stojanac et al. 2014). A preliminary study from the Prairie Swine Centre in Saskatchewan (Roy 2017) demonstrated that even a small difference of 0.04 m^2 (i.e., 0.26 m^2 versus 0.3 m^2) can positively influence growth as well as pig posture, feeding and drinking behaviour during the first five weeks after weaning. Therefore, it seems worthwhile examining the effects of further increases in space allowance (>0.3 m^2 per pig) while still working with values that are realistically achievable in a commercial setting to find optimal space allowance, which will maximise productivity and health in the weaner phase without compromising economic gain.

The current study was performed on a commercial farm and was divided into two parts. Part one focused on the significance of sorting pigs by body weight since it was a relatively easy intervention to apply on farm. The outcomes of part one were then applied to part two, which involved a slight change in pig flow on the farm to achieve greater space allowances for two out of the three treatment groups. Overall, the aim of the study was to examine the effects that i) sorting by body weight and ii) maximising space allowance can have on the social environment of weaner pigs as measured by post-weaning performance, aggression and indicators of morbidity and mortality. Labour efficiency was also measure in part one of the study. The two major hypotheses were:

1. Sorting pigs by body weight (light, medium and heavy) at weaning will take longer than weaning pigs into heterogeneous pens with no improvements in: i) post-weaning growth and voluntary feed intake, ii) incidence of fighting and oral manipulation, iii) expression of markers for inflammation or stress, iv) morbidity and mortality and v) faecal shedding of *Escherichia coli* during the weaner phase of production.
2. Minimal improvements in space allowance above the Model Code of Practice for the Welfare of Animals: Pigs (Third Edition, 2008) will improve: i) post-weaning growth and voluntary feed intake, ii) incidence of fighting and oral manipulation, iii) the expression of markers for inflammation or stress, iv) morbidity and mortality and v) faecal shedding of *Escherichia coli* during the weaner phase of production.

2. Methodology

This study was approved by the Murdoch University Animal Ethics Committee (Permit Number: R3007/17). All animal work took place between April and August 2018 over two batches (part one examined sorting by body weight and part two examined space allowance). The study was conducted at a Western Australian commercial piggery and included 1280 weaner pigs for part one and 1050 weaner pigs for part two (CEFN genetics). In total, 2330 pigs were used throughout the two experiments.

2.1 Animals, Housing and Diet

On the day of weaning (day 0), 1280 weaner pigs were randomly selected from a group of 2700 for part one and 1050 were randomly selected from a similar size group for part two. Both experiment groups were approximately three weeks of age and had been transported a short distance from multiple breeder sites to a grow out site. On arrival, the selected pigs were divided into sexes and allocated into treatment groups (see treatment descriptions below, sections 2.2 and 2.3). The pigs were housed in weaner pens (2.174 m x 5.620 m), which consisted of plastic slatted flooring, a single drinker with a bowl and a wet dry feeder with two water nipples. During the first seven days after weaning, a rotary feeder was available in each pen to encourage eating behaviour. A commercial weaner diet was fed *ad libitum* using a Feed Logic system. During the experiment, three-day courses of in-water amoxicillin were provided to all pigs in the shed due to clinical signs associated with respiratory disease. The treatment courses started on days 16, 23 and 32 of the experiment for part one of the study and on days 11 and 27 of the experiment for part two.

2.2 Treatments - Part one

Two grouping strategies were used for the 1280 selected pigs: i) homogeneous, where pigs were grouped into light, medium and heavy categories (n = 8 pens for each category with equal pens of males (n = 4) and females (n = 4)) and ii) heterogeneous, where the first 40 pigs of varying sizes were allowed to enter the pen (n = 8 with equal pens of males (n = 4) and females (n = 4)). The selection of pigs for homogeneous pens was not based on a predetermined body weight, but rather achieved by visual assessment. Each experimental pen was made up of 40 pigs.

2.3 Treatments - Part two

Three different space allowances were achieved by randomly allocating 1050 selected weaner pigs to pens of i) 40, ii) 35 and iii) 30 pigs per pen to achieve space allowances of 0.3 m^2, 0.35 m^2, and 0.4 m^2 respectively (n = 10 pens for each category with equal pens of males (n = 5) and females (n = 5) for each category). The space allowances were based on the Model Code of

Practice for the Welfare of Animals: Pigs (Third Edition, 2008), and were based on the assumption that pigs will reach an average weight of 30 kg at the of the nursery period. If a pig was removed from the pen due to death, euthanasia or requiring treatment in the hospital pen, it was replaced with a pig of a similar size from a group of non-experiment pigs in the same shed to maintain the set space allowance.

For both part one and two of the study, pigs less than 4 kg (visual assessment) were not included in the study. The remaining pigs which were weaned at the same time as the experiment pigs were housed in larger pens in the same room, opposite the experiment pigs.

2.4 Measurements

Time (part one only)

The time it took to sort pigs into homogeneous and heterogeneous groups was recorded by an observer. Since there were more homogeneous pens than heterogeneous pens less staff members were needed to allocate the heterogeneous pens. Therefore, the total time to complete weaning for each treatment group was expressed in full time equivalent (FTE) minutes per pen.

Performance

Body weights and feed disappearance were measured at weaning (day 0) and on days 7, 14 and 40 (part two) or 42 (part one) after weaning. These data were used to determine average daily gain (ADG) on a pen basis. Average daily feed intake (ADFI) was calculated by measuring the quantity of food remaining in the feeder hoppers on days 7, 14 and 40 (part two) or 42 (part one) after weaning and then calculating the feed disappearance divided by the number of pigs in the pen. Feed conversion ratio (FCR) was calculated on a pen basis using ADFI divided by ADG.

Blood samples

Blood samples were collected on days 6 and 13 after weaning for part one and on days 6 and 39 after weaning for part two. Samples were collected via jugular venipuncture into lithium heparin coated tube, which were immediately placed on ice. Samples were centrifuged at 2800 x g for 15 minutes at room temperature. Plasma was collected and sorted at -20° C.

Plasma was subsequently analysed at the Animal Health Laboratories (Department of Primary Industries and Regional Development, Western Australia) for the determination of alkaline phosphatase (ALP), C-reactive protein (CRP), haptoglobin (Hp) and urea using the Olympus AU400 Clinical Chemistry Analyser. Alkaline phosphatase and urea analysis were performed using the Beckman Coulter/Olympus Reagent kits (OSR6004 and OSR6134 for ALP and urea respectively). C-reactive protein concentrations were determined using a commercially available ELISA kit (DY2648, R and D systems). Haptoglobin content in the plasma sample was determined using an in-house method adapted from Eckersall et al. (1991). Analysis for cortisol and brain derived neurotrophic factor (BDNF) was performed at Murdoch University using commercially available ELISA kits (cortisol: ENZO LifeSciences ADI-900-071, BDNF: MBS263950). Analysis using commercial kits was in accordance with the manufacturers' instructions.

Injury scores

On the day of weaning, four pigs per pen were selected and made individually identifiable with numbered ear tags. More specifically, in part one of the study, the selection of individually identifiable pigs in the homogenous groups was random, however, for pigs in the heterogeneous group, there was an even selection of light, medium and heavy pigs across the eight different pens.

On the day of weaning (day 0) and on day 1 and day 6 after weaning, injury scores were recorded from all ear tagged pigs as an indicator of aggression. In part two of the study, injury scores were also recorded on day 39 after weaning when space was most limited. The injury scoring system was adapted from Widowski et al. (2003) and consisted of a four-point scale for scratches and redness around the head, ears and flank (Table 1)

Table 1. Injury scoring system using scratches and redness adapted from Widowski et al. (2003)

Score	0	1 (Mild)	2 (Moderate)	3 (Severe)
Scratches	No scratches were evident on the head, ears and flank	1 to 3 small (≤ 2cm) scratches or areas of abraded skin on head, ears or flank	1 to 3 large (> 2cm) scratches or areas of abraded skin on head, ears or flank	More than 3 scratches or larger areas of superficial skin loss on head, ears or flank
Redness	No redness or swelling on the head, ears or flank	Redness and swelling barely detectable on head, ears and flank	Redness or swelling were obvious on head, ears and flank	Irritation easily observed as darker reddening and/or moderate to severe swelling

Escherichia coli (*E. coli*) shedding

On days 7 and 14 of the experiments, one pooled faecal sample was collected from the floor of each pen. These samples were placed on ice and processed at the Murdoch University Antimicrobial Resistance and Infectious Disease Laboratory. Two grams of pooled faeces per sample was placed in a lateral filter bag (Edwards, 111425) and 18ml PBS was added followed by thorough mixing. The homogenate was then filtered and the filtrate serially diluted (10^{-1} to 10^{-6}) by the Tecan Evoware 150 liquid handling robot. Dilutions were then plated on to ECC plates (Edwards, CHROMagar MM1076) and incubated at 37 degrees C overnight. *Escherichia coli* (*E. coli*) colonies were counted by the Tecan Evoware 150 liquid handling robot.

Statistical analysis

Statistical analyses were performed using SPSS (IBM Corp, Version 21). The following description applies to both parts one and two of the study unless specified. All data were tested for normality using the Shapiro-Wilk value (>0.8 was considered normally distributed). Data for body weight, ADG, ADFI, FCR and faecal *E. coli* shedding were analysed on a per pen basis using a general linear model fit initially with treatment and sex as fixed effects. Due to a lack of sex effect, it was removed from the model, with the exception of ADFI and FCR for part two of the study for days 14 to 40 and overall (days 0-40). Extreme outliers (identified by the normality test) were removed from the blood marker data before analysis. The model used to analyse the blood markers and scratch scores was a linear mixed model with sex, treatment, day and the interaction of treatment x day as fixed effects and pen as a random effect. For part one of the study, treatment was defined as homogeneous vs heterogeneous within each of the different weight classes (light, medium and heavy). Sex was removed from all the linear mixed models with the exception of ALP in the heavy pigs for part one and urea for part two of the study. Brain derived neurotrophic factor (part one) and C-RP (part two) were not normally distributed and required square root transformation to force normality. The mean values and confidence intervals were then back-transformed and expressed as least square means. All post-hoc comparisons included a least significant difference correction for pairwise comparisons. The distribution of the redness injury score data was not normal and transformation of the data did not correct this. The redness data was therefore analysed non-parametrically with a Mann-Whitney U test (part one) and a Kruskal Wallis test with post hoc analysis (part two) to determine which treatment groups were different from each other. A non-parametric Friedman test was used to compare differences in redness score over the different days.

The percentage of removals was analysed using a chi-square test. For all analyses, statistical significance was accepted at $p \leq 0.05$ and a trend was considered at $p > 0.05$ and $p \leq 0.1$. Data are presented as raw means ± SEM, except when *n* is different between treatments, in which case data are presented as raw means ± SE unless otherwise stated.

3. Part one Results

3.1 Time recordings during sorting procedures

The time it took to sort pigs by weight (light, medium and heavy) across 24 pens was one session of 64 minutes with four people and one session of 42 minutes with three people. To allocate pigs into the eight heterogeneous pens (i.e. count first 40 pigs and follow them up the corridor), it took three staff members 12 minutes. This is equivalent to 382 paid minutes for sorting 24 pens ((64 x 4) + (42 x 3) = 382) vs 36 paid minutes for not sorting 8 pens (3 x 12 = 36), which is equal to 16 paid minutes per pen for sorting and 4.5 paid minutes per pen for not sorting. Therefore, it took staff one quarter of the time to not sort pigs by weight at weaning. The timing did not include the identification of runts (<4kg) which occurred before the sorting procedures.

3.2 Removals due to treatment, death or euthanasia

From the 1280 pigs at the start of the experiment (Day 0), a total of 92 were removed during the course of the experiment due to deaths, euthanasia or pigs requiring treatment in a hospital pen. This was a removal rate of 7.2%. There was no sex effect for removals (6.8% removal rate for females versus 8.6% for males, $p > 0.05$). There was also no treatment effect when the four treatment groups were compared (7.7%, 8.8%, 9.2% and 5.2% for light, medium, heavy and heterogeneous groups respectively, Figure 1A, $p > 0.05$). However, when the removal rates of the homogeneous groups were combined, there was a tendency for pigs not sorted according to body weight class to have a lower removal rate that pigs grouped by body weight class (Figure 1B, $p < 0.1$).

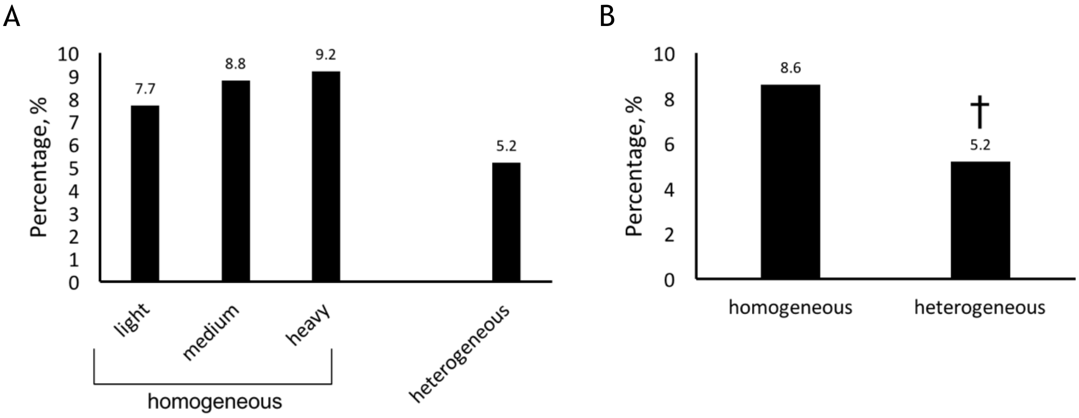

Figure 1. The removal rate of weanling pigs as affected by (A) body weight class within the homogeneous pens vs the heterogenous pens and (B) pooled homogenous pens vs heterogenous pens.

3.3 Performance

The body weight data confirms the accuracy of sorting by body weight using a visual assessment by farm staff (Table 2A). The light homogeneous pens were the lightest on the day of weaning and remained the lightest treatment group throughout the experiment (Table 2A, $p<0.05$). The heavy homogenous pens were the heaviest at weaning and remained the heaviest throughout the experiment (Table 2A, $p<0.05$). The heterogeneous pens remained heavier than the medium homogenous pens throughout the experiment (Table 2A, $p<0.05$). When the average body weight of the homogeneous pens was pooled, weight distribution within pens had no effect on body weight throughout the experiment (Table 2B, $p>0.05$).

Table 2A. Mean body weights for pigs sorted into pens by size (homogeneous: light, medium and heavy) and pigs unsorted on entry into weaner pens (heterogeneous).

	Body weight class					
	Homogenous			Heterogeneous		
Item	Light	Medium	Heavy		SEM	*p*-value
Number of pens	8	8	8	8		
Number of pigs	321	321	320	320		
BW Day 0	4.5^{a}	6.0^{b}	7.8^{c}	6.5^{d}	0.11	<0.001
BW Day 7	5.3^{a}	6.6^{b}	8.4^{c}	7.1^{d}	0.16	<0.001
BW Day 14	7.3^{a}	8.8^{b}	10.8^{c}	9.5^{d}	0.24	<0.001
BW Day 42	22.4^{a}	24.7^{b}	28.7^{c}	26.0^{d}	0.46	<0.001

$^{a-d}$ Within a row, means with a different superscript letter differ (p<0.05).

Table 2B. Mean body weights for pigs sorted into pens by size (homogenous: light, medium and heavy pens combined) and pigs unsorted into weaner pens (heterogeneous).

	Weight distribution within groups		
	Homogenous	Heterogeneous	*p*-value
Number of pens	24	8	
Number of pigs	962	320	
BW Day 0	6.1 ± 0.25	6.5 ± 0.43	0.45
BW Day 7	6.8 ± 0.24	7.1 ± 0.42	0.57
BW Day 14	9.0 ± 0.30	9.5 ± 0.51	0.38
BW Day 42	25.26 ± 0.54	26.0 ± 0.93	0.48

The ADG and ADFI did not differ ($p>0.05$) between body weight classes from day 0 to 7 (Table 3). However, both heavy and heterogenous pens grew faster ($p>0.01$) than the light and medium pens between days 7 and 14 of the experiment. During the same time interval, the light pigs tended ($p<0.1$) to eat less than the other treatment groups. For the remainder of the experiment (days 14-42), the heavy pens grew the fastest and ate the most and the light pens grew the slowest and ate the least ($p<0.001$). The heterogenous and medium pens were intermediate with the medium pens only tending to grow faster than the light pens (Table 3). For the overall growth period after weaning (days 0-42), ADG was highest in the heavy pens, intermediate in the heterogenous pens and lowest in the light pens ($p<0.001$). Growth performance did not differ between the medium and heterogenous pens and the medium and the light pens (Table 3). Feed intake data followed a similar pattern with the heavy pens eating the most, followed by the medium and heterogenous pens and the light pens eating the least during the overall growth period ($p<0.001$, Table 3).

Body weight distribution did not affect ($p>0.05$) FCR during the first 14 days of the experiment. However, while FCR did not differ between heavy and medium pens between days 14 and 42, it was lowest for the light pens ($p<0.05$) with the heterogenous pens only tending ($p<0.1$) to have a lower FCR than the heavy pigs (Table 3). A similar pattern was evident for the overall FCR data (days 0-42), except there was a stronger difference between the heterogeneous pens compared with the heavy pens ($p=0.01$).

Table 3. Performance of pigs[1] sorted into pens by size (homogenous: light, medium and heavy) and unsorted on entry into weaner pens (heterogenous)

	Body weight class					
	Homogenous			Heterogeneous[2]		
	Light[2]	Medium[2]	Heavy[2]		SEM	*p*-value
Mean production performance						
Days 0-7						
ADFI, g	150	146	155	155	10.9	0.923
ADG, g	116	96	82	83	19.2	0.560
FCR	1.52	1.15	1.95	1.00	0.44	0.434
Days 7-14						
ADFI, g	277^{x}	347^{y}	340^{y}	336^{y}	21.6	0.103
ADG, g	279^{a}	315^{a}	354^{b}	351^{b}	15.2	0.005
FCR	1.00	1.09	0.97	0.96	0.13	0.107
Days 14-42						
ADFI, g	779^{a}	866^{b}	990^{c}	881^{b}	19.1	<0.001
ADG, g	539^{ax}	568^{aby}	637^{c}	590^{b}	10.7	<0.001
FCR	1.44^{a}	1.53^{b}	1.56^{bx}	1.49^{aby}	0.03	0.021
Days 0-42						
ADFI, g	591^{a}	659^{b}	743^{c}	669^{b}	16.0	<0.001
ADG, g	425^{a}	447^{ab}	497^{c}	466^{b}	10.4	<0.001
FCR	1.39^{a}	1.48^{bc}	1.5^{b}	1.44^{ac}	0.02	0.010

[1] Data are presented as pen means and SEM. [2] n=8 for all treatment groups. $^{a-c}$ Within a row, means with a different superscript letter differ (p<0.05). ^{x,y} Within a row, means with a different superscript are a trend (p<0.1).

When mean performance values from the light, medium and heavy homogeneous pens were combined for each time point, there was a tendency (p<0.1) for the heterogenous pens to have a higher ADG than the homogenous pens between days 7 and 14 of the experiment, however, weight distribution did not have an effect on growth at any of the other time points during the experiment (p>0.05; Table 4). Average daily feed intake and FCR did not differ (p>0.05) between the homogenous and heterogenous pens throughout the duration of the experiment (Table 4).

Table 4. Performance of pigs[1] sorted into pens by size (homogeneous: light, medium and heavy pens combined) and unsorted on entry into weaner pens (heterogeneous).

	Weight distribution within groups		
	Homogeneous[3]	Heterogeneous[3]	*p*-value
Mean production performance			
Days 0-7			
ADFI, g	151±6.1	155±10.6	0.703
ADG, g	98±11.0	83±19.1	0.501
FCR	1.54±0.25	1.00±0.44	0.294
Days 7-14			
ADFI, g	322±13.3	336±23.1	0.582
ADG, g	316±10.1	351±17.5	0.092
FCR	1.02±0.02	0.96±0.04	0.218
Days 14-42			
ADFI, g	879±19.1	881±33.3	0.942
ADG, g	581±9.6	590±16.6	0.654
FCR	1.51±0.03	1.49±0.02	0.641
Days 0-42			
ADFI, g	664±14.5	669±25.0	0.860
ADG, g	457±8.0	466±13.8	0.569
FCR	1.45±0.02	1.44±0.03	0.629

[1] Data are presented as pen means and SEM. [2] *n*=24 for homogeneous pens. [3] *n*=8 for heterogenous pens.

3.4 Blood markers

An increase ($p<0.05$) in ALP and Hp was seen over time (day 6 to 13) in all body weight classes with the exception of medium pigs in which there was only a tendency for ALP to increase over time ($p<0.1$, Table 5). An increase over time was also detected in heavy pigs for C-RP and urea ($p<0.05$, Table 5) and there was tendency ($p<0.1$) for the cortisol levels in the heavy pigs to decrease over time. No other blood measures changed between days 6 and 13 of the experiment ($p>0.05$). A sex effect was present for the heavy pigs in the ALP data (353.0 ± 17.5 vs 289.8 ± 18.2 for heavy females and males respectively, $p<0.01$). With regard to the effect of body weight distribution on blood markers within the different weight classes of pigs, treatment differences were only detected in urea and Hp for light pigs. The light homogeneous pigs had higher ($p>0.05$) urea levels than the light heterogeneous pigs and, the light heterogeneous pigs had higher ($p>0.05$) Hp levels than the light homogeneous pigs. Medium heterogenous pigs also tended ($p<0.1$) to have higher Hp levels than the homogeneous pigs within the same weight category.

Table 5. Blood markers of weanling pigs of different body weight classes as affected by body weight distribution within pens

	Day 6		Day 13				
Item	Homogeneous	Heterogeneous	Homogeneous	Heterogeneous	Txt	Day	Txt x Day
ALP							
Light	294.7 ± 30.5	320.0 ± 37.7	382.3 ± 30.7	397.9 ± 38.8	0.649	<0.001	0.823
Medium	292.5 ± 25.3	321.0 ± 33.8	347.0 ± 29.3	355.6 ± 42.0	0.641	0.092	0.703
Heavy[2]	296.1 ± 19.5	270.8 ± 33.2	363.7 ± 19.4	355.0 ± 32.0	0.529	0.006	0.756
BDNF[3]							
Light	5.71 (2.1-11.2)	3.31 (0.4-9.0)	3.35 (0.8-7.6)	5.76 (1.6-12.5)	0.997	0.986	0.171
Medium	9.06 (5.2-13.9)	4.04 (0.2-12.8)	3.24 (1.3-6.1)	3.24 (0.5-8.3)	0.366	0.137	0.289
Heavy	6.15 (2.5-11.4)	4.08 (0.9-9.6)	4.49 (1.5-9.2)	2.76 (0.4-7.2)	0.442	0.252	0.997
C-RP							
Light	21.8 ± 3.5	20.1 ± 5.7	16.0 ± 2.3	20.0 ± 3.5	0.800	0.422	0.449
Medium	16.7 ± 2.8	14.0 ± 4.6	16.6 ± 2.9	20.6 ± 4.7	0.875	0.374	0.358
Heavy	11.5 ± 1.6	13.4 ± 2.6	15.5 ± 2.2	21.2 ± 3.7	0.165	0.028	0.485
Cortisol							
Light	16.8 ± 3.3	18.7 ± 4.7	11.7 ± 1.8	10.5 ± 2.6	0.920	0.049	0.633
Medium[4]	-	-	-	-			
Heavy	23.9 ± 3.2	21.4 ± 4.0	20.0 ± 3.6	14.3 ± 4.8	0.406	0.074	0.599
Haptoglobin							
Light	0.88 ± 0.1	0.81 ± 0.2	1.12 ± 0.1	1.34 ± 0.2	0.669	0.012	0.322
Medium	0.69 ± 0.1	1.03 ± 0.2	0.98 ± 0.1	1.34 ± 0.18	0.089	0.038	0.947
Heavy	0.67 ± 0.1	0.92 ± 0.1	1.03 ± 0.1	1.20 ± 0.2	0.156	0.006	0.722
Urea							
Light	3.94 ± 0.3	2.74 ± 0.5	3.83 ± 0.14	3.48 ± 0.2	0.021	0.336	0.201
Medium	3.62 ± 0.4	2.43 ± 0.5	4.21 ± 0.5	3.10 ± 0.7	0.095	0.138	0.936
Heavy	2.41 ± 0.2	2.45 ± 0.3	3.45 ± 0.2	3.18 ± 0.4	0.685	0.003	0.602

[1] Data are presented as raw means ± SE. [2] Analysis includes sex. Heavy females had higher levels of ALP than heavy males (355.0 ± 17.5 vs 289.8 ± 18.2 U/L respectively, p = 0.009).
[3] Square root transformed for analysis and then back transformed and presented with lower and upper confidence intervals in parentheses. [4] No data presented due to no values for mixed medium treatment group.

3.5 Injury scores

The scratch scores used to subjectively quantify the level of aggression in piglets differed across days for all treatment groups. Scratch scores were the highest at 24 hours after weaning (day 1), lowest at the time of weaning (day 0) and intermediate on day 6 for the light and medium categories (Figures 2A and 2B, $p<0.001$), and the heavy pigs had the highest level of scratch scores on both days 1 and 6 after weaning compared with day 0 (Figures 2C, $p<0.001$). The light homogeneous pigs had less scratches than their heterogeneous counterparts ($p<0.001$). However, the opposite was observed for the heavy pigs, with higher scratch scores in homogeneous pigs compared with the heterogeneous pigs (Figures 2A and B, $p<0.001$). Body weight distribution within the pen did not affect the scratch scores of the medium pigs ($p>0.05$). However, there was a treatment x day interaction for the medium pigs with the heterogeneous group experiencing a greater variation in scratch score levels over time compared their homogeneous counterparts (Figure 2B). There was a tendency for a day x treatment interaction for scratch scores in the heavy pigs, with the homogeneous group experiencing a greater variation in scores over time.

The redness scores, similar to the scratch scores, were lowest on the day of weaning and highest 24 hours later (day 1) with day 6 as intermediate (Figure 2D, E and F; $p<0.001$). Weight distribution (homogeneous vs heterogeneous) within the pens did not affect redness scores for the medium and heavy pigs, however, the heterogeneous pigs had higher redness scores than the homogeneous pigs within the light weight category (Figure 2D, $p<0.05$).

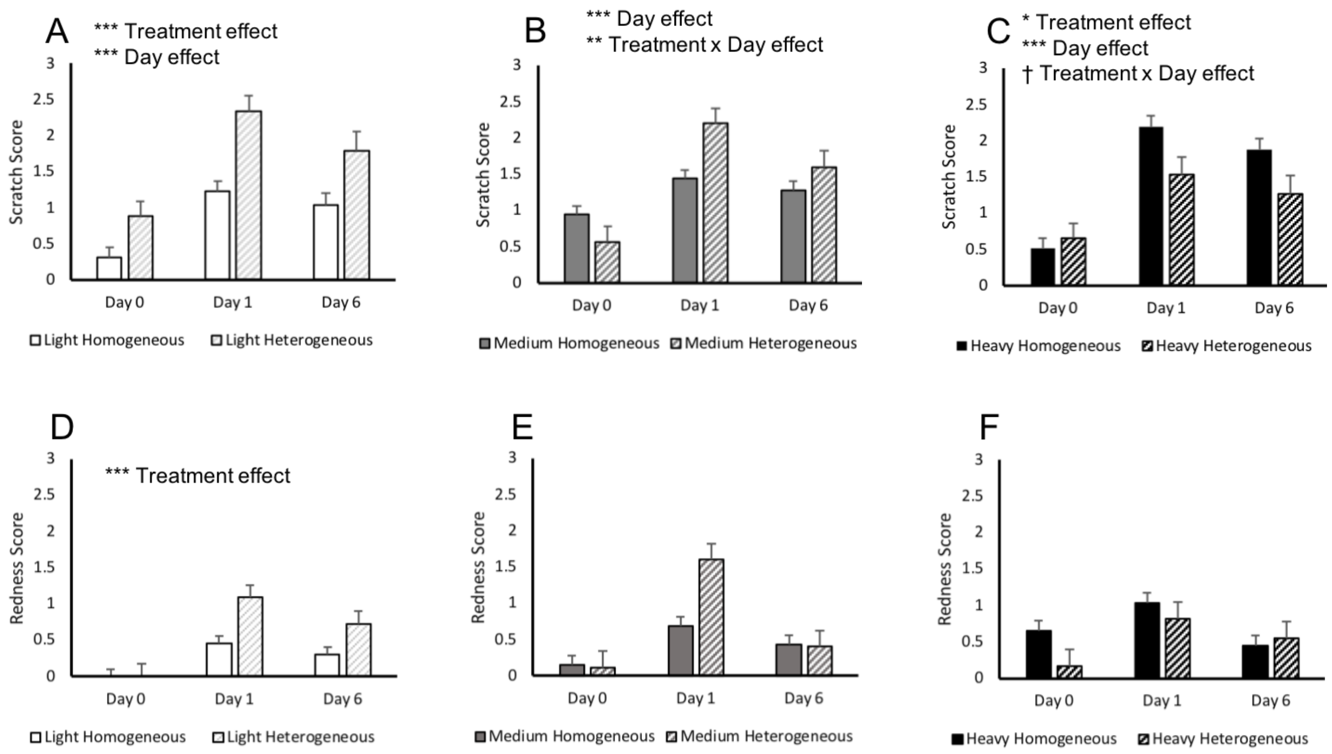

Figure 2. Scratch scores (mean ± SE) on different days relative to weaning for light (A), medium (B) and heavy (C) pigs in homogeneous vs heterogeneous pens. Redness scores (mean ± SE) on different days relative to weaning for light (A), medium (B) and heavy (C) pigs in homogeneous vs heterogeneous pens. Redness scores (tested non-parametrically, but expressed as mean ± SE) on different days relative to weaning for light (D), medium (E) and heavy (F) pigs.

3.6 Escherichia coli *counts*

There were no treatment differences in commensal *E coli* counts on day 7 of the experiment (light homogeneous: 6.5 ± 0.4, medium homogeneous: 5.3 ± 0.4, heavy homogeneous: 6.2 ± 0.4 and heterogeneous pens: 6.1 ± 0.4 log CFU/gram, p>0.05). Similarly, there were also no treatment differences on day 14 (light homogeneous: 5.7 ± 0.4, medium homogeneous: 5.8 ± 0.4, heavy homogeneous: 5.6 ± 0.4 and heterogeneous pens: 5.6 ± 0.4 log CFU/gram, p>0.05). Commensal *E. coli* levels for individual pens by treatment are presented in Figure 3A and B.

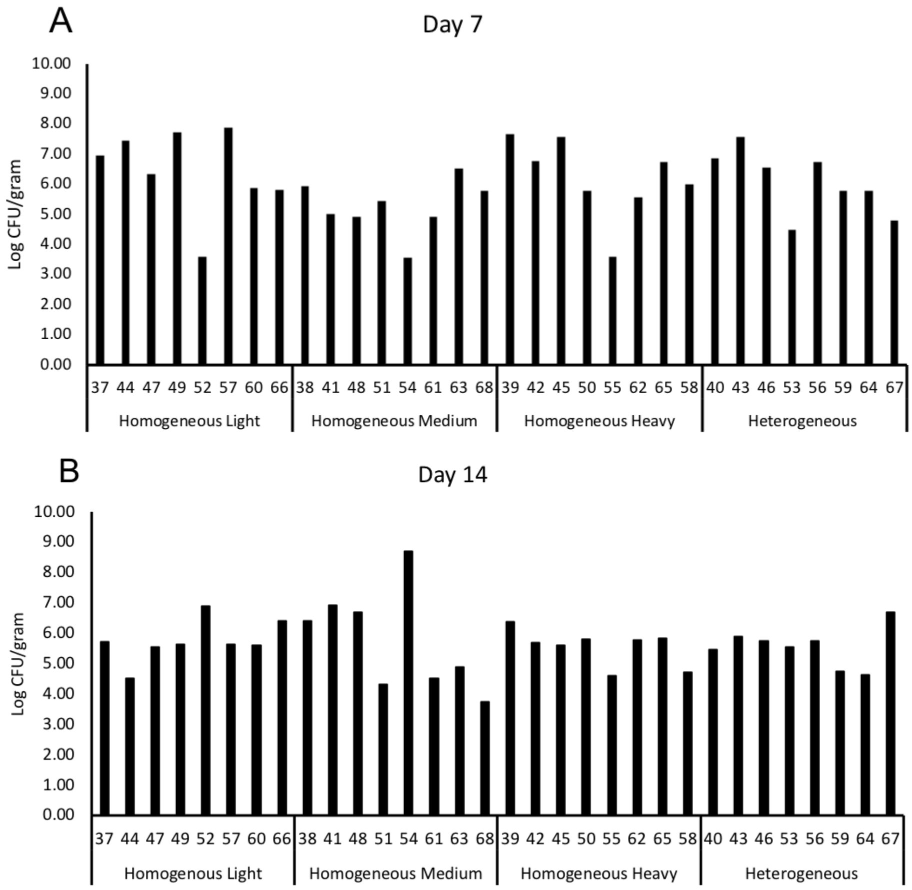

Figure 3. Commensal *E. coli* counts for pens sorted by size (homogenous: light, medium and heavy) and unsorted on entry into weaner pens (heterogenous) on days 7 (A) and 14 (B) after weaning.

4. Part two Results

4.1 Removals due to treatment, euthanasia or death

The experiment shed experienced an unexpected health challenge during the duration of the trial, which involved wasting in an usually higher number of pigs (>200 in a shed of 2700) two weeks after weaning. The affected pigs were also pizzle sucking and unresponsive to treatment. The experiment removal rate was 5.5% (i.e. 5.5% of experiment pigs had to be removed from experiment pens due to either treatment in the hospital pens, death or euthanasia). The highest removal rate occurred during the second week after weaning (42 of the 58 removals occurred during the second week of the experiment). The pigs in the 0.3 m^2 space allowance pens had a higher removal rate (p<0.05) than the pigs in the 0.35 m^2 and 0.4 m^2 space allowance pens over the duration of the experiment (Figure 4).

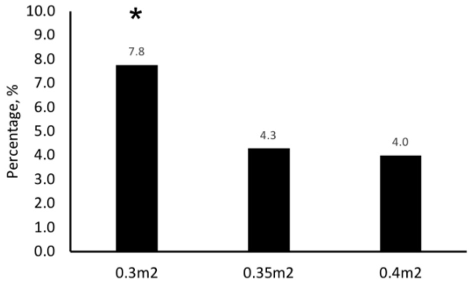

Figure 4. The removal rate of weanling pigs as affected by space allowance.

4.2 Performance

At the commencement of the experiment, all treatment pens had the same average weight (*p*>0.05, Table 6). This remained the case until the last day of the experiment (day 40) where pigs with more space allowance (0.4 m^2) finished heavier than pigs with the least amount of space allowance (0.3 m^2) (*p*<0.05, Table 6). The 0.35 m^2 pigs also tended (*p*<0.1) to finish heavier than the 0.3 m^2 pigs. There were no differences between treatment groups in feed intake, growth and FCR during the first 14 days of the experiment (*p*>0.05, Table 6).

Between days 14 and 40 of the experiment, pigs with a higher space allowance than what is stipulated in the Model Code of Practice for the Welfare of Animals: Pigs (Third Edition) grew the fastest (p<0.01, Table 6); however, space allowance did not have an effect on feed intake or FCR during the same timeframe (*p*>0.05). Overall (days 0-42) the 0.4 m^2 pens grew faster than the 0.3 m^2 pens and the 0.35 m^2 pens were intermediate (Table 6, *p*<0.05). Between days 14 to 40 and overall (days 0-40), female pens ate more (*p*=0.01) and had a higher (*p*<0.01) FCR than male pens, (655 ± 9.6 vs 595 ± 9.6 grams/pig/day and 1.4 ± 0.02 vs 1.3 ± 0.02 for females and males respectively) between days 0 and 40 of the experiment).

Table 6. Performance of pigs[1] subject to different space allowances by adjusting the number of pigs in the pen

	Space Allowance[2]				
	0.3m^2	0.35m^2	0.4m^2	SEM	*p*-value
Mean pen body weights, kg					
Day 0	6.5	6.6	6.5	0.13	0.947
Day 7	7.4	7.6	7.3	0.13	0.339
Day 14	10.0	10.1	10.2	0.15	0.733
Day 40	24.5^{ax}	25.3^{aby}	25.9^{b}	0.33	0.024
Mean production performance					
Days 0-7					
ADFI, g	108	100	107	6.9	0.724
ADG, g	199	143	117	26.0	0.729
FCR	1.2	0.97	1.1	0.20	0.660
Days 7-14					
ADFI, g	379	362	396	16.1	0.406
ADG, g	384	367	413	20.6	0.297
FCR	0.98	1.2	0.96	0.15	0.545
Days 14-40					
ADFI[3], g	809	832	854	16.1	0.162
ADG, g	558^{a}	585^{b}	603^{b}	8.6	0.003
FCR[3]	1.5	1.4	1.4	0.03	0.610
Days 0-40					
ADFI[3], g	611	621	643	11.7	0.162
ADG, g	450^{a}	469^{ab}	485^{b}	8.3	0.023
FCR[3]	1.4	1.3	1.3	0.03	0.577

[1] Data are presented as pen means and SEM. [2] n=10 for all treatment groups. [3] Analysis includes sex.
$^{a-c}$ Within a row, means with a different superscript letter differ (p<0.05). ^{x,y} Within a row, means with a different superscript are a trend (p<0.1).

4.3 Blood markers

Sex did not have an effect on blood markers with the exception of urea where females tended to have higher levels of urea than males (4.11 ± 0.1 vs 3.76 ± 0.1 mmol/L respectively, $p<0.1$). There was a tendency for pigs with the most amount of space (0.4 m^2) to have higher levels of BDNF than pigs with the least amount of space (0.3 m^2), and pigs with a space allowance of 0.35 m^2 were intermediate ($p=0.11$, Table 7). In contrast, Hp levels were higher in pigs with the most amount of space (0.4 m^2) compared with 0.3 m^2 and 0.35 m^2 pigs ($p<0.1$). Over time (days 6 to 39), urea and ALP levels increased ($p<0.001$) across treatments while Hp and BDNF levels decreased ($p\leq0.001$, Table 7). There was also a tendency for CRP levels to decrease over time (p<0.1).

Table 7. Blood markers[1] of weanling pigs as affected by space allowance

	Space Allowance					
Item	$0.3m^2$	$0.35m^2$	$0.4m^2$	Txt	Day	Txt x Day
ALP						
Day 6	312.3 ± 16.0	305.2 ± 15.9	329.4 ±15.9	0.988	<0.001	0.089
Day 39	370.4 ± 14.5	378.0 ± 14.5	349.0 ± 14.0			
BDNF						
Day 6	4.20 ± 1.2	5.96 ± 1.1	7.87 ± 1.2	0.109	0.001	0.451
Day 39	2.72 ± 0.8	2.78 ± 0.9	3.83 ± 0.8			
C-RP[2]						
Day 6	7.0 (4.3-10.5)	6.5 (4.0-9.8)	9.3 (0.1-13.1)	0.125	0.108	0.990
Day 39	5.4 (3.8-7.2)	5.2 (3.6-7.0)	7.7 (5.9-9.8)			
Cortisol						
Day 6	16.3 ± 2.6	14.1 ± 2.3	16.5 ± 2.5	0.165	0.668	0.163
Day 39	12.6 ± 2.8	14.8 ± 2.4	21.9 ± 2.6			
Haptoglobin						
Day 6	0.80 ± 0.1	0.74 ± 0.1	0.84 ± 0.1	0.083	<0.001	0.151
Day 39	0.41 ± 0.1	0.51 ± 0.1	0.76 ± 0. 1			
Urea[3]						
Day 6	2.74 ± 0.2	3.26 ± 0.2	2.98 ± 0.2	0.486	<0.001	0.594
Day 39	4.93 ± 0.3	4.97 ± 0.3	4.75 ± 0.3			

[1] Data are given as raw means ± SE.[2] Square root transformed for analysis and then back transformed and presented with lower and upper confidence intervals in parentheses. [3] Analysis includes sex. Females tended to have higher levels of Urea than males (4.11 ± 0.1 vs 3.76 ± 0.1 mmol/L respectively, p = 0.090).

4.4 Injury scores

The scores used to subjectively quantify the level of aggression of pigs differed over time, but not between treatments, with the exception of day 39 where pigs with a greater space allocation ($0.4m^2$) had a tendency (p<0.1) to have less scratches and redness than pigs with 0.35 m^2 and 0.3 m^2 space allocation pigs (Figure 5). Across treatments, scratch scores were the highest on days 1 and 6 after weaning, followed by day 39 and then day 0 (Figure 5, p<0.001). Redness scores were the highest 24 hours after weaning compared with the other timepoints (p<0.001, Figure 5).

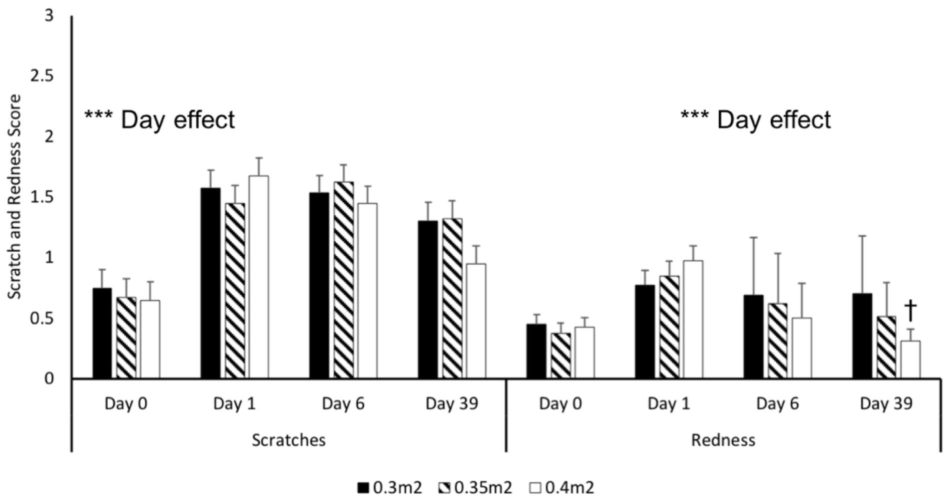

Figure 5. Scratch and redness scores (mean ± SE) and on different days relative to weaning for weaner pigs exposed to different space allowances. Redness scores were tested non-parametrically (Kruskal Wallis to compare between treatments on different days and Friedman test to compare across days). † indicates a trend between treatments.

4.6 Escherichia coli *counts*

There were no treatment differences in commensal *E. coli* counts on day 7 of the experiment (0.3 m^2: 5.7 ± 0.3, 0.35 m^2: 6.2 ± 0.3 and 0.4 m^2 pens: 5.9 ± 0.3 log CFU/gram, p>0.05). Similarly, there were also no treatment differences on day 14 (0.3 m^2: 5.2 ± 0.3, 0.35 m^2: 4.8 ± 0.3 and 0.4 m^2 pens: 4.4 ± 0.3 log CFU/gram, , p>0.05). Commensal *E. coli* levels for individual pens by treatment are presented in Figure 6A and B.

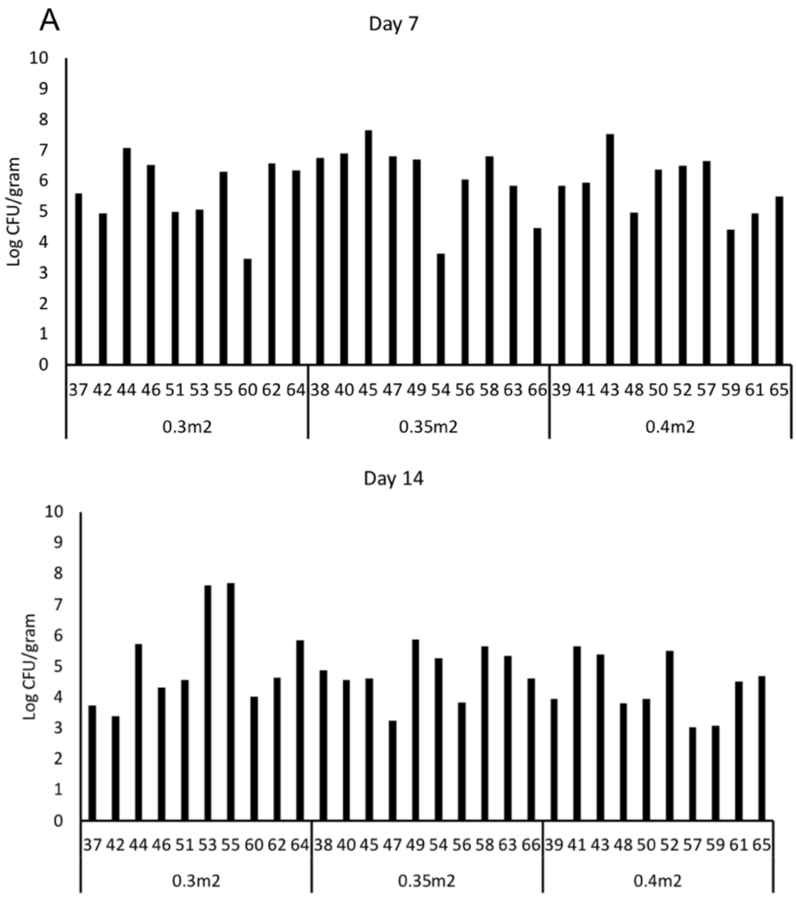

Figure 6. Commensal E coli counts for pens with different space allowances achieved by adjusting the number of pigs in the pens on days 7 (A) and 14 (B) after weaning.

5. Application of Research

The aim of this study was to investigate management strategies in the nursery to improve the social environment for weaner pigs and ultimately maximise post-weaning performance. Overall the study showed that sorting pigs by body weight resulted in reduced aggression in light pigs, but increased aggression in heavy pigs, and ultimately no improvement in post-weaning performance compared with pigs housed in heterogeneous body weight groups. Additionally, the results from part two of the study highlighted that farms would benefit from placing more focus on maximising space allowance in weaner pigs with results demonstrating an improvement in health and growth with increasing space allowance.

Sorting pigs by body weight (light, medium and heavy) is a time-consuming process for staff and in the current study it took nearly four times as long to complete compared with not sorting by body weight. Many farms perform this practice based on the assumption that lighter pigs will perform better without the potential threat of bullying. Results from the current study confirmed there was no difference in performance between pigs that had been sorted by body weight and pigs that had not been sorted, with the exception of heterogeneous pens which tended to grow faster in the second week of the experiment. Therefore, overall productivity was not negatively affected by variability in weight in the pen. Furthermore, the heavy pens at weaning were also heavier at every subsequent time point during the experiment, and the light pens remained the lightest. This was also reflected in the overall growth and feed intake data, and it is consistent with other studies that have confirmed weaning weight as an important determinant for post-weaning performance (McConnell et al., 1987, Bruininx et al., 2001, Lawlor et al., 2002, Dunshea et al., 2003). The improvement in FCR in the light pigs was unexpected and may have been due to less feed wastage compared with the medium and heavy weight class pens.

In contrast, providing weaner pigs with more space than what is stipulated the in The Model Code of Practice for the Welfare of Animals: Pigs (Third Edition) caused higher growth rates. Pigs offered one third more space finished the nursery phase nearly 1.5 kg heavier than pigs with the minimum space requirements. Gonyou et al. (2006) proposed a predicted optimal threshold for space allowance using an allometric formula which uses average body weight and a constant *k* value where, $k = m^2/(BW,kg)^{0.67}$. Gonyou et al. (2006) concluded that when *k* drops below 0.0336, ADG and ADFI will be decreased, which has been supported by other grower/finisher studies (Flohr et al., 2016, Thomas et al., 2017, Carpenter et al., 2018). The average weight of the pigs (based on average pen weights) at the end of the current study was 25.2 kg. Based on this weight, all the treatment groups in the current study were above a *k* value of 0.0336; however, performance differences were still seen. Roy (2017) examined optimal space allowance for weaner pigs and reported an increasing improvement in ADG between days 21 and 45 after weaning for *k* values of 0.0335, 0.037 and 0.039, which is consistent with the results of the current study. As well as affecting ADG and body weight, providing less than optimal space allowances also increases the risk of immune suppression and disease susceptibility while also increasing damaging behaviours (Roy, 2017). In the current study, the highest removal rates were seen in the treatment group with the least amount of space (0.3 m^2). However, it should be noted that the highest number of removals occurred in the second week of the experiment (days 7 to 14). During this time of the experiment, space allowances and *k* values were generous relative to the average weight of the pigs, therefore the improvement in removal rate in the 0.35 m^2 and 0.4 m^2 treatment groups may have been due to the fact there were less pigs in the pen rather than an effect of space allowance (McGlone and Newby 1994, Wolter et al., 2000, 2001, Olsen et al. 2018). However, the range of pigs per pen was much narrower (between 30-40 pigs per pen) in the current study compared with the previous studies listed.

In part one of the study, treatment differences in injury scores were not reflected in the results from blood markers. The increases in acute phase protein production (Hp and CRP), which occurred over the first week after weaning, is consistent with the physical, psychological and environmental stresses associated with weaning (Kim et al., 2013), and the increase in urea likely represents the metabolic waste of amino acids from the immune response with a stronger response in light weight pigs (Kim et al. 2016). The same differences were not appreciated over time in part two likely due to the longer period of time between the samples. Injury scores were highest 24 hours after weaning in both studies. The fact that scratch scores peaked 24 hours post-weaning for light and medium pigs, but peaked and remained at the same level on day 6 for heavy pigs in part one of the study, highlights that heavy pigs are more likely to fight. The scratch and redness score results suggest that light pigs may still benefit from being housed with similar sized pigs to reduce potential bullying, while body weight asymmetry in pens with pigs from the heavier cohort may reduce injury scores possibly due to a quicker establishment of hierarchy (Rushen, 1987). However, in saying this, the negative impact of aggression would have been transient given hierarchies are generally determined in the first two to three days after weaning (Meese and Ewbank, 1973). Furthermore, space did not have an impact on injury scores, even on the last day of the experiment when space could have been compromised for some pigs. This result once again highlights the point that social hierarchies would have been well established between pigs after 39 days in the pen together (Meese and Ewbank, 1973). However, space did have an impact on BDNF results. Brain derived neurotrophic factor has been linked to improved cognition (Novkovic et al., 2014) and greater stress resilience (Berton et al., 2006), with a study by Rault et al. (2018) reporting pigs that received enrichment during lactation and after weaning had significantly higher BDNF levels than pigs raised in a barren environment. The results from part two of the study suggest that the extra space allowance in the 0.4m^2 treatment group had a positive impact on pig welfare in addition to performance.

6. Conclusion

In conclusion, maximising space allowance for weaner pigs in the later part of the nursery period caused improved performance and welfare as measured by markers of cognitive state and removal rates. In contrast, sorting pigs by body weight at weaning took longer with no improvement in post-weaning performance. The injury scores results suggested that light pigs may still benefit from being housed with similar sized pigs to reduce potential bullying, while body weight asymmetry in pens with pigs from the heavier cohort may reduce injury scores possibly due to a quicker establishment of hierarchy. Although, the benefits of doing this would be minimal since hierarchies are established over a short period of time.

7. Limitations/Risks

In part one of this project, the weight categories (light, medium and heavy) for the homogeneous pens were achieved by visual assessment. This proved to be an acceptable technique as evidenced by differences in average starting weights between the homogeneous groups (see section 3.3). In contrast, heterogeneity was achieved in the current study by staff opening the gate and allowing the first 40 pigs to pass through into the pens. The commercial nature of the trial meant that only pen weights were collected and not the weight of individual pigs. This means that the standard deviation within each of the pens was not calculated to confirm heterogeneity compared with the homogeneous pens. The authors are confident, though, that the methodology reflects what would happen in commercial practice and that heterogeneity was achieved. In addition to confirming heterogeneity at the start of the experiment, individual weights of experiment pigs would have also enabled the authors to calculate the coefficient of variation at the end of the nursery phase. A low coefficient of variation at the end of the nursery phase is often desired since shed productivity is dependent upon emptying rate and efficiently meeting the narrow weight ranges as specified by the abattoirs. However, previous studies in finisher pigs have confirmed that regardless of sorting by body weight or not, there is no difference in end-point weight variability and that pigs grow to common end-point variability (Tindsley and Lean, 1984, Gonyou, 1998, O'Quinn et al., 2001). Therefore, it would have been interesting to confirm if similar results apply to younger age groups such as weaners. In addition to tracking the injury scores and blood markers in a subsample of individually identified pigs, the specific performance of the different weight classes within the heterogeneous pens in part one of the study could have also been examined with the collection of individual weights from this subset of pigs. A previous study has confirmed that that heavy pigs in homogeneous pens had 57% lower initial feed intake than its heterogeneous counterparts whereas light and middle weight pigs were not affected by weight distribution within groups (Bruininx et al., 2001).

The health challenge experienced during part two of the study resulted in a removal rate of 5.5%, which was lower than the removal rate recorded for part one of the study (7.2%). The reason for the higher removal rate in part one of the study compared with part two is that more strict criteria were placed on the farm staff with regard to removals in part two of the study since the treatment groups were defined by the number of pigs in the pen. However, despite more strict criteria, 58 pigs still had to be removed from part two of the study mostly due to the experiment shed experiencing an unusually high number of wasting pigs two weeks after weaning, possibly associated with failure of porcine circovirus virus type 2 vaccination. Every time a pig was removed from an experiment pen in part two of the study it had to be replaced with a pig of a similar size. This methodology was not ideal since the introduction of a new pig into the pen would result in aggression, which could have affected performance in the short term (McGlone et al., 1985). Further to this, the addition of new pigs to the pens could have impacted on overall pen performance if a substantial number of pigs were removed. However, without the option of changing the size of the pen, this methodology was unavoidable.

8. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

1. Sorting pigs by body weight at weaning does not result in long term benefits for the nursery phase as measured by performance and markers of aggression, health and welfare. Futhermore, sorting pigs by body weight adds additional labour costs.
2. Maximising space in latter part of the nursery period results in positive outcomes with respect to growth, body weight, health and welfare.

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