Dairy goats adjust their meal patterns to the fibre content of the diet

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Abstract

Few studies have investigated how meal patterns of ruminants are affected by diet fibre content. Dairy goats (N=32) in late lactation and early gestation were housed in eight groups of four goats, with all combinations of breed (Alpine and Saanen) and lactation number (1 and 2) represented in each group. Each goat had access to its own individual feed trough placed on a weigh scale with data logged automatically. All goats were fed the same total mixed ration (TMR; 30% concentrate and 44.6% NDF in DM) ad libitum for a control period of 22 days. Using the same feed ingredients, half of the groups were then offered a High fibre diet (20% concentrate; 47.3% NDF), and the other half a Low fibre diet (40% concentrate; 41.5% NDF) for a treatment period of 17 days. Daily meal patterns (meal frequency, duration and size, feeding rate, daily feed intake and daily feeding time) were computed for each animal using a meal criterion of 8 min. The last 10 days for each period (control and treatment) were used to calculate individual period means and individual differences between the two periods. During the control period, the goats ate on average 12.1±0.49 meals/day, consuming 4.2±0.10 kg fresh TMR daily. When the ration changed, all measures of feeding behaviour except meal size changed asymmetrically for the goats on the two diets. Goats fed the High fibre diet reduced their meal frequency by 10%, and the first meal after feed distribution lasted 11% longer, leading to a 9% reduction in feeding rate and no significant changes in daily feed intake and daily feeding time. Goats on the Low fibre diet did not significantly change their meal frequency or meal size, but the combined changes nevertheless led to a 9% increase in daily feed intake. On the Low fibre diet, goats were able to increase their feeding rate by a third, leading to a reduction in meal durations, thus reducing daily feeding time by 13%. Goats adapt their feeding behaviour to the fibre

proportion of the offered diet, with more changes when fibre content is lowered, which needs to be taken into account when comparing phenotypes and adaptability of small ruminants to different diets.

Key words: feeding behaviour; adaptation; diet composition; Saanen; Alpine

Implications

Composition of the diet can affect the daily feed intake of small ruminants, such as goats. However, even when no changes in daily intake occur, the feeding behaviour of the animals may change as a consequence of dietary changes. In the present study, changes in the fibre content of the diet affected the meal patterns of dairy goats, with most adjustments seen when fibre content was lowered compared to when it was increased. Such asymmetrical dietary effects should be taken into account when using feeding patterns as a way to phenotype small ruminants.

Introduction

Goats display highly adaptable feeding behaviour with both browsing and grazing seen in the wild (Goetsch et al., 2010). Like many ruminant species, their feeding patterns vary across the day, and are influenced by seasonal availability of forage (Aldezabal and Garin, 2000; Shi et al., 2003). Feeding behaviour and meal patterns have been extensively studied in monogastrics, such as rats, pigs and poultry (e.g. Glendinning and Smith, 1994; Nielsen et al., 1996; Masic et al., 1974). In ruminants, feeding behaviour has been studied less, mostly in cattle, and sometimes with only concentrate feeding measured in detail (Marti et al., 2014). Dairy goats kept in commercial conditions are often housed indoors with access to a mixed feed ration, and their feeding behaviour have received relatively sparse scientific attention (Giger-Reverdin et al., 2020).

Meal patterns based on time present at the feed trough have been reported for cows (DeVries et al., 2003; Joner et al., 2019), although this method can only estimate individual intakes by assuming similar feeding rates for all cows. Changes in meal patterns of dairy cows have been investigated following specific metabolic challenges (e.g. Gualdron-Duarte and Allen, 2017) and, like many monogastric species, dairy cows show variation in their feeding behaviour, and this variation is greater between individuals than within individuals (Friggens et al., 1998; Melin et al., 2005). In dairy goats, there is also evidence to suggest that the feeding behaviour of individual animals is relatively stable from one lactation to the next (Giger-Reverdin et al., 2020). Among dairy goats with similar daily intakes, variation in their feeding patterns was observed, with some having few but large meals, while other goats achieve the same daily intake in small but frequent feeding bouts (Cellier et al., 2021). Individual differences in animal robustness, defined as the ability to maintain life functions in the face of constraining environments (Kitano, 2004), have also been established in this species when exposed to extreme nutritional challenges (Friggens et al., 2016).

Studies on the effects of diet composition on ruminant feeding behaviour have also been done mostly in cattle. Different diets were found to affect feeding behaviour and rumination patterns in steers (Joner et al., 2019). In dairy cows, meal size decreased and meal frequency went up when the ratio of forage to concentrate in the diet increased (Friggens et al., 1998). Roughage proportion also affects the time budget of dairy cows, with less time spent lying down and a higher proportion of rumination done whilst standing when the fibre content of the diet is high (Nielsen et al., 2000). Few investigations have been made in smaller ruminants: Abijaoudé et al. (2000) found increased feeding rate and shorter feeding time when comparing goats fed a low fibre diet with those fed a high fibre diet. In a review on goat feeding behaviour, different methods to measure or estimate feeding behaviour whilst grazing and when housed were described, but with no mention of dietary effects (Goetsch et al., 2010).

Individual differences in the feeding behaviour of goats and the effects on these feeding patterns of changes to the diet composition have received very little scientific attention. Ability to adapt to sudden dietary changes has practical implications as disruption of feed ingredient supplies may give rise to such abrupt changes. Individual goats may respond differently to this, and it has been suggested that behavioural characteristic associated with feeding behaviour in ruminants may reflect an animal's ability to cope with changes in their environment (Neave et al., 2018). Thus, phenotyping goats on their feeding behaviour when the nutritional environment changes may potentially serve as a proxy for coping ability and resilience, the latter reflecting a high probability of completing several lactations (Adriaens et al., 2020). In order to develop this into an applicable method, we need to know more about how feeding behaviour and meal patterns of goats are affected by environmental changes, such as more or less inclusion of fibre in the diet.

Serment and Giger-Reverdin (2012) studied the feeding patterns changes in goats that were gradually shifted from a total mixed ration (TMR) containing 35% commercial concentrate to TMRs containing either 20% or 50% concentrate. The authors found that goats that changed to the high concentrate and thus low fibre diet reduced the duration of the first feeding bout when fresh feed was distributed, which over time led to a reduction in the overall dry matter intake by the goats on the low fibre diet. No changes were seen in various measures of feeding behaviour in the high fibre animals. The study by Serment and Giger-Reverdin (2012) used a small cohort of cannulated goats housed individually as part of an investigation into factors involved in subacute ruminal acidosis (SARA; Serment et al., 2011). In the present experiment, we wanted to compare feeding patterns of goats in a social environment and with little risk of SARA. This was achieved by using diets that were less extreme than those used by Serment and Giger-Reverdin (2012), with similar dry matter contents and fed to a larger cohort of (non-cannulated) dairy goats in a social setting. Under non-changing conditions, the feeding behaviour of dairy goats is relatively constant, allowing us to investigate the effect of a change in diet without any changes to the social environment of individual goats. Moreover, King et al. (2016) showed in dairy cows that feeding behaviour can be studied in individuals kept in a social environment. Our study aimed to investigate if and how goats adapt their individual feeding patterns to more or less dietary fibre within a range unlikely to cause metabolic problems. Based on the literature cited above, compared to a low fibre diet, we expected that an increase in dietary fibre content would lead to smaller, but more frequent meals and increased total feeding time in goats.

Material and methods

Animals and housing

From a herd of 130 dairy goats in late lactation and early gestation housed together in a straw-bedded pen, 32 goats were selected and housed in eight groups of four goats. The liveweight and milk production of these animals were representative of the overall herd. We were interested in studying the feeding behaviour of individual goats within a social environment, so we needed to ensure that data from each animal could be used in the analysis. This was achieved by using each goat as its own control by measuring the feeding behaviour for each goat during a period with access to a control feed (see Feeding treatments below). To minimize the social effect without keeping the animals in individual pens, we used the smallest group size possible (n=4), as using pairs would have resulted in very long and narrow pens in our experimental set-up. The groups were balanced for breed (Alpine and Saanen) and parity (1^{st} and 2^{nd} lactation) so that each group contained one of each of the four combinations. This way, each type of goat (breed and parity combination) was kept in groups of the same composition, and the within-group mean live weight (±SD) at the start of the trial was 66 ±5.2 kg. Measuring the feeding behaviour of individuals from each breed and parity combination when fed a control diet provided us with a baseline to which we could compare the only environmental change made during the treatment period: a change in the fibre content of the diet, allowing us to test effects on feeding behaviour within animal as also recommended by DeVries et al. (2003). In addition, the two treatment diets were divergent in fibre content around the control diet and were made by using the same ingredients in different proportions (see Feeding treatments below). In other words, a 50:50 mixture of the two treatment diets had the same composition as the control diet.

Stage of lactation at the start of the trial was confounded with lactation number (days in milk (DIM) ±SD: 1st lactation 230 ±5.9; 2nd lactation 259 ±8.5) as the primiparous goats were mated a month later than the multiparous goats, leading to similar levels of milk production at the time of the trial. The eight pens (3.6 m x 2.1 m = 7.6m^2; Figure 1a) had slatted floors and two drinking cups, and each of the four goats per pen had access, via an electronic ear-tag (Gabard systems, France), to its own individual feed trough placed on a weigh scale (SWR3P-BMC 301x275; Balea, France). The trough entrances consisted of folding down gates that were released when the goat allocated to the trough placed its head next to the antenna (Figure 1b). The troughs were separated by 60 cm long brackets (see Figure 1a) to prevent disturbance from neighbouring goats during feeding. All goats had previous experience with the feeding system. The small groups made it easy for each goat to find its allocated trough and ensured that the social environment was similar for all goats and identical for individual goats across the experimental period. A total mixed ration (TMR) was distributed into the troughs twice a day, one-third at 7h and two-thirds at 15h, whilst the goats were in the milking parlour. The initial quantity of feed distributed per goat was calculated based on the milk production and live weight of each goat and adjusted to ensure *ad libitum* access to feed (orts aimed at 7-10%).

Feeding treatments

All goats were fed the same TMR (**Control**; 30% concentrate and 44.6% NDF in DM) for a period of 22 days. Then, using the same ingredients in different proportions, four of the groups (n=16) were offered a diet with **High** fibre (20% concentrate; 47.3% NDF), and the other four groups (n=16) were offered a **Low** fibre diet (40%

concentrate; 41.5% NDF) for a period of 16 days. The chemical analyses of the ingredients and the composition of the three diets are shown in Tables 1 and 2. The proportion of sugar beet pulp silage was kept constant across all three diets to achieve similar dry matter (DM) contents. Due to a rupture in the supply of sugar beet pulp silage, a new batch was used in the High and Low feeds, but this did not differ markedly from the batch used previously (Table 1). Minerals and bicarbonate were included at 15 g each per goat.

Measurements

Weight of the feed troughs to a precision of 5 g was logged automatically every 2 s (see below for details on data handling). An overview of the feeding treatments and the measurements taken is shown in Figure 2. Samples of the four feed ingredients consisted of handfuls taken from different layers of each ingredient stock; these were thoroughly mixed within each sample, weighed, and processed for DM measures on the same day (24h at 87°C). The dried samples were stored in plastic bags at room temperature prior to chemical analyses. Due to time and labour constraints at feed delivery, it was not possible to collect and weigh spillage on an individual basis. Instead, volume of spillage of feed in 24 h around each trough was visually estimated weekly for individual goats by the same observer, then collected and weighed in total; based on the total weight and total estimated volume, the weight of individual spillage was calculated. Using an automatic device designed for milk recording in small ruminants (INRAE; European patent no.185 94916284.6), individual milk yield (±5 g) was measured at each milking and these two measures were added together to give daily milk yield. Individual live weights (±50g) were measured weekly at 14.00 h, and samples for milk composition were analysed weekly (see Giger-Reverdin et al., 2015 for method).

Feeding behaviour data handling

The raw feeding behaviour data consisted of time-stamped recordings every 2 s of the weight of each of the 32 feed troughs. A set of rules was applied, which identified the periods where the weight of a trough was stable for at least 10 s, i.e. five consecutive recordings (Blavy et al., 2020). These periods (or plateaus) indicate that the animal is not interacting with the feed and can be used to characterize the meal patterns of individual animals. A useful unit for describing feeding behaviour relates to feeder visits or feeding bouts, also referred to as meals, in terms of the duration, size, and daily frequency of meals (Nielsen, 1999). In order to separate pauses (i.e. plateaus) *within* meals from pauses *between* meals, a meal criterion needs to be identified. A biologically relevant method based on satiety is described in Tolkamp et al. (1998), where the distribution of log-transformed plateau durations falls into two populations separated by the most likely meal criterion. The minimum inter-meal interval (or meal criterion) found using this method was 8 min, i.e. plateaus longer than 8 min were considered as separating two meals (see Cellier et al., 2021), and the duration and size of meals were calculated accordingly. Data from the last 10 days for each period were used in the analyses, allowing 11 and 6 days of adaptation to the experimental set-up and the treatment diets, respectively (Figure 2), as previous work using the same feeding trough (Cellier, 2020) showed stabilisation of feeding patterns within 5 days of any change. If less than 10g of feed disappeared during a meal, it was considered as a non-feeding visit. From casual observation these occurred when goats used the feeding gates to view the corridor in front of the troughs. The mean daily number of these non-feeding visits was 5.3 (SE=0.097; median: 5; quartiles [Q1,Q3]: [3,7]; range: 1-11). This frequency was not affected by breed nor parity of the goats, and they were excluded from the data set. In addition, a small number of meals (0.1%) with negative intakes were excluded, as these were found to be caused by disturbances of the weigh-scale unrelated to feeding. As feeding behaviour is the animal engaging with the fresh feed and the DM content was similar across the three TMRs, all feeding behaviour variables are reported in fresh weight.

Sample analyses

Chemical composition of the four ingredients (Table 1) was determined as described in Giger-Reverdin et al. (2015). Briefly, DM, ash and starch were determined by standard ISO methods. Total nitrogen (N) was determined by the Dumas technique (Sweeney and Rexroad, 1987), and crude protein (CP) was estimated as 6.25xN. Cell wall content was estimated by the neutral detergent fibre method of Van Soest and Wine (1967) modified by Giger et al. (1987). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were obtained using a sequential approach on the NDF residue (Giger et al., 1987). Diet compositions in DM are given in Table 2. Fat, protein, and lactose contents of individual milk samples pooled from two consecutive milkings were analysed by infrared spectrophotometry (Union Régionale Interprofessionnelle d'Analyses du Nord Est (GIE), LaCapelle, France).

Statistical analyses

Within each period (control and treatment), feeding behaviour and milk production data from the last 10 days for each period (see Figure 2) were used to calculate individual period means. These were then used to calculate individual differences between the two periods, i.e. the mean value for the treatment period minus the mean values for the control period for each animal for all the variables. For the meal-based values, duration and size of meals, as well as feeding rate were calculated, and this was done separately for the first meal following each feed distribution, as these have been found to differ from the remaining meals (Giger-Reverdin et al., 2020; Cellier et al., 2021). Daily values were calculated for meal frequency, feed intake and feeding time. All data were analysed using a General Linear Model (Minitab, v. 17.1). Means of each variable across the last 10 days of the control period for individual goats were analysed to test for pre-treatment differences between breeds and parities using the following model: breed (Alpine or Saanen), parity (1 or 2) and treatment to come (High or Low) were fitted as fixed effects together with all interactions, and group (n=4 for each treatment) was fitted within treatment to adjust for any differences among groups. Because each group contained only one of each breed*parity type, animal could not be further adjusted for in the statistical model, which was one of the reasons each individual goat was used as its own control. The same model was subsequently applied to the data set containing individual differences between periods calculated for each goat, but here mean live weight and milk yield for each goat during the control period were fitted as covariates. Distributions of model residuals were checked for normality and homoscedasticity, and no individual data points were found to deviate by >3 standard residuals. Significant interactions were tested post hoc using pair-wise Bonferroni corrected comparisons. A one-sample Wald test was used on the Least Square (LS) means and SDs from the above analysis to determine if changes observed between the treatment and control periods were significantly different from zero. Results are presented as least square means with standard errors unless otherwise stated. Significance threshold used was $P<0.05$.

Results

Live weight and milk yield during the control feeding period differed between breeds and between parities: Alpines were lighter than Saanen goats (62.6 vs 74.2 (±1.55) kg; $F_{1,18}=28.0$; $P<0.001$) and produced less milk (1.54 vs. 1.98 (se=0.087) kg/d; $F_{1,18}=13.0$; $P=0.002$), and 1st parity goats were lighter than goats of 2nd parity (63.4 vs 73.4 (±1.55) kg; $F_{1,18}=20.7$; $P<0.001$), and produced less milk (1.63 vs. 1.89 (se=0.087) kg/d; $F_{1,18}=4.4$; $P=0.049$), although the latter only just reached significance due to the difference in lactational stage (DIM) between the two parities (see Material and Methods). It was to account for effects of these differences on the results that these two variables (live weight and milk yield during the control period) were fitted as covariates in the analyses.

Feeding behaviour and feed intake

When on the control diet, no significant effects were found of breed and parity. In Table 3, the overall means for the different feeding behaviour variables are shown for the control period, together with the changes induced by the change of diet. Figure 3 displays these changes as a percentage relative to the control period. Except for meal size, the goats on the two diets showed significant divergent responses for all feeding behaviour variables, as well as spillage (Table 3). The Low fibre diet led to the largest changes from the control period, whereas the changes seen in goats on the High fibre diet were confined to a reduction in meal frequency, and an increase in the duration of the 1st meal following feed distribution, leading to a significant reduction in feeding rate compared to the control period (Figure 3). Compared to the control period, spillage was increased by 33% ($t=2.5$; $df=15$; $P=0.012$) for the High fibre goats and reduced by more than half for goats fed the Low fibre diet (-54%; $t=4.1$; $df=15$; $P<0.001$).

Significant interactions with treatment were found only for feeding rate, with a significant interaction found with breed, both for the first meal after feed distribution ($F_{1,16}= 4.8$; $P=0.043$) and for the other meals ($F_{1,16}= 4.7$; $P=0.047$). In both cases, this interaction was only just significant and caused by the Alpine goats on the Low fibre diet not increasing their feeding rate to the same extent as the Saanen on the same diet (1st meal change: +3.0 ±0.96 vs +7.8 ±0.87 g/min; other meals change: +1.6 ±0.70 vs +3.5 ±0.63 g/min). The feeding rate seen during other meals was also affected by an interaction between parity and treatment ($F_{1,16}= 6.1$; $P=0.025$), as on the High fibre diet the 1st parity goats did but the 2nd parity goats did not reduce their feeding rate (other meals change: -1.2 ±0.51 vs +0.2 ± 0.65 g/min).

Changes in live weight, milk yield and milk composition

Live weight (overall mean ±s.e. during control period: 68.4 ±1.92 kg) increased between the two periods with goats on the High fibre diet increasing more in weight than goats on the Low fibre diet (+ 3.9 vs +2.6 (±0.37) kg; $F_{1,16}$=5.2; P=0.037). Milk yield (overall mean during control period: 1.76 ±0.099 kg/d) decreased for the goats on the High fibre diets, whereas goats on the Low fibre diet did not change their milk yield (-0.39 vs +0.05 (±0.082) kg/d; $F_{1,16}$=11.3; P=0.004).

A significant interaction between parity and treatment ($F_{1,16}$=8.2; P=0.011) was found for change in milk fat content (overall mean during control period: 36.7 ±0.91 g/L) between periods, with 1st parity goats on the Low fibre diet decreasing their milk fat content (-3.2 ±1.40 g/L), and all other goats showing an increase in milk fat content (+2.4 ±1.32 g/L) during the treatment period. Treatment significantly affected milk lactose content (overall mean during control period: 42.4 ±0.44 g/L), reflecting the effects on milk yield, with goats on the High fibre diet decreasing milk lactose content, whereas goats on the Low fibre diet did not change (-1.2 vs +0.4 (±0.37); $F_{1,16}$=7.3; P=0.016). Milk protein content was not affected by dietary treatment.

Discussion

This study confirmed that the feeding behaviour of small ruminants, such as goats in late lactation, is affected by the fibre content of the ration, with meal patterns divergently affected by increasing and decreasing amount of dietary fibre. When fed a diet with reduced fibre content, goats changed their feeding behaviour to the greatest extent, mainly by eating faster leading to shorter meals and thereby reducing the amount of time spent feeding each day. The lower fibre content of the diet also led to an increase in daily feed intake, which was not seen in goats fed the high fibre diet. Instead, those latter goats ate more slowly and spent more time feeding during the main meals of the day, whilst feeding less frequently than before the diet change. So, contrary to our expectations, increasing the fibre content of the diet led to few changes in the feeding patterns, whereas a reduction in fibre had a greater effect. Indeed, our findings did correspond well with those of previous studies on goat feeding behaviour when offered a low fibre diet leading to increased feeding rate and shorter feeding time (Abijaoudé et al., 2000). In accordance with the results from Serment and Giger-Reverdin (2012), who studied individually housed goats fed more divergent diets than used in the present trial, we also found a reduced duration of the first feeding bout, with fewer changes in feeding behaviour seen on the high fibre diet. In studies of other ruminant species, McLeod and Smith (1989) found no differences in the meal frequency of steers fed diets of different fibre content, but the animals were fed hourly, apparently to reduce diurnal variation, and the feeding behaviour was described by the authors as being erratic. Friggens et al. (1998) found that dairy cows increased their meal frequency and reduced their meal size when more roughage was included in the diet, which is the opposite to what was found in the present experiment, where an increase in fibre content reduced the number of daily meals. The concentrate inclusion in the high fibre TMR used by Friggens et al. (1998) was as low as 10%, compared to 20% in the present experiment, which may contribute to the differences in the results. Also, for the low fibre diet, our choice of 40% concentrate inclusion was made to lower the risk of SARA, compared to the 50% concentrate used by Serment et al. (2011). Although no measurements of rumen pH were made, none of the goats in the present experiment showed any signs of ruminal acidosis.

No differences between breeds were found for most of the feeding behaviour variables, and although interactions with treatment were found for feeding rate, these effects were small, not strongly significant, and, even after live weight differences were adjusted for in the analysis, appeared to be related to animal size: Alpine goats are smaller, and as bite mass is correlated with body weight (Boval and Sauvant, 2019), smaller mouth volume may have prevented them from increasing their feeding rate to that of the Saanen when fed the low fibre diet. In the present study, feeding rate was faster during the first meal after feed distribution than during secondary meals, which corresponds to Abijaoudé et al. (2000), who found feeding rates dropped to a third of those measured during the main meals. This may reflect a greater motivation to feed when fresh feed is made available, in the same way that hunger makes feed ingestion increase (Nielsen, 1999). Baumont et al. (2000) found that 60-80% of feed intake in goats were consumed during the main meals following feed delivery, and the corresponding value in the present experiment was 65%. The greater feeding rate during the first meal is achieved despite the increased likelihood that more pauses in feeding are included when meals are longer. However, the meal criterion of 8 min applied to these data is much shorter than estimates previously found for goats and other ruminants, e.g. an average of 13 min for goats, 22 min for sheep (Gorgulu et al., 2011), 28 min for early lactation dairy cows (DeVries et al., 2003) and 42 min for mid- to late lactation cows (Tolkamp et al., 1998). Our short meal criterion of 8 min thus affects the time-sensitive feeding behaviour measures (meal duration, feeding rate and time spent feeding) to a much lesser extent than when longer meal criteria are used.

As all feeds contained the same ingredients, the goats were familiar with the feeds and any differences in intake when the diets were changed would thus not be caused by novelty (Morand-Fehr, 2003). It is also important to keep in mind that the change in diet composition was the only difference experienced by the goats during the treatment period. The live weight of the goats increased by a few kilos across the experimental period, part of which is a result of the foetus growing (Sivachelvan et al., 1996). Goats fed the high fibre diet increased their liveweight slightly more, and it cannot be ruled out that the differences in gain between the two diets were due to varying degrees of gut fill (MLA, 2017). One aspect of feeding, which we did not measure in the present experiment, is sorting, where the animal spends time picking out specific parts of the TMR. Giger-Reverdin et al. (2020) found goats to exhibit a low level of sorting against fibre, measured as the ratio of NDF in the feed and the refusals. DeVries et al. (2007) found that although more sorting was seen when cows were fed a low compared to a high fibre diet, on both diets sorting was always against long and for short particles. In the present experiment, the increase in spillage when goats were fed the high fibre diet may be a consequence of more sorting, as more long particles were included on this diet. This, in turn, would have contributed to the longer duration of meals seen in goats fed the high fibre diet.

The experimental set-up was not sufficiently large to allow inclusion of groups continuing on the control diet, but it is worth noting that the observed differences between high and low fibre fed goats were not symmetrical around zero. This appears to indicate that changes would have occurred had the goats continued on the control diet, which was equal in composition to a 50:50 mixture of the two treatment diets. So why does the feeding behaviour change much more when fibre content is lowered? It may be that the control diet is already constraining certain feeding variables. We know that more rumination is seen when diet roughage proportion is high in both cows (Nielsen et al., 2000) and goats (Abijaoudé et al., 2000). The slight reduction in meal frequency, and the absence of an increase in daily feed intake seen in the high fibre goats, may reflect the increased time needed to ruminate.

The results from the present experiment show that changes in the meal patterns of goats can be induced by diet changes, especially when the proportion of roughage is reduced. This is important to take into account when conducting nutritional studies on small ruminants, as these behavioural adaptations can influence resting and rumination time. More extreme diets, which lead to feed-induced pathologies, such as acidosis, have been found to reduce feeding rate and meal frequency in dairy goats in mid-lactation (Desnoyers et al., 2009; Giger-Reverdin, 2018). The asymmetrical effects on feeding patterns of the divergent changes in diet fibre content indicate that more changes in meal patterns are needed to adjust to a reduction than to an increase in dietary fibre.

Acknowledgements

The authors would like to thank Joseph Tessier, Alexandra Eymard, Ophélie Dhumez, and the staff at the experimental goat farm for data and sample collection, as well as looking after the goats, Cindy Eyma for feed analysis, and Nicolas Friggens for useful comments on earlier versions of this paper.

Ethics approval

The study was carried out in 2019 at the INRAE farm at Thiverval-Grignon, France in accordance with the French legislation on animal experimentation and European legislation on the protection of animals used for scientific purposes (EU Directive 2010/63). All experimental procedures were approved by the Animal Welfare Advisory Board of the experimental unit (MoSAR, INRAE) and by the Animal Ethics Committee (No. 45; DAP number 18-06).

Data availability

None of the data have been deposited in an official repository but are available upon request.

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B.L. Nielsen: Project administration, Methodology, Formal analysis, Writing - Original Draft, Review & Editing; M. Cellier: Methodology, Investigation, Writing - Review & Editing; C. Duvaux-Ponter: Methodology, Writing - Review & Editing; S. Giger-Reverdin: Methodology, Resources, Writing - Review & Editing

Declaration of interest

The authors declare no financial or commercial conflicts of interest.

Financial support statement

This work was supported by internal INRAE funding.

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Tables

Table 1

Feed ingredients and their chemical analysis used for three total mixed rations fed to dairy goats in late lactation.

Item	Grass hay	Dried alfalfa	Sugar beet pulp silage (control diet)	Sugar beet pulp silage (treatment diets)	Concentrate
DM (g/kg fresh)	892	897	299	313	904
CP (g/kg DM)	112	164	91	91	186
NDF (g/kg DM)	618	438	477	462	254
ADF (g/kg DM)	328	305	216	224	101
ADL (g/kg DM)	42	67	112	191	29
Starch (g/kg DM)	-	-	-	-	384
Ash (g/kg DM)	82	124	81	73	72

Table 2

Composition (in DM and fresh) and calculated content for three total mixed rations (TMR) fed to dairy goats in late lactation. Control diet was fed during days 1-22 of the experimental period, whereas the treatment diets (High and Low fibre, respectively) were fed during days 23-38.

Item	Control	High fibre	Low fibre
Composition (in DM)			
Grass hay (%)	32	38	26
Dried alfalfa (%)	23	27	19
Sugar beet pulp silage (%)	15	15	15
Concentrate (%)	30	20	40
Composition (g/kg fresh TMR)			
Grass hay	248	299	205
Dried alfalfa	177	211	149
Sugar beet pulp silage	346	336	336
Concentrate	229	155	311
Composition (DM g/kg fresh TMR)			
Grass hay	221	267	183
Dried alfalfa	159	189	134
Sugar beet pulp silage	103	105	105
Concentrate	207	140	281
TMR	690	701	703
Calculated content			
CP (g/kg DM)	143	138	148
NDF (g/kg DM)	446	473	415
ADF (g/kg DM)	238	261	217
ADL (g/kg DM)	54	69	64
Starch (g/kg DM)	115	77	154
Ash (g/kg DM)	89	90	85

Table 3

Feeding behaviour variables (Least Square means and 95% confidence intervals) when dairy goats were fed a Control diet (baseline), and the subsequent changes when one of the two treatment diets, High or Low fibre, were fed. Values are given in fresh feed.

		Difference from Control		
	Control	High	Low	P-value[1]
	n=32	n=16	n=16	
Meal frequency (meals /d)	12.1 (*0.96*)	-1.2 (*0.69*)	+0.5 (*0.69*)	0.008
Meal size (g/meal)				
1st meal after feed delivery	1 352 (*97.2*)	+40 *(115.8)*	+78 *(115.8)*	0.693
Other meals	160 (*26.5*)	-1 (*22.0*)	+3 (*22.0*)	0.823
Meal duration (min/meal)				
1st meal after feed delivery	88.5 *(6.04)*	+10.1 (*7.02*)	-16.6 (*7.02*)	<0.001
Other meals	20.2 *(1.51)*	+1.0 *(2.23)*	-3.3 *(2.23)*	0.033
Feeding rate (g/min)				
1st meal after feed delivery[2]	16.0 (*2.15*)	-1.5 (*1.08)*	+5.4 (*1.08*)	<0.001
Other meals[2, 3]	8.9 (*0.73*)	-0.5 (*0.78)*	+2.5 (*0.78*)	<0.001
Daily feeding time (min/d)	365 (*17.1*)	+3.4 (*17.56*)	-47.5 *(17.56)*	0.003
Daily feed intake (kg/day)	4.16 *(0.200)*	-0.13 (*0.155*)	+0.36 *(0.155)*	0.002
Spillage (g/day)	70 (*18.4*)	+23 *(18.0)*	-38 *(18.0)*	0.001

[1] P-value refers to the treatment effect from the model indicating differences between High and Low in their change from the control diet.
[2] Significant interactions between breed and treatment were found for these two variables; see text for details.
[3] A significant interaction between parity and treatment was found for this variable; see text for details.

Figure headings

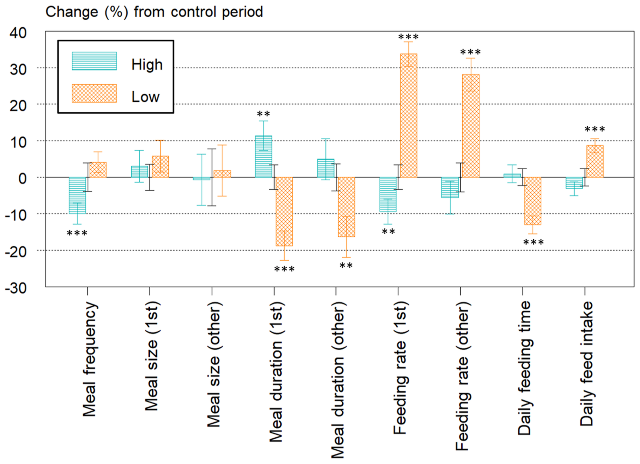
Figure 1 Goats feeding in the experimental set-up; **a)** Side view of the eight pens, showing the brackets separating the goats when feeding, the slatted floor and the drinking cups at the back of each pen. The inset in the upper right-hand corner shows a side-view of a feed trough, detailing the anti-spillage front (photos: Ophélie Dhumez); **b)** Front view showing the white feed troughs (T), each placed on a weigh scale (W), and the antennas (A) responding to the ear-tag of the goats, releasing the gate (G) when the correct goat is present (photo: Marjorie Cellier).

Figure 2 Schematic overview of the experimental protocol and the measurements used in the statistical and chemical analyses. All goats were fed a Control diet (C) for the first 22 days, followed by 16 days (days 23-38) of either a High (H; n=16) or a Low (L; n=16) fibre diet. The last 10 days of each period were used in the analysis of feeding behaviour data.

Figure 3. Percentage change (Least Square means ± SE) from control period in feeding behaviour variables for dairy goats on a High or a Low fibre diet, respectively. Meal size and meal duration as well as feeding rate are shown for the first meal after a distribution (1^{st}) and for other meals. The black error bars indicate the SE of each variable for the control period, and asterisks indicate significant change from the control period (** $P < 0.01$; *** $P < 0.001$), i.e. the change is different from zero (Wald test).


A
G
T
W

Day of trial:	1-11	12	13	14	15	16	17	18	19	20	21	22	23-28	29	30	31	32	33	34	35	36	37	38
Day of treatment:	1-11	12	13	14	15	16	17	18	19	20	21	22	1-6	7	8	9	10	11	12	13	14	15	16
Treatments:																							
High	Control diet	C	C	C	C	C	C	C	C	C	C	C	High fibre diet	H	H	H	H	H	H	H	H	H	H
Low	Control diet	C	C	C	C	C	C	C	C	C	C	C	Low fibre diet	L	L	L	L	L	L	L	L	L	L
Measurements:																							
Feeding behaviour																							
Live weight						X						X			X							X	
Milk yield			X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Milk composition						X									X								
Spillage estimate		X							X									X					X
Diet ingredients	X				X										X						X		



Change (%) from control period
40
30
20
10
0
-10
-20
-30
High
Low
***
**
***
**
***
***
**
***
***
Meal frequency
Meal size (1st)
Meal size (other)
Meal duration (1st)
Meal duration (other)
Feeding rate (1st)
Feeding rate (other)
Daily feeding time
Daily feed intake