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Effect of liquid feeding at different water-to-feed ratios on the growth performance of growing-finishing pigs

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The study examined the growth performance of pigs offered liquid feed or dry feed on either a restricted or an ad libitum *basis, and whether their growth performance was further influenced by the water-to-feed ratio. The study was split into two parts to enable unrestricted (trial 1;* n = 64*) and restricted (trial 2;* n = 48*) feeding to be compared. Male pigs were randomly allocated to six dietary treatment groups. A standard dry pellets diet (D) was offered either as: (i) unrestricted ration (UR); (ii) restricted ration (R); or D soaked in water at a feed-to-water ratio of (iii) 1 : 1.5 restricted (1 : 1.5 R); (iv) 1 : 3 unrestricted (1 : 3 UR); (v) 1 : 3 restricted (1 : 3 R); or (vi) 1 : 3 restricted with the addition of lactic acid to adjust the feed to pH 4 (1 : 3(4) R). Liquid feeding improved (*$P < 0.05$*) average daily live-weight gain (ADG) and lean tissue growth rate (LTGR) in the 1 : 3 UR compared with DUR but did not alter feed conversion ratio (FCR). Within the R groups, ADG were greater in all of the 1 : 3 diets, whereas feed intake, and hence FCR, was lower (*$P < 0.001$*) in these groups when offered the R ration. In conclusion, liquid feeding has a beneficial influence on the performance of modern porcine genotypes during the growth/finishing phase and this is further modulated by the water-to-feed ratio.*

Keywords: growth performance, liquid feeding, pigs

Introduction

The concepts of non-fermented liquid feeding (NFLF) and fermented liquid feeding (FLF) have been well described by Canibe and Jensen (2003). Liquid feeding of pigs can significantly reduce production costs as it allows the use of low, dry matter by-products and can, to some extent, offer welfare benefits under hot, summer conditions (Scott *et al*., 2007). The advantages of liquid compared with dry feeding include improved growth rates, shorter time to slaughter, improved feed to gain ratio or a combinations of these performance parameters (Braude, 1967 and 1971; Jensen and Mikkelsen, 1998; Lawlor *et al*., 2002; Canibe and Jensen, 2003). For example, average daily live-weight gain (ADG) of newly weaned pigs offered NFLF was 12 ± 9.4% higher than those observed following dry feeding (Jensen and Mikkelsen, 1998), and ADG was further increased by offering FLF (Dung *et al*., 2005). Pigs offered liquid feed acidified with lactic acid performed similar to those offered FLF (Geary *et al*., 1999). However, others have found that the benefits of FLF (Lawlor *et al*., 2002) and NFLF (Murphy, 2002) are no longer observed as the animal ages. Moreover, differences in carcass characteristics between pigs are not apparent between dry and liquid feeding systems (Murphy, 2002; Stotfold, 2005).

Although it is accepted that liquid feeding generally has a beneficial effect on pig performance, the amount of water in the feed influences the degree of improvement. For example, earlier work using feed-to-water ratios of 1 : 1.5 and 1 : 2.5 failed to report improvements (Barber *et al*., 1963; Braude and Rowell, 1967). In contrast, increasing the feed : water ratio to 1 : 3 or 1 : 3.5 improves growth and feed efficiency (Gill *et al*., 1987; Barber *et al*., 1991a and 1991b). However, when a higher water diet is fed (i.e. 1 : 6) dry matter intake, and hence ADG, is depressed (Rerat and Fevrier, 1965; Kornegay and Vander Noot, 1968). Much of the work on water-to-feed ratios was conducted more than 15 years ago and there is a limited number of recent investigations on the water-to-feed ratio using modern pig genotypes and management systems.

It has been suggested that the improved performance of newly weaned pigs offered a liquid diet is due to the increased daily feed intake (DFI) coupled with the maintenance of gut integrity following weaning, and changes in the structure of villi (Deprez *et al*., 1987; Pluske *et al*., 1997), which act to maintain the digestive capacity of the pig.

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Pig performance on FLF is claimed by some (e.g. Brooks, 1999a and 1999b) to be better than NFLF. The reduction in the pH of fermented and acidified feeds due to the activity of *Lactobacillus* sp. is thought to underline the improvements through effects on proteolysis in the stomach (Longland, 1991). It may also help to eradicate harmful Coliform microbes such as *Escherichia coli* from the digestive tract (Jensen and Mikkelsen, 1998), consequently reducing the incidence of scours and malabsorption. The overall objective of the study was to examine the growth performance of pigs offered liquid feed or dry feed as either a restricted or an *ad libitum* ration, and whether their growth performance was further influenced by the water-to-feed ratio.

Material and methods

Animals and experimental design

All pigs used in these studies were supplied by Cotswold Pig Development Company Ltd and maintained at their Pig Research and Development Unit at Wye, Kent, UK. At all stages of life animals were kept within the guidelines set out by the Department for Environment Food and Rural Affairs (DEFRA, 2003), and the study had been approved by the Local Ethical Committee. Pigs were housed in pens with the lying area measuring 2.54 × 2.75 m, with a dunging area of 2.75 × 1.8 m. Individual feeding crates were situated within the pens to enable feed intake to be restricted; pigs had free access to each of these feeding crates. All pens contained two self-drinkers and water was provided *ad libitum*. The pen floors were concrete with a covering of wood shavings, which were scraped out and replaced daily. The test house was mechanically ventilated and an ambient temperature of between 15°C and 20°C was maintained by adjusting the ventilation rate.

The study was split into two parts to enable unrestricted (trial 1) and restricted (trial 2) feeding to be compared. The first trial was designed as a completely randomised design with eight pens of male pigs ($n = 64$) randomly assigned to one of two treatments ($n = 32$ per treatment), which were offered as an unrestricted (UR) ration: (i) D diet (DUR) or (ii) D diet mixed with water at a feed-to-water ratio (w/w) of 1 : 3 (1 : 3 UR). The standard feeding systems for commercially reared pigs on the unit were used in this trial, and hence provided a baseline for production traits under this particular management system. Dry feed was offered from a single hopper in each pen. Liquid feed was prepared by mixing in a bulk tank and offered in the non-fermented form supplied by pipeline into a single trough in each pen (Hampshire Feeding System, Feed Manager 1, Hampshire Feeding Systems Ltd, New Milton, Hampshire, UK). The pH of the liquid feed was similar to the 1 : 3 diet offered in the second trial, indicating fermentation was not occurring. The DFI was calculated per group of pigs rather than for each individual animal; thus more replicates were included.

Trial two was arranged as a completely randomised design involving thirty-two boars, which was subsequently duplicated to give a total of 64 animals ($n = 16$ per group). Within each pen of eight pigs, two animals were randomly assigned to one of four treatments, which were subsequently offered as restricted (R) rations. The four treatments were: (i) Standard dry pellet diet (DR: BOCM Pauls Ltd; 19% CP, 1.15% lysine and 14 MJ/kg digestible energy (DE)) or D diet soaked in water at a feed-to-water ratio (w/w) of (ii) 1 : 1.5 (1 : 1.5 R) (iii) 1 : 3. (1 : 3 R) or (iv) 1 : 3 diet with the addition of lactic acid immediately prior to feeding (Lactic Acid Feed 80, Purac Biochem) to adjust the feed to a pH of 4 (1 : 3(4) R). The acid was substituted for an equal volume of water to maintain the same dry matter concentration as in (iii). The amount of lactic acid required to achieve the correct pH varied to some extent but was approximately 6 ml lactic acid per litre of wet feed. A ratio of 1 : 1.5 was chosen to act as an intermediate for the dry diet and at a 1 : 3 ratio, and these rations have been used by others (Barber *et al*., 1963; Holme and Robinson, 1965; Gill *et al*., 1987). Diet 1 : 3(4) represents a pH value similar to that of fermented feed (Brooks, 1999a). The pH of the water added to the feed and supplied to the pigs for drinking did not vary from 7.25 during the entire trial. The pH of each meal was tested and recorded immediately prior to feeding the pigs.

The rations were freshly prepared daily and on weekdays pigs were individually fed three times daily at 0700, 1200 and 1700 h. Water was available *ad libitum* at all times except during the meals. Animals voluntarily entered the individual feeding crates at the specific feeding times, and were allowed sufficient time to finish the ration following which they were released and all refusals collected and weighed. Feeding three times daily was adopted in order to ensure a high DFI with minimum refusals of feed. The total amount offered per day was approximately 5% to 10% below the *ad libitum* intakes previously recorded for similar genotype, dry-fed pigs in trial 1 above. Initially pigs were given 7 days to adapt to their respective experimental diets and the amount was adjusted to a level where all animals readily consumed their entire ration. The amount of feed offered was reviewed weekly and increased from 1.45 to 2.65 kg of air-dry feed per day from week 1 to slaughter (week 6).

The pigs on trial one were weighed at the start and again at the end of the study, while those on the second trial were weighed at weekly intervals throughout the 6-week experimental period. DFI and ADG were recorded to allow their feed conversion ratio (FCR) to be calculated. In addition, ultrasound measurements of backfat and eye muscle depth were recorded (Aloka-echo camera 550-500, Aloka Ltd, Japan) at the start and end of the study. Lean tissue growth rate (LTGR) was estimated using the following formula:

$$\begin{aligned}\text{LTGR} = [(&0.655 - 0.0115 \times \text{P2 backfat (mm)} + 0.00076 \\ &\times \text{Slaughter carcass weight } (W_c : \text{kg})) \\ &- (0.38 \times \text{Initial liveweight } (S : \text{kg}))]/ \\ &[\text{number of days of growth from S to } W_c]\end{aligned}$$

(Whittemore, 1998).

Although it is acknowledged that this equation may not be directly applicable to the porcine genotype and management system used in the current study, it does give an indication of differences between groups. In the second trial, the eating rate of pigs in the first replicate was recorded on 2 consecutive days each fortnight. On each day the pigs were brought into their feeding pens, presented with their meal and the time taken to finish it was recorded. On the few occasions when a pig failed to eat all of the meal, the total eating time recorded was divided by the amount actually eaten. If a pig totally refused to eat or was observed playing with the feed, these data were omitted from the analysis but in practice this was rare.

Feed analysis

Analysis of the feed was conducted in duplicate to determine crude protein %, ash %, oil %, and neutral detergent fibre % and water-soluble carbohydrate % (MAFF, 1986; Association of Official Analytical Chemists, 1990). The mean values were subsequently used to calculate the DE content of each dietary treatment (MAFF, 1993).

Statistical analysis

One animal in the 1 : 1.5 R dietary treatment group developed serious scours at the start of the trial and was removed. The data from the replicates were pooled as pen did not appear to influence the data. Statistical differences between dietary-treated groups were assessed using analysis of variance using Genstat 5.4. Regression analysis was used to determine ADG, DFI and FCR, and comparisons of the regression slopes and intercepts undertaken on ADG and FCR using Genstat 5.4. The eating rate data were subjected to analysis using the general linear model in Minitab 13 and further analysed by linear regression of eating rate against live weight.

Results

Chemical composition and physical characteristics of the diets

Chemical analyses of the diet showed marginal differences between DE, NDF, oils and ash components of the diet (Table 1). The biggest difference was in water-soluble carbohydrates but the values were subject to variation between samples both within and between dietary treatments. The mean pH values for all meals confirmed that the time allowed for soaking did not permit fermentation-induced changes in pH to occur. The average pH of the 1 : 3(4) diet was close to the intended pH of 4.0, which is generally observed in FLF.

Animal performance

Live weight of the pigs was similar between the dietary treatment groups at the start of the study (Table 2). ADG ($P < 0.001$) and hence their live weight ($P < 0.01$) at the end of trial 1 were greater in pigs offered the 1 : 3 UR diet compared with D UR animals. In contrast, there were no differences observed in either DFI or FCR between the two groups. Although backfat thickness, eye muscle depth and killing-out percentage were similar, LTGR was improved ($P < 0.01$) in animals receiving the 1 : 3 UR diet.

Within the restricted feeding groups, pigs offered the 1 : 3 diets were heavier ($P < 0.05$) and their ADG greater than those receiving dry pellets, with the greatest increases observed when lactic acid was added to the diet (Table 3). Although the 1 : 1.5 R group exhibited intermediate ADG ($P < 0.05$), there was no difference in their final live weight compared with the DR group The opposite was observed with respect to DFI, which was lower ($P < 0.01$) in the 1 : 3 R and 1 : 3(4) R animals, resulting in markedly improved ($P < 0.001$) FCR in these two groups. Backfat, eye muscle depth, killing-out yield and LTGR were similar between treatments (Table 3).

The gradients of the regression lines for FCR and ADG were similar between the four R groups as was the intercepts for ADG (Table 4). In terms of FCR, the intercepts of the 1 : 3 R and 1 : 3(4) R diets were significantly lower ($P < 0.05$) than

Table 1 *Analysis of the main nutrient components (g/kg DM unless otherwise stated) and calculated digestible energy (DE) contents of each dietary treatment*

	Feed : water (pH)			
	Dry	1 : 1.5	1 : 3	1 : 3(4)
DE (MJ/kg DM)	13.9	13.7	13.5	13.9
Crude protein	213	213	210	209
NDF	184	191	206	198
Oil	42.2	28.4	35.3	44.0
Ash	55	52.9	54.3	51.4
WSC (%)	8.6	11.7	11.5	14.3
pH as fed	6.45	6.25	6.29	3.97

NDF = neutral detergent fibre; WSC = water soluble carbohydrates.

Table 2 *The effects of water to feed ratio of the diet over a period of 6 weeks of unrestricted feeding on pig growth performance, daily feed intake, feed conversion ratio and carcass characteristics (FCR) of male pigs*

	Water : feed		
	Dry	1 : 3	s.e.d
No of pigs	32	32	
Initial weight (kg)	44.8	49.2	0.68
Final live weight (kg)	82.5^{A}	86.8^{B}	1.27
ADG (g/day)	831^{AA}	963^{BB}	26.9
DFI (g/day)	2241	2383	33.2
Mean FCR (g/g)	2.58	2.53	0.122
Backfat (mm)	10.3	10.8	0.18
Eye muscle depth (mm)	51.4	52.4	1.23
Killing-out yield (g/kg)	780	780	11.2
Lean tissue growth rate (g/day)	491^{A}	562^{B}	14.5

Values are presented as means. ADG = average daily gain; DFI = daily feed intake; FCR = feed conversion ratio. Within a row means with different superscripts are significantly different, $^{AB}P < 0.01$ and $^{AABB}P < 0.001$.

Table 3 *The effects of varying the water-to-feed ratio and pH of the diet over a period of six weeks of restricted feeding (5% to 10% below* ad libitum *intake) on pig growth performance, daily feed intake, feed conversion ratio and carcass characteristics (FCR) of male pigs*

	Water : feed ratio (pH)				
	Dry	1 : 1.5	1 : 3	1 : 3(4)	s.e.d
No of pigs	16	15	16	16	
Initial weight (kg)	46.8	46.6	47.1	48.3	1.55
Final live weight (kg)	82.9^{aA}	85.7	86.2^{b}	89.1^{bB}	2.9
ADG (g/day)	962^{aA}	1041^{b}	1051^{b}	1091^{bB}	40.0
DFI (g/day)	2000^{a}	1998^{a}	1935^{b}	1942^{b}	18.7
Mean FCR (g/g)	2.09^{a}	1.94^{a}	1.87^{b}	1.79^{b}	0.07
Backfat (mm)	10.3	10.4	10.6	10.7	0.41
Eye muscle depth (mm)	49.2	50.2	50.1	51.3	1.92
Killing out yield (g/kg)	764	726	711	720	71
Lean tissue growth rate (g/day)	463	495	490	487	55

Values are presented as means. ADG = average daily gain; DFI = daily feed intake; FCR = feed conversion ratio. Within a row means with different superscripts are significantly different, $^{ab}P < 0.05$ and $^{AB}P < 0.01$.

the D diet and the 1 : 3(4) R value was lower ($P < 0.05$) than the 1 : 3 R group. Liquid-fed R pigs had faster ($P < 0.001$) eating rates compared with the D pigs but generally there was little difference in the rate between the liquid treatments despite the fresh weight and volume of the 1 : 3 R diets being 60% greater than the 1 : 1.5 R (Table 5). A comparison between the eating rates at the 0700 h meal after the pigs had fasted overnight with those at the 1200 h meal revealed no statistical differences. There was a close correlation between eating rate (y) and live weight (x) for the D ($y = 0.5203x + 31.747$), 1 : 1.5 ($y = 0.7501x + 78.484$) and 1 : 3 ($y = 1.0747x + 53.552$) diets with R^2 values of 0.78, 0.67 and 0.83. The 1 : 3(4) diet had a much lower correlation of 0.256 ($y = 0.4262x + 89.961$) than observed in the other groups.

Discussion

There is a plethora of data to indicate that liquid feeding of pigs may significantly reduce production costs, improve growth rates, time to slaughter, lower feed to gain ratio or a combinations of these performance parameters besides offering welfare benefits (Braude 1967 and 1971; Jensen and Mikkelsen, 1998; Lawlor *et al.*, 2002; Canibe and Jensen, 2003; Scott *et al.*, 2007). However, there has been little new work on liquid feeding in growing-finishing modern porcine genotypes. Our findings clearly indicate benefits of feeding liquid diets to modern genotypes, whereas results obtained in earlier studies (e.g. Meade *et al.*, 1964, Braude and Rowell, 1967; Forbes and Walker, 1968; Klay *et al.*, 1969) were much more variable.

DFI was similar between D UR and 1 : 3 UR groups. Liquid feeding did improve ADG and LTGR, agreeing with previous results demonstrating an increase in ADG on liquid feeding

Table 4 *Regression intercept, slope and* R^2 *values for feed conversion ratio (FCR) and average daily live weight gain (ADG : g/day) between the restricted dietary treatments when parallel regression lines are fitted*

		Feed : water (pH)			
		Dry	1 : 1.5	1 : 3	1 : 3(4)
FCR	Intercept	0.7684^{B}	0.6496^{b}	0.555^{b}	0.356^{aA}
	Slope	0.0215	0.0215	0.0216	0.0212
	R^2	0.9014	0.7653	0.7488	0.7123
ADG	Intercept	0.5734	0.6367	0.6417	0.6820
	Slope	0.0056	0.0056	0.0056	0.0056
	R^2	0.4681	0.2957	0.1518	0.5492

Values with different superscripts are significantly different, $^{ab}P < 0.05$ and $^{AB}P < 0.01$.

Table 5 *Mean eating rates of pigs (expressed as eating rate of dry pellet equivalent in g/min) on liquid and dry diets measured during three 2-week periods at live weights of approximately 55, 75 and 90 kg*

	Feed : water (pH)			
LWT (kg)	Dry	1 : 1.5	1 : 3	1 : 3(4)
55	61.5^{b} (4.04)	125.2^{a} (4.84)	111.4^{a} (5.9)	109.4^{a} (6.55)
75	65.9^{b} (3.74)	130.0^{a} (5.32)	134.2^{a} (4.62)	133.5^{a} (7.89)
90	76.3^{b} (3.97)	144.7^{a} (7.3)	142.4^{a} (7.2)	130.2^{a} (6.67)
Overall	67.1^{b} (2.34)	132.6^{a} (3.4)	128.0^{a} (3.64)	123.9^{a} (4.31)

The means were calculated from four separate meals over 2 days. Means with different superscripts differ significantly, $P < 0.05$.

(Chae *et al.*, 1997). Both the FCR and ADG observed in the current study are comparable with the results published by Stotfold (2005) for finishing pigs reared on an unrestricted diet. It is of interest to note that ADG are greater when feed intake is restricted and hence FCR are substantially improved. FCR was 7% to 10% better in animals offered a restricted liquid diet and are in accordance with the findings of (Jensen and Mikkelsen, 1998), but these advantages disappeared on an *ad libitum* diet. Differences are most likely due to wastage or spillage around the trough (Forbes and Walker, 1968; Brooks, 1999a and 1999b) but may also be partially attributed to the eating behaviour and social hierarchies of grouped compared with individually fed pigs (Bryant and Ewbank, 1972; Vargas *et al.*, 1987).

Previous studies have used a range of water ratios and have reported a beneficial effect of increasing the water-to-feed ratio on the growth rate and FCR (Gill *et al.*, 1987). Other workers have reported better results obtained with ratios of 1 : 2.5 to 1 : 4, which coincidentally are also in the best operating range for pipeline distribution systems. Higher water ratios have been shown to increase digestibility (Barber *et al.*, 1991a). In contrast to the earlier work of Barber *et al.* (1963) and Braude and Rowell (1967), we have shown that a lower feed-to-water ratio of 1 : 1.5 R can result in improvements in both FCR and ADG compared with the D R diet. The lack of differences observed in the previous work may be because diets were offered *ad libitum* rather than as a restricted ration. While the present study shows improved performance with liquid feeding there was little difference between the water-to-feed ratios, suggesting the exact amount of water may not be critical in achieving better utilisation, a view supported by Yalda and Forbes (1996). The ADG of pigs offered FLF has been demonstrated to be approximately 13% higher than that found with NFLF (Jensen and Mikkelsen, 1998; Dung *et al*., 2005), and that pigs reared on liquid feed acidified with lactic acid perform similarly to those animals offered FLF (Geary *et al*., 1999). Following the addition of lactic acid to the 1 : 3 R diet, there was little improvement in ADG or FCR, which is not surprising as the feed intake was similar between both groups.

Eating rate was considerably higher in the liquid-fed compared with the dry-fed R pigs, roughly doubling their DM intake and of similar values to those reported by others (Hsia and Lu, 1985; Miyawaki *et al*., 1997). There were no further influences of the water : feed ratio as shown by others, which may be because the experimental diets offered were close to the range of optimum ratios (Miyawaki *et al*., 1997). Faster eating rates suggesting a reduced level of energy expenditure may be necessary in order to deal with wet food, which the pigs tend to drink with little mastication prior to swallowing. Post swallowing, the indications are that the flow of digesta, particularly the liquid phase, is quicker (Castle and Castle, 1957; Rayner and Miller, 1990) and presumably requires less energy to transport it along the gut, resulting in more energy being available for growth. A close correlation was observed between a higher eating rate and a live-weight gain, supporting the concept that liquid feed is more efficiently utilised for growth.

There is little evidence in the literature of changing responses to wet feed over time or weight range but Smith (1976) reported that between 30 and 45 kg live-weight liquid feeding made no difference to performance, but thereafter ADG and FCR were better. As seen in other production animals, FCR deteriorated progressively as live weight increased and the demand on nutrients for maintenance became a larger proportion of the energy intake. However, the animals on the 1 : 3 and 1 : 3(4) diets appeared to use their feed more efficiently throughout the growth period.

Backfat and LTGR were not significantly different between treatments, although in numerical terms pigs fed liquid diets, particularly on an *ad libitum* basis, had a slightly better LTGR. These findings are similar to those reported by others (e.g. Barber *et al*., 1963; Kornegay and Vander Noot, 1968; Patterson, 1989a and 1989b; Murphy, 2002; Stotfold, 2005). It has been suggested that the increased LTGR observed following liquid feeding may be due to extra nutrients being partitioned towards protein deposition. This further indicates that one of the main advantages of liquid feeding may be the ability to overcome appetite limitations and to access the genetic potential of the pig to lay down muscle. Several studies have reported no differences in the killing-out percentage (Forbes and Walker, 1968; Kornegay and Vander Noot, 1968; Chae *et al*., 1997) and a similar scenario was observed between our UR groups. In contrast, the killing-out percentage was consistently lower in the pigs offered a restricted ration on the three liquid diets compared with D and is in accordance with observations by others (Patterson, 1989a and 1989b). Alterations in killing-out percentage is not a constant feature of liquid feeding and any differences may be simply attributed to the different feeding regimes producing differences in gut fill or fasting time prior to slaughter.

Conclusions

It is concluded that liquid feeding has a beneficial influence on pig performance of modern porcine genotypes during the growth/finishing phase, and this is further modulated by the water-to-feed ratio. The addition of lactic acid to the liquid feed can improve pig performance beyond that seen for liquid feeding alone. Liquid feeding *ad libitum* rather than as a restricted ration reduces ADG of finishing pigs while increasing FCR, thus offering little production advantages.

References

Association of Official Analytical Chemists 1990. Official Methods of Analysis, 15th edition, Washington DC.

Barber RS, Braude R and Mitchell KG 1963. Further studies on the water requirements of the growing pig. Animal production 5, 277–282.

Barber J, Brooks PH and Carpenter JL 1991a. The effects of water to food ratio on the digestibility, digestible energy and nitrogen retention of a grower ration. Animal Production 52, 601.

Barber J, Brooks PH and Carpenter JL 1991b. The effect of four levels of food on the water intake and water to food ratio of growing pigs. Animal Production 52, 602.

Braude R 1967. The effect of changes in feeding patterns on the performance of pigs. The Proceedings of the Nutrition Society 26, 163–181.

Braude R 1971. Feeding Methods. In Pig production (ed. DJA Cole and Butterworths), pp. 279–291. University of Nottingham, London. Proceedings of the Eighteenth Easter School in Agricultural Science.

Braude R and Rowell JG 1967. Comparison of dry and liquid feeding of growing pigs. Journal of Agricultural Science, Cambridge 68, 325–330.

Brooks PH 1999a. The Potential of liquid feeding systems. In Concepts in Pig Science (ed. TP Lyons and DJA Cole), Chapter 7. Nottingham University Press.

Brooks PH 1999b. Can Fermented Liquid Feed (FLF) replace antibiotic growth promoters? Feed Compounder 19, 16–19.

Bryant MJ and Ewbank R 1972. Some effects of stocking rate and group size upon agonistic behaviour of growing pigs. The British Veterinary Journal 128, 64.

Canibe N and Jensen BB 2003. Fermented and non-fermented liquid feed to growing pigs: effect on aspects of gastrointestinal ecology and growth performance. Journal Animal Science 81, 2019–2031.

Castle EJ and Castle ME 1957. Further studies of the rate of passage of food through the alimentary tract of pigs. Journal of Agricultural Science, Cambridge 49, 106–112.

Chae BJ, Han IK, Kim JH, Yang CJ, Ohh SJ and Rhee YC 1997. Effects of feed processing and feeding methods on growth and carcass traits for growing-finishing pigs. Asian Australian Journal of Animal Science 10, 164–169.

DEFRA 2003. Code of Recommendations for the Welfare of Livestock. Available online: http://www.defra.gov.uk/animalh/welfare/farmed/pigs/pigcode.pdf

Deprez P, Deroose P, van den Hende C, Muyelle E and Oyaert W 1987. Liquid versus dry feeding in weaned pigs. Journal of Veterinary Medicine 34, 254–259.

Dung NNX, Manh LH, Ogle B 2005. Effects of fermented liquid feeds on the performance, digestibility, nitrogen retention and plasma urea nitrogen (PUN) of growing–finishing pigs. http://mekarn.org/proctu/xdun.htm

Forbes TJ and Walker N 1968. The utilization of wet feed by bacon pigs with special reference to pipeline feeding. Journal of Animal Science 71, 145–151.

Geary TM, Brooks PH, Beal JD and Campbell A 1999. Effect on weaner pig performance and diet microbiology of feeding a liquid diet acidified to pH 4 with either lactic acid or through fermentation with *Pediococcus acidilactici*. Journal of the Science of Food and Agriculture 79, 633–640.

Gill BP, Brooks PH and Carpenter JL 1987. Voluntary water use by growing pigs offered liquid foods of differing water-to-meal ratios. In Pig housing and the environment (ed. AT Smith and TLJ Lawrence), pp. 1–2. British society of Animal production, Edinburgh, UK. Occasional Publication No. 11.

Holme DW and Robinson KL 1965. A study of water allowances for the bacon pig. Animal Production 7, 377–384.

Hsia LC and Lu GH 1985. The effect of physical form of feed on eating speed of pigs. Journal of the Chinese Society of Animal Science 14, 43–46.

Jensen BB and Mikkelsen LL 1998. Feeding liquid diets to pigs. In Recent advances in animal nutrition, 1998 (ed. PC Garnsworthy and J Wiseman), Chapter 7, pp. 107–123. Nottingham University Press.

Klay RF, Smith GC and Weller MG 1969. Effect of restricted feed intake on performance, carcass measurements, flavor and tenderness of Hampshire and Palouse swine. Journal of Animal Science 29, 417–422.

Kornegay ET and Vander Noot GW 1968. Performance, digestibility and N-retention of swine fed diets with added water. Journal of Animal Science 27, 1307–1312.

Lawlor PG, Lynch PB, Gardiner GE, Caffrey PJ and O'Doherty JV 2002. Effect of liquid feeding weaned pigs on growth performance to harvest. Journal of Animal Science 80, 1725–1735.

Longland AC 1991. Digestive enzyme activities in pigs and poultry. In In vitro digestion for pigs and poultry (ed. MF Fuller), p. 3. CAB International, Wallingford, Oxon, UK.

MAFF 1986. The analysis of agricultural Materials. HMSO, London.

MAFF 1993. Prediction of the energy values of compound feeding stuffs for farm animals.

Meade RJ, Hanke HE, Tumbleson ME, Wass D and Hanson LE 1964. Effects of feed restriction and protein intake on performance of market hogs. Journal of Animal Science 23, 1201.

Miyawaki K, Hoshina K and Itoh S 1997. Effects of feed and water mixture for finishing pigs on eating speed and feed intake. Japanese Journal of Swine Science 34, 1–8.

Murphy J 2002. Liquid diets improve performance of weaned pigs. Ontario Ministry of Agriculture, Food and Rural Affairs. http://www.omafra.gov.on.ca/english/livestock/swine/facts/impperf.htm

Patterson DC 1989a. A comparison of various feeding systems for finishing pigs. Animal Feed Science and Technology 26, 251–261.

Patterson DC 1989b. A comparison of offering meal from a self-feed hopper having built-in watering with some conventional systems of offering meal and pellets to finishing pigs. Animal Feed Science and Technology 26, 261–270.

Pluske JR, Hampson DJ and Williams IH 1997. Factors influencing the structure and function of the small intestine in the weaned pig: a review. Livestock Production Science 51, 215–236.

Rayner DV and Miller S 1990. Cholecystokinin effects on wet and dry meals in pigs. The Proceedings of the Nutrition Society, 49, 222A.

Rerat A and Fevrier C 1965. Influence du taux d'hydraion du regime sur la croissance et la composition corporella du porc. Annuals of Zootechnology 14, 39.

Scott K, Chennells DJ, Armstrong D, Taylor L, Gill BP and Edwards SA 2007. The welfare of finishing pigs under different housing and feeding systems: liquid versus dry feeding in fully-slatted and straw-based housing. Animal Welfare 16, 53–62.

Smith P 1976. A comparison of dry, wet and soaked meal for fattening bacon pigs. Experimental Husbandry 30, 87–94.

Stotfold 2005. The British Pig Industry's Centre of Excellence. 2005 Finishing pigs: Systems of research production trial 1. http://www.stotfoldpigs.co.uk/research/fpsr_pt1.pdf

Vargas Vargas, Craig JV and Hines RH 1987. Effects of feeding systems on social and feeding behavior and performance of finishing pigs. Journal of Animal Science 65, 463–474.

Whittemore C 1998. Simulation Modelling. In The science and practice of pig production, pp. 569–572, 2nd edition. Blackwell Science.

Yalda AY and Forbes JM 1996. Effects of food intake, soaking time, enzyme and cornflour addition on the digestibility of the diet and performance of broilers given wet food. British Poultry Science 37, 797–807.