Effects of particle size, processing, and dry or liquid feeding on performance of piglets

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Abstract. Currently, most feed grains are processed by either hammer mill or roller mill before the inclusion in pig diets. However, the effect of these two types of milling and particle size on the performance and feed utilisation has not been adequately examined. The effect of milling processing (hammer mill v. roller mill), particle size, and feeding method (liquid v. dry) was assessed in a factorial design with 120 weaner pigs over 21 days. These pigs had been weaned for 7 days when the experiment commenced. The results revealed that pigs fed on hammer-milled diets had a better performance than those on roller-milled diets. Particle size of hammer-milled diets did not affect the performance of pigs, but influenced the digestible energy content of the diets. However, the feed conversion ratio was poorer for pigs fed coarsely or medium roller-milled diets only at Day 7–14 after weaning. There was a marked advantage in terms of feed efficiency associated with liquid feeding. For pigs offered the hammer-milled diets between 0 and 14 days, simply adding the feed to water improved feed efficiency by some 22%. For the roller-milled diets the corresponding improvement in feed efficiency was 28%. Liquid feeding improved digestible energy (DE) value by 1.5 MJ/kg for medium particle size and depressed DE value by 0.8 MJ/kg for fine particle size for hammer mill. Liquid feeding improved DE values for both medium and fine particle treatments by 0.9 MJ/kg for roller-milled diets. It should be noted that the full advantages of liquid feeding could only be taken if feed wastage from this system can be minimised as much as possible.

The study was conducted to investigate if processing method (roller v. hammer mill), particle size (coarse, medium, and fine), and feeding method (liquid v. dry) significantly improved the growth rate, feed intake, and feed conversion of the weaner pig.

Additional keywords: pigs, feed processing, feed conversion ratio, wheat, digestible energy.

Introduction

Processing of feed grains plays an integral role in determining the nutritive benefits gained by the animal and affects the effectiveness of exogenous enzymes. The success of a feeding method such as liquid feeding is also greatly influenced by the manner in which the grain has been initially processed. Thus it is not only important to address the physiological development of the animal when formulating a diet but also the type of grain and the manner in which it is processed during the milling phase. This will have important consequences to both the diet and cost of production.

There are several methods used in grain processing, but the most commonly used methods are the hammer mill and the roller mill. It has been recognised for quite some time that grinding feed by either of the aforementioned methods does a great deal towards improving the nutritional value of the feed by altering the physical makeup of components of the grain such as starch (Little 1997). However, the magnitude of such improvement is largely dependent on the particle size of the processed feed. Grain ground to a smaller particle size provides greater surface area open to enzyme activity, allowing more amino acids and energy to be extracted from the feed and absorbed through the small intestine of the animal. However, if the particle size of the grain is too small, this will result in a decrease in pig performance due to an increase in the likelihood of the development of gastric ulcers (Little 1997). It is also well known, for example with wheat, that the finer the particle size, the more sticky and unpalatable it becomes in the mouth of the pig (Little 1997).
On the other hand, a diet ground too coarsely is also inefficiently utilised due to the rapid passage of the large particles through the digestive tract of the animal, resulting in ineffective or incomplete mastication and digestion of the diet (Ivan et al. 1974). This suggests that the optimum particle size for hammer mill and roller mill becomes crucial for effective feed processing.

Apart from feed processing, the way that feed is delivered to pigs is also an important factor influencing the performance of piglets, especially in the immediate post-weaning phase when energy intake is often below the recommendation (16.5 MJ/day) (QAF Meat Industries, 1992). Russell and Frazer (1996) confirmed that providing a liquid diet could increase the dry matter intake of the piglet and produce a more regular eating pattern after weaning. This, in turn, may ensure that the piglet’s fluid intake is adequate, hence reducing the associated dehydration problems (Russell et al. 1996). With careful implementation and design of feeding systems, liquid feeding can also reduce feed wastage, increase acidity of the diet and the availability of phosphorus, improve the accessibility of substrates to the digestive enzymes and reduce viscosity in the gut which assists in improving the feed efficiency of the animal (Brooks 1994; Geary et al. 1996). With these advantages, there has been an increased move by piggeries to adopt a liquid feeding regime in several areas of production. However, Kornegay and Thomas (1981) found no significant difference in daily gain and daily feed intake between dry and liquid fed pigs and the feed conversion ratio was higher in the pigs fed the dry diet, which differs from results obtained in other trials.

The study reported here was conducted to investigate the effect of processing method (roller v. hammer mill), particle size (coarse, medium, and fine), and feeding method (liquid v. dry) on the growth rate, feed intake, and feed conversion of the weaner pig.

**Materials and methods**

**Diets and feeding**

The dietary treatment factors were particle size (coarse, medium, or fine), processing type (roller or hammer milled), and feeding method (dry or liquid for the fine and medium particle sizes of each processing type). Restrictions due to the number of liquid feed mixers meant that not all 6 dry mash diets were fed as liquid feed. Therefore, there were 10 treatments instead of the 12 indicated by the experimental design.

The basal diet was formulated according to recommended dietary requirements for weaner pigs (Table 1). Only the cereal component (wheat) of the diet was hammer or roller milled to 3 different particle sizes. The roller-milled feed was processed as either a coarse, medium, or fine particle size. The hammer-milled feed was processed through a 2.5-mm (fine), 3.2-mm (medium), or a 3.5-mm (coarse) screen. The analysis of the particle size for each of the diets is shown in Table 2. Due to the nature of a roller mill, the particle size of feed was larger than for the hammer mill. The spectrum of coarse, medium, and fine particle size in this study was different for roller mill and hammer mill. Hexatriacontane (C₃₆H₇₄), a long chain hydrocarbon, was added to the diets as a digestibility marker at a rate of 50 g/t.

Both processing types (of all 3 particle sizes) were fed as a dry feed (mash) to pigs (6 treatments); however, only the medium and fine particle sizes of both processing methods were fed to pigs as liquid feed (additional 4 treatments). Liquid-fed pigs were fed ad libitum from modified dry feeders (water-proofed for liquid feed), 4 times a day (0630, 0930, 1230, 1430 hours). This was done in an effort to minimise feed wastage. Feed was mixed in a 2.5:1 water:solid feed ratio overnight for 15 h before feeding.

Delivery of the liquid feed was done manually on a daily basis and was adjusted according to the consumption patterns of the individual pig. The volume of feed at each feeding session was recorded and pooled for each day. To avoid build up of stale feed, any feed not consumed on a given day was weighed out the following morning and discarded. This allowed for a more accurate quantification of feed intake.

**Animals**

One hundred (120) male weaner pigs (Large White × Landrace, weaned 27 days) were selected on a bodyweight basis (start weight of 8 kg liveweight) at weaning and randomly allocated among 10 treatments in a 2 × 2 × 2 factorial design. Animals were housed individually for the duration of all the experiments. Each pen had an area of 0.5 by 0.9 by 0.5 m and was equipped with a feeder (either conventional dry feeder or one slightly modified to allow feeding with a liquid diet) and a single drinking nipple.

Twelve pigs were allocated per treatment. Pigs were allowed a 7-day establishment period on the experimental diets, and were weighed upon completion of this period. The lightest pigs from each treatment were removed from the trial at this point in an effort to create an even start weight. Therefore, the weight at the end of the 7-day establishment period became the official start weight. Average start weight was 8.20 ± 0.09 kg. The experiment was run as 2 replicates, 50 pigs (5 per treatment) in the first replicate and 50 pigs (5 per treatment) in the second replicate 1 week later. All data were compiled into one set upon completion of the experiment.

The experiment was conducted in May and temperature averaged 27°C (metabolism shed at constant temperature).

**Table 1. Composition of basal diet**

<table>
<thead>
<tr>
<th>Raw material</th>
<th>kg/t</th>
<th>Raw material kg/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat (13.5% CP)</td>
<td>650.0</td>
<td>Threonine</td>
</tr>
<tr>
<td>Meat meal (55% CP)</td>
<td>55.0</td>
<td>t-Leucine</td>
</tr>
<tr>
<td>Fishmeal (67% CP)</td>
<td>100.0</td>
<td>Tryptosine</td>
</tr>
<tr>
<td>Blood meal</td>
<td>33.0</td>
<td>Valine</td>
</tr>
<tr>
<td>Skim milk</td>
<td>60.0</td>
<td>Zinc oxide</td>
</tr>
<tr>
<td>White powder</td>
<td>40.0</td>
<td>Black feed PremixA</td>
</tr>
<tr>
<td>Water</td>
<td>25.0</td>
<td>Endox</td>
</tr>
<tr>
<td>Canola oil</td>
<td>25.5</td>
<td>Amoxyl (10%)</td>
</tr>
<tr>
<td>Lysine</td>
<td>0.8</td>
<td>Pulmolit 200 PMX</td>
</tr>
</tbody>
</table>

APremix provided the following levels of vitamins and trace minerals per t mixed feed: vit A 15 ml/l, vit D₃ 2.5 ml/l, vit E 50 g, vit K 2 g, folic acid 0.5 g, niacin 20 g, Ca-å-pantethenate 10 g, riboflavin 5.0 g, vit B₆ 2.5 g, vit B₁₂ 20 mg, biotin 100 mg, Se 0.30 g, Cu 20 g, Fe 100 g, Mn 50 g, Zn 80 g, I 0.5 g, choline chloride 200 g, betaine 86.6 g, endox 100 g.
Measurements

Weight gains and feed intakes of each individual pig were taken on a weekly basis (0–7, 7–14, 14–21 days on trial). From these measurements, daily feed intake, feed to gain ratios, and rate of gain values were calculated on an individual pig basis. Feed intake is expressed on a dry matter basis.

Faecal samples were taken over 3 days during the second week of the experiment (7–14 days). These were frozen immediately and stored for estimating digestible energy content. The gross energy of diet and faecal samples was analysed using a DDS isoperibol calorimeter (Digital Data Systems, Johannesburg, South Africa).

The hydrocarbon in diet and faecal samples was determined as follows. To 100–500 mg samples, an appropriate amount (50–200 mg) of internal standard (C34H70 in dodecane) was added. The samples were then subjected to 1.5 M ethanolic KOH in a heating-block at 90°C for 1 h with stirring. After cooling, the hydrocarbons were extracted in n-hexane several times, filtered, purified, and quantified by gas chromatography.

The DE (MJ/kg) was calculated using the following equation:

\[ \text{DE} = \frac{\text{Diet GE (MJ/kg)}}{\text{diet marker (g/kg)}} \times \left( 1 - \frac{\text{faecal GE (MJ/kg)}/\text{faecal marker (g/kg)}}{\text{diet GE (MJ/kg)}/\text{diet marker (g/kg)}} \right) \]

Blood samples from the first replicate group were taken upon completion of their experimental period (21 days). These were then analysed by Vanderfeen Diagnostics, Bendigo, Vic. Tests included packed cell volume (PCV), haemoglobin analysis, red blood cell count to ascertain anaemia status, and a white blood cell count to indicate the presence of an infection.

Statistical analysis

Three pigs were removed from trial due to illness and subsequent poor performance. Two pigs were from the dry treatments, with one injuring himself by trying to jump out of the pen during the first week of the experiment and one having respiratory problems during the second week of the experiment. One sick pig was removed from the liquid treatment during the first week of the experiment. All remaining individual pig data were included in the statistical analysis. A 2 × 2 × 2 analysis of variance was conducted to determine the effects of processing, particle size, and feeding method (liquid or dry). Further analysis included a 2 × 3 analysis to determine the effects of processing and particle size. Least significant difference (l.s.d.) tests were also conducted to determine significance of differences between treatment means.

Results

Effects of grain processing methods

Days 0–7

Processing type and particle size had no significant effect \((P > 0.05)\) on either daily weight gain or feed intake (Table 3). However, processing type significantly \((P < 0.05)\) affected feed conversion ratio (FCR). Hammer milling, on average, resulted in a better FCR than roller milling \(1.29 \times 1.47\). Particle size did not affect FCR, but fine milling did remove the differences between roller and hammer milling.

Days 7–14

Daily weight gain was unaffected by individual treatments or treatment interactions (Table 3). Hammer milling did improve FCR \((P < 0.05)\) throughout this period, with average values being 1.99 for roller mill and 1.47 for hammer mill. The intake of animals fed on the coarsely milled diet was higher than of those on medium and fine milled diets for roller mill processing, but particle size did not influence intake of pigs \((P > 0.05)\) fed with hammer-milled diets.

Days 14–21

There were no significant results recorded over this period. Whilst the trends for growth parameters seen up until
Table 3. Effect of grain processing on the growth performance of pigs in a 21-day experiment starting from Day 30 of weaning

Treatment means within a column followed by the same letter are not significantly different ($P > 0.05$). Values for intake and FCR expressed are to 100% DM basis.

<table>
<thead>
<tr>
<th>Processing</th>
<th>Grind size</th>
<th>Start wt (kg)</th>
<th>0–7 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
<th>7–14 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
<th>14–21 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
<th>0–21 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller mill</td>
<td>Coarse</td>
<td>8.36</td>
<td>344ac</td>
<td>427</td>
<td>1.29ac</td>
<td>506</td>
<td>1000a</td>
<td>2.27a</td>
<td>549</td>
<td>1005</td>
<td>2.09</td>
<td>466</td>
<td>763</td>
<td>1.74a</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>8.34</td>
<td>295a</td>
<td>374</td>
<td>1.41a</td>
<td>435</td>
<td>735b</td>
<td>2.06ac</td>
<td>526</td>
<td>948</td>
<td>1.89</td>
<td>418</td>
<td>630</td>
<td>1.64a</td>
</tr>
<tr>
<td></td>
<td>Fine</td>
<td>8.37</td>
<td>354ab</td>
<td>418</td>
<td>1.25ab</td>
<td>475</td>
<td>736b</td>
<td>1.64bc</td>
<td>568</td>
<td>985</td>
<td>1.89</td>
<td>465</td>
<td>656</td>
<td>1.50ac</td>
</tr>
<tr>
<td>Hammer mill</td>
<td>Coarse</td>
<td>9.00</td>
<td>444b</td>
<td>467</td>
<td>1.06bc</td>
<td>584</td>
<td>818bc</td>
<td>1.40b</td>
<td>660</td>
<td>1006</td>
<td>1.61</td>
<td>563</td>
<td>721</td>
<td>1.28bc</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>8.93</td>
<td>432bc</td>
<td>430</td>
<td>1.01b</td>
<td>650</td>
<td>904ac</td>
<td>1.41b</td>
<td>608</td>
<td>1002</td>
<td>1.80</td>
<td>564</td>
<td>721</td>
<td>1.29bc</td>
</tr>
<tr>
<td></td>
<td>Fine</td>
<td>8.98</td>
<td>446b</td>
<td>443</td>
<td>1.02b</td>
<td>528</td>
<td>778bc</td>
<td>1.60bc</td>
<td>631</td>
<td>1004</td>
<td>1.69</td>
<td>535</td>
<td>696</td>
<td>1.30bc</td>
</tr>
</tbody>
</table>

$P$ value

| Process (P)      | 0.068      | 0.748        | 0.005                | 0.200          | 0.146  | 0.049                  | 0.255          | 0.847  | 0.162                  | 0.080          | 0.394  | 0.005                  |
| Particle size (S) | 0.607      | 0.406        | 0.710                | 0.520          | 0.010  | 0.572                  | 0.715          | 0.450  | 0.914                  | 0.823          | 0.097  | 0.565                  |
| $P \times S$     | 0.760      | 0.868        | 0.530                | 0.150          | 0.002  | 0.129                  | 0.890          | 0.815  | 0.493                  | 0.496          | 0.126  | 0.445                  |

Table 4. Effect of processing, grind size and diet on the performance of pigs in a 21-day experiment starting from Day 30 of weaning

Treatment means within a column followed by the same letter are not significantly different ($P > 0.05$). Values for intake and FCR expressed are to 100% DM basis.

<table>
<thead>
<tr>
<th>Processing type</th>
<th>Feeding method</th>
<th>Particle size</th>
<th>0–7 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
<th>7–14 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
<th>14–21 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
<th>0–21 days Gain (g/day)</th>
<th>Intake (g/day)</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller mill</td>
<td>Dry</td>
<td>Medium</td>
<td>295bc</td>
<td>374</td>
<td>1.41a</td>
<td>435a</td>
<td>735</td>
<td>2.06a</td>
<td>525a</td>
<td>948</td>
<td>1.89a</td>
<td>365a</td>
<td>518</td>
<td>1.64a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine</td>
<td>354ab</td>
<td>418</td>
<td>1.25ab</td>
<td>475</td>
<td>736b</td>
<td>1.64bc</td>
<td>568</td>
<td>985</td>
<td>1.89a</td>
<td>414ab</td>
<td>540</td>
<td>1.37b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid</td>
<td>284b</td>
<td>254</td>
<td>0.98bc</td>
<td>456a</td>
<td>577</td>
<td>1.31bc</td>
<td>566ab</td>
<td>839a</td>
<td>1.51b</td>
<td>365a</td>
<td>353</td>
<td>0.98c</td>
</tr>
<tr>
<td>Hammer mill</td>
<td>Dry</td>
<td>Medium</td>
<td>432a</td>
<td>430</td>
<td>1.03bc</td>
<td>650d</td>
<td>904</td>
<td>1.41bc</td>
<td>608ab</td>
<td>1002</td>
<td>1.81a</td>
<td>541b</td>
<td>622</td>
<td>1.16bc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine</td>
<td>445a</td>
<td>443</td>
<td>1.02bc</td>
<td>528ac</td>
<td>778</td>
<td>1.60bc</td>
<td>631ab</td>
<td>1004</td>
<td>1.69a</td>
<td>486bd</td>
<td>571</td>
<td>1.17bc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid</td>
<td>360ac</td>
<td>270</td>
<td>0.76c</td>
<td>607cd</td>
<td>703</td>
<td>1.19cd</td>
<td>671b</td>
<td>1007b</td>
<td>1.64b</td>
<td>471bd</td>
<td>390</td>
<td>0.82cd</td>
</tr>
</tbody>
</table>

$P$ value

| Processing (P)   | 0.017          | 0.520        | 0.006                | 0.018          | 0.193  | 0.182                  | 0.112          | 0.022  | 0.093                  | 0.082          | 0.189  | 0.003                  |
| Particle size (S) | 0.297          | 0.776        | 0.090                | 0.772          | 0.227  | 0.281                  | 0.868          | 0.889  | 0.971                  | 0.799          | 0.634  | 0.074                  |
| Feeding method (F) | 0.310         | 0.087        | 0.001                | 0.001          | 0.449  | 0.000                  | 0.045          | 0.764  | 0.025                  | 0.001          | 0.157  | 0.001                  |
| $P \times S$     | 0.580          | 0.784        | 0.240                | 0.270          | 0.205  | 0.298                  | 0.946          | 0.902  | 0.504                  | 0.369          | 0.329  | 0.438                  |
| $P \times F$     | 0.851          | 0.373        | 0.128                | 0.371          | 0.532  | 0.597                  | 0.461          | 0.041  | 0.443                  | 0.434          | 0.302  | 0.090                  |
| $S \times F$     | 0.773          | 0.333        | 0.581                | 0.210          | 0.321  | 0.909                  | 0.270          | 0.407  | 0.587                  | 0.554          | 0.708  | 0.651                  |
| $P \times S \times F$ | 0.691       | 0.601        | 0.913                | 0.093          | 0.286  | 0.088                  | 0.898          | 0.991  | 0.865                  | 0.129          | 0.432  | 0.094                  |
this point continued through the last week of the experiment, the differences between the roller-milled and the hammer-milled treatments were not as distinct (Table 3). Pigs during this final week of the experiment were outgrowing their individual cages and the feeder design. This may have led to boisterous behaviour and, consequently, ‘messy’ eating, particularly from the hammer-milled feed treatments.

Days 0–21

When the data were pooled over the 3 weeks, it was obvious that hammer milling improved FCR ($P < 0.05$) throughout the entire experiment. Feeding with the roller-milled diets resulted in much less efficient utilisation and conversion of feed as compared with that of the hammer-milled diets. This has important consequences, particularly with respect to the continued use of roller mills in the processing of pig diets (Table 3). However, particle size did not affect ($P > 0.05$) overall intake and daily weight gain.

**Discussion**

As feed costs represent a large percentage of total operating costs, improving the efficiency of feed utilisation will have significant consequences for the profitability of pig production (Goodband 1993). There are many approaches to improving feed efficiency. One, which is often outweighed due to the economics associated with processing in Australia, involves the manipulation of particle size and milling processes of grain. In this experiment, milling process and particle size were manipulated to determine their effects on digestibility and utilisation of both a dry mash diet and a liquid diet.
Nearly all grains are subjected to milling processing before inclusion in pig diets. A recurring question in the grain-processing debate is whether to implement a roller or hammer mill, although both are capable of producing a similar particle size. It is clear that hammer mills are easier to maintain and have a greater range of raw materials that they can process (Anon. 1996), but in the past, roller mills have been recommended for processing wheat for pig diets due to their ability to produce a uniform particle size with fewer fines. These fine particles are believed to be responsible for a reduced feed intake in pigs and increased incidence of gastric ulcers (Goodband 1993). In the present experiment, pigs offered the hammer-milled diets consistently ate more feed and grew faster than those offered the roller-milled diets, suggesting that the hammer mill may in fact be the preferable method of processing wheat for pig diets. It was noted that the difference between the hammer-milled diet and the roller-milled diet became less apparent, probably partly due to an increase in feed wastage during the final week of the experiment. Pigs fed the hammer-milled diet began to behave boisterously, spilling copious amounts of feed from the troughs. It is known that fine grinding of feed can increase the solubility of non-starch polysaccharides (NSPs), lengthening food transit time in poultry (Bedford et al. 1991). One of the consequences of increased soluble NSPs in the gut is elevated gut viscosity and change of gut microflora (Choct et al. 1995). Whether the behavioural changes noted in the pigs are related to a certain discomfort in the gut is speculative. Another possibility as to why the performance of the pigs fed diets processed differently (hammer or roller milled) became similar as the pigs aged may be related to the maturation of their digestive system to effectively handle coarser materials.

**Particle size**

Particle size did not show a clear effect on feed intake and utilisation efficiency in the current work. Although pigs consuming the dry hammer-milled diets consistently performed better than those fed the roller-milled diets, pigs fed coarsely, medium, and finely hammer-milled diets did not show any differences in growth rate, feed conversion, and intake, probably suggesting that milling wheat through a 3.5-mm sieve is enough for feeding weaner pigs. It is difficult to draw a conclusion on the optimum particle size for roller milling because the feed conversion ratio of coarsely and medium milled diets was poorer than of the
finely milled diet during days 7–14 after weaning. However, this difference was not apparent at any other periods or the overall experimental period.

The present study clearly demonstrated a significant effect of particle size on the digestible energy content of the wheat-based diet for weaner pigs. It is well understood that the reduction in particle size increases the surface area of the grain, thereby increasing its interaction with digestive enzymes in the gut (Goodband 1993). A reduction in particle size also leads to improved handling and mixing characteristics, although there may be associated increases in milling costs, the incidence of gastric ulcers, feed bridging in the trough (in mash feeds) and handling problems associated with dust (Goodband 1993). However, there is also conjecture over the optimum particle size for pig diets. To a certain extent, the particle size to which the diet is ground is determined by the grain to be included in the diet. In high fibre grains (such as barley), the nutritive value of the feed is greatly improved when they are finely ground (Goodband 1993). Wheat was the primary cereal source in this experiment, and as such, posed its own unique set of processing problems. Wheat has inherently high starch levels and tends to mill better than barley. These starch granules vary in size. It is possible that grinding may disrupt the cell wall matrix of the grain, leading to the rupture of some larger granules, making dietary starch more accessible to amylase and glucoamylase in the gut. Wheat also has a high gluten content and tends to become floury. If ground too finely, wheat becomes pasty and unpalatable and reduces feed intakes. Thus further study is required to define the optimum particle size for both hammer milling and roller milling for different types of feed grains.

**Liquid feeding**

Much of the poor performance associated with the post-weaning period can be attributed to a combination of inadequate feed intake by the pig and inability to make efficient use of the feed. These detrimental effects have been linked to weaning weight and, as a consequence, the gut capacity of the animal. The age and the weight of the piglet at weaning directly influence the physiological development of the digestive tract and digestive capacity of the animal (Crumby 1986). By hydrating the mash feed, the digestibility of the diet is increased and the feed is presented in a form that is more suitable to the immature digestive tract of the newly weaned pig. It is important to note that whilst the present experiment used weaner pigs as a model to elucidate the effects of grain processing on nutrient utilisation, questions still surround the application of the results to older pigs.

It has been demonstrated that liquid feeding can also improve growth rates and feed efficiency in grower-finisher pigs (Brooks et al. 1996). This work showed that in a comparison between dry, wet, and soaked meal, daily gain was significantly greater for both the wet and the soaked meal over the period 45 kg to slaughter. Overall, there was no significant effect on daily gain as a result of the wet or soaked meal. The work, however, showed that in terms of feed efficiency, dry meal consistently out-performed the wet and soaked meal in both the 20–45 kg and the 45 kg to slaughter growth periods. It is possible that this is a reflection of a large amount of feed wastage in the system, addressing the point that if a liquid feeding regime is to be successful, every effort must be made to minimise wastage from the system.

Liquid feeding is not widely used in Australia, but is a common practice in Europe and North America, largely as a means of utilising liquid by-products. Exponents of this feeding method pronounce that the benefits lie in the increased feed efficiency and thereby a reduction in production costs (Crumby 1986). Previous experiments comparing liquid feed with a dry mash have yielded mixed results. In some cases, liquid feeding increased growth rate and feed efficiency, whereas in other cases, there was no increase (Crumby 1986). The present results showed a marked advantage in terms of feed efficiency associated with liquid feeding. For example, comparing the result for pigs offered the hammer-milled diets between 0 and 14 days, simply adding the feed to water improved feed efficiency by some 22%. For the roller-milled diets the corresponding improvement in feed efficiency was 28%. The results also showed that the difference in feed efficiency between pigs offered the hammer-milled and roller-milled grains was mildly reduced when the diets were wet. This is attributed to the changes that occur once the diet is hydrated. It is thought that this improvement in the nutritive value of the diet in a liquid feeding system is the culmination of several key factors. First of all, increased moisture levels can activate the endogenous enzymes present in grains. At the time of harvest, grain consists of at least 2 living entities: the grains themselves and the microorganisms that colonise them. Both entities can bring about various degrees of physical, chemical, and biological changes during storage and soaking. One such change is the activation of the endogenous enzyme systems within the grain, which with time, can act on the cell wall structures in a similar way to that of exogenous feed enzymes. This action of enzymes can result in improved nutritive value of cereals for poultry (Choct and Hughes 1997) and could also have important consequences for the efficiency of digestion of cereal grain in other species. Some well documented cases demonstrating the importance of endogenous enzymes include large improvements in performance of birds fed germinated (Fengler et al. 1990), water-treated (Fernandez et al. 1973), or rain-damaged (Choct and Annison 1993) grains. The nutritive values for poultry increased from 10 to 13 MJ/kg dry matter over a 4-month period (Choct and Hughes 1997). Germination of wheat also results in a large decrease in the molecular weight and viscosity of the NSPs, with no
noticeable amounts of monosaccharides released (Mares and Stone 1973; Fincher and Stone 1974; Corder and Henry 1989). Secondly, increasing the liquid content of the diet may permit more effective permeation of the digesta by digestive enzymes inherent to the pig, and enzymes produced by the gut microflora.

The current findings are contrary to results reported by Brooks et al. (1996). In their work, feed conversion was better in the dry fed pigs than in liquid fed pigs. This decrease in feed efficiency was apparently a consequence of feed wastage by the liquid fed pigs. In the current experiment, although feed wastage was not entirely eliminated, the frequent feeding regime acted to minimise the waste. This is reflected in the feed conversion ratio.

It has also been reported that liquid feeding may increase the feed intake of weaner pigs (Crumby 1986). Such an effect was not apparent in the current work, where the dry fed pigs had higher feed intakes. This might be due to the feeders used in this study. Pigs were fed the liquid diet using a conventional dry feeder that was quite deep and, as such, posed physical limitations to the pigs eating large amounts of feed without resulting in large amounts of feed wastage. Thus the liquid fed pigs were fed small amounts frequently throughout the day in order to minimise feed wastage. As a consequence, the pigs were slightly restrict-fed and consequently the growth rates were lower in the liquid fed pigs due to the decreased feed intake.

Liquid feeding did not result in any health problems for pigs in the current experiment. Packed cell volumes (PCV), haemoglobin, red blood cell count, and white blood cell count were within the normal ranges for these blood parameters. Benefits of such a liquid feeding system also lie in environmental issues. By liquid feeding it is possible to reduce the amount of substances that are not used by the pig and therefore, nutrients that are contained in the manure (Brooks et al. 2001). Once the composition of the effluent is changed, this reduces the threat of polluting the environment.

Conclusions

The current results demonstrate the need to address the issue of particle size of the grain in the diet and the method by which the grain is processed. Dry hammer-milled grain is much better utilised than a roller-milled feed, but the magnitude is reduced with liquid feeding. Therefore, liquid feeding per se appears to have a lot to offer for pig production.

Although currently, about 60% of commercial feed mills throughout Australia rely on hammer milling, and at the home-milled level, approximately 50% would use a roller mill, little or no attention has been paid to the effect of particle size on performance of pigs. Although the current results indicate that there is not a highly significant difference between particle size treatments for hammer-milled diets, the performance of pigs may vary as the degree of coarseness increases, especially for roller milling. Hammer milling also significantly improved DE of the diet, due to the increase in surface area of the particles allowing increased interaction between enzymes in the pig's digestive tract and the substrate. Offering pigs finely hammer-milled feed in a liquid form, however, appears to have negative effect on the DE value, perhaps due to over-exposure of nutrients to microbial fermentation during liquid mixing. Thus, a medium grind using a hammer mill may be advantageous for pigs fed diets in a liquid form.

It is also important to note that if a liquid feeding system is to affect a production system to the fullest extent possible, it is imperative that feed wastage from the system be minimised as much as possible. To this end, extra capital outlay may be required in the initial development phase of a liquid feeding system so that the advantages of using a liquid diet are not marred by the element of waste.

Although this experiment used weaner pigs, they are simply a model on which to base future decisions. The benefits accrued by liquid feeding a medium hammer-milled mash to weaners will carry on and have important consequences for the growth performance of pigs throughout the grower/finisher phase of production. By increasing efficiency of feed utilisation, cost of production can be drastically reduced, thereby affecting cost of production margins.

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