Inter-and intra-individual variability of feeding behaviour in group housed dairy goats

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Abstract

The emergence of precision livestock farming (PLF), and with it the increasing capacity to record behaviour and production parameters automatically, makes it possible to monitor feeding behaviour of individual animals over time. This study reports some of the first quantifications of feeding behaviour variables for individual dairy goats whilst group housed. The feeding behaviour of 16 non-lactating goats (NoLact), 32 goats in the middle of their first lactation (MidLact) and 24 goats (including 20 goats from MidLact) at the end of their first lactation (EndLact) from two breeds (Alpine and Saanen) was recorded. The goats were housed in groups of four individuals and each had access to one weight-monitored feeding station where they received a total mixed ration *ad libitum* twice a day. Following a habituation period, feeding behaviour was measured for nine days (NoLact), 10 days (MidLact) and six days (EndLact). After merging feeder visits into meals (≥8-min inter-meal-interval), six variables were calculated for each individual: meal frequency (number of daily meals, NDM), size (feed intake per meal, FIM) and duration (DUM), as well as feeding rate (FR), daily feeding time (DFT) and daily feed intake (DFI). The inter- and intra-individual variabilities of these six variables were investigated and the intra-class correlation coefficients calculated. Particular attention was paid to the first meal following feed distribution and to the stability of individual feeding behaviour between lactation stages. Effects of body weight, breed, and stage of lactation on the six feeding behaviour variables were analysed using a general linear model. Our study confirmed previous findings from individually housed dairy goats that feeding behaviour variables are relatively stable within an individual but show greater variability between individuals. Although there were differences between the lactation stages studied, the feeding behaviour of individuals tested in two lactation stages (mid- and end of lactation) remained relatively stable. The feeding behaviour variables were normally distributed, and smaller meals were linked with a higher meal frequency and vice versa. The first meal after a feed distribution, in addition to being positively correlated with the DFI, appeared to be stable in size for individual goats with a larger variability among individuals and could potentially be used to characterize the individuals, whereas time-related feeding behaviour variables appeared less useful for this purpose. Characterization of individuals based on their feeding behaviour can potentially be used to refine individual management for disease prevention or as a trait used in genetic selection.

1. Introduction

The advent of precision livestock farming (PLF), and in particular the increasing capacity to record behaviour and production parameters automatically, makes it possible to monitor detailed changes in the behaviour of farmed animals. Although only some farms are currently able to benefit from the more advanced PLF technology, it is a promising tool which can also help to increase our knowledge on livestock behaviour. The use of automated monitoring could replace visual observations in scientific studies because this method is less time-consuming, requires less work, allows information to be obtained in the field in real time, and thus, in some cases, early identification of vulnerable or at-risk individuals, facilitating their treatment. In the case of feeding behaviour studies, using data from automated sensors, Thorup et al. (2016) showed that lameness affects the feeding behaviour of dairy cows, with lame cows being characterized by fewer visits to feeding stations, higher feeding rate, less time spent feeding and more inter-individual variation in feeding behaviour. In goats, Desnoyers et al. (2011) demonstrated a link between longer, less frequent meals and low rumen pH, indicating an increased risk of rumen acidosis. Overall, the use of PLF could therefore allow the characterization of feeding behaviour for targeted individual management or disease prevention.

Individual variability of feeding behaviour is high. For example, Melin et al. (2005) showed that 84 to 98% of the variability in feeding behaviour patterns can be attributed to individual differences between dairy cows. Several studies have thus shown a high variability between individuals for the frequency of meals or the time spent feeding per day (Schwartzkopf-Genswein et al., 2002; DeVries et al., 2003b). In goats, Giger-Reverdin et al. (2012) found that individual goats were distributed on a continuum ranging from so-called “nibblers”, i.e. individuals that feed in often small meals, to so-called “big loaders” that feed less frequently but in larger meals each time. In addition to evidence of inter-individual variability, Melin et al. (2005) showed that, in cows, feeding behaviour patterns also remained relatively constant over time. This is not to say that the behaviour is inflexible, but that when the environment is relatively stable, feeding behaviour remains the same for each individual. Individual stability of feeding behaviour over time would allow early selection of the most adaptable animals to specific husbandry conditions.

Although it is known that feeding behaviour can be influenced by parameters characterizing the animal (e.g. age, weight and physiological stage) and by the level and efficiency of production (e.g. body weight gain for growing animals or milk yield for dairy animals; Albright, 1993; Forbes, 2007), it is still not well understood why individuals within a herd differ in their feeding behaviour, why these differences are relatively stable over time and how these differences can vary with changes in the individuals' environment. In indoor farming systems, animals often undergo changes in their social groups, in the space available for each individual and in their diet. For example, the timing and frequency of feed delivery are characteristics that can affect the feeding behaviour of cattle (von Keyserlingk and Weary, 2010). In addition, ruminants are known to make trade-offs for the choice of diets that match the requirements of their internal condition, such as hunger, and stage of gestation or lactation

(Forbes, 2007). Nevertheless, few studies have investigated the influence of the stage of lactation on feeding behaviour. In ruminants, feed intake is dependent on both physical constraints (rumen size) and physiological constraints (metabolic/energy needs). During early lactation, the demand for nutrients and energy for milk synthesis is very high and females need to feed as much as possible while at the same time mobilizing body reserves. The demand for nutrients and energy will therefore be high, which will affect feeding behaviour. For example, DeVries et al. (2003b) measured the feeding behaviour of the same group of cows at three different periods between 35 ± 16 and 94 ± 16 days in milk and showed changes in their feeding behaviour such as an increase in total daily feeding time, meal frequency and meal duration between the first and second period studied, reflecting the increase in daily feed intake from early to peak lactation. Another factor that could influence feeding behaviour would be the breed: differences in feeding behaviour have been found between breeds of cattle (Senn et al., 1995; Schwartzkopf-Genswein et al., 2003), but there are very few studies on such breed effects in goats. Finally, a large part of the studies on feeding behaviour of goats have been carried out in individual pens (Abijaoudé et al., 2000; Desnoyers et al., 2011). However, goats are social animals (Miranda de la Lama and Mattiello, 2010), and we know from studies in pigs that feeding behaviour differs greatly between group and single housed animals (De Haer and Merks, 1992), but that differences among pigs in a group are relatively stable, also when subsequently measured when individually housed (Nielsen et al., 1996).

Dairy goats are an important part of milk production systems in many countries and there is a paucity of information on their feeding behaviour. Two breeds, Alpine and Saanen, are commonly used in France, representing 55% and 42% of the French national herds, respectively (France Génétique Elevage, 2014). The present study provides some of the first quantifications of feeding behaviour variables for individual dairy goats whilst group housed. The aims of this study were 1) to characterize the inter- and intra-individual variability in feeding behaviour of two breeds of dairy goats; 2) to evaluate the stability of their feeding behaviour between two lactation stages; 3) to evaluate the impact of producing milk on their feeding behaviour. As Saanen goats are heavier than Alpine goats, it was expected that their feeding behaviour would be different, notably that their daily intake would be higher. It was also expected that the inter-individual variability would be greater than intra-individual variability and that individuals would be distributed within a normal distribution of feeding patterns. It was assumed that intake would be highest in goats in mid-lactation when the nutritional needs are greater than in end-lactation and lowest in non-lactating goats. We wanted to investigate, if these differences gave rise to corresponding (and consistent) differences in feeding patterns.

2. Materials and methods

The study was carried out in 2018 at the INRA experimental farm at Thiverval-Grignon, France in accordance with 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 research unit and by the local Animal Ethics Committee (N°045) under the DAP number 18-06.

2.1. Animals, Design, and Feeding

The feeding behaviour of two breeds of dairy goats (Alpine and Saanen) was characterized in three experimental periods according to their stage of lactation:

- 16 goats born in 2018 (eight Alpine goats, eight Saanen goats) at the middle of their first gestation and therefore non-lactating (NoLact);
- 32 goats born in 2017 (20 Alpine goats, 12 Saanen goats) in the middle of their first lactation (MidLact);
- 24 goats also born in 2017 (12 Alpine goats, 12 Saanen goats, including 20 goats already tested in MidLact), at the end of their first lactation and the middle of their second gestation (EndLact); two goats were replaced due to illness and adaptation problems.

In each experimental period, the goats were assigned to groups of four individuals with one to two Saanen in each group, balanced for age, body weight (BW) at the start of the experimental period and – when occurring – milk production (MP). For the EndLact trial, each group had two or three goats originating from the same group as MidLact. The groups were small (n=4) and of similar composition in terms of breeds and live weight variation to make the social environment as similar as possible.

The groups were housed in 7.6 m² group pens with slatted floors. Each pen was equipped with four feed stations, one feed station consisting of a trough system fitted on a scale, manufactured by Baléa (Saint-Mathieu de Tréviers, France) and an antenna manufactured by Gabard (Argentonnay, France) to receive the signal from the electronic ear-tag worn by the animals. A goat could gain access to the feed trough via its ear-tag, and each goat had access to one feed station only. The use of metal brackets between the feed station spaces and the allocation of one feed station per animal minimized the competition and social influences while feeding.

After an adaptation to the experimental set-up of six days on average, in order to ensure that each goat learned the position of its allocated feed trough, the feeding behaviour was recorded for nine days (NoLact), 10 days (MidLact**)** and six days (EndLact). During adaptation, the goats were housed and fed exactly the same way as during the feeding behaviour measurements.

The animals were fed *ad libitum* with the same total mixed ration (TMR) consisting of (on a DM basis) 25 % meadow hay, 28 % chopped dried alfalfa (Rumiluz, Désialis, Paris, France), 27 % pressed sugar beet pulp, 15 % commercial concentrate (Fluvialac, Agralys Aliment, Châteaudun, France) and 5 % rapeseed meal. The TMR (DM content 54.9 %) contained (on a DM basis) 14.1 % CP, 4.7 % starch, 9.3 % ash, 42.8 % NDF, 23.7 % ADF and 4.7 % ADL.

Quantities of feed offered were adjusted daily to ensure at least 10 % refusals. The TMR was offered twice daily, shortly after milking in lactating animals, in the proportion of 2/3 at 15:00 h and 1/3 at 07:00 h, according to the usual time interval between milking. Refusals were removed daily. The goats in lactation were milked twice daily in MidLact and once daily in EndLact. Those in lactation (MidLact and EndLact) were weighed at each milking and non-lactating animals (NoLact) were weighed weekly. Milking was performed in a rotary milking parlour with a low line at a vacuum pressure of 35kPA, a pulsation rate of 85 pulses/min and a pulsation ratio of 65/35. Raw milk yield was recorded using an automatic device designed for milk recording in small ruminants developed by INRAE (European patent no. 94916284.6).

2.2. Intake measurements and determination of meals

The feeding station system recorded the weight of the feed contained in the trough every 2 s with an accuracy of 5 g. Measurements for one day started at 15:00 h and ended with the collection of refusals around 15:00 h the next day. There was an interruption in the afternoon of around 30 min in NoLact and 1 h in MidLact and EndLact to allow delivery of the TMR, milking and the backup of the feed station software. In the morning, the interruption was around 5 min in NoLact**,** 40 min in MidLact and 10 min in EndLact to allow delivery of the TMR and milking for goats in MidLact (goats in EndLact being milked once daily in the afternoon). This interruption was performed by blocking access to the feed troughs.

From the feed weight data collected, an algorithm was created to identify plateaus (adapted from Blavy et al., 2020), i.e. times when the feed weight was stable. Between these plateaus, the feed weight was unstable because the goat was interacting with the feeding station, and these unstable events were referred to as visits. To group visits into meals, an intra-meal interval was determined using the method described by Tolkamp et al. (1998). Briefly, the log frequency of the plateaus (pauses between visits) was calculated, and a frequency plot was performed for each individual. However, unlike Tolkamp et al. (1998), we did not find two normal distributions, but one clear normal distribution followed by a flat distribution for intervals ≥8 min. The first part of the distribution corresponds to the high frequencies of the short intervals (intra-meal intervals) and the rest of the distribution includes longer intervals (between meal intervals). We combined in one meal the weight of the feed consumed and the occupancy time of the feeding station for all visits spaced less than 8 min apart. Given the accuracy of our scales (5 g), meals with less than 10 g of feed consumed were removed, as were meals with durations of less than 10 s, as these were considered experimental artefacts. Using this method, we were able to determine six variables of feeding behaviour (**Table 1**). In accordance with previous work (Giger-Reverdin et al., 2019), special emphasis was given to the first meal after feed delivery.

2.3. Statistical Analysis

All analyses were performed using R (version 3.6.1; R Core Team, 2019). Two goats in NoLact and two goats in EndLact were excluded from the analyses due to loss of data. In our final analyses, we used data from 14 goats in NoLact, 32 goats in MidLact, and 22 goats in

EndLact (including 20 goats also studied in MidLact) recorded during nine days (NoLact), 10 days (MidLact**)** and six days (EndLact). It is impossible to completely avoid confounding effects between age, growth and milk yield, but during both NoLact and EndLact the goats were in mid-gestation and the milk yield of the EndLact goats was coming to an end, hence the main difference between these two groups were their age and the associated differences in growth.

Table 1*: Description of the six variables of feeding behaviour used in the analyses.*

Variable	Abbreviation	Definition	Unit
Number of daily meals	NDM	Number of meals occurring during a period between 15:00 h day N and 15:00 h day N+1, corresponding to meal frequency	meals/day
Feed intake per meal	FIM	Amount eaten per meal, corresponding to meal size.	g/meal
Duration of a meal	DUM	Length of time each meal lasts corresponding to meal duration.	min/meal
Daily feed intake	DFI	Calculated as the sum of the FIM per day and corresponds to the total quantity of feed eaten per day.	g/day
Daily feeding time	DFT	Sum of DUM per day and corresponds to the total time spent eating per day.	min/day
Feeding rate[1]	FR	Calculated based on visits as the ratio between the size of a visit (g/visit) and its duration (min/visit) and corresponds to the speed with which the feed is ingested.	g/min

[1] This is calculated based on visits instead of meals in order to prevent the pauses within meals artificially lowering the calculated speed of ingestion.

Three datasets were used to investigate feeding behaviour variables: 1) for each individual, in each stage and for each day, each meal was characterized by their duration and the quantity of feed eaten during that meal whereas the feeding rate was calculated on the basis of visits to the trough and not meals. This was done to ensure that the feeding rate was independent of the pauses that inevitably occur when a meal criterion is used. A graphical comparison of the first meal versus the other meals, for each individual, was made to study the variability between meals within days. The intra-class correlation coefficient, ICC, for goats in EndLact and NoLact was calculated on the variables of the first meal, with the R package *ICC* (Wolak, 2016). MidLact individuals were not used to calculate the ICC to avoid repeated measurements. In addition, the EndLact and NoLact stages were chosen because, except for the age of the individuals, they were similar in terms of stage of gestation. 2) For each individual, in each stage and for each day, the mean quantity of feed eaten per meal (FIM), the mean duration of a meal (DUM) and the mean feeding rate (of visits; FR) were calculated. The total quantity of feed eaten (DFI), the total feeding time (DFT) and the total number of meals (NDM) for each day were also summarized. These six variables of feeding behaviour are either meal/visit related (FIM, DUM and FR) or daily variables (NDM, DFI and DFT). From this dataset, the intra-individual and inter-individual variabilities were investigated using box plots and were expressed as the ICC, for goats in EndLact and NoLact. The correlation between the size of the first meal and the daily feed intake was calculated using Pearson's coefficient of correlation. 3) For each individual, in each stage the mean over the entire experimental period was calculated for each of the six feeding behaviour variables, as well as body weight (BW) and milk yield. From this dataset, BW and milk yield were compared between breeds and between lactation stages by Kruskal-Wallis test and Wilcoxon test, respectively. Correlations between stages for daily variables (NDM, DFI and DFT) were investigated using Pearson's coefficient of correlation. Using a general linear model (LM), a type II Anova with Wald test was conducted to test the effects of BW, breed, and stage of lactation on NDM, DFI, DFT, FIM, DUM, and FR. The model included individuals as a random effect, BW as a covariate, with breed and stage of lactation fitted as fixed effects, together with their interaction. Homoscedasticity and normality of errors of the model were scrutinized with the Breusch-Pagan test and Shapiro test, respectively. When these parameters could not be validated, for DFI and FIM, transformation using the function *transformTukey* in the R package *rcompanion* (Mangiafico, 2020) was used. Transformations x^lambda was applied on these two variables. If the results of the Anova were significant, pairwise comparisons were carried for the different factors with the Tukey test adjusted by Bonferroni. Significance was declared at $p < 0.05$, and tendencies at $0.05 < p < 0.10$.

3. Results

3.1. Intra- and inter-individual variability in feeding behaviour within a day

Figure 1a shows the FIM for individual goats in MidLact. Although some intra-individual variability was observed for a few individuals, the intake during the first meal was relatively stable for most individuals, but variable between individuals. The size of the first meal was positively correlated with the daily feed intake (r=0.69; p<0.001). There was little intra- and inter-individual variability in the size of the other meals (**Figure 1a**), and for the duration of a meal (DUM), intra- and inter-individual variability were again higher for the first meal than for the others (**Figure 1b**). Similar results were obtained for individuals in NoLact and EndLact (data not shown).

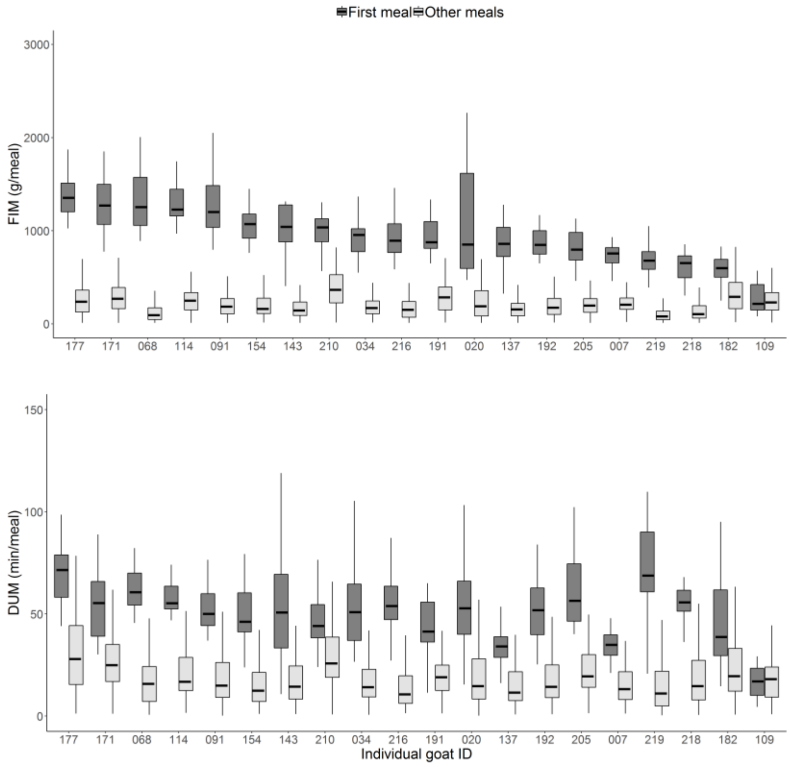

Figure 1: *Boxplots (n=20) representing the variability of the feed intake per meal (FIM; g/meal), and of the duration of a meal (DUM; min/meal) in mid lactation (MidLact, milked twice a day, recorded during 10 days), for the first meal after the morning and afternoon feed delivery (in dark; 20 individual meal values per individual) and for all the other meals of the day (in light). Boxplots show the median (dark bar) and quartiles.*

3.2. Intra- and inter-individual variability in feeding behaviour between days

Intra-individual variability was low between days for the number of daily meals, the daily feed intake, and the daily feeding time, i.e. feeding behaviour of individuals was relatively stable from one day to the next (**Figure 2**). Similar results were obtained for individuals in NoLact and MidLact (data not shown). However, all six feeding behaviour parameters and two first meal variables (the size and the duration) varied greatly among goats and the ICC results (**Table 2**) showed that there was more inter-individual variability than intra-individual variability for goats in EndLact and NoLact (goats in MidLact were not included in the calculation of this coefficient because the majority of these goats also featured in the data for EndLact).

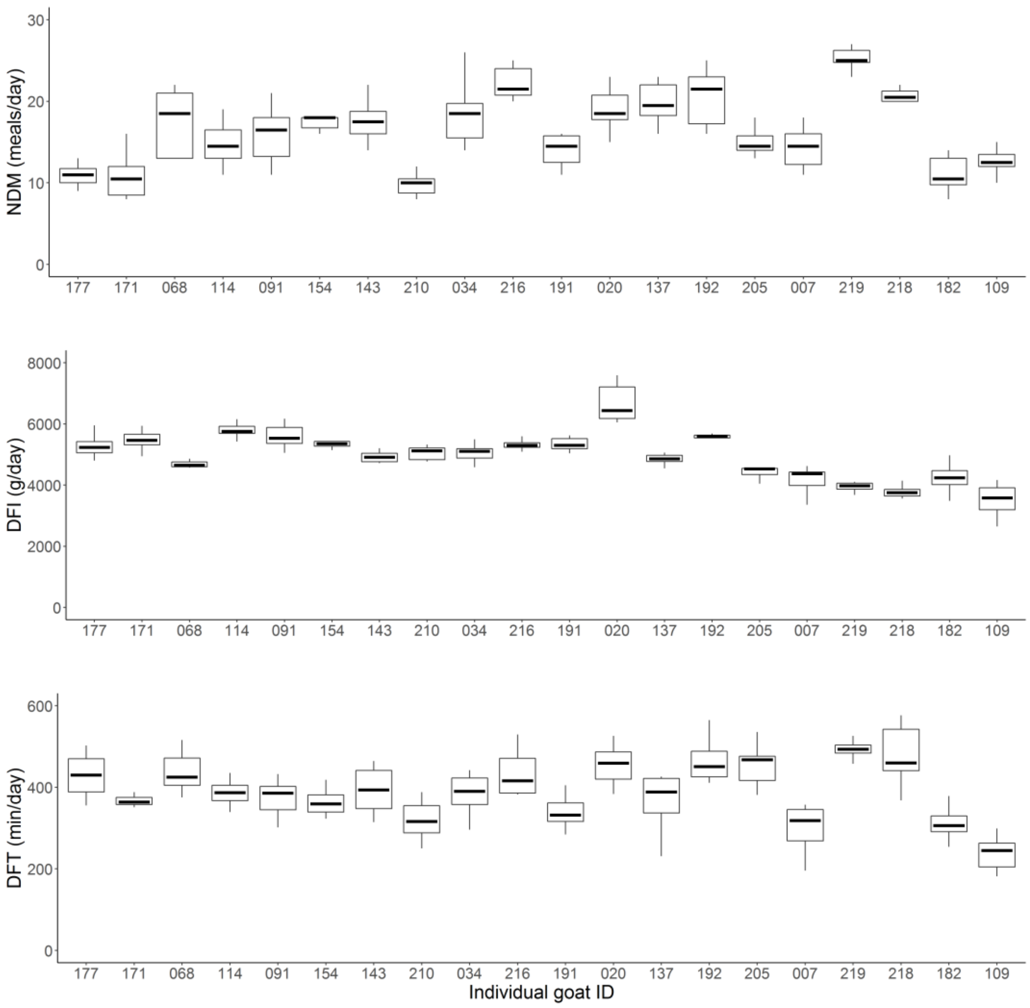

Figure 2*: Boxplot (n=20) representing the variability between days of the number of daily meals (NDM), of the daily feed intake (DFI; g/d) and of the daily feeding time (DFT; min/d) in mid lactation (MidLact, milked twice a day, recorded during 10 days). Boxplots show the median (dark bar) and quartiles.*

***Table 2**: Parameters of the Intra-class Correlation Coefficient (ICC) test of measures of daily variables (DFI, DFT, NDM), variables based on meals (DUM and FIM, 1st indicates first meal following delivery) and variable based on visits (FR) for 36 goats (n=14 in NoLact: no lactation, recorded during nine days, n=22 in EndLact: mid lactation, milked once a day, recorded during six days).*

	NDM (meals/day)	DFI (g/day)	DFT (min/day)	FIM (g/meal)	FIM 1st (g/meal)	DUM (min/meal)	DUM 1st (min/meal)	FR (g/min)
ICC	0.67	0.96	0.57	0.78	0.81	0.34	0.29	0.76
Lower CI	0.55	0.93	0.44	0.69	0.73	0.21	0.17	0.66
Upper CI	0.78	0.97	0.71	0.87	0.88	0.50	0.45	0.85
Var W	4.86	68664	2579	1086	21206	22.3	248	14.6
SD W	2.21	262	50.8	33.0	146	4.72	15.8	3.82
Var A	9.77	1485158	3439	3919	90523	11.4	101	45.1
SD A	3.13	1219	58.7	62.6	301	3.38	10.1	6.72
Var A/Var W	2.01	21.6	1.33	3.61	4.27	0.51	0.41	3.09
Overall mean	14.4	3884	321	175	837	18.9	48.1	41.1
Overall SD	3.21	1207	61.5	70.0	310	5.78	12.0	6.69

CI: Confidence Interval, Var W: Variance within individuals, SD W: Standard Deviation within individuals, Var A: Variance among individuals, SD A: Standard Deviation among individuals. DFI: daily feed intake; FIM: feed intake per meal; DFT: daily feeding time; NDM: number of daily meals; DUM: duration of a meal; FR: feeding rate.

In **Figure 3**, the mean feed intake per meal of each individual goat is plotted against their mean number of daily meals. Overall, the data points clustered around the mean for each lactation stage, reflecting the normal distribution of the data with a few individuals showing more extreme feeding patterns with either few, but large meals, or many small meals.

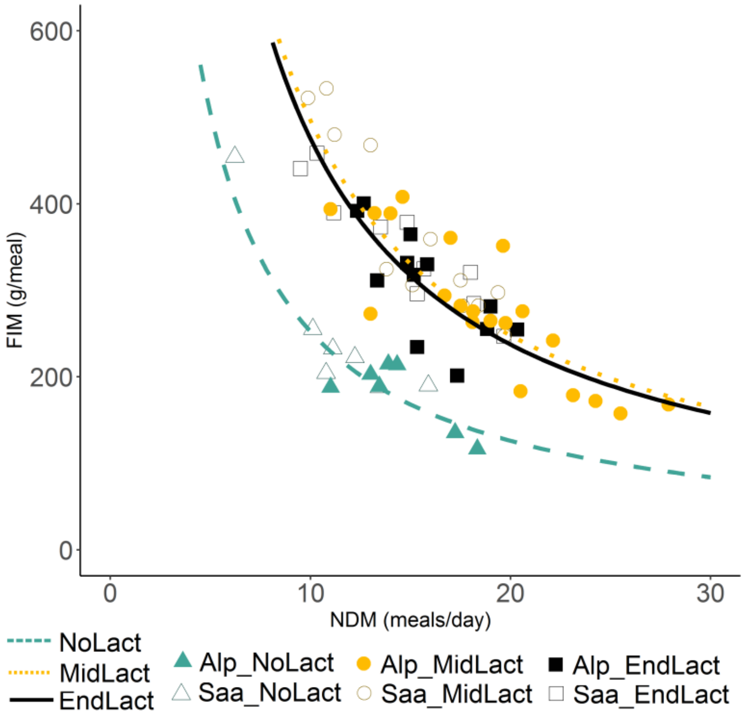

Figure 3*: Scatterplot of mean feed intake per meal (FIM; g/meal) plotted against mean number of daily meals (NDM) for goats tested in three lactation stages: NoLact (n=14): no lactation, recorded during nine days; MidLact (n=32): mid lactation, milked twice a day, recorded during 10 days; EndLact (n=22): end of lactation, milked once a day, recorded during six days. Alpines goats (Alp) are indicated with solid markers and Saanen goats (Saa) with open markers. The isoclines (x*y) indicate overall mean daily feed intake (DFI; g) for each stage of lactation.*

3.3. Feeding behaviour across stages of lactation

Some of the goats (n=20) were tested in both MidLact and EndLact. Within each variable, number of daily meals, daily feed intake and daily feeding time were significantly correlated between the two lactation stages (**Figure 4**).

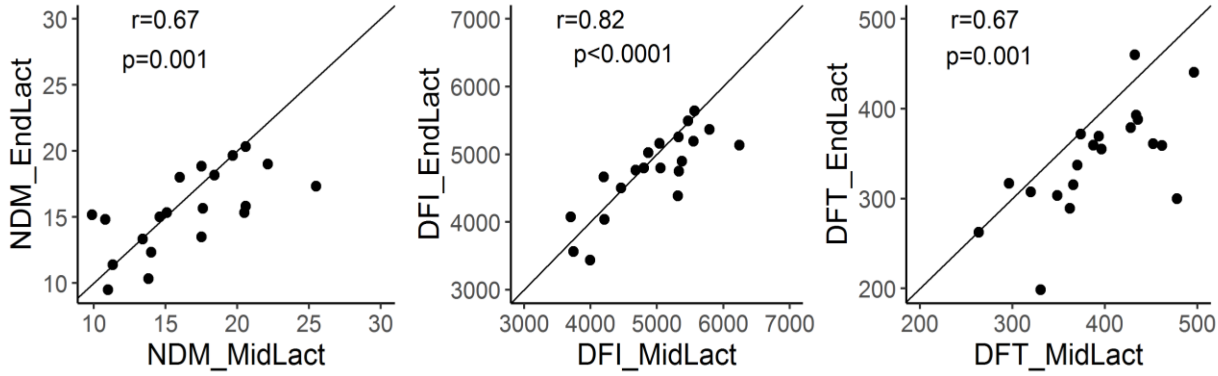

***Figure 4**: Scatterplots of individual means (n=20) of NDM, DFI and DFT in MidLact (x-axis; 10 days of measurement) tested and EndLact (y-axis; six days of measurement). For better clarity, the axes do not start at zero. MidLact: mid lactation, milked twice a day; EndLact: end of lactation, milked once a day. NDM: number of daily meals (meals/day); DFI: daily feed intake (g/day); DFT: daily feeding time (min/day).*

3.4. Effects of breed and stage of lactation on feeding behaviour

Saanen goats were heavier than Alpine goats (59.6 ± 5.90 kg vs 51.1 ± 6.31 kg in NoLact, 58.5 ± 6.41 kg vs 53.7 ± 6.34 kg in MidLact, and 67.3 ± 10.1 kg vs 61.8 ± 9.08 kg in EndLact, respectively; p=0.003). The goats in MidLact produced more milk than goats in EndLact (respectively 3.56 ± 0.51 kg/day and 2.05 ± 0.49 kg/day, p<0.0001), and there was no difference in milk yield between breeds (Alp: 2.9 ± 0.89 kg/day; Saa: 3.0 ± 0.93 kg/day, p=0.773). The interaction between breed and stage of lactation was not significant, and Alpine and Saanen goats did not differ in their feeding behaviour. Details on the feeding behaviour variables for each breed within each stage of lactation are shown in **Table 3.**

***Table 3**: Mean (± SD) for six variables of feeding behaviour of goats according to their stage of lactation and breed (Alpine or Saanen).*

	NoLact		**MidLact**		**EndLact**		**Breed effect (p-value)**	**Stage of lactation effect (p-value)**	**Pairwise comparison (p-value)**		
	Alpine (n=7)	Saanen (n=7)	Alpine (n=20)	Saanen (n=12)	Alpine (n=12)	Saanen (n=10)			NoLact vs MidLact	NoLact vs EndLact	MidLact vs EndLact
NDM (meal/day)	14.5 ± 2.52	11.4 ± 3.00	18.8 ± 4.42	16.2 ± 3.51	15.8 ± 2.57	14.6 ± 3.48	0.237	**0.005**	**0.004**	**0.004**	**0.004**
FIM (g/meal)	180 ± 38.8	250 ± 93.4	279 ± 81.4	368 ± 103	306 ± 62.5	351 ± 68.5	0.185	**0.0007**	**<0.0001**	**<0.0001**	**<0.0001**
DUM (min/meal)	21.6 ± 4.82	25.6 ± 5.12	22.7 ± 4.99	27.0 ± 6.70	22.9 ± 2.63	23.7 ± 5.29	0.856	0.796	-	-	-
DFI (g/day)	2487 ± 386	2559 ± 225	4847 ± 786	5148 ± 515	4683 ± 647	4829 ± 538	0.457	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
DFT (min/day)	302 ± 63.1	274 ± 46.3	404 ± 72.9	383 ± 44.5	356 ± 58.4	327 ± 52.6	0.167	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
FR (g/min)	37.9 ± 7.33	45.5 ± 6.87	35.0 ± 5.40	37.4 ± 6.23	40.2 ± 5.66	41.2 ± 6.61	0.760	0.175	-	-	-

NoLact: no lactation, recorded during nine days; MidLact: mid lactation, milked twice a day, recorded during 10 days; EndLact: end of lactation, milked once a day, recorded during six days. NDM: number of daily meals; FIM: feed intake per meal; DUM: duration of a meal; DFI: daily feed intake; DFT: daily feeding time; FR: feeding rate.

4. Discussion

Our study showed a high variability among goats for three feeding behaviour variables (daily feed intake, number of daily meals and feed intake per meal) but with a relatively low variability within individuals. However, the duration-related feeding behaviour variables (duration of a meal and daily feeding time) appeared to be less useful for characterizing variability between individuals. The size of the first meal following a feed distribution appeared to differ more between than within individuals compared to the remaining meals of the day. The size of the first meal was positively correlated with the daily feed intake. The feeding behaviour was relatively stable from one day to the next for a given individual, with a good correlation between different lactation stages. In addition, stage of lactation affected the feeding behaviour of dairy goats.

As expected, our results showed that daily feed intake was relatively stable within an individual, whereas the variability between individuals was found to be 18 times greater. In order to obtain a given daily feed intake, goats can use different combinations of meal size and frequency and, likewise, the only way to achieve different daily feed intakes is to differ in either meal frequency or meal size or both (Nielsen, 1999). This is particularly clear for the daily feed intake of non-lactating goats that was significantly lower than that of their milk producing conspecifics, due to lower energy and metabolic needs. The reduced daily feed intake was a result of both a lower number of daily meals and less feed eaten per meal. Unfortunately, the non-lactating goats used in the present study did not have their feeding patterns monitored during lactation, so we do not know the spread in feeding patterns after parturition, and to what extent goats with the more extreme patterns remained like that.

Nielsen (1999) argued that within a given environment feeding behaviour can be considered as a characteristic of an individual. Given that the goats in the present experiment were kept in near-identical conditions, what causes the observed variability between individuals? Our results showed that the number of daily meals and the feed intake per meal were relatively stable within an individual, whereas the variability between individuals was three times greater. More precisely, phenotyping of goats showed a normal distribution of feeding patterns with very different patterns in terms of number of daily meals and feed intake per meal for the extremes. As described in the introduction, Giger-Reverdin et al. (2012) found a range of feeding patterns in goats, and this individual variability in feeding behaviour has also been observed in cows (Morita et al., 1996; Friggens et al., 1998b). Many factors can cause individuals to vary in their feeding strategy to maintain a stable daily feed intake from one day to the next. For example, competition for feed access induced by a social environment can affect the feeding behaviour (DeVries et al., 2004), although our design limited this possibility. Indeed Fernández et al. (2007) showed that the grouping of goats led to an increase in aggressive interactions that could affect feeding behaviour by reducing the amount of feed consumed by some goats. However, three days after regrouping, aggression had returned to the same level as before regrouping the animals. This indicates that, for the group size used in their study, seven to eight animals per group, three days were sufficient to reinstate a stable social organization. It would therefore be expected that in our groups of four individuals, social relationships would be restored within the same time span. We deliberately kept the goats in small groups (n=4) of similar composition in terms of breeds and live weight variation to make the social environment as similar as possible between the groups, and we allowed the goats to adapt to their environment before starting the measurements. Moreover, the use of brackets between the trough spaces and the allocation of one trough per animal minimized competition and social influences while feeding.

Our study showed that the duration-related feeding behaviour variables, i.e. meal duration and daily feeding time, appeared to be less useful for characterizing variability among individuals. Indeed, their inter-individual variability was less than twice their intra-individual variability. The calculation of these variables uses the notion of a meal criterion to define what constitutes a meal. The definition of a meal can vary between studies and depends on the species (Abijaoudé et al., 2000; Landau et al., 2000). As a reminder, we chose to combine in one meal the weight of the feed consumed and the occupancy time of the feeding station for all visits spaced less than 8 min apart. This method lengthens the duration of a meal and the daily feeding time because short pauses within each meal are integrated in the durations included in the calculation of these two variables. For this reason, the feeding rate was calculated not based on meals but based on visits only. Nielsen (1999) proposed that individual animals had a preferred feeding rate, and that this feeding rate would change only if the animals were hungry or if competition for access to feed increased. None of these causes apply to the present experimental set-up, as all animals were fed *ad libitum* from their own, individual feed trough, and the feeding rates remained relatively stable within individuals.

Looking into the variability in more detail, our study appeared to show that the first meal after fresh feed has been delivered was more variable between individuals than within individuals in terms of feed intake per meal, while the other meals were relatively stable between and within individuals. Human activity at the goat farm is more pronounced at feeding and milking times than during the rest of the day. This peak activity can influence differently individual animal behaviour (Grant and Albright, 2001; DeVries et al., 2003a), and the addition of fresh feed stimulates feeding behaviour, which may make the first meal more suitable for detecting individual differences. Giger-Reverdin et al. (2019) found that the proportion of feed consumed during the 90 or 180 min following feed distribution was the most relevant criteria for characterizing feeding behaviour. In our study, the size of the first meal reflected the daily feed intake of the individual goats. However, using the first meal to characterize the feeding behaviour of goats still necessitates some form of automatic recording to be able to quantify it at an individual level.

A previous study in individually housed goats (Giger-Reverdin et al., 2019) has shown a good repeatability of individual feeding behaviour between the end of their first gestation and the middle of their second gestation. Our study also showed a good repeatability between goats tested in mid- and late lactation. Giger-Reverdin et al. (2019) recommended phenotyping individual dairy goats during their first pregnancy to allow farmers to adapt their herd management. Another option could be to use feeding behaviour phenotyping from an early age when individuals are still fed milk from an artificial feeding device with automatic measurements. Provided that stable feeding patterns are established from an early age in a stable environment, if they reflect adult behavioural patterns, the most suitable and flexible individuals for the herd could be selected at an early age. However, in a preliminary experiment no clear relationship between the individual feeding pattern measured at pre-weaning stage and the feeding pattern measured in adult life was found (Cellier et al., 2019). Being able to measure feeding behaviour at an individual level could provide useful information for characterizing production animals, to be used as a tool in feeding management and genetic selection with potential benefits for disease prevention. Indeed, there are indications that rumination patterns differ when certain diseases are present (e.g. Marchesini et al., 2018), although this may be an indirect effect of changes in overall activity. More studies with large data sets including both individual feeding behaviour and disease recordings are needed to elucidate these associations.

It is known that feeding behaviour can be influenced by individual characteristics, in particular by physiological stage and production level (Albright, 1993, Forbes, 2007). It is however difficult to avoid confounding effects of age, body weight changes and milk yield. Nevertheless, during lactation, the demand for nutrients and energy is high, which influences feeding behaviour. In our experiment, daily feed intake was higher in lactating goats compared to non-lactating goats, although the latter were still growing. Indeed, Friggens et al. (1998a) have shown that for cows fed with a high concentrate diet the intake pattern reflected the milk yield curve, i.e. the dry matter intake increased to a peak and then declined as milk yield and energy requirements declined while for cows fed a low concentrate diet, there was no effect of stage of lactation on dry matter intake. In order to obtain different daily feed intakes, goats appear to use different strategies: compared to non-lactating goats, the goats with the highest energy demand (i.e. mid-lactation) increased both their number of daily meals and their feed intake per meals to a greater extent than goats in end-lactation . This highlights the effect of milk production on the nutritional requirements of individuals and consequently on their feeding behaviour.

As Saanen goats were heavier than Alpine goats, we expected a difference in daily feed intake between the breeds, which – all other things being equal – would have led to changes in the meal pattern. Indeed, Giger-Reverdin et al. (2019) reported that Saanen goats ate faster, for less time and with fewer feeding periods than Alpine goats. However, they also found that Saanen goats ate less dry matter daily than Alpine goats, although Saanen goats are heavier, and hypothesized that Saanen have less stable rumen conditions and poorer digestion than Alpine animals. Nevertheless, in our study, no differences in feeding behaviour were found between these two breeds.

The present study provides some of the first quantifications of feeding behaviour variables for individual dairy goats whilst group housed. It is true that the apparatus used in this study, i.e. one goat per feeding station, is difficult to apply on-farm in commercial conditions. Nevertheless, this study has emphasised individual differences in feeding behaviour which confirms the importance of taking into account the individual in the management of a herd.

The confirmation of the variability of feeding behaviour between individuals raises questions about the flexibility of the different feeding patterns when there is an unpredictable change in the environment, as can happen on-farm when feed supplies are interrupted. It has been shown that when ruminants were confronted with a feed of low palatability, the number of meals increased and the size of the meals was reduced (Baumont et al., 1990). Using the nomenclature of Giger-Reverdin et al. (2012), "nibblers" which already displayed this type of feeding pattern could be less constrained in such situations. In contrast, "big loaders" could be more affected by changes in their environment such as feed shortages or increased social competition, as they would have to adjust their feeding behaviour to a much greater extent. Further studies need to be carried out to continue to improve our knowledge on feeding behaviour of ruminants and, in particular, on the factors that can lead to variability between individuals from the same herd and the flexibility of their feeding patterns.

Our study showed that three feeding behaviour variables (daily feed intake, number of daily meals and feed intake per meal) were relatively stable within an individual but showed a high variability between individuals. However, the duration-related feeding behaviour variables (duration of meal and daily feeding time) were less useful for characterizing variability. Although stage of lactation affected the feeding behaviour of dairy goats, the feeding behaviour appeared relatively stable from one day to the next for a given individual, with a good correlation between different lactation stages. Feeding behaviour was not found to differ between breeds. It is not yet fully understood why individuals in a herd differ in terms of feeding behaviour, and why these differences are relatively stable, both in the short (day) and long term (lactation).

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Declaration of interest

The authors declare no conflicts of interest.

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