Rearing in female-only groups and dietary mineral supplementation improves sow welfare in the early parities and lifetime performance

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ABSTRACT: The lifetime performance of commercial sows relies on longevity, which is dependent on good health and reproductive performance. However, there is a high rate of wastage of sows in the early parities, which is influenced by the way they are managed and housed during rearing. This study investigated the carry-over effect of gilt rearing strategy on the measures of welfare and performance. Eighty sows were reared using a two by two factorial design: rearing group composition [GC; female-only (FEM) or mixed-sex (MIX) from weaning] with or without supplementary minerals (CON = control diet; SUPP = control + Cu, Zn, and Mn) from 5 wk into the finisher stage. Once served, gilts were managed in a dynamic group gestation pen and fed a standard gestating sow diet. Locomotory ability was scored (0 to 5) and salivary cortisol measured five times during the first gestation, and human approach tests were carried out on day 108. Hooves were scored for injuries and legs for bursas at day 70 of the first gestation, at first weaning, and at the second farrowing. Sow behavior in the hoof scoring crate (movement, vocalization, and handling ease) was also recorded. The number of piglets born alive and dead during the first five parities was recorded as was the performance of the first litter to finish. Data were analyzed using general or generalized linear mixed models, as appropriate, using SAS (v 9.4). There was no effect ($P > 0.05$) of rearing treatment on locomotory ability, bursa score, the total number of piglets born, or on offspring growth. However, there was an interaction between GC and supplementary minerals ($P < 0.05$) on salivary cortisol levels with MIX × SUPP sows having the highest levels. Total hoof scores and heel erosion scores were higher in sows reared in MIX groups ($P < 0.01$), and CON sows tended to have higher horizontal crack scores ($P = 0.06$). Sows from MIX kicked more at weaning than FEM ($P < 0.05$) and tended to be more fearful in the forced human approach test ($P = 0.1$) where they are scored on their reaction to being approached. They also had more stillborn piglets across all five parities than FEM ($P < 0.05$). Overall, rearing replacement sows in FEM groups and dietary mineral supplementation had minimal but beneficial effects on their subsequent welfare and performance.

Key words: gilt rearing, group composition, longevity, mineral supplementation, sow welfare

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INTRODUCTION

Replacement gilts are the most valuable animals in the herd, as they are an investment with the potential to generate a profit (Stalder et al., 2003). Approximately, 40% to 50% of sows are culled before their third or fourth parity (D'Allaire et al., 1987; Boyle et al., 1998; Schenck et al., 2008). However, they have not covered their replacement costs by this time (Stalder et al., 2003; Schenck et al., 2008). Rearing conditions for replacement gilts can affect the development of the skeletal and other systems with subsequent effects on their health and performance in later life (Dewey, 2006). Many studies show that the majority of skeletal development occurs in young animals, which indicates that the most important time for preventing muscular-skeletal issues is during early development (Loitz and Zernicke, 1992; Umemura et al., 1995; Iwamoto et al., 2000). Nutrients and management factors affect issues of structural integrity (Nakano et al., 1987; Crenshaw, 2006; Ytrehus et al., 2007; Crenshaw et al., 2013). Indeed Dijkhuizen et al. (1989) suggested that the greatest economic losses related to culling were due to locomotory problems.

Trace minerals Copper (Cu), Zinc (Zn), and Manganese (Mn) are important for maintaining fertility and claw integrity (Ballantine et al., 2002), and they also have roles in immune function (Tomlinson et al., 2004). Several studies demonstrate the benefits of supplementing sows with minerals during gestation (Anil et al., 2009; Ferket et al., 2009; Nair, 2011). There is less work investigating how supplementation during rearing could impact welfare, performance, and longevity. Nevertheless, a gilt rearing diet should clearly be fortified with specific minerals to aid reproduction stimulation and to establish strong bones and legs for a lengthy breeding life (Close and Cole, 2000).

Housing during rearing could also have long-term negative implications for sow welfare and longevity. In Ireland, approximately 90% of farms rear their own replacement gilts, and these are often reared in the same pens as finisher pigs and kept in mixed-sex groups up to slaughter age (Boyle and Bjorklund, 2007; Quinn, 2014; C. Carroll, personal communication). In Ireland, pigs are not castrated, and as such replacement gilts are exposed to the high levels of aggressive and mounting behavior, which entire male pigs perform (O'Driscoll et al., 2013; Teixeira and Boyle, 2014). These behaviors increase the risk of injuries, such as limb and cartilage damage (Hartnett et al., 2019b), which are associated with lameness.

Osteochondrosis (OC) is a chronic degenerative joint disease (Dewey, 2006; Nalon et al., 2013), which reduces sow longevity. However, OC lesions do not always produce clinical signs of pain and discomfort, as is the case in horses with severe pathological damage (Jeffcott, 1996). There is already significant structural damage present in the joints of gilts at breeding age (Hartnett et al., 2019b). Although we did not find any association between the level of damage observed and the locomotory ability of these young animals, it is known that OC is associated with pain (Frantz, 2006). Thus, it can be assumed that progressive damage to the joints could ultimately progress to lameness in later life and potentially chronic stress associated with chronic pain (Kovács et al., 2015). Prolonged stress and associated elevated cortisol levels can, in turn, disrupt reproduction in female pigs, which is a further risk factor for culling and reduced longevity (Turner et al., 2005).

A stressful prenatal environment can lead to permanent postnatal changes in offspring metabolism (Armitage et al., 2004; Wu et al., 2006; Hill et al., 2010). Both Haussmann et al. (2000) and Otten et al. (2000) indicated that prenatally stressed piglets from sows that were administered adrenocorticotropic hormone (ACTH) exogenously tended to be lighter than piglets from gilts not exposed to ACTH. Prenatal stress is also associated with low birth weights in rodents and humans (Welberg and Seckl, 2001). With regard to lameness specifically, Parada et al. (2017) found that this disorder in pregnant gilts had negative effects on their offspring's growth and behavior.

The aim of this study was to investigate the carryover effects of rearing replacement sows in female-only groups and of a trace mineral (Cu, Zn, and Mn) supplemented diet, on aspects of their welfare in their early parities and on their lifetime performance. We previously showed that these strategies had benefits for several aspects of gilt welfare up to breeding age (Hartnett et al., 2020), so we hypothesized that this would improve gilt welfare during the first pregnancy and have long-term benefits for longevity and reproductive performance. A secondary hypothesis was that offspring from gilts reared in female-only groups and supplemented with dietary minerals would have higher birth weights and improved performance from birth to finish.

MATERIALS AND METHODS

Care and Use of Animals

This study was carried out in the 200-sow unit at the Pig Development Department in Moorepark, Fermoy, Co. Cork, Ireland, between December 2016 and August 2017. The experimental work was authorized by the Teagasc Animal Ethics Committee (Approval no: TAEC136-2016) and licensed by the Health Products Regulatory Authority (License no: AE19132-P057).

Experimental Design

Details of the experimental design including the treatments applied during the gilt rearing stage are outlined in Hartnett et al. (2020). In brief, a two by two factorial arrangement was applied to 288 gilts. The gilts were born from 52 sows, which had been served using maternal line semen from Landrace sires (0153H Longo and 0096H Grande from Hermitage Pedigree Pigs Ltd., The Hermitage, Sion Road, Kilkenny, Ireland). They were born across four replicates, each replicate being 3 wk apart.

The first factor in the experiment consisted of group composition (GC), whereby half of the gilts were reared in female-only (FEM) groups of 12 animals from weaning onwards, and the other half were reared in mixed-sex (MIX) groups (6 females and 6 males). The second factor consisted of mineral supplementation; half of each of the GC treatments was fed a standard finisher diet until breeding age (CON), and the other half were fed the same diet, but with supplementary levels of Cu, Mn, and Zn applied (SUPP) from 17 wk of age (5 wk into the finisher stage) until breeding age. The CON diet represented a typical standard finisher diet used on Irish commercial pig farms (50% barley, 33.5% wheat, and 12% soybean oil). The SUPP groups were fed the same diet, but supplemented with Availa Sow minerals (Zinpro Corp, Eden Prairie, MN, USA), which provided additional Cu, Zn, and Mn. Levels of CU, Zn, and Mn for both diets, and the percentage supplied relative to the recommended amounts for gestating and lactating sows (NRC, 2012), can be seen in Table 1. All feed was in dry-pelleted form (3 mm).

Flooring in the weaner stage was plastic, and the finisher stage was concrete. At slaughter age, half of the pen mates (all males and 50% of the females) went to the abattoir. The remaining 182 gilts stayed in the same pens (6 females per pen) until breeding age when 102 of these gilts were sent for slaughter to allow for postmortem limb analysis. The remaining 80 gilts were kept for breeding as replacements.

Table 1. Mineral inclusion rates in the CON diets (fed to all pigs) and the SUPP diet (from day 117.5 ± 0.6 of age) finisher pigs[a]

	NRC, mg/kg[b]	CON, mg/kg	SUPP, mg/kg	CON, %[c]	SUPP, %[c]
Mn	25	25.1	51.45	101	206
Zn	100	55.6	122.29	56	122
Cu	10	4.5	17.89	45	179

CON = control; SUPP control + Cu, Zn, and Mn ; FEM = female; MIX= mixed.

[a]Values are expressed as mg/kg (i.e., parts per million, and as a % of NRC recommendations for gestating and lactating sows

[b]NRC gestating and lactating sow requirements.

[c]Values in the control and mineral diet as a percentage of the NRC recommendations.

Gestation Management

Twenty gilts from each rearing treatment group were kept for breeding (n = 80). A trained technician served the gilts twice using terminal line semen (Hermitage Genetics, Ireland) by artificial insemination, firstly at the onset of standing estrus and then 24 h later. Hereafter, they are referred to as sows. Each batch of sows was served 3 wk apart.

After service, sows were housed in a dynamic group of approximately 120 sows. The building had fully slatted concrete passageways between insulated solid concrete-floored lying bays, and the temperature was maintained at 18 to 20 °C by mechanical ventilation. The sows had access to two electronic sow feeders (ESF; Schauer Feeding System, Prambachkirchen, Austria) that recognized each animal by a transponder tag programmed to her individual daily feed allowance. Sows had access to ad libitum water from single-bite drinkers in the ESFs and five separate drinker bowls.

Approximately, 2 wk prior to their "due to farrow" date, pregnant sows were moved to a smaller pen for management purposes (ease of inspection and ease of movement to farrowing crates) for 1 wk. The feed system, water access, heating, and ventilation were the same as in the larger area described above. One week prior to farrowing sows were moved to the farrowing accommodation where they were penned in individual farrowing crates, in rooms housing either 7 or 14 sows. In the farrowing room, the temperature was approximately 24 °C at the time of farrowing, thereafter gradually reducing to 21 °C by weaning age (day 27 postpartum).

Heating was generated by hot water pipes (controlled via computer). In all houses, there was artificial lighting (on from 0700 to 1700 h). There was also natural lighting through the windows. The light to darkness cycle was approximately 12:12 (h) to allow for normal circadian rhythm.

Sows were provided with wooden chew posts in the gestation housing and a length of synthetic rope in the farrowing crate. Sows were inspected daily, and sick/injured animals were treated immediately; all antibiotic treatments were recorded.

Live-Weight and Back-Fat Thickness

All animals were weighed individually on days 7 and 108 of gestation and at weaning using an electronic sow scales (EziWeigh 7i, O′Donovan Engineering, Co. Cork, Ireland). Back-fat thickness was measured on days 7 and 108 of gestation and on day of weaning using a Renco Lean Meter back-fat scanner on the P2 spot (last rib, 65 mm down the dorsal middle line) on both sides of the body. Both recordings were averaged to provide a single back-fat measurement for each animal at each time point.

Locomotory Ability

Sows were locomotion scored approximately every 3 wk (22.8 ± 8.43 d) during the first gestation and at weaning (day 27 postpartum) after their first litter. All sows had five inspections (days 52, 71, 92, and 108 of gestation, and weaning day 143). Locomotory ability was scored while the sows walked on solid concrete for a distance of approximately 30 m, from the front, rear, and side of the animal. All observations were carried out by one trained observer. Locomotion was assessed using the scoring system of Hartnett et al. (2019b), which was adapted from Calderón Díaz et al. (2013), and ranged from 0 (perfect locomotion) to 5 (unable to move).

Salivary Cortisol

Saliva samples were collected on four occasions during gestation (on days 51, 71, 93, and 107) between 0930 and 1000 h on the morning of collection. A fifth sample was also collected the morning after entering the farrowing house. Sows remained in the home pen for saliva sampling. They were encouraged to chew on a large cotton bud (Salivette, Sarstedt, Wexford, Ireland) until it was thoroughly moistened (approximately 30 to 60 s). The samples were placed in tubes and centrifuged for 15 min at 2,500 × g, and then stored at −20 °C until analysis.

Saliva samples were analyzed using a commercially available cortisol assay kit (Salimetrics Europe Ltd., Suffolk, UK). Cortisol was detected at a minimum concentration of <0.003 µg/dL. Inter-assay coefficient of variation (CV; n = 24) = 4.69% and intra-assay CV (n = 794) = 7.68%.

Hoof Lesion Scoring and Bursitis

Hoof lesion scoring was by visual inspection on days 70 and 109 of gestation and on the day of weaning of the first litter. On day 109 of gestation, the sows' hooves were scored while they were lying down in the farrowing crates. For all other inspections, the sows were raised 0.75 m above the ground using a hydraulic chute (FeetFirst Sow Chute; Zinpro Performance Minerals, Eden Prairie, Minnesota, USA). The medial and lateral toes, medial and lateral dewclaws, and sole and heels of both hind feet were inspected, and the severity of the following lesions scored: heel erosion, heel-sole separation, white line separation, dewclaw length, dewclaw cracks, toe length, and vertical and horizontal toe cracks. The scoring system was a modified version of the FeetFirst claw lesion scoring guide from Zinpro Corporation. Details of the scoring system are described in Table 2.

While the animals were raised in the crate on day 70 of gestation and on the day of weaning, the hind legs were palpated, and bursa was scored on their size as follows (with 3 being the most severe): 0 = none, 1= hazelnut, 2 = walnut, and 3 = hens' egg (Mouttotou et al., 1998). If more than one bursa was present, each was scored separately.

Sow Behavior

We monitored the behavior of sows in response to the hoof lesion scoring procedure in mid-gestation and at the first weaning. The ease with which the sow entered the crate, the amount of kicking she performed during the examination, and whether or not she vocalized while in the crate were scored according to the descriptions in Table 3, which were adapted from D'Eath et al. (2009).

At day 106 of gestation, all gilts underwent a forced human approach (FHA) and forced human touch (FHT) test, as described by Kongsted (2006). These were carried out in the home pen. For the FHA, the researcher entered the pen, approached each gilt, and squatted approximately 20 cm in front of her for 30 s. The behavior of the gilts was

Table 2. Claw lesion scoring system[a]

Scores	Toe length	Dewclaw length	Dewclaw injuries	Heel over-growth and erosion	Heel sole crack	White line damage	Horizontal wall crack	Vertical wall crack
0	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
1	≥1 toes slightly longer than normal: difference detected only when the sole is pressed flat	Slightly longer than normal	Short crack or cracks	Flaking of the skin of the heel	Separation at the juncture has just begun; length of separation <0.5 cm	Shallow and/or short separation along white line	Hemorrhage evident, short/shallow horizontal crack in toe wall	Short/shallow vertical crack in the wall
2	≥1 toes moderately longer than normal: difference obvious without flattening sole	Significantly longer than normal	Long but shallow crack or cracks in dewclaw wall	Slight overgrowth and/or erosion in soft heel tissue	Separation slightly longer than score 1, but still shallow	Long separation along white line	Long but shallow horizontal crack in toe wall	Long but shallow vertical crack in wall
3	≥1 claws much longer than normal and/or the toes are torn and/or partially or completely missing	≥1 claws much longer than normal and/or the claws are torn	Multiple or deep crack or cracks in dewclaw and or/partially or completely missing	Numerous cracks with obvious overgrowth and erosion	Long separation at the juncture, which is deeper than score 2	Long and deep separation along white line	Multiple or deep horizontal crack or cracks in toe wall	Multiple or deep vertical crack or cracks in the wall
4	≥1 toes significantly longer than normal			Large amount of erosion and overgrowth with cracks	Long and deep separation at the juncture			

[a]Zinpro Corporation, USA.

Table 3. Scoring system for the reaction of sows to entering and being confined in the hoof scoring crate[a]

Aspect of behavior	Score	Description
Movement into crate	0	Pig walks voluntarily into crate
	1	Short, single push needed to get pig into crate
	2	Constant pushing required
	3	Total refusal by the pig
Kicking	0	None—pig relaxed
	1	Intermittent kicking
	2	Continuous kicking
Vocalizations	0	No vocalizations while confined
	1	The sow vocalized at least once while confined

[a]Adapted from D'Eath et al. (2009).

scored as per Table 4. Immediately after the FHA was complete, the FHT test commenced. The researcher attempted to touch the gilt's neck and recorded the gilt's reaction according to Table 4.

The final behavior observation was carried out when gilts were moved to the farrowing pens. As soon as the head reached the corner of the pen, a timer was started and the time it took the gilt to enter the farrowing crate was recorded.

Sow Performance at First Farrowing

Sows that became pregnant at first service were monitored at farrowing (day 114.6 ± 1.1 of gestation). Data collected included numbers of piglets born alive (BA), stillborn, and mummified. At birth, the weight and sex of each piglet were recorded, and all received an ear tag for identification. Piglets were weighed again at weaning age (27 d old). Cross-fostering was kept to a minimum, and piglets were cross-fostered within treatment.

Lifetime Performance

All performance data from the time of first service until the fifth farrowing were recorded and managed using PigChamp software (PigChamp Inc., Ames, Iowa, USA). Recorded data included dates of service, farrowing, weaning, and the number of piglets BA, and dead at each farrowing. At each parity, sows that did not become pregnant after two services were excluded from the dataset,

Table 4. Scoring system for the FHA and FHT tests that gilts underwent on days 106 and 107 of gestation

Test	Score	Definition
FHA	1	Fled when human was >1 m from her
	2	Gilt turned head away, or moved a few steps from human, once the human got into the test position. The gilt stayed in that area or continued what she was doing for the remainder of the test period.
	3	Gilt turned head away or moved a few steps but initiated contact with the human within the test period.
	4	Gilt did not react to the human approach. Remained in the same position or continued with its own activity.
	5	Did not react to the human approach but initiated contact with the human.
	6	Approached the human and initiated physical contact.
FHT	1	Pig fled before human-made contact, with or without squealing, stood still holding head stiff while keeping eyes fixed.
	2	Pig walked away without vocalizing.
	3	Pig stood calmly, approached the human.

so as to mimic practices on a commercial pig unit. The age of the animal and the reason for culling were recorded.

Offspring Performance

At weaning, piglets were assigned to pens of 12 animals within treatment. Pigs were assigned to pens on the basis of sex and weight and from approximately four sows per treatment combination (3.7 ± 1.1 sows contributing piglets per pen). As much as possible, equal numbers of male and female pigs were assigned to each pen (5.36 ± 1.03 males per pen across all treatments). The average weaning weight for pigs included in this part of the experiment was 7.36 ± 1.5 kg. At weaning, there were a total of nine pens of piglets from sows that had been reared in FEM pens with a standard finisher diet, and eight pens each from sows reared on the other three treatment combinations. Weaner pens were 2.4 × 2.6 m with a fully slatted plastic floor. The temperature was maintained by automatic heating and negative pressure mechanical ventilation at 28 °C in the weaner house immediately postweaning. It was lowered by 2 °C every 2 wk thereafter.

After approximately 7 wk (45.9 ± 2.6 d) in the weaner accommodation, pigs were moved in their groups to the finisher accommodation (concrete slatted floors 4 × 2.4 m). In the finisher house, the temperature was maintained at 20 °C with the same ventilation system as in the weaner house, only without heating. All rooms were naturally illuminated by the windows. There was also artificial lighting (150 lux in the weaner house and 130 lux in the finisher house) for 10 to 12 h/d. Pigs remained in the finisher accommodation for approximately another 11 wk (79.0 ± 0.6 d), before being sent to slaughter at a target weight of ~110 kg. Only pens that had at least 11 pigs remaining by the time of slaughter were retained in the analysis to control for the effect of space allowance on performance. Thus, the analysis included seven pens of pigs from both sows that had been reared in FEM pens with a standard finisher diet, from sows reared in MIX pens on the SUPP diet, eight pens from sows reared in FEM pens on the mineral diet, and six pens from sows reared in MIX pens on the CON diet.

Pigs were weighed (not fasted) at the move from the weaner house to the finisher house and on the day before slaughter. Throughout the production cycle, the pigs were fed ad libitum by a single-spaced wet-dry feeder with dry pelleted feed (one nipple drinker inside the feeder), with another nipple drinker providing water (i.e., two drinkers in the pen in total). Feed delivered to each pen in the weaner and finisher stage was recorded daily from the feed system and downloaded twice per week. These data were used to calculate the average daily feed intake (ADFI) at the pen level. Combined with pen weights at weaning, the move to the finisher house and at the slaughter date, average daily gain (ADG), and feed conversion efficiency (FCE; ADFI / ADG) for both weaner and finisher stages were calculated.

Statistical Analysis

Data were analyzed using the Statistical Analysis Systems statistical software package version 9.4 (SAS Institute Inc., 1989). The sow was used as the experimental unit for live weight (LW), locomotory ability, salivary cortisol, hoof and bursa scores, and performance data. Degrees of freedom were estimated using Kenwood–Rogers adjustment. Data are presented as LSmeans and standard errors. The Tukey–Kramer adjustment was used for multiple comparisons where least squares means (LSmeans) were determined. PROC UNIVARIATE was used initially for evaluating data distribution. For all models, fixed effects included GC (MIX vs. FEM), dietary treatment

(CON vs. SUPP), and the interaction, as well as replicate. Inspection day was included as a fixed effect for sow LW, back fat, cortisol and hoof score analysis, and farrowing number for analysis of the number of piglets BA. For cortisol analysis, plate was included in the analysis as a random effect. Results were deemed statistically significant when α level was ≤ 0.05, and a tendency was considered when the α level was between 0.05 and 0.1.

General linear mixed models (PROC MIXED) were used to analyze LW, back-fat cortisol, and total hoof score data, and residuals were examined to verify normality and homogeneity of variances. Generalized linear mixed models were used for locomotion and bursitis data, individual hoof disorders, and the behavior tests (PROC GLIMMIX and PROC GENMOD).

For analysis of salivary cortisol, we carried out two analyses; 1) the four sampling points while in the group pen and 2) cortisol level the morning after entering the farrowing crates. For the latter, the sows cortisol level the morning before moving to the farrowing crate (i.e., the last sampling point in the group pen) was considered a covariate. We used a log transformation to normalize the data. Only sows that became pregnant on their first service were included in the analysis ($n = 56$).

The individual hoof disorders were also analyzed using generalized linear models (PROC GENMOD) as the data were ordinal, using a similar model to that used for locomotion scores. The maximum score present for each sow on each inspection day was the value included in analysis.

Locomotory behavior, sow behavior variables related to the use of the hoof inspection crate (ease of entry, kicks, vocalizations, and the sum of all measures), and the FHA and FHT were analyzed using generalized linear mixed models (PROC GLIMMIX). A multinomial distribution with a cumlogit link function was fitted. The models could not converge when data from each inspection day were included as repeated measures, and as such, each inspection day was analyzed separately, and *P*-values adjusted post hoc using a Bonferroni adjustment. The time it took to enter the farrowing crate was analyzed using a linear model (PROC MIXED).

The total number of piglets born and the number BA were analyzed across five parities using a mixed model as before. The number of piglets born dead was analyzed using a generalized mixed model (PROC GLIMMIX) with farrowing number as a random effect. Due to the low number of gilts from each treatment selected at breeding age ($n = 20$ per treatment combination), the numbers surviving through each parity were not statistically analyzed, but raw data were summarized.

RESULTS

Live Weight and Back-Fat Thickness

There was no effect of either diet or GC on sow LW or on back-fat thickness. Live weight ($P < 0.001$) and back-fat thickness ($P < 0.001$) changed over time, yet there was no interaction between time and treatment. There was a significant difference between back-fat measurement at each time point (day 7 of gestation, 16.24 ± 0.27 mm; day 108 of gestation, 17.31 ± 0.34 mm; weaning, 14.08 ± 0.37 mm; $P < 0.001$ for all comparisons).

Locomotory Ability

There was no effect of either GC or diet on locomotion scores of sows during pregnancy. The median locomotion score was 2 (interquartile range 1 – 2). In general, the sows showed good locomotion with only 13 incidences ($n = 12$ sows) of score 3 over the whole experimental period. No sow received a score of 4 or 5 throughout the experimental period.

Salivary Cortisol

There was an interaction between GC and diet ($P < 0.05$; Figure 1) on salivary cortisol levels with

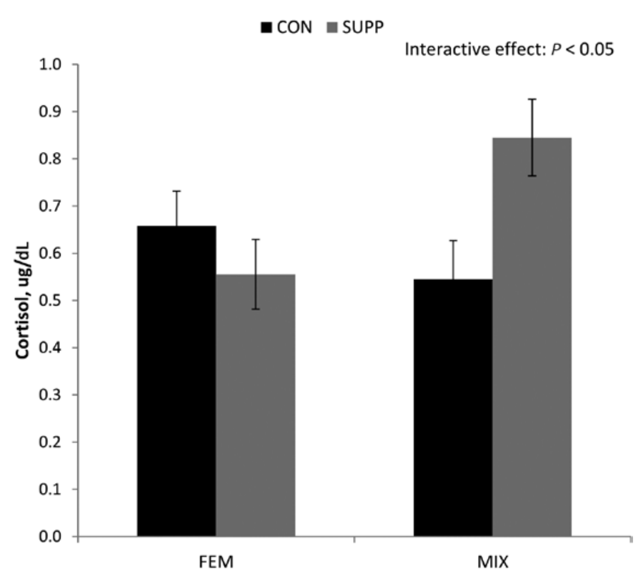

Figure 1. Salivary cortisol levels during gestation in sows reared in either FEM or MIX pens and fed a CON diet or the SUPP diet. Cortisol levels were log-transformed prior to analysis. Data are presented using back-transformed means and standard errors..

sows reared in MIX groups and on a SUPP diet having the highest cortisol levels during pregnancy. Although there was an effect of the sample point on cortisol levels, there was no discernible pattern over time ($P < 0.01$). There was a tendency for SUPP sows to have higher cortisol levels than CON ($P < 0.1$).

On the first morning after moving from group housing to the farrowing house, we found no effect of either GC (back-transformed means from the log: FEM, 0.175 µg/dL vs. MIX, 0.171 µg/dL) or diet (CON, 0.175 µg/dL vs. SUPP, 0.171 µg/dL) during rearing on salivary cortisol levels.

Hoof Lesion Scores

Total hoof scores were higher (i.e., worse) in the MIX (22.20 ± 0.61) sows than in the FEM (19.72 ± 0.59) sows ($P < 0.005$) across the study period. There was also an effect of inspection day, with hoof scores increasing over time (mid-first gestation, 15.01 ± 0.53; farrowing second gestation, 17.30 ± 0.49; weaning of second farrowing, 30.58 ± 0.92; $P < 0.001$). When comparing treatment groups, we found that within the CON treatment, there was a significant increase in total hoof scores in sows reared in MIX groups ($P < 0.01$; Figure 2). In the SUPP group, we found no difference in hoof scores when comparing MIX and FEM sows ($P > 0.6$). Sows reared on the CON diet tended to have higher horizontal crack scores than SUPP sows ($P < 0.1$). Sows reared in FEM groups had lower heel erosion scores compared with sows reared in MIX groups ($P < 0.05$). There were no other effects of mineral supplementation or GC on individual hoof disorders (Table 5).

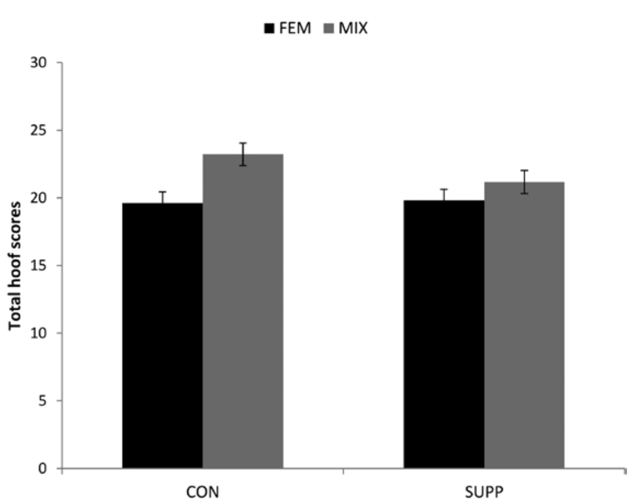

Figure 2. Total hoof scores in sows showing an effect of GC (FEM and MIX) when reared on the CON diet compared with no effect of GC when reared on the SUPP diet. Eight different aspects of hoof health (heel erosion, heel–sole separation, white line separation, dewclaw length, dewclaw cracks, toe length, and vertical and horizontal toe cracks) were scored from 0 (perfect) to 3 or 4 (extreme damage), and the scores summed to provide a total score. Thus, the higher the score, the more damage to the hoof.

Bursitis

There was no effect of GC ($P = 0.31$) or mineral supplementation ($P = 0.50$) on bursitis scores (FEM, 2.03 ± 0.05; MIX, 1.96 ± 0.05; CON 2.02 ± 0.05; SUPP, 1.97 ± 0.05).

Sow Behavior

There was no effect of either GC or mineral supplementation on the sows' movement score ($P > 0.5$ for all comparisons), or whether she vocalized or not ($P > 0.12$ for all comparisons), when being moved into and confined in the hoof scoring crate on any testing occasion. Neither did these factors have an effect on kicking at mid-gestation ($P = 0.29$; Figure 3). However, at weaning, although there was no effect of mineral supplementation on kicking score, MIX sows kicked more than FEM sows ($P < 0.05$; Figure 3). Likewise, on this test day, when all scores were added together, there was no effect of diet, but again, MIX sows tended to have higher scores than FEM sows ($P = 0.1$; Figure 4).

MIX gilts tended to have higher scores than FEM in the FHA test ($P = 0.1$; Figure 5). There was no effect on the FHT test ($P > 0.45$ for both the effect of diet and grouping strategy).

There was no effect of any factor on the time it took sows to walk into the farrowing crate. In general, this took 01:18 ± 00:08 (mm:ss) on average.

Sow Performance

A percentage of the total number of sows that farrowed in each parity and the total number of piglets born to sows in each of the treatments at each parity are provided in Tables 6 and 7, respectively. There was no effect of GC or diet on the total number of pigs BA for each sow, the number of piglets BA per farrowing, or the total number of piglets born at each farrowing (Table 8). However, there was an effect of GC on the numbers of stillborn piglets, with MIX gilts having the highest number of stillborn piglets across all five parities ($P < 0.05$; Table 8).

Offspring Growth Performance

There was no effect of GC or mineral supplementation during maternal rearing on offspring

Table 5. Individual hoof disorders of gestating sows reared in either MIX or FEM groups and on a CON diet or a SUPP diet[a]

	Diet			GC		
	CON	SUPP	*P*-value	FEM	MIX	*P*-value
Heel erosion[2]	1 (1 to 2)	2 (1 to 2)	0.92	2 (1 to 2)	2 (2 to 3)	0.05
Heel sole separation[2]	1 (0 to 2)	1 (0 to 2)	0.97	1 (0 to 2)	1 (0 to 2)	0.93
White line separartion[2]	2 (1 to 3)	2 (1 to 2)	0.17	2 (1 to 2)	2 (1 to 2)	0.43
Vertical cracks[2]	1 (0 to 1)	0 (0 to 1)	0.25	0 (0 to 1)	1 (0 to 1)	0.15
Horizontal cracks[2]	0 (0 to 1)	0 (0 to 0)	0.06	0 (0 to 0)	0 (0 to 0)	1.00
Dewclaw length[2]	1 (1 to 2)	1 (1 to 2)	0.41	1 (1 to 2)	1 (1 to 2)	0.54
Dewclaw cracks[2]	1 (0 to 1)	1 (0 to 1)	0.83	0 (0 to 1)	1 (0 to 2)	0.15
Toe length[2]	1 (1 to 1)	1 (1 to 1)	NS	1 (1 to 1)	1 (1 to 1)	NS

CON = control; SUPP control + Cu, Zn, and Mn ; FEM = female; MIX= mixed.

[a]Data are provided as median and interquartile ranges. There were no interactive effects between diet and GC.

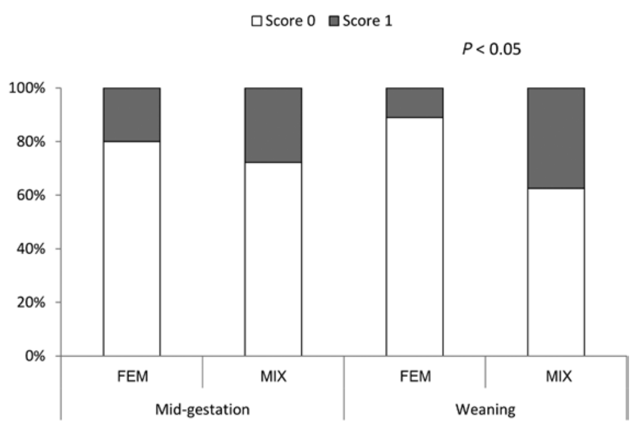

Figure 3. The percentage of gilts that either did not kick (score 0) or did kick (score 1) when they were raised above the ground in the hoof scoring chute and their hooves were handled for scoring.

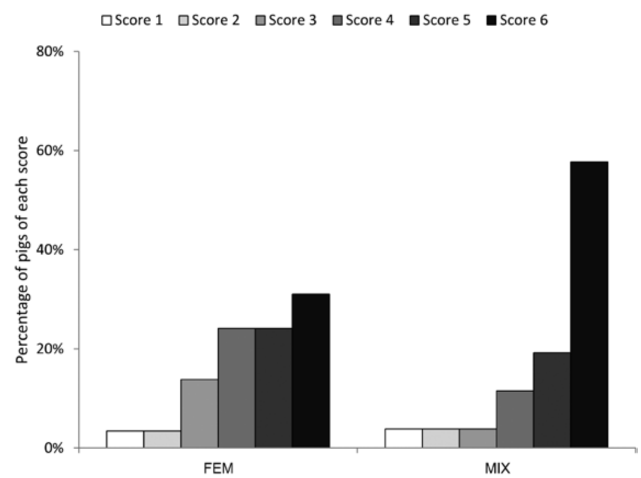

Figure 5. The proportion of gilts in each scoring category for the FHA test. A higher score indicates a greater level of fearfulness. Gilts had been reared in either FEM or MIX pens from weaning age (28 d) until finisher age (140 d of age).

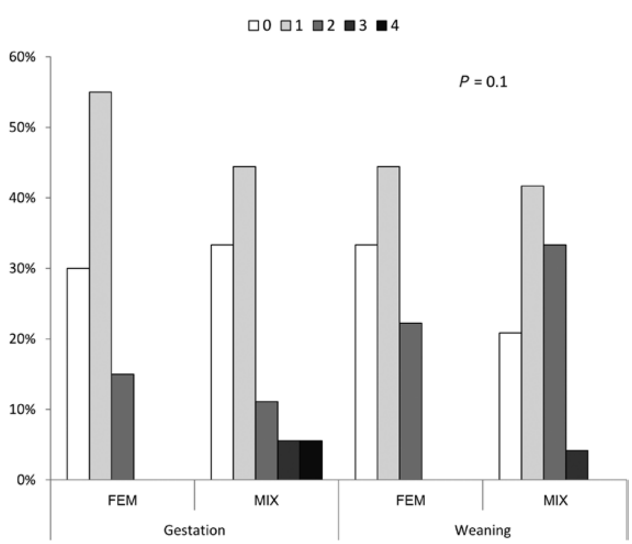

Figure 4. The percentage of gilts that fell into each category when the scores from all three reactions to the hoof crate observations were summed. At weaning, more sows that had been reared in MIX groups tended to have higher scores (i.e., worse, indicating that they were more fearful) than sows that had been reared in FEM groups.

weight at any production stage, ADG (from birth to weaning, weaning stage, and finisher stage), ADFI (weaning and finisher stage), or FCE (weaner and finisher stage). Data are presented in Table 9.

DISCUSSION

There is evidence that improvements to the management and housing of a replacement gilt during rearing could help to improve sow longevity, primarily through reduced culling for lameness (Dewey, 2006) with associated benefits to animal health and welfare. As such, this study investigated the effect of two specific improvements to gilt nutrition and management (supplementation with minerals and rearing in FEM groups) during the rearing period, having already demonstrated that these strategies had welfare benefits for gilts during the rearing period (Hartnett et al., 2019b).

Table 7. The total number of piglets BA to breeding females within each treatment at each parity[a]

	CON		SUPP		FEM		MIX	
	Total	Per sow	Total	Per sow	Total	Per sow	Total	Per sow
Piglets BA								
Parity 1	368	11.9	391	11.5	394	11.9	365	11.4
Parity 2	292	12.7	362	13.9	285	13.0	369	13.7
Parity 3	216	13.5	281	14.8	248	14.6	249	13.8
Parity 4	210	15.0	243	15.2	214	15.3	239	14.9
Parity 5	207	15.9	206	15.8	186	15.5	227	16.2
All parities	1,293		1,483		1,327		1,449	

CON = control; SUPP control + Cu, Zn, and Mn ; FEM = female; MIX= mixed.

[a]Data are presented as raw figures without statistical analysis. All gilts that reached each parity are included in the summary, to provide a total per "herd".

Table 6. The percentage of breeding females that remained in the herd at each parity[a]

	CON, %	SUPP, %	FEM, %	MIX, %
Parity 1	78	85	83	80
Parity 2	58	65	55	68
Parity 3	40	48	43	45
Parity 4	35	40	35	40
Parity 5	33	33	30	35

CON = control; SUPP control + Cu, Zn, and Mn ; FEM = female; MIX= mixed.

[a]A total of 40 breeding females were selected for service within each treatment at breeding age. Sows that were culled, did not become pregnant after being served twice at any parity, or failed to return to estrus after farrowing were removed from the data set.

However, in the current study, we found that there were few effects of either strategy on the sows welfare or performance in later life.

Overall, locomotion scores were good during the study period, with very few incidences of clinical lameness (sows scoring 3 or greater) and no incidences of scores 4 and 5. Even though there was little lameness in the animals during rearing (Hartnett et al., 2019b), we expected that differences between the treatments may have manifested later in life, due to the cumulative effects of the damage, which occurred during rearing exacerbated by the weight demand of pregnancy on the sow. The two most commonly used breeds of sow in Ireland are the Landrace and Large White. Of these, the Landrace is hypothesized to be more susceptible to OC, and leg weakness in general, than the Large White (Jorgensen and Andersen, 2000), which is why we selected this breed for the study. Thus, it is promising that locomotion scores remained so low and may have been lower yet, if Large White sows were used. Nevertheless, the numbers used in the study were small, and it has to be noted that the gilts we selected for breeding were considered the healthiest of the pool of 182 which were available (no obvious health issues or locomotory problems and closest to the average weight of the group). All of the 102 gilts that were sent to slaughter at breeding age had visually detectable OC lesions when we examined their limbs (Hartnett et al., 2019b). As such, in a commercial situation, it is possible that there could be a greater likelihood of animals staying in the sow herd, which subsequently develop lameness. Although the median lameness score increased from 1 during rearing to 2 during pregnancy, which demonstrates that there was a slight impairment to locomotion overall, relative to the rearing period, the locomotory ability of the animals in the different rearing treatments did not diverge. The increase during gestation may simply have been due to added weight and growth during gestation, as well as potentially to the accumulation of injuries.

Hoof lesion scores in mid-gestation were considerably higher compared with the scores recorded in the same gilts during rearing (Hartnett et al., 2020). Furthermore, they continued to increase until the last inspection, when sows farrowed for the second time. The increase in hoof scores over time was likely due to general wear and tear with age, as the hooves must support more weight as body weight and size increase. This is further complicated by housing on fully slatted floors, which can result in injuries due to claws becoming caught or trapped in the slats (Gjein and Larssen, 1995a; Pluym et al., 2011). Hoof lesions can be associated with pain and irritation as the lesions on the surface of the hoof affect sensitive tissues, and secondary infections may occur as a result (Zoric et al., 2004). Nevertheless, none of the hoof disorders we observed were severe, and this could explain why no differences in locomotion scores were observed. In line with findings on the same animals during rearing (Hartnett et al., 2020), total hoof lesion scores were higher in the sows reared in the MIX

Table 8. Sow performance data from breeding females showing lifetime performance over five parities and also an average performance by farrowing[a]

	Diet			GC		
	CON	SUPP	*P*-value	FEM	MIX	*P*-value
Lifetime BA[b]	34.34 ± 5.03	40.53 ± 5.03	0.39	35.06 ± 5.03	39.81 ± 5.03	0.51
Stillborn[c]	78	103	0.45	62	119	0.02
By farrowing						
BA	13.81 ± 0.39	14.01 ± 0.38	0.71	14.01 ± 0.39	13.80 ± 0.38	0.69
Total born	14.98 ± 0.40	15.60 ± 0.39	0.26	15.14 ± 0.40	15.44 ± 0.39	0.58

CON = control; SUPP control + Cu, Zn, and Mn ; FEM = female; MIX= mixed.

[a]There was no interaction between diet and GC for any measure.

[b]The average number of piglets BA to a sow within each treatment. Data were collected over five parities.

[c]Data represent the total number of stillborn piglets from all sows within each treatment, over five parities. Data were analyzed on a per sow basis, including parity as a random effect, to generate *P*-values.

groups compared with sows reared in the FEM groups. Thus, the claw horn damage resulting from more activity (mounting, aggression, and play) on the concrete slatted floors during rearing persisted (Gjein and Larssen, 1995a; Pluym et al., 2011; Quinn et al., 2015). This is not surprising as concrete floors offer little opportunity for claw horn lesions to resolve (Heinonen et al., 2013), and the animals were managed on fully slatted concrete floors throughout their lives.

When considering only sows that were reared on the CON diet, we found that those in the MIX groups had higher total hoof lesion scores than those reared in the FEM groups, whereas this was not the case for sows reared on the SUPP diet. This suggests that the SUPP diet had a long-term protective effect on hoof health. Thus, if space or other constraints do not permit separate sex rearing, supplementation with the minerals used in the current study could have long-term benefits for hoof health in sows.

In other studies, the heel and horn wall regions were the most affected areas of the hoof (Gjein and Larssen, 1995a; Kirk et al., 2005; Anil et al., 2007; Pluym et al., 2011), and indeed these were the two regions of the claw where we saw the greatest treatment effect. Sows reared on the CON diet tended to have higher horizontal crack scores than SUPP sows, and sows reared in the FEM groups had lower heel erosion scores compared with sows reared in the MIX groups. Studies with pregnant sows found that the addition of the trace minerals similar to the ones used in the current study improved claw health (Nair, 2011) and reduced the prevalence of lameness and leg abnormalities (Ferket et al., 2009). Nair (2011) found that the addition of trace minerals such as Cu, Zn, and Mn to the diet of the breeding sow resulted in the reduction of heel erosion and white line lesions. However, similar to Quinn et al. (2015), we found that overall there was a low prevalence of severe lesions and a high prevalence of mild lesions. Mild lesions do not appear to influence locomotory ability (Gjein and Larssen, 1995b; Anil et al., 2007; Quinn et al., 2015), which could explain the lack of effect of treatment on the locomotion scores in the current study.

Surprisingly, we found that sows reared in SUPP groups tended to have higher cortisol levels than those reared on a standard finisher diet. Nevertheless, it is important to note that the difference was only a tendency, and thus the result must be interpreted with caution. In fact, the difference was driven by sows that were reared in the MIX groups having higher cortisol levels when they were supplemented with minerals than when they were reared on the CON diet; there was no effect of supplementation for gilts reared in the FEM groups. This result is in contrast to what we expected, and it is not clear why when supplemented the MIX sows had such high levels; levels were also numerically much higher than sows that had been reared on the CON diet, using either grouping strategy. However, cortisol levels are affected by more than stress, and factors such as exercise level and excitement can also increase secretion levels. Moreover, although statistically different, levels detected were within the normal range for salivary cortisol levels of pregnant gilts (e.g., Rooney et al., 2019). When measuring the effect of chronic stress (e.g., due to lameness and social stress), patterns of cortisol secretion throughout the day or the ability of the animal to increase cortisol secretion in response to a stressor may be more informative than simply sampling the animal at one sampling point a day. A blunted circadian pattern of secretion, or inability to mount a cortisol response, are considered more reliable indicators of chronic stress than basal cortisol levels (Munsterhjelm et al., 2010).

Table 9. Preweaning and postweaning growth performance of the offspring of sows reared in either FEM or MIX groups and on a CON diet or a SUPP diet

	Diet			GC		
	CON	SUPP	*P*-value	FEM	MIX	*P*-value
Weight (kg)[a]						
Total born	1.19 ± 0.06	1.20 ± 0.06	0.97	1.19 ± 0.06	1.20 ± 0.06	0.93
Live born	1.35 ± 0.05	1.40 ± 0.04	0.43	1.36 ± 0.04	1.38 ± 0.05	0.75
ADG	0.21 ± 0.01	0.22 ± 0.01	0.59	0.22 ± 0.01	0.22 ± 0.01	0.93
Weaning	7.49 ± 0.25	7.30 ± 0.23	0.59	7.22 ± 0.21	7.57 ± 0.25	0.29
ADG (kg/day)[a]						
Weaner	0.57 ± 0.02	0.58 ± 0.01	0.95	0.58 ± 0.01	0.57 ± 0.02	0.97
Finisher	0.90 ± 0.02	0.91 ± 0.01	0.95	0.90 ± 0.01	0.92 ± 0.02	0.87
ADFI (Kg/day)[a]						
Weaner	0.86 ± 0.03	0.92 ± 0.03	0.54	0.90 ± 0.03	0.88 ± 0.03	0.93
Finisher	1.99 ± 0.03	2.02 ± 0.03	0.92	2.00 ± 0.03	2.01 ± 0.03	0.99
FCE (g/g)						
Weaner	1.51 ± 0.03	1.57 ± 0.03	0.54	1.55 ± 0.02	1.53 ± 0.03	0.94
Finisher	2.22 ± 0.03	2.22 ± 0.02	0.99	2.22 ± 0.02	2.21 ± 0.03	0.99

CON = control; SUPP control + Cu, Zn, and Mn ; FEM = female; MIX= mixed.

[a]Data are provided as least squares means and standard errors.

We decided to record handling ease, incidence of kicking, and vocalizing as we hypothesized that they would provide a simple objective measurement of a lack of "calmness" or in other words, an elevated level of re-activity, and similar measures have previously been used to assess pig temperament (D'Eath et al., 2009). Even though we did not see differences in locomotory ability, gilts reared in the MIX groups kicked more during confinement in the hoof crate and performed more avoidance behavior of a human, than gilts reared in the FEM groups. These gilts may have been experiencing more limb discomfort in general. Hartnett et al. (2019a,b) found that gilts reared with males had more cartilage damage at breeding age, particularly on the humeral condyle, than those reared in the FEM groups, which aligns with our finding that sows reared with males had more hoof damage during gestation and into the second parity. The sows in the current paper represent the gilts in the study by Hartnett et al. (2019a,b) at an older age so it is possible that any damage sustained to cartilage deteriorated faster in the gilts reared with male pigs than those reared with females. Cartilage damage is considered progressive and healing response is limited (Lin et al., 2017). It is possible that any discomfort due to cartilage degeneration could have caused pigs to have a heightened response to the unusual sensation of being raised in the hoof examination crate, and their limbs and hooves being handled. Indeed, Mohling et al. (2014) found that the mechanical nociceptive threshold was reduced even in the cannon area of the limb, after injection of amphotericin B into the interphalangeal joint space. This is not to say that the gilts reared with males in the current experiment experienced pain while having their hooves examined, but rather they may have been more reactive to an unexpected experience of pressure or release on the limbs.

With regard to the increased avoidance response by MIX sows to the FHA test, again, this could be due to a slightly reduced ability to tolerate a novel experience. Rearing conditions have lifelong effects on animal behavior (Beattie et al., 1995) and stress responses (Olssen et al., 1999), and the gilts reared with males were exposed to much higher levels of activity, aggressive behavior, and mounting, for the first 7 mo of their lives, relative to gilts in the FEM groups (Hartnett et al., 2020). We were unable to source information in the literature regarding the long-term behavioral effect on gilts of rearing with un-castrated male pigs. However, Olsson et al. (1999) found that rearing conditions up to 10 wk of age can affect the behavioral response to challenges when gilts were aged between 9 and 11 mo old.

It is unfortunate that the sample size was so low that the statistical analysis of the data pertaining to sow longevity and total piglet output at each farrowing would not yield useful results, which would be robust enough to be transferrable to industry. Nevertheless, we can see from the raw data that sows reared with the optimal diet (i.e., the mineral supplement) numerically stayed in the herd longer than those on the CON diet. With regard to the grouping strategies, sows reared with males seemed to remain longer. Thus, numerically gilts reared with the mineral supplement produced more piglets "BA" over five parities than those on the CON diet, whereas gilts reared with males produced numerically more "BA" piglets than those in the FEM groups. At the same time, gilts reared with males had significantly more piglets born dead over the five parities. Although these data are preliminary and more animals are needed to make a meaningful comparison of sow longevity having been reared in these treatments, we feel that they may be useful as pilot data for researchers planning future studies and generating a hypothesis, and as such a useful addition to the literature. Moreover, it would also be interesting to investigate further the effect of rearing with males on time to the first estrus, and whether this could enhance reproductive performance.

As we have confirmed that both hoof health and cartilage condition (Hartnett et al. 2019a,b) were negatively impacted by both rearing with males and the standard finisher diet, we expected that sows from these treatments would have experienced pain and stress during gestation, even if there were no overt signs of lameness. There is evidence in the literature that maternal stress during pregnancy can affect the developing piglets and negatively affect their growth. For instance, social stress in gestating pigs can cause reduced offspring weight gain postweaning (Rutherford et al., 2012). However, we found no effect of either treatment on offspring performance prior to weaning and post weaning. This was the case even though we found higher salivary cortisol levels in gilts reared with males and provided with the mineral supplement. Thus, it appears that neither rearing strategy had a long-term effect on offspring growth or efficiency.

Physical growth is not the only trait that can be affected by exposure to stress in utero. In a sister study to the current one, we carried out open field tests on a subsample of the piglets born to the sows used in the current study, and we found a range of behavioral differences in offspring born to gilts from the different treatment groups in the current study (Hartnett et al., 2019a). Piglets from gilts reared with males screamed (i.e., sudden and loud vocalization) more in an open arena test than those from the FEM groups, and piglets from SUPP gilts explored more, stood still less, than those on the CON diet. Thus, although there was no effect on physical performance, there is yet the possibility that piglets were behaviorally affected by maternal rearing (Hartnett et al., 2019a).

CONCLUSIONS

During gestation, hoof health was poorest in sows fed a standard finisher diet without supplementation and reared in MIX pens compared with all other treatment combinations; therefore, if space is limited, supplementary minerals may help ameliorate some of the negative effects of rearing gilts with entire male pigs. However, supplementing gilts with minerals during rearing resulted in minor albeit positive effects on the severity of hoof cracks during pregnancy. Overall, rearing gilts in the FEM groups had minor, but beneficial effects on their welfare subsequent to the rearing period. The addition of supplementary minerals to the diet was also beneficial for hoof health when gilts were reared in the MIX groups.

Conflict of interest statement. None declared.

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