Grain excretion by goats fed whole or processed cereals with various roughages

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Abstract

Despite cereal grains being grown on 5 continents where goats are kept, there is little information on the excretion of whole cereal grains when fed to goats. We determined the effects of various dietary treatments on whole grain and starch loss in the faeces of Angora goats. In Experiment 1 there were 4 replicates of the factorial design: a) 2 grain types (barley, oats); b) whole grain or processing (milled barley or rolled oats); c) 2 roughage qualities (Persian clover hay, barley straw); and d) 2 feeding levels (level 1, 150 g/d of grain, 250 g/d of roughage; level 2, 250 g/d of grain, *ad libitum* roughage). In Experiment 2, which immediately followed Experiment 1, and aimed to detect carry over effects of previous feeding of barley straw and grain processing, feed levels were either 650 g/d grain or 400 g/d grain with 550 g/d Persian clover hay. Data were analysed by ANOVA. In Experiment 1, processing had no effect on digestible dry matter intake. The number of whole grains lost per 100 g of fresh faeces and whole grains loss as the % of grain dry matter intake were affected by an interaction between processing and roughage quality. Whole grain fed with Persian clover hay had greater grain loss than all other diets. Whole grain loss was greater with whole grain than with processed grain. Level of feeding had no effects on grain loss. In Experiment 2, more whole grains were lost in fresh faeces when fed with Persian clover hay than when fed without hay, an effect of previous feeding with barley straw reduced whole grain excretion, and more barley grains were lost than oat grain. Faecal starch was affected, with higher levels when whole barley grain was fed, particularly with Persian clover hay, or when previously fed barley straw at a high level. Feeding grain at 650 g/d did not increase grain or starch excretion. Whole grains represented a small loss of grain dry matter intake in faeces, averaging 0.8% with a maximum recorded of 2.6%. Faecal concentration of the whole grains may be altered by grain size and the digestibility of the roughage component of the diet. In this study an additional cost of 3% for processing grains would not have provided economic benefits.

Keywords: Angora goats; Associative effects; Barley; Digestion; Oats; Ration composition; Roughage quality; Starch; Supplementary feeding

1. Introduction

For goat production, grains are used in processed rations in housed production systems, are fed strategically to overcome nutritional deficiencies during lactation, following weaning (Economides et al., 1989; Hadjipanayiotou, 1990; McGregor et al., 2010), when finishing goats for meat (McGregor, 1996) or in times of drought, after floods or when wildfires destroy pastures (McGregor, 1998, 2005, 2006). In Australia, grain supplements provided when forage is of low digestibility during the summer period moderate the expected 25-30% loss of live weight in grazing goats and sheep, which reduces their carcass weight, reproductive rate, mohair, cashmere and wool growth (McGregor, 2010; McGregor and Umar, 2000). Similar nutritional outcomes are expected in other harsh temperate and tropical environments where goats are kept.

Despite cereal grains being grown on a large scale on 5 continents where goats are kept, and that goats frequently graze cereal crop stubbles in these regions, there is little information on the loss of whole cereal grains when fed to goats (Iñiguez, 2004; McGregor, 2005). Many farmers, who have fed whole barley and oat grains to goats, have remarked to the authors about the apparent level of undigested whole grain excreted in faeces and questioned the need to process grain prior to feeding.

Processing grains in animal production systems is undertaken for a variety of reasons, including the need to mix components of a ration and to influence the extent and location of digestion of starch (Rowe et al., 1999). Grain processing is less important for sheep than for cattle because sheep masticate grains more completely. Neither the level of grain in the ration of sheep nor the methods of processing alter the digestibility of grain by sheep (Hale and Theurer, 1974; Orskov, l976a). Orskov (1976b) concluded that whole grains appear in the faeces of sheep on occasions and more often when grains are a supplement to forage-based diets. Though faecal loss may convince farmers to process cereal grains, faecal loss is of no quantitative importance. However, the reported retention time of feeds in the gastro-intestinal tract of the goat is shorter than that of sheep and cattle so rate of passage is greater (Huston et al., 1986). Differences between goats and sheep in their rumination behaviour have been reported (Focant et al., 1986);

this may be related to their mixed feeding behaviour compared with the grazing style behavior of sheep (Hofmann, 1989; Pérez-Barberia et al., 2001).

Therefore, the issue of whether goat producers should process whole cereal grains prior to feeding them to goats in order to obtain high feed utilization remains unresolved. In the absence of literature on the extent of whole cereal grain loss in faeces of goats we studied the effects of: grain type, processing, roughage quality and feeding level, on faecal loss of whole barley and whole oat grain, as these factors may affect the rate of passage of digesta from the rumen. The present work used grain feeding at three different levels and used roughages of different digestibility to simulate lower digestibility senescent summer and autumn pastures typical of drought conditions, and contrasted this with higher digestibility roughage and the effects of carryover effects of previous feeding.

2. Materials and methods

2.1. Source and management of goats

Angora goats (*n*=32), castrated at 6 weeks of age, were purchased at 4 months of age and grazed on annual temperate pastures. Goat were properly vaccinated against enterotoxaemia and tetanus as kids and every 6 months thereafter. At 3 years of age, the goats were shorn and dipped to eliminate external parasites. Goats were weighed 4 weeks later, to the nearest 0.5 kg, (mean ± s.d. live weight was 35.8 ± 4.41 kg). Two experiments were conducted in sequence, using the same materials but different dietary combinations and feed levels.

2.2. Methods

2.2.1. Design of Experiment 1

The experiment had 2 replicates of the factorial design: 2 levels of grain type × 2 levels of grain processing × 2 levels of roughage quality × 2 feeding levels. The factors were:

Grain type: barley (*Hordeum vulgare* L.); oats (*Avena sativa* L.).

Grain processing: whole grain; processed.

Roughage quality: Persian clover hay (*Trifolium resupinatum* L.); barley straw.

Feeding level: Level 1; Level 2. Feeding level 1 was 150 g/d of grain with 250 g/d of roughage. Feeding level 2 was 250 g/d of grain with roughage available *ad libitum* (adjusted daily to minimize waste and selection).

There were 4 replicates of 1 goat per treatment. This was obtained by having 2 replicate goats in each of 2 time periods as follows. For Period 1, the 16 treatment combinations were allocated randomly to the 16 lightest goats (Rep 1, mean ± s.d. 32 ± 2.5 kg) and again to the 16 heaviest goats (Rep 2, mean ± s.d. 39 ± 2.5 kg). For Period 2, each goat received the same combination of grain type, roughage quality and feeding level, but if the goat had been fed processed grain, it received whole grain in Period 2 and *vice versa*. This provided 4 goats for each combination of treatments.

This design was chosen because the main effect of processing and all the interactions of processing with other effects are not confounded with the between animal variation nor with the time period effect as shown in Table 1.

2.2.2. Design of Experiment 2

This aimed to detect carry over effects of previous feeding of barley straw and grain processing, and to investigate higher feeding levels of grain. The experiment had 2 replicates of the factorial design: 2 levels of grain type × 1 level of roughage quality × 3 levels of previous feeding levels within straw (**PFLINS)** × 3 levels of previous processing treatment within straw (**PROCINS**) × 3 levels of processing within hay (**PROCINH**). Goats fed Persian clover hay at the low feeding level from Experiment 1 were excluded. The factors were:

Grain type and **roughage quality**: as in Experiment 1 except no treatment was fed barley straw.

PFLINS: Low, if low feeding level in previous periods; High, if high feeding level in previous periods; NA, if Persian clover hay fed in previous periods.

PROCINS: P_W, if processed grain fed in period 1 and whole grain fed in period 2; W_P, if whole grain fed in period 1 and processed grain fed in period 2; NA, if Persian clover hay fed in previous periods.

PROCINH: W, if fed Persian clover hay and whole grain in current period; P, if fed Persian clover hay and processed grain in current period; NA, if fed Barley straw.

There were 2 replicates of 1 goat for each of the treatment combinations of grain type × roughage quality × PFLINS × PROCINS, and 4 replicates for each of the treatment combinations of grain type × roughage quality × PROCINH. Feeding level of whole grain was 650 g/d as fed. For the Persian clover hay fed treatments, the feeding level was: grain 400 g/d as fed plus 550 g/d of hay as fed.

2.2.3. Experimental procedures

Commercially grown whole oats and barley were purchased. Half of this barley was cracked (gristed) using a roller mill to break > 90% of the whole grains. Commercially rolled oats was purchased. All roughage was passed through a chaff cutter (Jas Smith Machinery and Engineering, Ballarat, Victoria, Australia) to a mean length of ≈ 2 cm to ease handling, to obtain uniformity of composition and to minimize animal selection.

Goats were housed in a barn in individual metabolism crates in clear sight of other goats. The goats in the high liveweight replicate were housed on one side of the barn in random order and the low liveweight replicate were housed on the other side of the barn in random order. Goats were provided with fresh water and feed each day in the same routine manner. At ≈ 0800 h the metabolism cages were cleaned and any food was removed, weighed and bulked. Dry matter was determined at the end of each collection period. During sampling periods faeces also were collected at this time. Each goat was fed its specific ration in a large feed bin.

Goats were acclimated over a 14 day period following accepted procedures (McGregor, 1998, 2005) by replacing chopped hay with whole grain at a rate of 50 g/d every second day. One goat, that refused its ration, was removed and replaced on day 3 of the acclimatization period. For Period 2, goats were acclimated for 10 days, followed by a collection period of 7 days. The daily ration was fed in 2 portions, grain and 50% of the roughage at ≈ 0830 h with the remaining roughage at ≈ 1100 h. In all cases the grain was fed first followed by the hay about 10 minutes later.

At the end of Experiment 1, the rations for Experiment 2 were introduced over a 10 day period by increasing the grain intake at a rate of 100 g/d every second day and reducing straw intake to zero or increasing Persian clover hay intake from about 370 g/d to 550 g/d over the first 7 days of this period. The faster rate of change was possible as the goats had been acclimatized to cereal grain for > 30 days.

2.3. Samples and measurements

Each day during the 7 day collection periods a random grab sample of each feed was taken and bulked in a sealed bag for later analysis. Every second day during collection periods the dry matter (DM) of each feed was determined. During collection periods the total wet faeces weight for each animal was recorded. The faeces were mixed, a 10% sub-sample removed each day and placed into a labelled sealed jar and frozen for later analysis for whole grain content. The remaining faeces were dried at 100 °C and the dry weight was recorded.

For each feed, the bulked sample was assayed for crude protein (CP; Kjeldahl block digestion method; Method-1.4R; AFIA, 2011), acid detergent (ADF; van Soest et al., 1991; Method 1.9A(a) Ankom; AFIA, 2011) and neutral detergent fibre (NDF; van Soest et al., 1991; Method – 1.8A(a) Ankom; AFIA, 2011).

Metabolisable energy (ME) (MJ/kg DM) values were calculated from dry matter digestibility values, using the pepsin-cellulase technique of Clarke et al. (1982), after first converting them to digestible organic matter in the dry matter (DOMD), and using the following formulae: forages: ME = 0.203 DOMD% – 3.001 (AFIA, 2011); grains: ME = 0.138 DOMD% + 0.272 Ether extract% + 0.858 (AFIA, 2011).

The faeces bulked dry samples were ground through a 1.0 mm screen in a Christy and Norris Mill for analysis of starch content (Method 996.11, AOAC, 1995). As the grain samples for starch testing were lost during testing, values from samples, with similar other test results from this region, were used (Agrifood Technology, Werribee, Victoria, Australia). To determine the content of grain in the faeces, each frozen sample was well mixed and two 50 g sub-samples were taken. Each sub-sample was thawed, mixed in water, gently agitated, and passed through 3 grades of sieves to separate large pieces of grain. Grain was dried at 80°C for 24 h, sorted and whole grain weighed. For samples of feed, the number of grains/kg of sample was determined by the dry weight of 100 grains of each grain type (n = 10). The number of grains in the barley straw also was determined.

For each grain, roughage and faeces the DM content was determined. DM intake (DMI), DM digestibility (DMD = total DMI – faecal DM output), and digestible DMI (DDMI = total DMI × DMD) were determined. The proportion of whole grain intake lost in faeces (whole grain loss), starch loss, and number of grains voided on a fresh faeces and dry faeces basis were determined.

2.4. Statistical analyses

Analysis of variance (ANOVA) was used to determine the effect and interactions between treatments for measured variables using GenStat (Payne, 2010). The blocking structure for this design was (Replicate/Animal) × Time Period (Table 1, Payne 2010). This design provided 21 degrees of freedom (d.f.) for the error term, which allows more precise detection of treatment effects and interactions with processing than a design with less d.f. Data for 1 goat in the second period, which failed to eat its ration when the diet was changed from whole barley grain (fed at the high feed level with barley straw) to processed barley, was removed. The missing d.f. is shown in brackets. Standard errors of difference are provided as s.e.d. Differences between treatments were determined at $P < 0.05$. Normal statistical checking for outliers confirmed that all data points were acceptable.

Linear regression analysis was used to determine the correlation coefficient (r) between faecal starch concentration and total grain loss (Payne, 2010).

For Experiment 2, the design was: Grain type × roughage quality/ (PFLINS × PPROCINS + PROCINH), the blocking structure was the liveweight Block (Payne 2010). This design was chosen to cover potential carryover effects from previous feeding treatments and provided 10 d.f. for the error term. Data for the number of grains excreted in fresh faeces, the % of whole grains excreted as DMI or as % number of grains eaten were log plus 10 transformed and data for % faecal starch and starch output per day were square root transformed.

3. Results

3.1. Rations

The composition of the grains, Persian clover hay and barley straw are summarized in Table 2. The number of whole grains in each kg of dry feed was: whole barley 26280; processed barley 1990; whole oats 19800; processed oats 2400; barley grains in barley straw 150.

3.2. Experiment 1 DMI, DDMI and DDM

There was no effect of grain type (barley 184, oats 180 g/d; s.e.d. 2.8; $P = 0.23$), roughage quality (Persian clover hay 183, barley straw 181 g/d; s.e.d. 2.8; $P = 0.39$) or processing (whole grain 181, processed 183 g/d; s.e.d. 2.9; $P = 0.63$) on grain DMI. For roughage DMI there was a significant interaction between feed level and roughage quality (low Persian hay 210, low barley straw 212, high Persian hay 336, high barley straw 262 g/d; s.e.d. 17.1; $P = 0.005$). There was no effect of grain type (barley 249, oats 261 g/d; s.e.d. 12.1; $P = 0.36$) or processing (whole grain 257, processed 253 g/d; s.e.d. 9.3; $P = 0.68$) on roughage DMI. For total DMI there was a significant interaction between feed level and roughage quality (low Persian hay 351, low barley straw 348, high Persian hay 561, high barley straw 489 g/d; s.e.d. 17.8; $P = 0.011$). There was no effect of grain type (barley 433, oats 441 g/d; s.e.d. 12.6; $P = 0.53$) or processing (whole grain 438, processed 436 g/d; s.e.d. 10.0; $P = 0.81$) on total DMI.

DDMI was affected by an interaction between feed level and roughage quality (low Persian hay 269, low barley straw 183, high Persian hay 425, high barley straw 271 g/d; s.e.d. 7.3; $P < 0.001$). The rations fed with Persian clover hay at feed level 2 had greater DDMI than all other rations ($P < 0.001$) and rations using barley straw fed at feed level 1 had less DDMI than all other rations ($P < 0.001$). Grain type had a significant effect on DDMI (barley 299, oats 275 g/d; s.e.d. 5.2; $P < 0.001$). Processing had no effect on DDMI (whole grain 291, processed grain 284 g/d; s.e.d. 10.5; $P = 0.52$).

DMD was affected by an interaction between grain type and roughage quality ($P = 0.009$, Table 3). Rations with Persian clover hay had greater DMD than rations using barley straw ($P < 0.001$) and rations with barley grain had greater DMD than rations with oat grain ($P < 0.001$; Table 3). DMD was not affected by feed level (low 0.652, high 0.665; s.e.d. 0.0125; $P = 0.41$) or processing (whole grain 0.661, processed 0.656; s.e.d. 0.0119; $P = 0.27$).

3.3. Experiment 1 voided whole grains and starch

The number of whole grains lost per 100 g of fresh faeces was affected by an interaction between processing and roughage quality ($P = 0.002$, Table 4). Whole grain rations fed with Persian clover hay had significantly greater grain loss per 100 g faeces than all other rations (Table 4). Whole grain loss was reduced by processing (whole grain 23.8, processed 4.1/100 g; s.e.d.

0.139; $P < 0.001$) and affected by roughage quality (Persian clover hay 26.5, barley straw 1.4/100 g; s.e.d. 6.64; $P < 0.001$). The number of whole grains lost per 100 g of fresh faeces was not affected by grain type (barley 19.5, oats 8.4/100 g; s.e.d. 6.64; $P = 0.11$) or feed level (low 11.7, high 16.1/100 g; s.e.d. 6.64; $P = 0.51$).

Whole grain loss, when calculated as a proportion of grain DMI, was affected by an interaction between processing and roughage quality ($P = 0.008$, Table 4). Whole grain loss was affected by processing (whole grain 0.015, processed 0.002; s.e.d. 0.0033; $P < 0.001$) and roughage quality (Persian clover hay 0.015, barley straw 0.001; s.e.d. 0.0039; $P = 0.002$). Whole grains loss as a proportion of grain DMI was not affected by grain type (barley 0.011, oats 0.005; s.e.d. 0.0039; $P = 0.16$) or feed level (low 0.007, high 0.010; s.e.d. 0.0039; $P = 0.50$).

The number of whole grains lost in faeces as a proportion of the number of whole grains fed was affected by an interaction of processing, grain type and roughage quality ($P = 0.002$, Table 5). The main effects of grain type (barley 0.038, oats 0.009; s.e.d. 0.0108; $P = 0.013$), processing (whole grain 0.017, processed grain 0.030; s.e.d. 0.0052; $P = 0.015$) and roughage quality were significant (Persian clover hay 0.043; barley straw 0.004; s.e.d 1.08; $P < 0.001$). There was no effect of feed level (low 0.026, high 0.021; s.e.d. 0.0108; $P = 0.66$). Similar treatment interactions were obtained when the number of whole grains lost were expressed as DM of grain lost as a proportion of faecal DM ($P = 0.003$, Table 5). The proportion of whole barley lost when fed with Persian clover hay in faecal DM was higher than all other treatment combinations. There was no effect of feed level on the proportion of whole barley lost (low 0.008, high 0.008; s.e.d. 0.0444; $P > 0.50$).

Faecal starch concentration (% faecal DM) was significantly affected by roughage quality (Persian clover hay 3.89, barley straw 2.71%; s.e.d. 0.325; $P = 0.002$). There were no main effects of grain type (barley 3.45, oats 3.15%; s.e.d. 0.325; $P = 0.36$), processing (whole grain 3.57, processed grain 3.03%; s.e.d. 0.399; $P = 0.19$) or feed level (low 3.09; high 3.50%; s.e.d. 0.325; $P = 0.22$) on faecal starch concentration. Faecal starch concentration (% faecal DM) was associated with total whole grain loss (%) ($r = 0.61$; $P < 0.001$).

Total faecal starch output (g/d) was significantly affected by an interaction between roughage quality and grain type (*P* = 0.020, Table 3). This was associated with an apparent reduction in starch digestibility affected by an interaction between roughage quality and grain type (*P* = 0.016, Table 3) where the digestibility of oats fed with barley straw was lower than the other treatments. While the three way interaction between processing, grain type and roughage quality was not significant (*P* = 0.37, Table 5), the raw data indicate that some goats fed processed oats with barley straw had lower starch digestibility (87-89%). There was no main effect of processing (whole grain 4.9, processed grain 4.6 g/d; s.e.d. 0.60; *P* = 0.66) on total faecal starch output per day but as expected from the design there was a significant effect of feed level on faecal starch output (low 3.6; high 5.9 g/d; s.e.d 0.52; *P* < 0.001).

3.4. Experiment 2

The mean total DMI for diets fed only grain was 582 g/d. For treatments fed Persian clover hay the mean total DMI was 824 g/d consisting of 344 g/d of grain and 480 g/d of hay.

The number of whole grains lost per 100 g of fresh faeces was affected by an interaction between roughage quality and PROCINH (Persian clover hay with whole grain 40.6^{a}, Persian clover hay with processed grain 4.9^{b}, whole grain with no roughage 6.0^{b}; *P* = 0.002; means with different superscripts differ at *P* = 0.05). The number of whole grains lost per 100 g of fresh faeces was affected by an interaction between roughage quality and PFLINS (Treatments fed Persian clover hay 22.8^{a}, previously fed straw at high level 11.4^{a}, previously fed straw at low level 0.6^{b}; *P* = 0.042; means with different superscripts differ at *P* = 0.05). Grain type affected the number of whole grains lost per 100 g of fresh faeces (barley 17.5, oats 5.7; *P* = 0.023).

Whole grains loss when determined as the proportion of grain DMI was only affected by grain type (Barley 0.0033, oats 0.0002; *P* = 0.021). The number of whole grains lost in faeces as a proportion of the number of whole grains fed was affected by an interaction between roughage quality and PROCINH (Persian clover hay with whole grain 0.0190^{a}, Persian clover with processed grain 0.0030^{b}, whole grain with no roughage 0.0006^{b}; *P* = 0.013; means with different superscripts differ at *P* = 0.05).

Faecal starch concentration (% faecal DM) was affected by an interaction between grain type, roughage quality and PROCINH (Table 6, *P* = 0.016) and by an interaction between grain type, roughage quality and PFLINS (Table 7, *P* = 0.002). The main effect being higher faecal starch when whole barley grain was fed, particularly with Persian clover hay, or when previously fed barley straw at a high level. Lower faecal starch was detected when whole oats were fed to goats with Persian clover hay or previously fed barley straw at any feed levels. Low faecal starch was also recorded when barley grain was fed to goats previously fed barley straw at low levels. These findings were supported by differences in estimated starch digestibility which was affected by an interaction between grain type, roughage quality and PROCINH (Table 6, *P* = 0.003). Starch digestibility was highest when barley straw had previously been fed and lowest when whole grain barley was fed with Persian clover hay. There were no interaction effects of PFLINS on starch digestibility (*P* = 0.43-0.91).

4. Discussion

The main finding was that the extent of whole barley and oat grain loss in the faeces of Angora goats was low, representing at a maximum 0.026 of the grain DMI. The second main result was that processing, grain size (barley *versus* oats) and roughage quality, and the previous feeding level of barley straw, but not level of feeding, affected the proportion of whole grain that were eaten and subsequently lost in the faeces and the resultant digestibility of starch.

The design of Experiment 1 resulted in grain DMI at feeding level 2 being 60% greater than the DMI of grain at feeding level 1. For roughage, feeding level 2 consumed 25% more barley straw and 60% more Persian clover hay compared with feeding level 1. This difference in roughage DMI at feeding level 2 reflected the differences among roughage sources in their CP, ADF, ME and DMD (Tables 2, 3) with intake being higher for the higher quality more digestible

Persian clover hay diets. As a consequence of the differences in roughage intake, the proportion of total DMI represented as grain was ≈ 0.40 for most diets but 0.48 for barley straw diets with feeding level 2. In Experiment 2, grain DMI represented 41% of total DMI for treatments fed Persian clover hay, or 100% for the grain only treatment. While we altered intake in both experiments, feeding levels applied did not affect faecal loss of whole grains or starch digestibility.

In terms of the quantities of grain DMI, the amounts ranged from 138 to 226 g/d in Experiment 1, and 344 to 582 g/d in Experiment 2. These intakes are typical of the levels of whole grain provided under Australian pastoral conditions. Higher levels of cereal grain intake by goats are possible under complete feeding situations (McGregor and Hodge, 1988). Processing the grain had no significant effect on DMD and DDMI of the rations used in the present study.

When farmers feed whole barley and oats to goats they can only assess the amount of grain lost in faeces based on visual observation. The amount of whole grain passing in 100 g of fresh faeces was affected by the type of roughage consumed, with high quality Persian clover hay diets leading to more whole grains present in faeces than barley straw based-diets (Table 4). In Experiment 2, whole grain loss was very low when whole grain was fed without roughage and much higher when grain was fed with Persian clover hay. While this seems counter intuitive, the digestibility of the Persian clover hay diets was 15 - 25% units higher than barley straw diets (Table 5). This means less faeces were produced per unit of grain intake. This resulted in a higher faecal concentration of grain per unit of faeces from goats fed Persian clover hay diets. However, when whole grain in faeces is expressed per kernel fed (Table 4), only 0.026 of whole grain DMI was excreted as whole grain by goats fed Persian clover hay diets.

The main animal factor responsible for the mechanical reduction of food to smaller particle sizes is mastication during eating and rumination. In Experiment 2 there appeared to be a carryover effect of a low level of feeding of barley straw associated with low excretion of whole grain with a resultant higher digestibility of dry matter and starch (Table 6). This suggests that for at least the 17 day duration of the introduction and experimental periods in Experiment 2 either rumination behaviour was altered, and/or the rate of passage was reduced with the goats previously fed the lower digestibility barley straw. In Experiment 2 we did detect an effect of processing of barley on the diet DMD, faecal starch concentration and starch digestibility (Table 6). This can be explained by reduced mastication and rumination by goats in fracturing the seed coats when fed whole grain barley compared with the larger grain oats as indicated by the higher proportion of whole barley grain found in the faeces. The rate of passage is important in goats in affecting ration digestibility (Castle, 1956). In Experiment 2, while the previous level of feed intake of barley straw did affect faecal starch concentration (Table 7), it did not affect ration or starch digesitility. Interestingly, the DM loss of whole grain was less than the proportion of the number of grains excreted in faeces (Table 4 compared with Table 5). This suggests some digestion of the starch from the grains we classified as “whole”, an observation also made in other reports (Toland, 1979; Pauly et al., 1992). It may be that some of these “whole” grains had partial starch digestion from cracked grains. This observation needs to be confirmed by further examination of whole grains recovered from faeces and assayed for starch content.

Thus while farmers may see an apparently large number of whole grains in faeces, whole grains in faeces examined in the present work represented a very small proportion of the total number of grains consumed. The net effect of feeding whole grain barley and oats to goats was a small loss of grain DMI in faeces averaging about 0.008 with the maximum recorded of 0.026 (Table 4). Further whole grain loss only explained 36% of the variance in starch content of the faeces as faecal starch levels were higher than the incidence of whole grains in faeces.

Grain size may be related to faecal loss of whole grains. More whole grain was passed in faeces from the smaller whole barley than the larger whole oats in both experiments. This loss was affected by processing and roughage quality. Loss of whole barley grain was greater when fed with high quality Persian clover hay and in Experiment 1 when processed grain was fed. The maximum portional loss of whole grains was 0.037 which occurred when barley was fed with the Persian clover hay. This may be explained by the greater fractional rate of passage of Persian clover hay diet leading to a reduced time for ruminal digestion of grain or less ruminal stratification and rumination.

The percentage of faecal starch loss is another method of determining the influence of grain digestion. Zinn et al. (2007) analysed data from 32 metabolism trials involving > 600 starch measurements. They concluded that the percentage of faecal starch explained 96% of the variation in total gastro-intestinal starch digestion, with faecal starch of ≤ 5% associated with total starch digestion of > 96%. The results of the present study indicate that both whole and processed grain were similarly digested, and generally with both having ≤ 3.5% faecal starch. In Experiment 2, at the higher levels of whole barley feeding, faecal starch reached 5.6% and this was associated with a depressed starch digestibility of 91% compared with the starch digestibility of the other treatments of 94-99% (Table 6). There was no benefit of processing to achieve similar concentrations of faecal starch in Experiment 1, but in Experiment 2 processing of barley reduced faecal starch by 3% and increased starch digestibility by 3.5% units (Table 6). The results indicate that the total starch excreted on oat diets fed with barley straw (6.2 g/d, Table 3) did not originate from whole grains as no whole grains were detected in faecal samples from these diets (Table 5). This is supported by the evidence that the digestion of starch from oat diets fed with barley straw was less efficient than the other dietary treatments (Table 3) as differences in feed intake were not significant in this study. There was evidence that previous intake of roughage and the effect of processing grain affected faecal starch concentration and starch digestibility (Tables 6, 7) so the economic justification for processing of grain for goats will depend upon the costs of processing, the grain size used and the quality of previous roughage intake .

The detection of effects of roughage quality on whole grain excretion indicates that seasonal effects related to changes in pasture digestibly should be expected even at relatively low levels of whole grain intake of 0.4 to 0.8% as in Experiment 1. However when the level of grain fed was increased to 1.7% of live weight in Experiment 2 there was little change in whole grain excretion. If higher rates of grain feeding are practiced at pasture than those used in this study then substitution effects may occur resulting in a reduced intake of pasture (Allden, 1969; Huston, 1994).

Under the conditions of this work, the small rate of whole grain loss or increased starch digestion does not justify paying > 3% extra for processed than unprocessed barley and oat grain for goats. Further, if processed grain is stored, it may separate and deteriorate (Rowe et al., 1999).

5. Conclusion

Processing whole barely and oat grain may reduce visible whole grain in the faeces but in this study, the portion of whole barley and oat grain loss in the faeces of goats was < 3%. The additional cost of processing is not likely to provide economic benefits. Faecal concentration of the whole grains may be altered by grain size and the digestibility of the roughage component of the diet. In this study, feed intake level had little effect on faecal output of whole grain or starch.

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Table 1

Analysis of variance terms and degrees of freedom (d.f.) for measurements indicating the number of d.f. for the residual term

Terms	d.f.
Replicate stratum	1
Time stratum	1
Rep.Animal stratum	
Grain type	1
Roughage quality	1
Feed level	1
Grain type.Roughage quality	1
Grain type.Feed level	1
Roughage quality.Feed level	1
Grain type.Roughage quality.Feed level	1
Residual	23
Replicate.Time stratum	1
Rep.Animal.Time stratum	
Processing	1
Processing.Grain type	1
Processing.Roughage quality	1
Processing.Feed level	1
Processing.Grain type.Roughage quality	1
Processing.Grain type.Feed level	1
Processing.Roughage quality.Feed level	1
Processing.Grain type.Roughage quality.Feed level	1
Residual	21 (1)
Total	63

Table 2

The crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), starch and metabolisable energy (ME) content of the various feeds used in the experiment

	Whole and cracked barley grain	Whole oat grain	Rolled oats	Persian clover	Barley straw
CP (g/kg DM)	92	85	71	214	28
ADF (g/kg DM)	57	106	129	237	407
NDF (g/kg DM)	-	-	-	341	698
Starch (g/kg DM)	570	500	470	-	-
ME (MJ/kg DM)	12.4	11.0	10.2	10.4	7.8

Table 3

The effects of grain type and roughage quality on the dry matter digestibility (DMD) of the ration, total daily starch output (g/d) and starch digestibility. *P*-value and standard errors of difference (s.e.d.) are shown

Grain type	Barley		Oats		For 2 way interaction	
Roughage quality	Persian clover hay	Barley straw	Persian clover hay	Barley straw	s.e.d.	*P*-value
Ration DMD	0.755^{a}	0.593^{b}	0.747^{a}	0.493^{c}	0.0176	0.009
Total daily starch output g/d						
	4.6^{b}	3.9^{b}	4.0^{b}	6.2^{a}	0.73	0.020
Estimated starch digestibility (%)						
	95.7^{a}	96.0^{a}	95.5^{a}	92.9^{b}	0.80	0.016

Values with different superscripts differ at $P = 0.05$

Table 4

The effects of processing and roughage quality on the loss of whole grain in faeces. *P*-value and standard errors of difference (s.e.d.) are shown

Processing	Whole grain		Processed		For 2 way interaction	
Roughage quality	Persian clover hay	Barley straw	Persian clover hay	Barley straw	s.e.d.	*P*-value
Whole grains per 100 g fresh faeces	44.4^{a}	3.1^{b}	8.5^{b}	0.0^{b}	8.02	0.002
Whole grain loss as proportion of grain dry matter intake	0.026^{a}	0.003^{b}	0.004^{b}	0.000^{b}	0.0051	0.008

Values with different superscripts differ at $P = 0.05$

Table 5

The effects of processing, grain type and roughage quality on the loss of whole grain in faeces as a proportion by number of whole grains fed and estimated starch digestibility. *P*-value and standard errors of difference (s.e.d.) are shown

Processing	Whole grain				Processed				For 3 way interaction	
Grain type	Barley		Oats		Barley		Oats		s.e.d.	*P*-value
Roughage quality	Persian clover hay	Barley straw	Persian clover hay	Barley straw	Persian clover hay	Barley straw	Persian clover hay	Barley straw		
Whole grain loss as proportion of number of whole grains fed	0.037^{b}	0.006^{bc}	0.024^{bc}	0.000^{c}	0.100^{a}	0.009^{bc}	0.012^{bc}	0.000^{c}	0.0169	0.002
Whole grain loss as proportion of faecal dry matter	0.048^{a}	0.004^{b}	0.002^{b}	0.000^{b}	0.007^{b}	0.002^{b}	0.001^{b}	0.000^{b}	0.0073	0.003
Estimated starch digestibility (%)	94.9	95.6	95.2	94.1	96.5	96.4	95.8	91.6	1.20	0.37

Values with different superscripts differ at *P* = 0.05

Table 6

The effects of grain type, roughage quality and processing grain within the feeding of Persian clover hay on the dry matter digestibility (DMD) of the ration, faecal starch concentration and estimated starch digestibility of goats fed barley and oat grain diets in Experiment 2. *P*-value and standard error of difference (s.e.d.) are shown

Roughage quality	Persian clover hay		Previously fed barley straw	s.e.d.[A]	*P*-value
	Processed grain	Whole grain			
Ration DMD					
Grain type					
Barley	0.529^{d}	0.626^{c}	0.862^{a}	0.0196-	0.033
Oats	0.613^{cd}	0.572^{cd}	0.799^{b}	0.0392	
Faecal starch (% DM)					
Grain type					
Barley	2.65^{bc}	5.65^{a}	3.34^{bc}	0.124-	0.016
Oats	3.75^{ab}	2.80^{bc}	2.30^{c}	0.248	
Estimated starch digestibility (%)					
Grain type					
Barley	94.6^{b}	91.1^{c}	99.2^{a}	0.48-	0.003
Oats	92.6^{bc}	94.3^{bc}	99.1^{a}	0.97	

Values with different superscripts differ at $P = 0.05$

[A] s.e.d. not retransformed

Table 7

The effects of grain type, roughage quality and previous feeding level within Barley straw diets on faecal starch (%) of goats fed barley and oat grain diets in Experiment 2. *P*-value and standard error of difference (s.e.d.) are shown

Roughage quality	Previous feed level of barley straw		Fed Persian clover hay		
Feeding level	Low	High		s.e.d.[A]	*P*-value
Grain type					
Barley	1.90^{c}	4.77^{a}	4.15^{ab}	0.176	0.002
Oats	2.68^{bc}	1.92^{c}	3.27^{ab}		

Values with different superscripts differ at $P = 0.05$

[A] s.e.d. not retransformed