Physical processing of barley and its effects on intra-caecal fermentation parameters in ponies

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Abstract

Intra-caecal fermentation parameters in caecally-fistulated ponies offered barley based diets in which the barley had been physically processed by either rolling (RB), micronising (MB) or extruding (EB). Three ponies were offered 4 kg dry matter (DM) per day of either 100% hay cubes (HC), or one of three diets consisting of a 50:50 barley:HC mix. Due to small refusals of HC, the actual DM intakes (kg per day) were 3.74, 3.67, 3.57 and 3.52 (S.E.D. 0.18) for the HC, RB:HC, MB:HC and EB:HC diets, respectively. With the exception of butyrate, all intra-caecal fermentation parameters 4–8 h post feeding in ponies given diet RB:HC were significantly (\(P<0.05\)) different from those observed in ponies fed diet HC. Thus, in ponies fed diet RB:HC, intra-caecal pH and acetate molar proportions were reduced whilst lactate concentration and propionate molar proportions were increased (\(P<0.05\)) compared with values recorded in ponies fed diet HC. By contrast, intra-caecal total VFA, lactate and pH levels of ponies fed diets MB:HC or EB:HC were similar to those in ponies fed HC at all time points measured, although acetate and propionate molar proportions were lower and higher, respectively, in ponies fed diets EB:HC and MB:HC compared with those fed HC. These results suggest that micronisation or extrusion of barley offer advantages over rolling barley in that the values for the intra-caecal fermentation parameters in ponies fed MB:HC or EB:HC were largely similar to those of ponies fed the HC forage diet. Where equines are to be given substantial quantities of cereals in their diet then use of micronised or extruded products may be beneficial in minimising hindgut dysfunction. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Horse; Barley; Physical processing; Intra-caecal fermentation parameters

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1. Introduction

Physically processed cereal grains are used extensively in diets for equines (Frape, 1998). Starch is the largest component of cereal grains but starch plays only a minor role in the diet of wild equids. In addition, the activity of the starch digesting enzyme, α-amylase is reported to be low in the small intestine of the horse (Alexander and Chowdhury, 1958; Alexander and Hickson, 1970; Kienzle et al., 1995). Whilst this may limit the extent of pre-caecal digestion, in vivo apparent digestibility of starch measured over the whole digestive tract of equines is uniformly high (967–970 g/kg) for different cereal types (Arnold et al., 1981). Starch which escapes digestion in the equine small intestine will enter the caecum where it may considerably alter microbial fermentation parameters, resulting in lower pH levels and substantial changes in lactate concentration and the molar proportions of acetate, propionate and butyrate (Radicke et al., 1991). Such changes can result in a number of debilitating metabolic disorders in equines including acidosis (Meyer et al., 1995), colic (Clarke et al., 1990) and laminitis (Garner et al., 1977).

A limited number of studies have examined the effect of physical processing of cereals on the digestibility of starch in the small intestine of equines (Householder, 1978; Kienzle et al., 1992). In general, the results indicated that small intestinal starch digestibility was improved by physical processing of cereals although the magnitude of the effect was dependent on both cereal type and method of processing. However, these studies have not examined any effects that physical processing of cereals may have on equine hindgut fermentation parameters. The objective of this study was to determine if physically processing barley in different ways can reduce the changes in intra-caecal fermentation parameters normally associated with feeding cereal grains which have undergone minimal processing.

2. Materials and methods

Three mature Welsh cross pony geldings, each fitted with a permanent caecal cannula at the top of the caecum (caecal base) (Cottrell et al., 1998) were used in a 3×4 incomplete Latin square changeover design experiment consisting of four 21-day periods. Ponies were individually loose housed in pens bedded with wood shavings and with water available ad libitum. Ponies were offered 4 kg dry matter (DM) per day of either 100% grass hay which had been ground and cubed (HC) or one of three diets consisting of a 50:50 barley:hay cubes mix. The barley in the mixed diets was either rolled (RB), micronised (MB) or extruded (EB) each of which was provided by Dodson and Horrell Ltd., Ringstead, Kettering, UK. During micronisation, whole barley (DM of 820 g/kg) was passed under infra-red burners and then through rollers to produce barley flakes. The extruded barley was prepared by mixing ground barley with water to form a dough. The dough was then sequentially passed through a single screw extruder and then through a die (9.4 mm diameter, with 10 holes open), and the emergent material was then dried at 110°C for 23 min, forming nuggets of ca. 1.5 cm³. Diets were offered in two equal meals per day at 09:00 and 17:00 hours where the barleys and HC were offered simultaneously.
but in different containers so that feed refusals of each dietary component could be recorded. Hay cubes were soaked in 1.5 times their own weight in water prior to feeding and 30 g of a mineral and vitamin supplement (Table 1) was added to each meal. Each 21-day period consisted of a 16-day adaptation phase and a 5-day recording phase where intra-caecal fermentation parameters were recorded. Pony liveweight (LW) was recorded weekly.

On Days 18–21 of each period, caecal digesta samples were taken 5 h after the 09:00 hours meal as it has been demonstrated that caecal pH is lowest 4–6 h post-feeding (Garner et al., 1977; Willard et al., 1977). Digesta samples were removed from the caecum via suction through an indwelling plastic tube (13 mm i.d.) attached to the cap of the caecal cannula. Similarly, on Day 20 of each period, caecal digesta samples were taken at 09:00 hours and thereafter hourly until the 17:00 hours meal. pH was immediately determined on each sample using a Mettler Toledo 320 pH meter (Mettler–Toledo Ltd., 64 Boston Road Beaumont Leys, Leicester, UK) and 9 ml of the sample was preserved with the addition of 1 ml of 1.8 M H₂SO₄. Samples were then stored at −20°C until subsequently analysed for lactate and volatile fatty acid (VFA). Lactic acid was quantified as L and D isomers using L and D lactate dehydrogenases (Boehringer Test Kit No. 139084, BCL, Lewes, Sussex, UK). Acetate, propionate and butyrate concentrations (mmol/l) in the caecal digesta samples were determined by gas chromatography according to the method described by Merry et al. (1995).

### 2.1. Statistical analysis

All statistical analyses were carried out using GENSTAT 5 (Lawes Agricultural Trust, 1993). Dry matter intakes (DMI), and intra-caecal fermentation parameters measured 5 h following the 09:00 hours meal were analysed by analysis of variance (ANOVA). Due to the repeated nature of the measurements, the intra-caecal fermentation parameters measured hourly between the 09:00 and 17:00 hours meals were summarised to give average values for 0–3 and 4–8 h following the 09:00 hours meal and analysed by split plot ANOVA.

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<table>
<thead>
<tr>
<th>Constituent</th>
<th>HC</th>
<th>RB</th>
<th>MB</th>
<th>EB</th>
</tr>
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<tbody>
<tr>
<td>DM (g/kg)</td>
<td>905</td>
<td>880</td>
<td>891</td>
<td>892</td>
</tr>
<tr>
<td>OM</td>
<td>917</td>
<td>977</td>
<td>977</td>
<td>969</td>
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<tr>
<td>STC</td>
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<td>614</td>
<td>614</td>
<td>621</td>
</tr>
<tr>
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<td>91</td>
<td>119</td>
<td>130</td>
<td>118</td>
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<td>NDF</td>
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<td>203</td>
<td>167</td>
</tr>
<tr>
<td>ADF</td>
<td>335</td>
<td>44</td>
<td>58</td>
<td>36</td>
</tr>
<tr>
<td>GE (mJ/kg)</td>
<td>18.9</td>
<td>18.6</td>
<td>18.5</td>
<td>18.8</td>
</tr>
</tbody>
</table>

*Composition of mineral and vitamin supplement: (g/kg) Ca 160, P 117, Mg 67, Na 67; (mg/kg) Cu 683, Zn 2730, Fe 2730, Mn 2730, I 6.7, Co 6.7; (i.u.) Vitamin A 136670, Vitamin D₃ 20500, Vitamin E 3417.
3. Results

3.1. Feed composition and DMI

The chemical composition of the four individual feedstuffs is detailed in Table 1. Values observed are consistent with published data for both barley and grass hays (MAFF, 1992). Dry matter intakes are detailed in Table 2. There were no significant differences in total DMI between diets, however, due to small feed refusals the barley:HC diets were no longer a 50:50 mix. Actual dietary proportions were 54:46, 55:45 and 55:45 on a DM basis for the RB:HC, MB:HC and EB:HC diets, respectively, and starch intakes averaged 2.14 g kg\(^{-1}\) LW per meal. Pony live weight averaged 284 kg across the dietary treatments.

3.2. Intra-caecal fermentation parameters

Table 3 gives the intra-caecal fermentation parameters measured at 5 h following the 09:00 hours meal on Days 18–21 of each period. Inclusion of RB significantly \((P<0.05)\) reduced pH and acetate molar proportion whilst significantly increasing \((P<0.05)\) lactate concentration and propionate molar proportions compared with the 100% HC diet. The pH of caecal digesta from ponies fed RB:HC (6.26) was not significantly lower \((P>0.05)\) than the pH of digesta from ponies fed either the MB:HC (6.33) or the EB:HC (6.36) the pHs of which were not significantly different \((P>0.05)\) from the intra caecal pH recorded for ponies on diet HC (6.50). Lactate concentration in the caecal digesta of ponies fed RB:HC (0.97 mmol/l) was significantly higher \((P<0.05)\) compared to caecal lactate concentration in ponies fed diet HC (0.11 mmol/l). Caecal lactate levels in ponies fed either MB:HC (0.18 mmol/l) or EB:HC (0.26 mmol/l) diets were not significantly different to either RB:HC or HC diets, but were considerably closer to the values recorded for HC than for RB:HC. Total volatile fatty acid concentration and butyrate molar proportion did not differ significantly \((P>0.05)\) between diets. Acetate and propionate molar proportions in caecal digesta from ponies fed EB:HC were similar to those fed RB:HC \((P>0.05)\). However, feeding MB:HC increased acetate values and decreased

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### Table 2

<table>
<thead>
<tr>
<th></th>
<th>HC</th>
<th>RB:HC</th>
<th>MB:HC</th>
<th>EB:HC</th>
<th>S.E.D.</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW (kg)</td>
<td>289</td>
<td>284</td>
<td>277</td>
<td>285</td>
<td>6.14</td>
<td>NS</td>
</tr>
<tr>
<td>DMI (kg per day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley(^b)</td>
<td>0.05 a</td>
<td>1.97 b</td>
<td>1.96 b</td>
<td>1.95 b</td>
<td>0.07</td>
<td>***</td>
</tr>
<tr>
<td>HC</td>
<td>3.69 a</td>
<td>1.70 b</td>
<td>1.61 b</td>
<td>1.58 b</td>
<td>0.17</td>
<td>***</td>
</tr>
<tr>
<td>Total DMI</td>
<td>3.74</td>
<td>3.67</td>
<td>3.57</td>
<td>3.53</td>
<td>0.18</td>
<td>NS</td>
</tr>
<tr>
<td>Starch intake (g kg(^{-1}) LW)</td>
<td>0.00 a</td>
<td>4.16 b</td>
<td>4.25 b</td>
<td>4.16 b</td>
<td>0.23</td>
<td>***</td>
</tr>
</tbody>
</table>

\(^a\) Values in the same row not sharing common letters differ significantly \((P<0.05)\).

\(^b\) Includes mineral and vitamin supplement.

\(***) \(P<0.001\).
propionate values significantly \((P<0.05)\) compared to RB. There were no significant differences \((P>0.05)\) in acetate or propionate molar proportions in digesta from ponies fed MB:HC or EB:HC. However, it was only when MB:HC was fed that acetate and propionate values were similar \((P>0.05)\) to the values observed when diet HC was fed.

Table 4 shows the intra-caecal fermentation parameters measured hourly throughout the day summarised as average values for 0–3 and 4–8 h following the 09:00 hours meal. In general, pH declined and TVFA levels increased following the 09:00 hours meal in all ponies for approximately 3 h after which levels remained relatively constant until the end of the measurement period at 17:00 hours. With the exception of the HC diet, pH values were lower \((P<0.05)\) and TVFA values were higher \((P<0.05)\) during the 4–8 h period compared with the 0–3 h period indicating that ingested barley only affected intra-caecal fermentation parameters several hours after consumption.

There was a significant increase in lactate levels \((P<0.05)\) during the 4–8 h period when ponies were fed the RB diet compared to both the 0–3 h period (2.23 and 0.20 mmol/l, respectively) and to the lactate levels recorded in ponies fed the other diets. However, intra-caecal lactate levels in ponies fed diets MB:HC, EB:HC and HC were not significantly different during the 4–8 h period compared to the 0–3 h period.

In general, the HC diet maintained acetate molar proportions above 730 mmol/mol and propionate molar proportions below 200 mmol/mol throughout the day. However, inclusion of RB in the diet led to significantly lower and higher acetate and propionate molar proportions \((P<0.05)\), respectively, when compared to the HC and MB:HC diets during the 4–8 h period post-feeding. There were no significant differences between the MB:HC and HC diets in either acetate or propionate molar proportions. Over the same time period, values for the EB:HC diet were intermediate between RB:HC and the HC diet.

### 4. Discussion

When the basal forage diet (HC) was offered without barley supplementation, caecal pH was maintained above 6.5 and the intra-caecal VFA profile was characterised by acetate molar proportions above 730 mmol/mol and propionate molar proportions below...
200 mmol/mol throughout the measurement period accompanied by low levels of butyrate and lactate. This observation concurs with results reported by Moore-Colyer et al. (2000) for a different batch of the same ground and pelleted hay cubes and for other fibre-based diets. In addition, similar values for intra-caecal pH and VFA parameters have been reported in equines given predominantly forage-based diets (Argenzio et al., 1974; Glinsky et al., 1976; Goodson et al., 1988).

Compared to studies in ruminants, only a limited number of experiments have been conducted in equines where the effects of cereals on intra-caecal fermentation parameters have been studied. In the current study, although the amounts of acetate+propionate remained the same for the four diets throughout the experimental period, the three barley diets elicited a decrease in the molar proportions of acetate with a concomitant increase in propionate, relative to the HC diet, with the greatest effect being observed for RB. These results concur with those of Hintz et al. (1971) who offered ponies diets varying in forage (alfalfa):concentrate (maize/soybean) ratios. Furthermore, Stillons et al. (1970), Willard et al. (1977), Goodson et al. (1988) and Radicke et al. (1991) have all published similar changes in caecal fermentation patterns in relation to low forage:concentrate ratios in equine diets.

In the present experiment, the intra-caecal pH of HC-fed ponies remained stable throughout the 8 h post-feeding period, whereas that of ponies fed the barley diets
declined during the latter half of the measurement period, the greatest decline being in ponies fed diet RB. These results are similar to the findings of Willard et al. (1977), who observed that when caecally fistulated horses were offered a 100% hay diet, intra-caecal pH was 6.75, 6–7 h post-feeding, whereas in animals fed a 100% cereal-based concentrate, the corresponding value was 6.12. Intra-caecal lactate levels in ponies fed the HC diet were low at all time points measured. However, when fed the RB:HC diet, intra-caecal lactate levels were 33, 13 and six-fold greater than the corresponding values for HC, MB and EB 4–8 h post-feeding, and these differences are reflected in the respective intra-caecal pH values. These large differences in caecal lactate levels in ponies fed diet RB:HC compared with those given diets MB:HC and EB:HC may suggest decreased small intestinal digestion of RB compared with MB or EB. The dramatic difference in intra-caecal lactate levels in ponies fed forage or concentrate diets have also been observed by Radicke et al. (1991) who found a 70-fold increase in intra-caecal lactate of horses fed a corn diet compared with those fed hay. Furthermore, Willard et al. (1977) reported intra-caecal lactate levels in horses fed a 100% concentrate diet to be 25 times greater than those in the caeca of horses fed a 100% hay diet. High levels of intra-caecal lactate can contribute to hind-gut acidosis (Garner et al., 1977), with a loss of mucosal integrity (Clarke et al., 1990) and an increase in absorption of endotoxins (Moore et al., 1979), leading to metabolic disorders such as laminitis and colic. It has been suggested that when intra-caecal pH falls below 6.0 equines may be regarded as exhibiting sub-clinical acidosis. (Radicke et al., 1991). In the experiment reported here, average intra-caecal pH declined to approximately 6.2 at its lowest point on the RB:HC diet, however, variation between ponies was such that in one pony caecal pH declined below 6.0, and this pony may well have been acidicotic. Indeed, other authors have reported that acidosis does not occur uniformly in horses given the same amount of cereal starch (Rowe et al., 1994).

In the experiment reported here starch intake averaged 2.1 g kg$^{-1}$ LW per meal which is similar to and approximately half of the maxima of 2.0 and 4.0 g starch kg$^{-1}$ LW per meal recommended by Potter et al. (1992) and Meyer et al. (1995), respectively, to prevent caecal acidosis and hind-gut dysfunction. However, in the current study, when 2.1 g kg$^{-1}$ LW of starch was consumed as RB significant unfavourable changes occurred in intra-caecal fermentation parameters, which were not observed when this amount of EB or MB starch was fed.

In conclusion, where hard-working horses such as racing thoroughbreds receive a considerable portion of their diet as cereal starch, then changes in hindgut fermentation patterns may be a particular problem. From the results of the study reported here, it is recommended that in order to minimise changes in hindgut fermentation patterns, micronised or extruded barley should be fed in preference to barley which has merely been rolled.

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