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The welfare of finishing pigs under different housing and feeding systems: liquid versus dry feeding in fully-slatted and straw-based housing

K Scott*†, DJ Chennells‡, D Armstrong§, L Taylor§, BP Gill§ and SA Edwards†

† School of Agriculture, Food and Rural Development, University of Newcastle, Newcastle upon Tyne, NE1 7RU, UK
‡ Acorn House Veterinary Surgery, Linnet Way, Brickhill, Bedford, MK41 7HN, UK
§ Meat & Livestock Commission, Winterhill House, Milton Keynes, MK6 1AX, UK
* Contact for correspondence and request for reprints: Kamara.Scott@newcastle.ac.uk

Abstract

This study assessed the health and welfare implications of feeding pigs a dry or liquid diet when housed in either fully-slatted or straw-based accommodation. Between April and October 2002, 1024 (Large White × Landrace) × Large White pigs, housed in pens of 32, were fed ad libitum *from 34 kg to slaughter at 104 kg liveweight. Data were collected on a range of welfare parameters. Feeding system affected only respiratory health losses. Lameness and tail-biting tended to be more prevalent health conditions in the fully-slatted system, while in the straw-based system pigs showed significantly more enteric and respiratory disease. There were no significant treatment effects on skin lesions or bursitis of the hock. Liquid fed pigs had poorer hygiene scores than dry fed pigs, especially in straw-based housing. Liquid feeding reduced activity level and investigatory behaviours directed towards other pigs. Pigs with straw spent a large proportion of their time manipulating it. Pigs without straw were less active and spent more time manipulating the pen hardware. In post-slaughter assessments, there were no systems differences in lung lesions or osteochondrosis, but other measures differed between housing or feeding systems; pigs with straw had more severe toe erosions on the foot, while pigs without straw had more severe heel erosions. Gastric lesions were more pronounced with dry feeding and in the fully-slatted system. The results highlight the relative health and welfare advantages and disadvantages of these systems for finishing pigs.*

Keywords: *animal welfare, fully-slatted, housing, liquid feeding, pig, straw*

Introduction

Liquid feeding of pigs offers the possibility of a significant reduction in the cost of production through use of low dry matter by-products; however, there is limited information in the literature on the health and welfare implications of liquid feeding systems and the way in which they interact with other aspects of the housing system, in particular the availability of bedding. Finishing pigs are currently maintained in a wide variety of housing and management systems. Historically pig production was based on deep-straw bedded systems, but these were displaced by slatted floors in the 1950's for economic reasons. Recent years have seen an increased concern for pig welfare amongst consumers, leading to renewed interest in systems using straw. Pressure is mounting on producers to house pigs in systems that are both 'welfare friendly' and economically viable; however choosing a system that combines the two is not easy.

The assessment of animal welfare must be a multi-disciplinary process (English & Edwards 1999), since different parameters can give apparently different conclusions for the same system (Mason & Mendl 1993) and single parameters may fail to offer a true reflection due to variable coping strategies in individual animals (Hessing *et al* 1994). The 'Five Freedoms', proposed by the Farm Animal Welfare Council (FAWC 1992), require an integrated consideration of health, behavioural and physical/physiological indicators and thus provide an effective framework against which welfare may be assessed. Producers may perceive good performance as indicative of an adequate level of welfare; however in certain instances animals express their response to an unsatisfactory environment through behavioural modification rather than through changes in physiology or production (Edwards 2000). Physical damage may be used as an indicator of welfare; for example, Lyons *et al* (1995) reported that more injuries were sustained by pigs in treatments without straw than by pigs with straw, and the type of flooring has been shown to affect the prevalence of foot lesions and lameness (Arey 1993). Factors including the absence of bedding material (Ramis *et al* 2005) and stress and overcrowding (Smith 1980) have also been linked to the occurrence of gastric lesions in the pig.

This study was carried out as part of the UK Finishing Systems Research Programme, an integrated investigation to evaluate two contrasting housing systems (fully-slatted versus straw-bedded) and liquid feeding technologies for pig performance, carcase quality, cost of production, pig health and welfare, microbial status, environmental impact

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and meat quality (MLC [Meat and Livestock Commission] 2004). Four major production trials were conducted over a three-year period and this paper reports the findings from the first of these. Health and welfare implications were assessed for finishing pigs when they were given either dry as opposed to liquid feed, and when they were housed in straw-based compared to fully-slatted accommodation. The level of interaction between housing system and feeding system was also explored.

Materials and methods

Treatments

A 2 × 2 factorial design was employed to investigate the separate and/or interactive effects of feeding system (automated liquid feeding and dry hopper feeding) and housing system (fully-slatted and straw-based). The study was conducted from April to October 2002, over what proved to be particularly hot summer conditions.

Housing system

Animals were housed in either a fully-slatted (FS) or straw-based (ST) building, purpose-built on the same site to an otherwise similar design (full details can be found in MLC 2004). Each house consisted of four rooms containing four pens. The ST pens measured 5.8 × 3.7 m (length × breadth), including the scrape-through passage, which was cleaned out daily while pigs were shut in the lying area. After cleaning out, fresh barley straw was added to the pens at the rate of 0.49 kg straw pig^{-1} day^{-1}. FS pens measured 5.5 × 3.7 m (length × breadth) and had flooring that consisted of concrete slats with 83 mm width and 18 mm gap.

Pigs were housed in pen groups of 32 with a mean weight of 34 ± 4 kg at entry. Numbers per pen were reduced at week six (mid-point) to 25 in the FS system and 20 in the ST system, in accordance with normal commercial stocking densities for these housing types. Pigs were slaughtered at approximately 104 kg.

The ventilation and environment in both housing systems was automatically controlled (Euromatic DOL34H, Skov, Denmark) to set maximum and minimum ventilation, relative humidity and temperature against occupancy day. Each room had two windows, allowing natural daylight, however additional artificial light was used during husbandry tasks, weighing and behavioural observations.

Feeding system

Two feeding systems, either automated liquid feeding (L) or dry hopper feeding of a pelleted compound diet (D), were replicated between rooms within each housing system. The liquid feeding troughs were 120 cm in length and provided sub-divided feeding spaces for four pigs. The hoppers for the dry feed were 122 cm in length and provided five feeding spaces. Although the number of feeding spaces per group was lower for the liquid feeding system, the total trough length was the same and these animals had significantly higher daily live weight gains than dry fed pigs ($P < 0.001$; MLC 2004). This suggests that trough space was not limiting in the liquid feeding system. Both dry and liquid diets were formulated to the same nutrient specification using similar ingredients. In both feeding systems a grower diet was offered from entry to approximately 60 kg (formulated to 14.7 MJ DE kg^{-1}, 1.2% total lysine) and a finisher diet from 60 kg to slaughter (formulated to 14.2 MJ DE kg^{-1}, 0.9% total lysine). Dry diets were commercially manufactured in 3 mm pellets and offered in *ad libitum* hoppers, which were manually replenished each day as required. Liquid diets were produced on site by milling cereals and mixing individual ingredients and were available *ad libitum* except for the period between 2400 and 0100h, when the system was automatically paused to allow pigs to clear troughs of any accumulated residues. Liquid-feeding was computer controlled by feed demand at the troughs using sensors. Water was freely available from four nipple drinkers per pen.

Animals

1024 externally sourced (Large White × Landrace) × Large White pigs were received in eight equal batches of 128 over 11 weeks from April through to June 2002. The pigs came from two different 'sister' units of equal health status, effectively run as one unit. Pigs had previously been housed in both slatted and straw-bedded accommodation and this background was randomised across treatment groups. Pigs were approximately 12 weeks of age at entry. Batches were allocated alternately between the housing systems until all rooms were full. After a 4-day period of acclimatisation to the housing system, each pig was ear-tagged for individual identification and then weighed. The batch was divided into four groups of 32 pigs in order of weight, and each group was randomly allocated to one of four pens within a single room. Groups were of mixed gender, with entire males and females. Three males and three females in each group were selected to serve as 'focal' animals according to the following criteria: two pigs (one of each sex) at approximately median weight for the group, two within the upper quartile weight band and two within the lower quartile band. These animals were used for more detailed investigations of behaviour, skin lesions and cleanliness and post-slaughter welfare indicators.

Measurements

Health records

Pigs were inspected twice daily by two trained observers for signs of ill health and to check general welfare (eg scouring, respiratory distress, loss of body condition, physical injury). A health record was kept that included drug administration of any kind or any other health related treatments and reasons for removing any animals from the experiment which did not respond to treatment. Clinical diagnoses were made by a veterinarian according to criteria detailed within Taylor (1999). All deaths and culls for health reasons were recorded and a post mortem was conducted by a veterinary surgeon to assess the cause of death.

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Table 1 The experimental ethogram.

Behaviour	Description
Posture	
Standing	Bodyweight supported by all four legs
Sitting	Bodyweight supported by front legs and hindquarters
Kneeling	Bodyweight supported by knees and hind-quarters
Lying on side	Bodyweight supported by side
Lying on belly	Bodyweight supported by belly
Behaviour	
Inactive	Motionless with eyes closed
Alert	Motionless with eyes open
Feeding	Eating from the feeder or chewing food
Drinking	Mouth in contact with the drinker and water being ingested
Chewing substrate	Substrate in mouth (with/without visible chews)
Rooting substrate	Displacing substrate with circular movements of the snout
Nosing substrate	Movement of snout along or close to a substrate
Fighting	Interacting aggressively with another pig
Mounting	Placing front hooves in the back of a standing pen-mate
Eliminating	Defaecating or urinating
Other	Other unlisted activity
Substrates	
Other pigs	Any part of pen-mate
Straw	Straw bedding
Pen component	Any part of the pen
Feeder	Food trough
Drinker	Water drinker
Enrichment	Additional environmental enrichment device
None	Behaviour not directed at any substrate

Body damage

Skin lesions, including bruises, scratches and wounds, and adventitious bursitis of the hock were assessed weekly in focal pigs. Each animal was scored for the frequency of all skin lesions (penetration of the epidermis of > 1 cm length) for seven body areas: face and ears, neck, shoulders, flank, rump, buttocks and tail (after Stewart *et al* 1993). For each area, excluding the tail, lesions on the left and right hand sides of the body were recorded separately. The presence and severity of adventitious bursitis of the hock was visually assessed using subjective scores from 0 to 5; with 0 representing no swelling and 5 representing a large, eroded swelling (after Lyons *et al* 1995).

Hygiene

The hygiene status of focal pigs was scored on a weekly basis by visual assessment of the percentage of body surface which was clean as opposed to soiled.

Behaviour

Behavioural time budgets were recorded during direct observations by the same single observer over three × 2 h periods (0900-1100h, 1200-1400h, 1500-1700h) in the week of entry, week before group reduction (mid-point) and week before slaughter. The six focal pigs per pen were individually identified for distant observation using stock marker spray. Behaviours were recorded by scan sampling at 10 minute intervals according to a pre-determined ethogram (Table 1) based on the method of Day *et al* (2002).

Post-slaughter measurements

Pigs were transported a distance of 40 miles to the abattoir and slaughtered under commercial conditions.

Foot damage

Foot damage of focal pigs was evaluated based on a method developed from Smith and Morgan (1997). Both claws of the left hind foot were inspected for the presence of white line lesions, toe erosions, sole erosions and heel erosions. Subjective scores from 0 to 3 were given for the severity of each condition as follows: 0 (no damage); 1 (mild damage – surface abrasion without significant penetration); 2 (moderate damage – shallow penetration of the tissue); 3 (severe damage – a deep wound, sometimes ulcerated or infected).

Lung and cardiac lesions

The degree of lung damage as a result of enzootic pneumonia was assessed for all pigs following a technique described by Goodwin and Whittlestone (1979). This involved scoring the consolidated area of all seven lobes of the lung to give a maximum score of 55. The heart of each pig was assessed for the presence of pericarditis and subjec-

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Table 2 Deaths and removals (number of animals from a starting total of 256 in eight pens for each treatment combination) by feeding system (F) within housing system (H).

	Fully-slatted		Straw-based		P-value	
	Liquid	Dry	Liquid	Dry	H	F
Deaths	2	1	4	2		
Removals						
Respiratory	1	4	0	4		**
Enteric	1	0	0	1		
Lameness	7	2	1	1		
Tail bitten	5	8	0	1		
Thin/poor	0	1	0	2		
Other	3	2	1	2		
Total	17	17	2	11	*	

* $P < 0.05$, ** $P < 0.01$.

tively scored from 0 to 3 as follows: 0 (no pericarditis); 1 (mild pericarditis – fibrin tags on the surface of the heart); 2 (moderate pericarditis – extensive fibrin tags on the surface of the heart and the pericardium); 3 (severe pericarditis – pericardium totally adhered to the surface of the heart).

Gastric ulceration

The stomach of each focal pig was collected and assessed for signs of parakeratosis and ulceration in the pars-oesophageal region using a graded scoring system, where 0 indicated no abnormality and 5 indicated a large and bleeding ulcer (after Potkins *et al* 1989a).

Osteochondrosis

The left forelimb of two pairs (equal sexes) of focal pigs per pen was dissected to expose the distal end of the humerus. Lesions on the surface were scored for the area of damaged cartilage on the front and rear aspects of the joint according to the method of Slevin *et al* (2001), where 0 represented no gross lesion, 1 represented thinning or dulling of the cartilage in a small localised area, and 4 represented extensive erosion of the whole area, ulceration or absence of cartilage; 2 and 3 represented intermediate scores as characterised in detail by Arthur *et al* (1983).

Statistical analyses

For all data analyses the pen was the experimental unit. Health data were expressed as the proportion of affected pigs in the pen; these data were not normally distributed and could not be normalised by transformation, therefore the Kruskal-Wallis non-parametric test was used. All other data were analysed using analysis of variance (Minitab Release 13.1), with housing system and feeding system as main factors and their interaction. Tukey's HSD (Honestly Significantly Different) was used for pair-wise comparison of the means of the treatments. Behaviour data were first collated and the frequency at which each category of the ethogram occurred was expressed as a percentage of the total number of observations.

Results

Health records

Overall mortality was low (0.9%) and did not differ significantly between the feeding systems and housing systems. A total of 47 pigs (4.6%) were removed from the study for health and welfare reasons, with more removed from the FS system than the ST system ($P < 0.05$). Reasons for rejection are summarised in Table 2. More pigs were removed from the D diet as a result of respiratory conditions than from the L diet ($P < 0.01$). Removals for lameness ($P = 0.09$) and tail-biting ($P = 0.06$) tended to be higher from the FS system than the ST system.

The number of veterinary treatment episodes (courses of defined antibiotic treatment administered to individual pigs) was greater in the ST system ($P < 0.01$) as a consequence of respiratory ($P < 0.01$) and enteric conditions ($P < 0.01$), whereas the FS system received more treatments for tail-biting ($P = 0.07$) and lameness, although this difference was not statistically significant (Table 3). Days spent on treatment followed a similar pattern: pigs in the ST system spent more total days on treatment ($P < 0.01$), due to respiratory ($P < 0.01$) and enteric conditions ($P < 0.01$), whilst pigs in the FS system tended to spend more days on treatment as a result of tail-biting ($P = 0.07$) and lameness ($P = 0.1$). There were no significant effects of feeding system on the number of pig days spent on treatment.

Body damage

There were no significant treatment effects on body damage (Table 4). The mean number of skin lesions per pig was similar across both feeding systems and housing systems. Pigs had previously been housed in both slatted and straw-based accommodation; consequently bursitis score at the start of the study was used as a covariate in the analysis of mean bursitis score. Despite this, there were no significant effects of housing system or feeding system on mean bursitis score.

Table 3 Veterinary treatments by feeding system (F) within housing system (H) (over a total of 256 animals in eight pens for each housing × feeding combination).

	Fully-slatted		Straw-based		*P*-value	
	Liquid	Dry	Liquid	Dry	H	F
Treatment episodes						
Respiratory	1	5	29	22	**	
Enteric	0	0	8	4	**	
Lameness	19	3	6	9		
Tail bitten	7	0	0	0		
Thin/poor	0	0	1	1		
Other	3	2	1	1		
Total	30	10	45	37	**	
Pig days on treatment						
Respiratory	5	21	145	110	**	
Enteric	0	0	40	4	**	
Lameness	56	22	22	26		
Tail bitten	23	0	0	0		
Thin/poor	0	0	5	3		
Other	9	5	3	3		
Total	93	48	215	146	**	

** $P < 0.01$.

Table 4 Mean body damage and hygiene scores by feeding system (F) within housing system (H) and their interaction (I).

	Fully-slatted		Straw-based			*P*-value		
	Liquid	Dry	Liquid	Dry	SEM	H	F	I
Skin lesions per pig	14	11	13	16	1.2			
Bursitis score (0 - 5)	1.1	1.0	1.0	1.1	0.1			
Hygiene score (% clean)	82	87	60	76	2.1	***	***	**

** $P < 0.01$, *** $P < 0.001$.

Hygiene

The proportion of clean skin was greater in D fed pigs compared with L fed pigs ($P < 0.001$) and in pigs from the FS system than the ST system ($P < 0.001$) (Table 4). An interaction was observed between feeding system and housing system, with L fed pigs having a lower proportion of clean skin relative to D fed pigs in straw-based housing ($P < 0.01$).

Behaviour

Behavioural results, averaged across all observation periods, are given in Table 5. There were significant differences between both feeding system and housing system in respect of levels of activity, as measured by frequency of standing, and levels of inactivity, as measured by frequency of 'sleeping' (lying down with eyes shut). L fed pigs spent more observations sleeping ($P < 0.01$) and fewer observations standing ($P < 0.05$) than D fed pigs. Pigs in the ST system were less often observed sleeping ($P < 0.001$) and correspondingly more often standing ($P < 0.01$) than pigs in the FS system. Motionless but alert behaviour tended to be observed more often in FS pigs than ST pigs (15.3% vs 14.0%, $P = 0.07$), however no such difference was observed between the feeding systems. There was no apparent difference between the feeding systems in the number of observations spent eating; however there was a tendency for ST pigs to spend more observations eating than FS pigs ($P < 0.07$). As anticipated, D fed pigs spent more observations drinking than L fed pigs ($P < 0.001$).

Investigatory behaviours (nosing, chewing, rooting or biting any available substrate) were performed more often by D fed pigs than L fed pigs ($P < 0.05$) and more often by pigs in the ST system than pigs in the FS system ($P < 0.001$). Behaviour directed at both pen components ($P < 0.001$) and pen-mates ($P < 0.01$) was performed more by D fed pigs than by L fed pigs. Pigs in the ST system spent 14% of observations in straw-directed behaviour. They spent fewer observations in behaviour directed at pen components than

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Table 5 Mean percentage of observations where pigs were recorded performing various behaviours according to feeding system (F) within housing system (H) and their interaction (I).

	Fully-Slatted		Straw-based			*P*-value		
	Liquid	**Dry**	**Liquid**	**Dry**	**SEM**	**H**	**F**	**I**
Standing	19.4	25.7	27.6	31.2	1.86	***	*	
'Sleeping'	65.0	56.4	52.3	48.6	2.10	***	**	
Eating	3.9	4.4	4.6	5.0	0.32			
Drinking	0.4	1.2	0.7	1.2	0.13		***	
Investigating	15.2	21.9	27.6	30.9	1.93	***	*	
Oral behaviour towards:								
Straw	-	-	14.3	14.0	0..95			
Pen components	6.9	10.6	5.7	7.6	0.79	*	***	
Another pig	7.0	10.0	7.9	8.8	0.67		**	

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 6 Foot damage (0-3 scale) by feeding system (F) within housing system (H) and their interaction (I).

	Fully-slatted		Straw-based		SEM	*P*-value		
	Liquid	**Dry**	**Liquid**	**Dry**		**H**	**F**	**I**
Foot damage								
White line lesion	0.8	1.0	1.1	1.2	0.14			
Toe erosion	0.5	0.4	1.2	1.1	0.14	***		
Sole erosion	0.7	0.9	0.7	0.8	0.14			
Heel erosion	1.0	1.3	0.3	0.3	0.19	***		

*** $P < 0.001$.

pigs in the FS system ($P < 0.05$), although there was no significant difference between the housing systems in behaviour directed at pen-mates.

Post-slaughter measurements

Foot damage

There were no significant effects of feeding system on foot damage. There was no consistent difference in the overall level of foot damage between treatments; however the type of damage did differ significantly between the housing systems (Table 6). Pigs in the ST system had more severe toe erosions ($P < 0.001$) while pigs in the FS system had more severe heel erosions ($P < 0.001$).

Lung and cardiac lesions

There were no significant differences between treatments with respect to lung or cardiac lesions (Table 7).

Gastric lesions

The frequencies of gastric lesions and the mean gastric lesion scores are shown in Table 8. Moderate parakeratosis of the gastric mucosa was found in 19 cases (10.2%). Severe parakeratosis was observed in 20 cases (10.8%) and only in animals fed the D diet. There were significant effects of both housing system and feeding system on mean gastric lesion scores; mean lesion scores were higher in D pigs than L pigs ($P < 0.001$) and higher in FS pigs than ST pigs ($P < 0.01$).

Osteochondrosis

There were no significant effects of treatment on the extent of osteochondrosis (Table 7).

Discussion

This study was the first in a series of four designed to cumulatively compare the welfare of finishing pigs in straw-based and fully-slatted housing (refer to Scott *et al* 2006 for full details) and was unique in comparing dry and liquid feeding. Consequently, the main focus of this discussion will be on the implications of dry and liquid feeding systems for pig welfare, and the interactions between feeding and housing systems.

The overall level of mortality observed in the present study was low, and did not differ significantly between feeding or housing systems. Guy *et al* (2002) observed similarly low levels of mortality across the different finishing systems in their study; however, they reported significantly higher levels of mortality in fully-slatted pens compared with straw yards. They attributed this difference to significantly poorer respiratory health in a situation where, unlike the present study, floor type and ventilation system were confounded. There were no significant effects of feeding system on the

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Table 7 Lung and cardiac lesions and osteochondrosis by feeding system (F) within housing system (H) and their interaction (I).

	Fully-slatted		Straw-based			*P*-value		
	Liquid	Dry	Liquid	Dry	SEM	H	F	I
Lung lesions (0 - 55 scale)	1.5	1.0	1.5	1.3	0.34			
Cardiac lesions (0 - 3 scale)	0.96	0.97	0.96	0.98	0.01			
Osteochondrosis (0 - 4 scale)								
Front score	2.5	2.5	2.5	2.7	0.10			
Rear score	2.0	2.0	2.0	1.9	0.10			

Table 8 Frequencies of gastric lesions (% of pigs) and mean gastric lesion score by feeding system within housing system.

	Fully-slatted		Straw-based	
Lesion score	Liquid	Dry	Liquid	Dry
0	18.8	2.2	41.7	4.4
1	31.2	4.4	37.5	24.4
2	25.0	26.7	10.4	15.6
3	14.6	24.4	10.4	22.2
4	10.4	20.0	0	11.1
5	0	22.2	0	22.2
Mean[#]	1.7[b]	3.2[a]	0.9[c]	2.8[a]

[#] SEM = 0.19.
[a], [b], [c], [d] different superscripts in the same row are significantly different ($P < 0.001$).

total number of animals removed from the current study; however significantly more pigs were removed as a result of respiratory conditions from the D diet than from the L diet. Liquid feeding systems are often associated with reduced levels of atmospheric dust (Forbes & Walker 1968); reducing the irritant effect of high dust levels may in turn reduce pulmonary disease (Jericho & Harries 1975). However, environmental impact measures made on this study found no significant effects of feeding system on dust emissions or dust concentration (Demmers *et al* 2004). In addition, results from the present study revealed no statistical difference between dry and liquid feeding systems in the frequency of veterinary treatments for respiratory conditions or in the post-slaughter assessment of lung damage. Similarly, while the frequency of veterinary treatments for respiratory problems was higher in the ST housing, this was not reflected in a difference in the number of removals or in lung lesion score at slaughter. Furthermore, these findings could not be linked to measured differences in air quality between the housing systems (Demmers *et al* 2004); however the opening of the scrape-through dunging passage of the ST system daily for cleaning purposes may have influenced these measures.

Previous studies (eg Russell *et al* 1996; Geary *et al* 1996) have demonstrated potential benefits of liquid feeding on pig gut health. In the present study, liquid feeding was found to have favourably increased the lactic acid bacteria to coliform ratio in the gut, and significantly reduced the proportion of pigs which tested positive for *Salmonella* (ELISA) at slaughter (Hillman *et al* 2004). However, in spite of these benefits of liquid feeding on gut health, no significant effects of feeding system were observed on clinical indicators of enteric conditions, which may be attributable to a low level of challenge. ST pigs received more veterinary treatments for enteric conditions than FS pigs. Wet bedding in combination with the warm temperatures of a finishing house can provide a medium for bacterial proliferation, and therefore poses an increased risk of enteric disease (Allen & Hinton 1993). Faecal material can be a source of infectious agents; therefore minimising contact between pigs and their excreta is important in terms of reducing possible disease risks. L pigs had significantly lower hygiene scores than D pigs in both housing systems, attributable to the ingestion of large volumes of water and the associated increase in water excretion. In slatted systems much of this additional water will pass straight through the slats, however in bedded systems it is absorbed by the bedding material, resulting in a much greater difference in cleanliness between liquid and dry feeding in the ST housing. The difference in hygiene score between the housing systems in this study may also have been attributable to ST pigs soiling their lying area in order to wallow under the hot summer conditions, when external temperatures frequently reached 34ºC. In addition to having the lowest hygiene score of all the treatments, L pigs in the ST system received more veterinary treatments for enteric conditions than pigs from the other treatments, thus highlighting the potential implications of liquid feeding in bedded systems for enteric health.

Having absorbed animal excretions, straw becomes damp and has an alkaline pH; this can soften the hooves and diminish the ability of the horn to resist pressure and abrasion (Mouttotou *et al* 1999). Despite the wetter and more soiled floor conditions of L pigs in ST housing, there were no significant differences in foot lesions or lameness between the feeding systems. However, pigs in the slatted system showed a tendency for more removals due to lameness, and a numerically greater number of treatments for this problem. The aetiology of lameness includes high feeding intensity (Jørgensen 1995), lack of physical exercise (Petersen *et al* 1998) and factors associated with floor type (Jørgensen 2003). One major cause of lameness in growing pigs is osteochondrosis, a non-infectious, degenerative condition of cartilage (Nakano *et al* 1981). However, as in previous studies (Jørgensen 2003; Sather & Fredeen 1982), there was no evidence in the present study that this differed between housing types. Physical injury to the foot may also result in the clinical onset of lameness, by providing a point of entry to a pathogen, or by alteration of the foot itself (eg 'bush' foot). While there was no consistent overall difference in the level of foot damage, the type of damage did differ between the housing systems. The slatted flooring produced more severe lesions of the heel, while the bedded system gave more toe lesions. This result is in accordance with previous studies (Gentry *et al* 2002; Mouttotou *et al* 1999). The impact pressure on the weight-bearing surface of the foot is reduced when animals walk on a bedded floor, and this may explain why lesions on the volar surface of the feet (eg heel erosions) are less prevalent in pigs kept on straw-bedded floors (Mouttotou *et al* 1999). The welfare significance of such claw lesions at slaughter is uncertain, since they were not directly reflected in lameness of the animals prior to slaughter.

Floor type has also been implicated in the aetiology of bursitis. Lyons *et al* (1995) found that bursitis was significantly reduced on deep-straw compared to bare concrete or slatted floors, and concluded that slats were conducive to producing bursitis. No such effects were observed in the current study; ST pens had only a shallow covering of straw, which was often soiled in hot conditions, and therefore appears to have been unable to offer adequate physical cushioning benefits to reduce bursitis.

Tail-biting is possibly one of the most serious forms of harmful social behaviour, due to its damaging nature and associated risks of infection (Van de Weerd *et al* 2005). The prevalence of tail injuries was not affected by feeding system, but the FS housing system tended to have more removals and more veterinary treatments for this problem. Van Putten (1969) believed that outbreaks of tail-biting originated from the chewing and rooting of pen-mates that generally occur within a group of pigs. Fraser *et al* (1991) found that rooting and chewing of pen-mates was reduced when straw was provided, and they concluded that straw was important in this respect in that it provided an alternative stimulus and outlet for exploratory and manipulative activities. Many studies (eg Beattie *et al* 2000; Kelly *et al* 2000; Lyons *et al* 1995) agree with these findings, where straw provision reduced behaviour directed at pen-mates. Van de Weerd *et al* (2005) found that, compared with pigs in a straw-bedded system, pigs in part-slatted housing spent significantly more time expressing pig-directed behaviours and were at a higher risk of tail-biting. In the present study, the greater prevalence of tail-biting in the FS system was not mirrored by a higher frequency of pig-directed behaviours, possibly because of reduced activity levels in hotter weather, although the greater frequency of pen-directed behaviours suggests a degree of redirected investigatory behaviour in the absence of straw. Conversely, tail-biting behaviour was not affected by feeding system, despite the fact that L pigs spent significantly less time in pig-directed behaviours than D pigs.

Feeding system also influenced the amount of behaviour directed at pen components, with L pigs displaying significantly less pen-directed behaviour than D pigs. The ingestion of large volumes of dilute feed may have resulted in a greater gut fill and sense of satiety, and consequently reduced motivation for exploration, as has been shown in a study with sows (Baynes *et al* 1994). In addition to the decrease in investigatory behaviours, liquid feeding was responsible for a decrease in the general activity of the pigs, as indicated by the increased proportion of time spent sleeping.

Feed intake was higher with L feeding than D feeding (Thompson *et al* 2005), however the amount of time spent eating was similar, suggesting that the liquid diet was ingested more quickly. Although FS pigs had significantly higher feed intakes, there was only a tendency for time spent eating to differ between housing systems. The severity of gastric ulceration was reduced in L pigs when compared to D pigs. Potkins *et al* (1989b) reported that fine grinding barley increased the number and severity of oesophagogastric lesions in growing pigs, and Flatlandsmo and Slagsvold (1971) found that pelleting, which can gelatinise cereal starches and reduce dietary particle sizes, was associated in some cases with an increased incidence of gastric lesions. Pigs in this study were also observed to eat the straw bedding in ST housing, and this was subsequently confirmed by the presence of straw in the stomach contents after slaughter. Ingestion of straw adds fibre to the diet, which appears to have a beneficial effect on the development of gastric lesions (Potkins *et al* 1989a) and may explain the difference between housing systems observed in this and other studies (eg Guy *et al* 2002). L fed pigs in the ST system had the lowest mean gastric lesion score of all, which may have been due to the combined advantage of increased fibre consumption in the form of straw and the lack of pelleting of the diet.

Conclusions and animal welfare implications

The results highlight the relative advantages and disadvantages of each feeding and housing system for pig welfare. Under often hot summer conditions, liquid feeding,

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compared to feeding a dry pelleted diet, offered welfare benefits in less investigatory behaviour and reduced gastric ulceration, but reduced hygiene, particularly in straw-based housing. The straw-based system, compared to a fully slatted system, gave better behavioural occupation and less vice, but poorer hygiene and respiratory and enteric health, with an interaction resulting in particularly poor hygiene for liquid-fed pigs in straw-based housing.

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