Beefing up starch digestion

A.F. Channon¹ and J.B. Rowe²

¹Cooperative Research Centre for Cattle and Beef Quality, Animal Science, University of New England, Armidale NSW 2351
²Australian Sheep Industry CRC, Locked Bag 1, Armidale NSW 2350
achanno2@metz.une.edu.au

Summary

Any improvements in starch digestion in cattle would undoubtedly be of great benefit to the feedlot industry. There are numerous factors that are likely to vary between animals that may affect both the efficiency and site of starch digestion. The benefits of starch digestion in the small intestine, as opposed to in the rumen, include a higher energetic efficiency, and a reduced risk of acidosis provided that high levels of starch do not reach the hindgut. Recent research has identified genetic differences between similar cattle in their ability to digest starch. The evidence is provided by differences between progeny groups of steers in the level of fermentation occurring in the hindgut. We have also found between-animal differences in total tract starch digestibility that are consistent across diets.

Keywords: starch, digestion, fermentation, faeces, genetic variation, cattle, hindgut

Introduction

Profitable beef production in feedlots relies heavily on efficient grain–starch digestion. For this reason, the opportunity of being able to identify and select for cattle that are more efficient at digesting starch is of great potential importance to the industry. Aside from economic and environmental benefits, identification of animals that are more efficient at starch digestion may also improve the safety of grain feeding.

Our interest in the concept of genetic variation in starch digestion has been stimulated by the relatively recent finding that genetic variation in feed conversion efficiency exists between animals of the same breed (Archer et al. 1999). It is not known exactly why some animals are more efficient; differences in the ability to digest feed may be one of the biological mechanisms involved (Oddy and Herd 2000). This paper develops the idea that variation in the efficiency of starch digestion exists throughout the gastrointestinal tract and shows that this variation may be an important factor influencing feed efficiency in intensive grain–feeding systems.

The importance of site of digestion

There are three sites of importance: the rumen, small intestine, and hindgut (large intestine–caecum and colon) (see Figure 1). The rumen is the major site of starch digestion (Huntington 1997). Microorganisms ferment substrate entering the rumen to short–chain volatile fatty acids (VFA), methane (CH₄) and carbon dioxide (CO₂). CH₄ is of no use to either the microbes or the host animal and, coupled with the heat of fermentation, represents a loss of energy. The host animal absorbs and utilises VFA as the major source of energy and carbon (Wolin 1981) and microbial materials (carbohydrate, lipid and protein) pass into the small intestine for subsequent digestion and absorption. A similar pattern of fermentation also occurs in the hindgut. Unfortunately, microbial peptides and amino acids produced here cannot be absorbed and are lost in the faeces (Orskov et al. 1970b). Fermentation in the hindgut also suffers from the same sort of energetic losses as those that occur in the rumen.

Acidosis can arise when microbial populations in the rumen (Nocek 1997) or hindgut (Zust et al. 2000) rapidly ferment starch. The deleterious effects of clinical acidosis have been widely documented (Al Jassim and Rowe 1999; Owens et al. 1998). It is now understood that sub–clinical acidosis may be an even more widespread and costly problem in grain–fed cattle than the clinical condition (Beauchemin 2000; Rowe 1999). In this situation, animals appear to be healthy but the acid concentration in the rumen is unusually high (greater than 120 mM; Goad et al. 1998) and pH is typically between 5.0 and 5.8. This is below optimal for fibre fermentation (Russell and Wilson 1996). It can be seen that there is a conflict between avoiding acidosis and extensively processing grain to maximize digestibility in the rumen.
In contrast to the two sites of fermentation, the small intestine contains the animal’s own digestive enzymes that break down starch to glucose for absorption (Bauer et al. 1995; Harmon 1993). The small intestine does host a relatively small microbial population (Allison 1993) and there is some evidence that microbial metabolism may make a small contribution to small intestinal starch disappearance (Kreikemeier et al. 1991).

In a summary of experimental findings and theoretical calculations, Harmon and McLeod (2001) concluded that starch fermentation was 25–30% less energetically efficient than starch digestion. This is because of the losses associated with fermentation (methane and heat) and with differences in partial efficiencies of the absorbed substrates. It appears that for the energetic benefits of starch digestion and glucose assimilation in the small intestine to be fully realised, starch digestion must be sufficiently complete to minimise the amount of starch reaching, and subsequently being fermented in, the hindgut (Harmon and McLeod 2001). Fermentation in the hindgut would be even less energetically efficient than rumen fermentation given that the energy incorporated into the microbial biomass is lost in the faeces (Knowlton et al. 1998; Orskov et al. 1970b; Orskov et al. 1972). The hindgut is the least desirable site of starch digestion.

Given this information, we can hypothesise that an animal should theoretically be more efficient if it can maximise starch digestion in the rumen and, in particular, in the small intestine. Experiments to test this hypothesis are described later in this paper.

Why is variation in starch digestion likely to exist in cattle?

There is variation in any biological system and differences will always occur between animals. The process of natural and human selection of ruminants has traditionally occurred under grazing conditions based largely on pasture and/or supplements of hay or silage. Therefore, it is not surprising that the digestive tract of ruminants is ideally suited to utilizing low quality fibrous material and is not particularly well adapted to processing cereal grain. The pancreatic and duodenal digestive enzyme systems and the absorptive mechanisms of the small intestine have never needed to evolve to handle high levels of starch.

There has been no direct genetic selection for efficient starch digestion in cattle. This is despite the fact that more than 700,000 were being fed in Australian feedlots in December 2002 (ALFA 2003). The fact that a feedlot steer still spends over half of its life in a paddock may have contributed to the lack of interest in this area of selection. Breeding females must also still perform on a forage diet.

Conversely, poultry and pigs have been much more intensively selected for efficient intestinal starch digestion on the basis of performance on grain–based diets. Despite this selection pressure, high phenotypic variability in starch digestibility has been shown to exist in young broilers eating wheat–based diets (Rogel 1985). In that instance there was no difference in weight gain between birds because poor starch digesters ate much more to compensate for poor energy utilisation. Svihus (2003) also reported that poor starch digestibility was a problem for a small percentage of birds and suggested that digestion in these birds was impaired due to a high feed intake and passage rate. Evidence of variation in starch digestion in these species gives reason to believe that it would exist in cattle.

Likely mechanisms behind variation in starch digestion

There are numerous factors likely to vary between animals that may have an effect on the site, rate, and extent of starch digestion throughout the gastrointestinal
tract. Animal factors that could possibly be under genetic control include a number discussed in this section.

**Feeding and intake**

Feeding behaviour, voluntary feed intake, dentition, and the quantity and composition of saliva production (Slyter 1976) may all vary between animals. The level of mastication/rumination influences feed particle size and saliva production. Ruminants eating grain-based diets are particularly dependent on the buffering capacity that saliva provides in the rumen (Argenzio 1993d; Beauchemin 2000). This is needed because of the rapid rate of acid production from the fermentation of starch, compared to forage. The efficiency of microbial growth and overall animal health strongly depends on their capacity to maintain a normal rumen pH (Russell and Wilson 1996; Slyter 1976).

Feed intake is dependent on animal, environmental and dietary factors. It has been shown that sheep selected for clean fleece weight have a higher dry matter intake (DMI) than sheep selected against fleece weight (Kahn et al. 2000; Thompson et al. 1989). Eating rate has also been reported to be highly variable between animals (Frisch and Vercoe 1977). Eating rate is negatively related to whole tract digesta retention time and positively related to DMI. It has been shown that steers selected for high feed efficiency (low residual feed intake; RFI) had a lower DMI and ate less often during the day than low feed efficiency (high RFI) steers (Richardson et al. 2000). The implications of this feeding behaviour on digestive function and starch digestion are unclear. However it is likely that certain animals will ingest grain in a way that will ensure a pattern of fermentation where the rate of acid removal can match the rate of acid production. In contrast, other animals with rapid feed consumption may be more likely to experience acidosis-related problems.

**Rumen**

The frequency and efficiency of rumination, rumen motility and residence time of particles may differ between similar individuals given the same diet (Hegarty 2000). Differences in digesta turnover rate may affect starch digestion in a number of ways:

- changes in the microbial species within the rumen;
- changes in the pattern of VFA and methane production;
- changes in microbial efficiency;
- changes in the amount of undegraded starch and dietary protein supplied to the small intestine.

There is evidence that selection for and against wool growth in Merino sheep has resulted in concomitant changes in rumen function. Kahn (1996) discovered that the sheep selected for high wool yield produced significantly more microbial protein per kg of DMI, than sheep selected for low wool yield. Selection for wool yield had evidently caused changes in the rumen environment that were more favourable to microbial growth. This would most likely be a change in the rumen dilution rate. Variation between sheep selection lines in the retention time of digesta in the rumen was also reported by Thompson et al. (1989) and Smuts et al. (1995). Orskov et al. (1971a) reported large differences in digestion between two sheep fed a diet containing 93% pelleted corn. Whilst around 97% of the available starch was fermented in the rumen of one sheep, only 57% of the available starch was fermented in the rumen of the other. This second sheep produced much less microbial protein in the rumen and much more starch was delivered to the small intestine and hindgut. The authors attributed these differences to variation in rumen outflow rate between the sheep. Very importantly, Smuts et al. (1995) demonstrated that the retention time of digesta in the rumen was a heritable trait in sheep (heritability of 0.45–0.6). This is likely to be similar for cattle. Variation in rumen outflow rate in cattle was reported by Orskov et al. (1988). They found that differences in rumen outflow rates between cows persisted with both ad libitum and restricted intakes of high and low roughage diets. The consistency in the differences between cows under controlled experimental conditions indicates that rumen outflow rate is under genetic control.

There are unlikely to be inherent, measurable differences in the rumen microbial populations of cattle. The microbial composition of the rumen varies between different layers of digesta (Hungate 1966). Furthermore, a single animal on a constant ration will exhibit fluctuations in rumen characteristics over time (Hungate 1966). Any between–animal differences in the rumen microbial population are likely to be downstream effects of variation in diet composition and rumen dilution rate (Hegarty 2000).

Oesophageal (reticular) groove physiology and activation stimuli (Orskov et al. 1970a) are other factors that may influence the efficiency of starch digestion in the rumen. However, the usefulness of this mechanism in mature ruminants remains dubious. There may also be physiological differences in the structural integrity of the rumen, small intestine and hindgut wall. For example, considerable variation in the rate of ruminal parakeratosis development has been demonstrated in a group of similar steers fed pelleted lucerne (Hinders and Owen 1965).

**Abomasum**

Residence time and rate of HCl secretion in the abomasum may vary between animals. Protein digestion is initiated in the abomasum with the secretion of pepsinogen (Argenzio 1993d). Pepsinogen is converted to its active form, pepsin, in the presence of acid in the lumen. Similarly, the pancreas secretes inactive trypsinogen into the small intestine. In the intestinal lumen, trypsinogen is then activated to the protease,
trypsin (Argenzio 1993d). Trypsin then activates the remaining trypsinogen as well as the other proteolytic proenzymes, chymotrypsin and elastase (Argenzio 1993a). Proteases are important in breaking down cell walls and structural protein and the extent of starch–protein interactions in cereal grain are known to affect starch digestibility (Rooney and Plughelder 1986). The speculative implication of this association is that animals that are more efficient at digesting protein may indirectly be more efficient at starch digestion.

Small intestine

The ruminant has the capacity to adapt to diets delivering more starch to the small intestine by increasing the output of pancreatic α–amylase (Clary et al. 1969; Owens et al. 1986; Russell et al. 1981) and glucose absorption capacity (Bauer et al. 1995; Shirazi–Beechey et al. 1991). This ability to adapt to high–starch diets may vary between individuals. For example, Ørskov et al. (1971b) demonstrated considerable variation between two sheep in the capacity to absorb glucose from the small intestine. This variation is depicted in Figure 2.

It could be assumed that an animal with more starch or free glucose leaving the small intestine would be more susceptible to hindgut acidosis. In this example, an increased supply of glucose to the hindgut resulted in watery faeces and reduced faecal pH. This sort of variation may help to explain the differences between animals in their susceptibility to acidosis.

The physiological mechanisms controlling pancreatic function in ruminants are not well understood but are likely to involve the central nervous system, gastrointestinal hormones (cholecystokinin and secretin) and possibly VFA concentration (Argenzio 1993c; Croom et al. 1992). Metabolizable energy intake also appears to exert a major influence on pancreatic α–amylase concentration (Harmon 1992). A better understanding of this regulation may lead to methods of improving digestion in the small intestine. Taniguchi et al. (1995) speculated that protein/peptide entry into the small intestine stimulated an increase in α–amylase production and glucose absorption. If this is true, starch digestion in the duodenum is likely to be increased by the outflow of microbial and bypass protein from the rumen.

Small intestinal motility may vary between individuals. This influences the time that substrate is available for enzymatic digestion. Digesta are moved through the small intestine by peristaltic (propulsion) and segmentation (mixing) reflexes (Argenzio 1993b). On average, digesta spend less than 3 h in the small intestine of steers (Zinn and Owens 1980, cited by Owens et al. 1986). A slow rate of passage through the small intestine is ideal to ensure more complete digestion of carbohydrate before it reaches the hindgut.

Hindgut

Factors affecting the ability of microorganisms in the hindgut to ferment starch will be similar to those influencing fermentation in the rumen. Digesta intermittently fills and empties from the caecum with the flow being influenced by the type of diet and DMI (Grosvum and Hecker 1973; Ulyatt et al. 1975). An increase in the proportion of grain in the diet typically delivers more starch to the hindgut (DeGregorio et al. 1982; Siciliano–Jones and Murphy 1989a; Siciliano–Jones and Murphy 1989b). The microbial population of the hindgut readily responds to substrate changes in a similar fashion to that of the rumen (Mann and Ørskov 1973; Ørskov et al. 1970b). The efficiency of digestion in the rumen and small intestine will indirectly affect the quantity and quality of digesta reaching the hindgut.

Evidence of genetic variation in starch digestion

We have now established that site of starch digestion is important and there are reasons to expect between–animal differences that may be physiologically important. Unfortunately, there appears to have been

![Figure 2](image-url) Effect of the level of glucose infused into the abomasum on glucose passing the terminal ileum (—) and excreted in faeces (——) of sheep 1 (•) and sheep 2 (o). Adapted from Ørskov et al. (1971b).
very little research directly designed to identify genetic variation in starch digestion in cattle. It is important to point out that this is a discussion of the possibility that cattle may vary in their capacity to digest starch as distinct from their ability to convert starch–based feeds into liveweight gain. We already know that overall feed efficiency in cattle has genetic variation (Herd et al. 1997; Richardson et al. 1998). We could expect feed conversion ratio (FCR) to be associated with the efficiency of starch digestion but the two do not necessarily correlate. For example, two animals might have a similar capacity to digest feed but other factors (e.g., metabolism, maintenance requirements or activity levels) may cause one animal to exhibit a better FCR. Much of the available information concerns variation in animal performance and total tract dry matter (DM) digestibility without directly quantifying any differences that exist in starch digestion. Nonetheless, this information does help to build the argument that genetic variation in the ability to digest starch does exist in cattle.

In terms of between–breed differences, it is difficult to conclude if Bos indicus content influences starch digestibility. Warwick and Cobb (1975) reviewed genetic variation in cattle in the ability to digest nutrients but did not focus on starch. These researchers reported inconsistent results but reached the general conclusion that cattle with B. indicus content were slightly more efficient than their B. taurus counterparts in digesting DM and crude protein. For starch–based diets, it has been reported that there are no differences in DMI, ADG and FCR between B. indicus crossbred and B. taurus cattle (Boyles and Riley 1991; Krehbiel et al. 2000). Beaver et al. (1989) fed a finishing corn silage–whole shelled corn–based diet to Angus and Brangus steers over two years. The Angus cattle had a greater DMI for the first year but they were no more efficient than the Brangus steers. In the second year, the Angus steers had higher DM and starch digestibilities than the Brangus. This indicates that B. indicus cattle did not increase their starch digestibility, as did the B. taurus animals. This suggests that there may be genetic differences in long–term adaptation to high–starch diets.

Richardson et al. (1996) reported small but significant differences in DM digestibility between cattle of high and low RFI. Cattle with high net feed conversion efficiency had a one–percentage unit higher DM digestibility than cattle with low net feed conversion efficiency (fed a pelleted 70% lucerne: 30% wheat mixture). Likewise, low RFI (high efficiency) Angus steers tended to digest about two–percentage units more DM from a feedlot ration than high RFI (low efficiency) Angus steers (calculated DM digestibility = 78%; R.M. Herd et al. unpublished data).

Meissner et al. (1996) observed substantial differences between corn–fed steers in non–ammonia nitrogen and starch availability in the duodenum. The data are shown in Table 1.

Organic matter digestibility in the rumen (OMD_R) was significantly negatively associated with NAN (r^2 = 0.37) and starch (r^2 = 0.77) passage to the duodenum (Meissner et al. 1996). The effect of the variation in OMD_R meant that some animals had more than twice the amount of NAN and starch entering the duodenum (Meissner et al. 1996). OMD_R is known to be associated with rumen retention time, which in turn, is usually correlated with feed intake. There was a very poor relationship between feed intake and OMD_R in this experiment. Consequently, this meant that the observed variation in OMD_R and the passage of starch and non–ammonia nitrogen to the small intestine was the result of inherent variability in rumen retention time.

In the feedlot perhaps the most obvious sign that animals vary in their capacity to efficiently and safely digest starch is the noticeable variation in faecal

<table>
<thead>
<tr>
<th>Steer</th>
<th>OMD_R (%)</th>
<th>Flow to duodenum (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NAN</td>
</tr>
<tr>
<td>1</td>
<td>85.0^c</td>
<td>51.7^ab</td>
</tr>
<tr>
<td>2</td>
<td>80.5^bc</td>
<td>37.4^a</td>
</tr>
<tr>
<td>3</td>
<td>76.1^abc</td>
<td>44.0^a</td>
</tr>
<tr>
<td>4</td>
<td>72.7^abc</td>
<td>70.1^bc</td>
</tr>
<tr>
<td>5</td>
<td>72.1^abc</td>
<td>65.2^bc</td>
</tr>
<tr>
<td>6</td>
<td>71.8^abc</td>
<td>90.8^d</td>
</tr>
<tr>
<td>7</td>
<td>70.7^a</td>
<td>67.7^bc</td>
</tr>
<tr>
<td>8</td>
<td>66.4^a</td>
<td>78.4^cd</td>
</tr>
<tr>
<td>Average</td>
<td>74.4</td>
<td>63.2</td>
</tr>
<tr>
<td>SD</td>
<td>1.43</td>
<td>2.26</td>
</tr>
</tbody>
</table>

Values in the same column with different superscripts differ significantly (P<0.05)
consistency and pH. It is very hard to predict which animals will be susceptible to acidosis upon entry into the feedlot and the variability between animals has made it quite difficult to study the condition (Rowe and Pethick 1994; Syler 1976). Considerable variation in the ability of animals to cope with a ‘carbohydrate challenge’ has been reported by Brown et al. (2000) and Dougherty et al. (1975). In the latter study, 7 g of grain (75:25 whole corn:whole oats)/kg of body weight was administered directly into the rumen of 3 steers. Whilst the rumen pH in one steer did not fall below 5.5, the other 2 steers experienced acute acidosis. One of these animals had to be euthanased.

The question is whilst some animals experience acute acidosis, how do other individuals maintain good health and feed intake when fed a diet high in fermentable starch? The reasons for this variation are not clear but could involve differences in salivary buffering, the microbial population (before and after exposure to a large amount of fermentable carbohydrate), varying digestive efficiency throughout the gastrointestinal tract, differences in the immune response to tissue damage/disease or variable changes in the gut wall characteristics and the extent of inflammation and leakage. The ability to efficiently and safely digest starch is certainly likely to be involved and there may be scope for genetic selection for ‘resistance to acidosis’ on this basis. In particular, if an animal has the ability to extensively digest starch in the small intestine, there is less chance of delivering starch to be fermented in the hindgut.

New findings

Some relevant new work (Channon et al. in press, 2003) has provided good evidence that genetic differences in starch digestion do exist. Steer progeny of lines selected for either low RFI (high efficiency) or high RFI (low efficiency) were finished in a feedlot on a 75% barley ration. Measurements of feed intake, liveweight gain and faecal parameters were combined to investigate associations between starch digestion and feed efficiency. Faecal pH, DM and nitrogen (N) content were used as indirect indicators of the amount of starch being fermented in the hindgut. The results are presented in Tables 2, 3 and 4.

Table 2 shows that there were significant differences between sire progeny groups in faecal pH and faecal DM content indicating genetic differences in these parameters. This variation was occurring even after results were corrected by covariance for differences in DMI. That these faecal parameters are likely to reflect the extent of starch fermentation in the hindgut (low pH and DM content indicating more fermentation), provides evidence of genetic variation in the amount of starch reaching the hindgut.

### Table 2 Differences between sire progeny groups in faecal parameters.

<table>
<thead>
<tr>
<th>Sire</th>
<th>Progeny</th>
<th>pH</th>
<th>DM %</th>
<th>N %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q002</td>
<td>17</td>
<td>6.85a</td>
<td>14.61a</td>
<td>2.30</td>
</tr>
<tr>
<td>Q072</td>
<td>13</td>
<td>6.90ab</td>
<td>15.54abc</td>
<td>2.35</td>
</tr>
<tr>
<td>Q018</td>
<td>14</td>
<td>6.91ab</td>
<td>15.97bcd</td>
<td>2.21</td>
</tr>
<tr>
<td>Q048</td>
<td>12</td>
<td>6.91ab</td>
<td>15.68abc</td>
<td>2.25</td>
</tr>
<tr>
<td>Q312</td>
<td>12</td>
<td>6.94abc</td>
<td>14.73de</td>
<td>2.41</td>
</tr>
<tr>
<td>Q106</td>
<td>11</td>
<td>6.96abc</td>
<td>15.83bcde</td>
<td>2.25</td>
</tr>
<tr>
<td>Q006</td>
<td>10</td>
<td>6.98c</td>
<td>16.36bc</td>
<td>2.20</td>
</tr>
<tr>
<td>Q167</td>
<td>14</td>
<td>7.00c</td>
<td>14.99de</td>
<td>2.26</td>
</tr>
<tr>
<td>Q198</td>
<td>19</td>
<td>7.04c</td>
<td>15.75de</td>
<td>2.22</td>
</tr>
</tbody>
</table>

Means within a column with different superscripts differ significantly (P<0.05)

### Table 3 Phenotypic associations between dry matter intake, kg/d, and residual feed intake, kg DM/d, with faecal parameters.

<table>
<thead>
<tr>
<th>Repeated measures</th>
<th>DMI</th>
<th>RFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faecal pH</td>
<td>0.02*</td>
<td>0.01</td>
</tr>
<tr>
<td>Faecal DM (%)</td>
<td>–0.20*</td>
<td>–0.47**</td>
</tr>
<tr>
<td>Faecal N (%)</td>
<td>0.02</td>
<td>–0.02</td>
</tr>
</tbody>
</table>

*P<0.05, **P<0.01; indicate that the regression coefficient (b value) is significantly different from zero

### Table 4 The genetic association between faecal parameters in progeny and mid–parent estimated breeding value (EBV) for residual feed intake, kg DM/d.

<table>
<thead>
<tr>
<th>Repeated measures</th>
<th>RFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faecal pH</td>
<td>–0.07*</td>
</tr>
<tr>
<td>Faecal DM (%)</td>
<td>–0.80**</td>
</tr>
<tr>
<td>Faecal N (%)</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*P<0.05, **P<0.01; indicate that the regression coefficient (b value) is significantly different from zero
Table 3 shows that in these feedlot animals, low faecal DM content was associated with higher RFI (i.e. lower efficiency). Therefore, those animals that were more efficient in the feedlot (lower RFI) tended to have firmer faeces (indicating less hindgut fermentation).

Table 4 shows that there was a significant association between faecal pH and DM content and mid–parent Estimated Breeding Values (EBV) for RFI. This means that high efficiency parents (selected for low RFI) generally produced progeny that had a higher faecal pH and faecal DM content than the progeny of low efficiency sires (selected for high RFI) when fed high–starch diets. This was confirmation of an association between parameters believed to describe starch digestion and the genetic variation in an important production trait. This means that there could be an opportunity to identify and select for animals, within a breed, that are more efficient at rumen + small intestinal starch digestion.

We have also identified between–animal variation in starch digestion in a recent grain–feeding trial (Channon and Rowe 2003, unpublished). Six crossbred cows (Low–Line x Angus, 28 months old, 398 kg liveweight) were used in a crossover design and fed diets based on dry–rolled wheat, poorly flaked wheat (coarse steam–flaked) and well flaked wheat (thin steam–flaked). Chromic oxide was used as a digestibility marker. Spot faecal samples were taken and the marker ratio technique was used to calculate a value for total tract starch digestibility for each cow–diet combination. The results are shown in Table 5.

The consistency of ranking of cows for total tract starch digestibility of diets differing in grain processing method, determined by coefficient of concordance, was significant ($P<0.01$). This is a non–parametric statistic that is used for ranking results by ignoring the actual values (Moroney 1968). Animal 1 appears to have the highest capacity for starch digestion whereas animal 6 tends to have the poorest capacity. That the environment, treatment and feeding of these animals has been the same for most of their lives suggests that there is a genetic component to these between–animal differences in starch digestion. The mechanisms behind these differences are unknown but are likely to involve the factors discussed earlier in this paper.

It was interesting to see that the between–animal differences are greatest for the diet of the lowest average digestibility, the dry rolled wheat diet. The highly digestible, well flaked wheat diet enabled the poorer animals to attain starch digestibility values comparable to the best animals. Similarly, the variability in starch digestibility in chickens is greater for poorly digestible wheat diets compared to relatively well digested corn diets (Rogel 1985).

The cows also had similar rankings for faecal starch percentage ($P<0.01$), and faecal starch was very closely correlated to starch digestibility ($r^2 = 0.94$; $P=0.01$). This is very consistent with the results of Zinn (1994) and Zinn et al. (2002). This result suggests that faecal starch could be a useful tool for assessing the efficiency of grain processing and for identifying between–animal differences.

**Future**

Identification of cattle that are more efficient at starch digestion may provide an important opportunity to improve the profitability of our grain–feeding systems. There is a need to explore fully the extent of genetic variation in starch digestion to see if it is large enough in magnitude to be of practical significance. If the variability is low, the rate of genetic improvement would be small.

In future trials, it would be useful to relate total tract starch digestibility to faecal pH and DM content as well as faecal VFA and lactate levels. An easily obtained faecal measurement such as pH would make it easier to estimate variation in starch digestion in a larger number of cattle and thereby enable estimations of genetic parameters. The use of a relatively poorly digestible grain such as sorghum may be useful in attempts to clearly identify those individuals that have the greatest capacity for starch digestion.

Traditionally, feedlotters have put considerable effort into diet preparation for feedlot cattle in order to

<table>
<thead>
<tr>
<th>Animal</th>
<th>Digestibility</th>
<th>Animal</th>
<th>Digestibility</th>
<th>Animal</th>
<th>Digestibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>95.6</td>
<td>6</td>
<td>96.9</td>
<td>3</td>
<td>98.5</td>
</tr>
<tr>
<td>2</td>
<td>96.7</td>
<td>2</td>
<td>97.6</td>
<td>2</td>
<td>98.5</td>
</tr>
<tr>
<td>3</td>
<td>97.1</td>
<td>3</td>
<td>98.7</td>
<td>6</td>
<td>98.6</td>
</tr>
<tr>
<td>4</td>
<td>97.2</td>
<td>4</td>
<td>98.7</td>
<td>5</td>
<td>98.9</td>
</tr>
<tr>
<td>5</td>
<td>97.3</td>
<td>5</td>
<td>99.0</td>
<td>1</td>
<td>98.9</td>
</tr>
<tr>
<td>1</td>
<td>98.5</td>
<td>1</td>
<td>99.2</td>
<td>4</td>
<td>99.9</td>
</tr>
<tr>
<td>Average</td>
<td>97.07</td>
<td></td>
<td>98.36</td>
<td></td>
<td>98.75</td>
</tr>
</tbody>
</table>
increase starch digestibility. Whilst there is no denying that starch digestibility can be significantly improved using processing techniques such as steam flaking, perhaps we should now start thinking about feeding this costly and well-prepared grain to those animals that can digest the starch most efficiently?

Acknowledgements

Andrew Channon has a PhD scholarship provided by the Cooperative Research Centre for Cattle and Beef Quality. We are very grateful for the support provided by this organisation.

References


Archer, R. M. Herd and P. F. Arthur), CRC for Cattle and Beef Quality, Armidale, Australia.


