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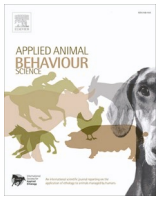

A preliminary investigation of the feeding behaviour of dairy goat kids reared away from their dams on a computerised ad libitum milk feeding system

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ABSTRACT

Most commercial dairy goat famers use ad libitum milk feeding set-ups that allow constant, unrestricted milk access to artificially rear goat kids. No detailed information on how kids use these ad libitum milk systems exists and characterising this would help target future research and improve management. The aim was to describe and characterise the individual and group milk feeding behaviour of 16 castrated male dairy breed goat kids from 22 to 56 days of age, in two pens fed from a computerised milk feeder supplying one teat per pen. Solid feed and water intakes were measured from 15 to 70 days of age and Average Daily Gain (ADG) calculated. Repeated measures mixed models produced weekly estimated marginal means of milk feeding variables. Factors influencing ADG were investigated using residual maximum likelihood analysis. Spearman's rank correlations investigated the relationship between pen-level feeding behaviour variables and age. Meal criterions were created by fitting a mixture of Gaussians to determine a threshold value. On average it took 7.8 days before kids were reliably suckling alone (range 2–15 days). Each day kids spent on average 24.3 ± 1.80 min feeding and consumed 1968 ± 99.6 ml of milk. Mean individual daily milk consumption increased with age ($p < 0.001$; 1623 ml/day week four to 2222 ml/day week 8), as did milk intake per meal ($p < 0.001$). The number of daily rewarded milk station visits averaged 8.4 ± 0.14 (range 2 – 19). Daily milk meals and time spent milk feeding was not impacted by age (p 0.666; p 0.095). ADG was not associated with age (p 0.226; weekly average 0.19 – 0.22) and was most impacted by an interaction between daily milk intake and week ($p < 0.001$). All solid feed and water intakes were positively correlated with age during the milk-feeding period ($p < 0.001$) and increased steeply when weaning occurred at the industry average of 56 days old. Each kid consumed 5.9 ± 0.28 meals per day (1.4 ± 0.9 visits to the teat per meal), which lasted 4.1 ± 0.22 min and resulted in a consumption of 342.8 ± 20.7 ml. There was little evidence of close consecutive feeding, 57% within the 'social' meal Gaussian-defined time criteria were individual feeds, only 21% consisted of two kids, 10% three and 12% four or more kids, however, 74% of milk intake occurred during meals with > 2 kids. This study showed that a computerised milk feeder can provide data on goat kid feeding which can be used as a baseline for future research.

1. Introduction

In the dairy goat industry it is widespread practice to remove kids from dams and rear them using artificial milk feeding systems (Anzuino et al., 2019; Belanger-Naud et al., 2021; Hempstead et al., 2021), whilst the length of time kids spend with their dams varies, removing immediately after birth is common practice (21.7% of farmers UK, Anzuino et al., 2019; 65% Canada, Belanger-Naud et al., 2021; 76% USA, Hempstead et al., 2021). Optimising survival and growth during this stage is essential for raising quality replacement animals to ensure future

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productivity (reviewed for cows by Palczynski et al., 2022). Feeding a fixed number of restricted quantity meals per day or allowing unrestricted access to milk through an automated feeding machine is common, and the likelihood of the latter (ad libitum milk feeding) increases with number of kids reared (Vickery et al., 2022).

Automated ad libitum systems are the most common system used in commercial dairy goat rearing (UK, Anzuino et al., 2019; Canada, Belanger-Naud et al., 2021; USA, Hempstead et al., 2021), as they represent lower labour inputs than meal-based systems that feed fixed, and limited quantities of milk at set times. In calves, higher milk intakes from ad libitum systems have been evidenced as having advantages over restricted milk feeding, including increased milk intakes (Appleby et al., 2001; Hammon et al., 2002), improved weight gains (Jasper and Weary, 2002), and allowing the expression of natural suckling behaviours (Hammell et al., 1988). In ad libitum systems for goats, milk is typically fed through teats attached via tubes to an automated milk machine (Vickery et al., 2022). However, these systems do not utilise the individualised technology increasingly common in calf systems (Rutten et al., 2013), that allows for the computerised monitoring of individual milk intake. Due to the low economic worth of individual goat kids compared to calves, and high investment required for this technology, they have not yet been adapted for use on goat farms. Therefore, no literature has reported how kids use these ad libitum milk teats and the amount of milk consumed before weaning.

Initially goat kids rely on milk, but they begin to consume solid feedstuffs within the first few weeks (Nicol and Sharafeldin, 1975). Whilst benefits of ad libitum milk systems have been described (Appleby et al., 2001; Jasper and Weary, 2002), lower solid feed intake and slower rumen development may be an issue, particularly during abrupt weaning (Jasper and Weary, 2002; Khan et al., 2007). Although there is extensive research on calf feeding behaviour, limited information is available for goat kids (last reviewed by Lu and Potchoiba, 1988). Increasing our knowledge of the development of both milk and solid feedstuff feeding behaviour under commercial artificial rearing conditions could have implications for management and welfare, particularly around understanding goat kid individuality and improving animal welfare and performance during weaning transition.

This study is the first to present an analysis of feeding behaviour of dairy goat kids reared away from their dams on an ad libitum milk feeding system, using individualised calf feeder technology to monitor individual goat kid milk feeding behaviour, alongside assessments of weight gain, video observations, and pen-level solid feed and water intake. The aims of the present study were: (1) to describe the individual milk feeding behaviour of goat kids reared with ad libitum milk access, (2) to quantify solid feed and water intakes and identify the effect of weaning on them, (3) to identify the relative importance of milk feeding variables (quantity of milk consumed, time spent feeding, number of meals) to Average Daily Gain (ADG), (4) to identify a meal criterion (by fitting a mixture of Gaussians to determine a threshold value) for individual and social milk feeding behaviour. The information presented has implications for farmers and researchers and can help to form the basis for future goat kid work during the milk-feeding stage and weaning transition.

2. Material and methods

Ethical approval was granted by the University of Reading, School of Agriculture, Policy, and Development (ref. 001561) and Dalhousie University (ref. 2021–010). The kids were kept in accordance with the DEFRA code of recommendations for goats (2013).

2.1. Animals, housing and feeding

From June to September 2021 mixed dairy crossbred (Alpine, Toggenburg and Saneen) male kids were collected in two groups (one group for each pen) from a single private farm at three to seven days of age and taken to the rearing facility (Somerset, England) comprising of standard livestock barn housing with enclosed sides. The kids (who had been grouped upon separation from their dams at the private farm) were allocated to two pens and twelve and eleven kids per pen were initially allocated. Due to an outbreak of rotavirus upon arrival, any kids showing signs of ill health or reluctance to feed were removed before the study began (within four days of arrival). As a result, Pen 1 housed eight kids (one died of pneumonia at 20 days of age leaving seven kids in pen 1), and pen 2 housed nine kids for the duration of the study.

Kids were cared for according to standard commercial practice, castrated via elastration at < 7 days of age, bedded on straw and received Heptavac P + vaccinations at three and seven weeks of age. Kids had access to ad libitum creep feed (Mole Valley Farmers prime calf rearer nuts; 87% dry matter (DM), 19% CP), barley straw (89% DM, 3% CP) and grass hay (89% DM, 6% CP) in raised feeders (hay and straw feeders L:590 mm W:430 mm H:565 mm; creep feeder L:590 mm W:590 mm H:580 mm – all mounted with the base 500 mm from the floor) from 14 days of age. Animals were fed with one milk teat per pen, connected to a Förster-Technik Vario smart milk feeder (Förster-Technik, Engen, Germany). Volac Blossom Hi-Spec milk powder (25% CP) was fed at 38 degrees Celsius at a mixing rate that gave 15% dry matter. Once per day the milk feeder components and feeding station were cleaned with a sterilising solution. Physical enrichment was provided in the form of one wooden cable spool per pen.

Kids were kept within a 2.44 m^2 pen for the first five days and assisted to feed four times/day; when a kid was recorded successfully feeding without help, training ceased for that kid. Each pen was then enlarged to 3.66 m^2 for the study duration, giving a minimum stocking density of 1.49 m^2/kid (greater area per kid than the recommended 0.9 m^2/kid for kids >8wks of age (NFCC, 2022). Data collection began when the kids were 15 days of age for solid feed and water intake, and 22 days of age for milk feeding records – this allowed sufficient time for the kids to acclimatise to the setting and the ad libitum milk feeding system, be reliably teat trained, and allow reliable RFID detection of individual kids. At 1700hrs at age 56 days full abrupt weaning (removal of all milk access) occurred (abrupt weaning was chosen to be reflective of standard UK commercial practice: Anzuino et al., 2019; Vickery et al., 2022).

2.2. Measures of health

In addition to daily visual monitoring of kids, during weekly weighing sessions a health examination occurred including ocular and nasal discharge, ear droop, induced cough, audible lung sounds, faecal soiling, and 'other' health concerns. The examination was adapted from the AWIN welfare assessment for lactating dairy goats, 2015, and the Calf Health Scorer app (University of Wisconsin), and symptoms were scored as either 'present' (score of one) or 'absent' (score of zero). If a kid scored > 3, at any one point once the study began, it would be considered 'sick,' and its data removed from analysis – however this did not occur.

2.3. Measuring milk intake and feeding behaviour

Milk intakes were recorded via specially fabricated milk feeding stations (W: 195 mm, H: 700 mm, L: 600 mm, teat set at 450 mm from floor: Supplementary material 1) made from steel and lined with hygienic parlour board. These stations allowed one kid access to the teat at a time, and built-in Radio Frequency Identification (RFID) readers recorded kids' individual ear tag identification. A kidney dialysis pump was triggered by suckling and each turn of the pump was recorded as dispensing 5 ml of milk (accurate to ± 5 ml per 500 ml). Monitoring occurred for 24hrs/day; time, duration, milk intake and kid ID were recorded for each visit; these data were continuously stored via the Förster-Technik 'CalfApp GO'.

2.4. Solid feed and water intake

Between 0830 and 1000 each day, solid feed refusals from the previous day were removed and weighed (± 1 g), fresh feed was then weighed (± 1 g), and added. Daily feed intake (kg DM/kid) was calculated as: kg DM feed offered - kg DM refusals. Water intake was measured in the same way; the water bucket was mounted to the wall to minimise spillage but if the bucket had been disturbed, data was not recorded for that day.

2.5. Weight gain measurement

Kid enrolment weights were recorded upon arrival when kids were placed inside a canvas bag which was suspended from a Weighmate® digital scale (tared to include the bag weight), then kids were weighed weekly using a Marsden V-100 veterinary scale, until ten weeks old.

2.6. Video observations

A Swann four-camera CCTV system (1080p Full HD DVR-4580 with 1TB HDD) recorded footage for six hrs/day (1000–1200; 1330–1530; 1630–1830) which was downloaded and stored in external hard drives. All focal kids could be individually differentiated and were continuously observed during the observation periods. A behavioural ethogram of target behaviours was created (Supplementary material 2) focusing on behaviours related to Feeding Competition (queueing for feed station access; unsuccessful and successful displacements from the milk feeding station), Milk Feeding (enters and exits milk feeding station), and Solid Feeding (feeding on hay, creep, or straw). All behaviour groups were analysed pre-weaning, but only solid feeding was analysed post-weaning (when milk access was removed). CCTV malfunctions resulted in missing days and corrupt footage which could not be analysed, consequently only nine days across the study could be selected; five days pre weaning (Pen 1: age 24 and 25 days, 35 and 36 days, 45 days; Pen 2: age 24 days, 35 and 36 days, 45 and 46 days) and four days post weaning (57, 58, 66 and 67 days of age for both pens).

2.7. Missing data

Milk intake was monitored twice daily and if a kid had not consumed milk by 1000hrs, or if by 2000hrs a kid was < 50% of the average milk consumption of other kids in the pen, they were encouraged to feed and the milk feeding data was removed for that kid for that day. This resulted in two one-day removals of milk feeding data for two kids. Two days of creep feed intake were unable to be recorded due to spillage. Five days of water intake were not recorded due to spillage or data sheet damage.

2.8. Statistical analysis

Data from 16 kids were analysed (seven from pen 1, and nine from pen 2 using IBM SPSS, version 25; SPSS Inc., Chicago, IL, USA. Average Daily Gain (ADG) was used to represent growth rate and calculated using weekly weights (Weight 2 – Weight 1/ days between weighing). The milk feeding period was between day 22 and day 55 (day 56 was not included as weaning occurred at 1700hrs). Model residuals were checked for normality using the Shapiro-Wilks statistic, and homogeneity of variance was assessed visually via scatter plots, some variables showed non-normality and heteroskedasticity, so analyses were repeated after applying normalising and stabilising transforms. Untransformed data are presented when results did not alter the statistical significance, in cases where the results were affected, we present the statistics for the transformed data (clearly noted in the presented results).

2.8.1. Solid feed intakes

Spearman's rank correlations were used to assess the relationship between pen-level daily feeding behaviour variables (Creep, Straw, Hay, and Water intakes) and age for the milk feeding period.

2.8.2. Evaluating milk feeding variables and average daily gain

To investigate the relative importance of factors influencing ADG, the latter was used as the response variable in univariate general linear models with kid ID (nested within pen) and week treated as fixed factors, and all other possible explanatory variables presented as daily averages per week of the study (milk duration, rewarded visits, unrewarded visits, and unrewarded duration) treated as covariates. The optimum model was developed using a stepwise elimination of the least significant explanatory variable until all predictors showed a significant effect (residual maximum likelihood analysis: Searle et al., 2009).

2.8.3. Individual meal criterion

Gaps between feeding times were defined to be the duration from the end of one visit to the start of the next. A mixture of two Gaussians was fitted to the log of the intervals between individual visits, and visits that belonged by maximum likelihood to the first Gaussian were compressed into a single individual meal as in David et al., (2014). To investigate the patterns of individual feeding, the same six metrics as in David et al., (2014) were computed, these were:

- the number of visits making up that meal,
- duration of that meal and
- total milk consumed during that meal.

These were aggregated into daily individual kid summaries capturing:

- the number of meals per day,
- the total feeding duration per day,
- total milk consumption per day.

To each of these metrics, a mixed model was fitted, with week (polynomial contrasts), pen (sum contrasts) and their interaction as fixed factors, and kid IDs and dates modelled as random factors. Random slopes for the week effect were also included within the kid random effect, as well as the random intercepts. After careful model simplification to remove singularities (following the approach of Matuschek et al., 2017), estimated marginal means per week, omnibus p-values and linear contrasts were obtained. Further, for each of the metrics, correlations per-kid were calculated, along with repeatabilities, which were calculated using mixed models according to the IntraClass Correlation Coefficient (ICC) (2,1) metric of McGraw and Wong (1996), with kid ID and date modelled as random factors. This was determined the natural measure of repeatability for the daily measures since daily conditions may impact feeding.

2.8.4. Social meal criterion

A similar approach was used to identify whether kids feed in "social meals"— visits in which several individuals choose to feed temporally close together. Time gaps between the end of a visit and start of next visit were calculated between all kids within a pen, to measure the lengths of time the feeder remained empty. A mixture of two Gaussians were fitted to the logarithms of all > 0 s time gaps, and the intersection of the Gaussian curves used to identify a time threshold below which two visits might be considered part of the same social meal. The number of kids attending each social meal and the duration of time spent and quantity of milk consumed in social meals of different sizes was calculated.

2.8.5. Video observations

The two consecutive observation days were combined and averaged (per day) to give five values per kid, per pen (three pre-weaning, two post-weaning). These five periods were analysed using a mixed model, with kid ID (with random slope and intercept included) as random

factor, and period, pen, and period*pen as fixed factors to generate estimated marginal means for all duration-based variables (feeding on straw, creep, or hay).

3. Results

3.1. Describing milk feeding behaviour

On average it took 7.75 days before kids were reliably consuming milk without human assistance, with a range from 2 to 15 days. Of the 5619 milk station visits recorded for the 16 kids across the milk feeding period 4434 (78.9%) were 'rewarded' (milk intake occurred). The remaining 1185 (21.1%), were 'unrewarded' (no milk intake took place), occurring an average of 2.29 ± 0.114 times daily (range 0–15 per kid). Across the study milk feeding was recorded in every hour of the day, with no peaks observed in any hour. The mean number of daily rewarded visits to the milk station per kid was 8.39 ± 0.139 (range 2–19) and when observed by kid, there were visible differences in the feeding behaviour of individuals (Fig. 1), with some consistently visiting the feeding station fewer times per day (for example see 'kid ID 1593, 1606, 1609 and 1613). Across the study a large range in daily milk intakes was observed (average individual intakes from 1382 to 2690 ml/ day).

3.2. Solid feed intakes

All measures of solid feed and water intake were positively correlated with age (days) for the milk feeding period (d22–55) (Fig. 2), and sudden and steep increases in intakes are visible in weeks nine and ten when kids had no milk access.

3.3. Evaluating average daily gain

ADG was most significantly impacted by an interaction between average daily milk intake and week ($p < 0.001$, Fig. 3), and was not significantly affected by week alone (p 0.226, EMMs: 0.19 week 4; 0.21 week 5, 0.22 week 6 and 7, 0.20 week 8, 0.19 weeks 9 and 10). With all possible explanatory variables included the R^2 value was 0.464, F 16.247 and p values were: Week 0.010, Milk intake < 0.001, Duration of time spent milk feeding 0.721, and Number of rewarded milk station visits 0.124). Average kid weights in week 4 (first week recording milk intake) were 8.04 ± 1.471 kg (Pen 1) and 9.43 ± 1.719 kg (Pen 2) and milk intake as percentage of liveweight averaged 2.0 ± 0.23% (Pen 1, range: 1.7–2.4%) and 1.8 ± 0.20% (Pen 2, range: 1.5–2.1%). By week 8 (the last weight before milk weaning occurred) kids weighed on average 14.29 ± 2.094 kg (Pen 1) and 14.99 ± 2.613 kg (Pen 2), milk intake as percentage of liveweight averaged 1.4 ± 0.23% (Pen 1, range: 1.0–1.7%) and 1.3 ± 0.13% (Pen 2, range 1.0–1.5%).

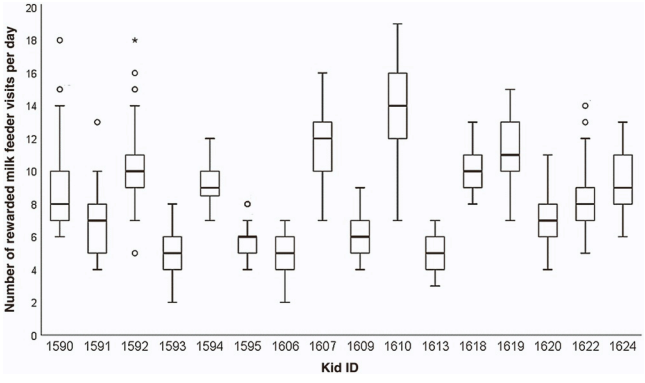

Fig. 1. Box plot of number of the daily number of rewarded feeder of each individual kid artificially reared on an ad libitum milk feeding system and weaned at 56 days of age.

3.4. Individual milk meals

The fit of the Gaussian mixture model for individual meals identified a threshold value of 1 hr 24 min to separate milk station visits into individual meals (Fig. 4). EMMs (weekly) and omnibus tests from the mixed models revealed that daily milk intake showed a significant increase over time, as did milk intake per meal, however, the meals did not grow in length, nor were there more meals per day (Table 1). Table 2 shows that individual meal metrics have lower repeatability than daily metrics (ICC (2, 1) repeatability measures: No. of feeding events/ meal 0.09, Length of meals 0.04, and Milk intake/ meal 0.17 versus No. of meals/ day 0.43, Time spent feeding/ day 0.49, and Milk intake/ day 0.63).

3.5. Social milk meals

The Gaussian mixture fitted to social meals identified a threshold value of 3 min 10 s (Fig. 5), therefore if the milk station was empty for less than that between two visits, those visits were considered part of the same "social meal". This criterion identified an average of 35 daily meals, with an average of 1.9 kids at each social meal. Following the analysis of David et al., (2014), our study found that 57% of "social meals" were attended alone; 21% had two kids in attendance, 10% had three and only 12% of meals > 4 kids in attendance. However, when considering meals as the percentage of milk intake consumed, meals with more kids in attendance result in higher milk consumptions than a solo session. The average percentage of meals each kid attended of different sizes, found that on average a kid went to 28% alone (accounting for 26% of their milk intake), whereas 74% of milk consumption occurred during meals with > 2 kids present, and 67% of time spent at the feeder was as part of social meals with > 2 kids. Supplementary materials 3 shows that most kids followed a similar pattern in the number and size of social meals attended but three show distinct individuality with unusually low probability of feeding alone.

3.6. Video observations

The milk feeding system was validated against behavioural observations; all incidences when the kid was observed entering the milk feeding station were accurately identified in < 22 s. Across the observations 22 occasions where a kid visibly entered the milk station but was not identified by the machine were recorded, these visits lasted < 34 s and are explained by kids entering the station, but not feeding or placing their heads far enough forwards for the RFID reader to register their ear tag. Attempted displacements from the milk station were observed 46 times (Pen 1: 34, Pen 2: 12) across the five pre-weaning days and successful displacements were observed 7 times (Pen 1: 5, Pen 2: 2). On average kids in Pen 1 queued for access to the milk station for 21.18 ± 5.788 s and Pen 2 for 17.63 ± 5.135 s in each six-hour preweaning observation period. The amount of time spent feeding on solid feeds significantly increased over time, with the largest increase seen between pre and post weaning periods (Table 3).

4. Discussion

Our study is the first to quantify the milk feeding behaviour of goat kids reared away from their dams on ad libitum milk. Findings show that milk intake continuously rises until weaning at 56 days of age, which as expected coincides with a sudden, substantial increase in solid feed and water consumption and time spent feeding on solid feeds. A meal criterion of 1 hr 24 min and 3 min 10 s was identified for individual and social-level meals respectively. Number of individual daily milk meals was consistent over time but varied between individuals. The most significant predictor of ADG identified was an interaction between milk

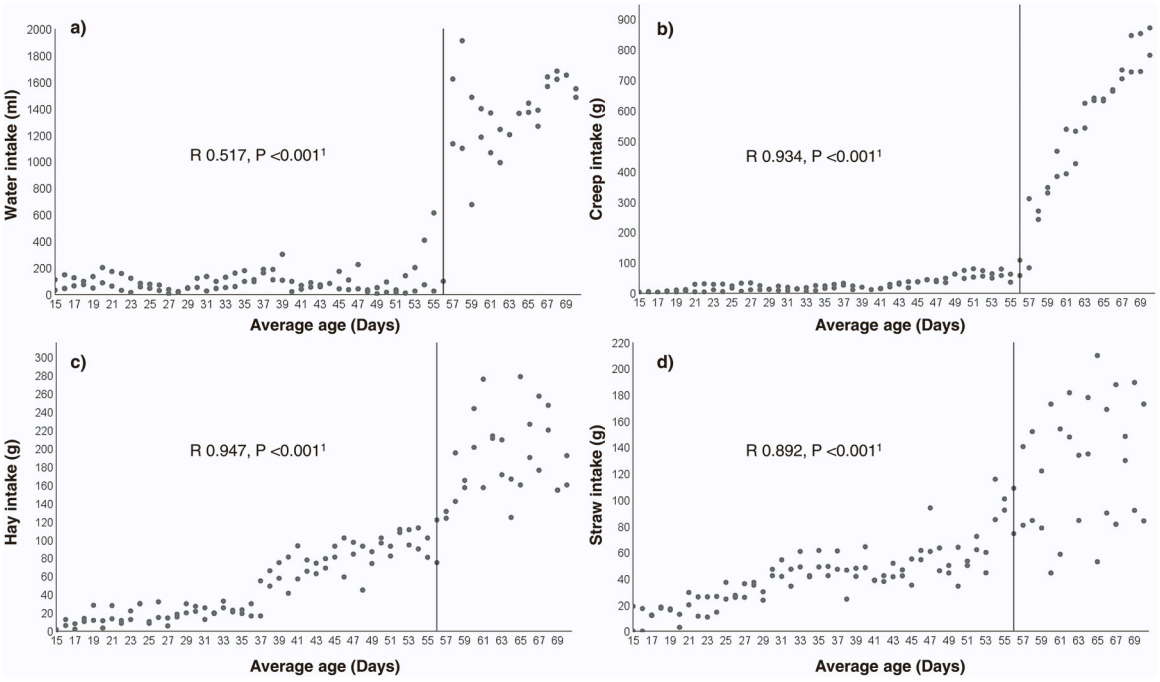

Fig. 2. Pen level daily water (a), creep (b), hay (c) and straw (d) intakes for goat kids reared on a computerised milk-feeder with free-choice ad libitum feed and weaned from milk at 56 days of age (indicated with a solid marker line).

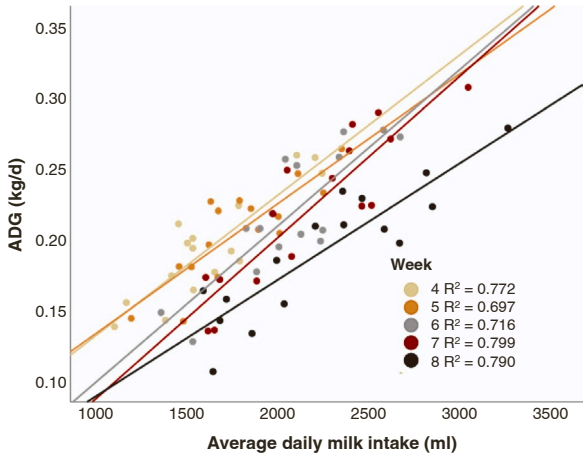

Fig. 3. Relationships between goat kids' predicted values for Average Daily Gain (ADG; kg/d) and average daily milk intake (ml) per week of age when reared on ad libitum milk, creep, straw, and hay; all weeks significant to $p < 0.001$.

intake and week, as milk intake was positively correlated with age. Variations in individual feeding behaviour that could impact productivity warrant further consideration.

Our kids varied considerably in their ability to learn to use the milk feeding system, with some feeding independently within two days of arrival and others taking up to 15 days (average: 7.75 days), this alongside two kids squeezing into the milk station together when young meant milk feeding variables were not recorded until later than originally planned. There are limited studies describing adaptation to an artificial milk feeding system in small ruminant species; however, Veissier and Stefanova, (1993) found that lambs learned to suckle from an artificial teat faster when grouped with lambs that had previously learned this behaviour (lambs with experienced partners learnt within three days, whereas those without took up to nine). Therefore, it seems likely that despite potential species differences, our kids were also impacted by their collective naivety, as it took considerable time for them to begin suckling independently.

Once kids had learnt to use the system the proportion of unrewarded visits (21.1%) was similar to the 27% reported by David et al., (2014) of artificially reared lambs. Whilst it has been suggested that unrewarded visits indicate hunger (De Paula Vieira et al., 2008), milk was available ad libitum for our study and David et al., (2014) so the cause of these visits remains unknown and was not hypothesised upon by David et al., (2014). However, the environment of the milk feeding station differed to their home pen (plastic sides, metal fixings, and wood shaving floor) and as the behavioural observations showed kids licking the sides and chewing on wood shavings within this area, we suggest in this case some unrewarded visits may reflect a desire to spend time engaged in

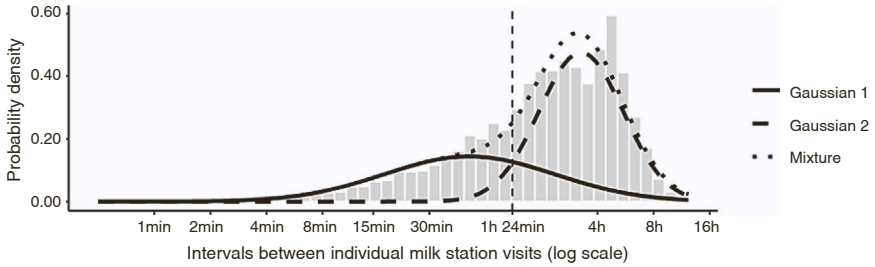

Fig. 4. Fit of a probability density function of a mixture of Gaussian distributions on the log-transformed gaps between individual goat kid milk meals.

Table 1
Estimated Marginal Means (with standard errors in parentheses) of milk-feeding variables for individual goat kid meal metrics when reared on ad libitum milk from a computerised feeder and weaned at 56 days of age.

	Weeks					*p values*[1]	
Week	*4*	*5*	*6*	*7*	*8*	*Week*	*Week*Pen*
Feeding events /meal (n)	1.4 (0.09)	1.4 (0.08)	1.5 (0.09)	1.3 (0.09)	1.4 (0.09)	0.104	0.948
Meals per day (n)	5.9 (0.28)	5.8 (0.28)	6.0 (0.28)	5.9 (0.26)	5.8 (0.25)	0.666	0.049
Length of 'meals' (min)	4.2 (0.27)	4.2 (0.19)	4.2 (0.19)	3.9 (0.19)	4.1 (0.24)	0.311	0.836
Feeding time /day (min)	24.5 (2.09)	24.5 (1.73)	25.6 (1.71)	23.0 (1.61)	24.2 (1.85)	0.095	0.232
Milk intake /meal (ml)	289 (18.6)	317 (19.8)	348 (20.0)	373 (20.4)	387 (24.6)	< 0.001	0.085
Milk intake /day (ml)	1623 (86.9)	1781 (83.8)	2056 (91.7)	2160 (110.3)	2222 (125.1)	< 0.001	0.040

1p values are stated for 'Week' and 'Week*Pen' only, as values for 'Pen' were all >0.436

Table 2
ICC (2, 1) repeatability measures on the main diagonal (bold), and inter-kid correlations on the off diagonal, of the six metrics of individual goat kid feeding behaviour.

	No. of feeding events /meal	No. of meals /day	Length of meals	Time spent feeding /day	Milk intake /meal	Milk intake /day
No. of feeding events /meal	**0.09**	0.72	0.88	0.90	-0.72	-0.21
No. of meals /day		**0.43**	0.56	0.92	-0.63	0.13
Length of meals			**0.04**	0.84	-0.54	-0.13
Time spent feeding /day				**0.49**	-0.66	0.03
Milk intake /meal					**0.17**	0.68
Milk intake /day						**0.63**

exploration-based behaviours.

The number of rewarded visits to the milk feeder remained consistent at around 8/day throughout the study; similar to the results published for artificially reared calves (around 10/d: Appleby et al., 2001; von Keyserlingk et al., 2004). This is markedly different from dam-reared lambs, (22 times in 16 h: Munro, 1956), and whilst this could be due to species-specific differences there is no research regarding goat kids dam-reared, suggesting that behavioural differences could be caused by artificial versus natural rearing. This may be due to the consistency of artificial milk supply compared to the variable nature of dam milk supply which impacts suckling behaviour (Day et al., 1987), and a lack of dam related cues that reduce milk intake, as calves age dam terminated suckling bouts increase (Reinhardt and Reinhardt, 1981).

When structured into individual meals, our goat kids fed in fewer meals than artificially reared lambs (5.9 versus 9.5: David et al., 2014). Despite using the same methodology our threshold value for the meal criterion was longer (1 hr 24 min versus 49 min: David et al., 2014), however our study had the same average number of feeding events per meal (1.4); therefore it appears this longer criterion and species difference had little impact on meal averages. No preferential milk feeding times were observed throughout the day, which agrees with evidence from artificially reared lambs (David et al., 2014) and calves (Borderas et al., 2009), and shows that for individuals to fulfil their preferred milk intake patterns, access to a milk feeding station should be provided throughout a full 24 h period.

The average number of daily individual milk meals (5.9) shows a considerable difference from how kids are reared in meal-based systems – as internationally most farms (78.3%) feed three or four meals daily, with 10% feeding two, and 89.5% further decreasing the daily number of meals after eight days (Vickery et al., 2022). Our study found differences in the number of daily milk meals each kid consumed (Fig. 1), suggesting individual variation in the coping ability of kids reared on a restricted meal-based system. Our goat kids also varied considerably in the amount of milk they consumed when available ad libitum (intake from 1.4 to 2.7 L/day), and this individuality could contribute to observed differences in growth rates (ADG from 0.12 to 0.22 kg: Fig. 3), however some of this variation could be explained by reporting milk intake as a percentage of bodyweight, which in week 4 had a slightly smaller range (1.5–2.4%). Similar variability has been reported in calves (milk intake from 2.4 to 12 L/day; ADG from 0.07 to 1.2 kg; Rushen, 2016) and lambs (milk intake from 0.3 to 2.9 L/day; David et al., 2014). Practical constraints limited our study to collecting data from only male goat kids, and this should be considered when generalising the results. There is limited information regarding how sex affects ruminant milk feeding behaviour, however David et al., (2014) found that lamb sex impacted daily number of milk meals and intake per meal (females eating smaller amounts more frequently, which agrees with pig

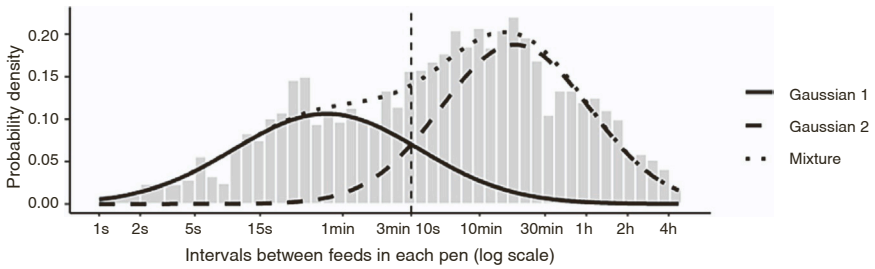

Fig. 5. Fit of a probability density function of a mixture of Gaussian distributions on the log-transformed gaps between social goat kid milk meals.

Table 3
Estimated Marginal Means (with 95% confidence intervals) of time spent feeding (minutes) per six-hour observation period of individual goat kids when reared on ad libitum feed and water and weaned at 56 days of age.

	Period							
	PreWean		*PostWean*			*p values*		
Variable	*1*	*2*	*3*	*4*	*5*	*Period*	*Period* Pen*	*Pen*
Creep[1]	2.1 (0.1, 0.2)	4.3 (0.2, 0.3)	6.2 (0.3, 0.4)	22.9 (0.6, 0.7)	31.2 (0.7, 0.8)	< 0.001	0.435	0.060
Straw	3.7 (0.8, 14.3)	5.6 (6.6, 20.1)	21.7 (10.8, 24.3)	40.3 (17.6, 31.1)	26.9 (19.4, 32.9)	< 0.001	< 0.001	0.929
Hay	7.5 (−2.1, 9.4)	13.3 (−0.1, 11.4)	17.6 (16.0, 27.5)	24.3 (34.6, 46.1)	26.2 (21.2, 32.7)	0.001	0.098	0.004

1Values for creep are presented from a square root transformation as this was required to ensure the model met assumptions and altered significance levels, estimated marginal means have been back transformed

research: de Haer and de Vries, 1993) but did not influence time spent milk feeding, overall milk intake or feed conversion efficiency. This suggests that daily number of meals fed could impact female goat kids more severely.

Each day, kids spent on average 23.0–25.6 min milk feeding, and as they aged the time spent feeding and number of daily meals did not significantly change but they did increase the quantity of milk they consumed per meal and per day. No correlation was found between daily time spent feeding and overall intake; however, findings indicate that individuals that visited the feeding station more frequently consumed less milk per meal and per day. The daily time spent feeding was lower than observed for artificially reared lambs (38.3 min: David et al., 2014), but similar to dam-reared lambs (24 min: Teke and Akdağ, 2011). David et al., (2014) reported that over time lambs increased the milk quantity consumed per meal, and per day, indicating that intake capacity and speed increase with age, which agrees with our findings for goat kids, but unlike our study the lambs reduced their time spent feeding, and number of daily meals. It should be noted that David et al., (2014)weaned lambs much younger than our study (28 days of age) and provided no access to solid feed during this time, whereas before weaning our kids spent on average 45.5 min out of six hours feeding on solid feedstuffs. The finding that individuals who visited the feeding station more frequently had lower intakes was not observed by David et al., (2014). This points to a need to further understand the individuality of goat kid feeding behaviour, additional investigation into this could help to understand why kids' responses vary and could contribute towards selection programmes aiming to identify and increase the genetics of individuals which are most able to cope with artificial rearing.

Rojo-Rubio et al., (2016) observed that dam-reared male dairy breed kids had an ADG slightly lower than observed in our study (190–220 g versus 163 g; Rojo-Rubio et al., 2016) during the milk-feeding period, suggesting that weight gains of artificially reared kids are comparable to those reared naturally. Rojo-Rubio et al., (2016) observed that neither litter size or breed (Anglo Nubian, Alpine or Saneen) had an impact on weight gain, therefore using crossbred kids in our study is unlikely to have impacted ADG. Our results may not be directly applicable to females due to their lower ADG (Davis et al., 1998; Rojo-Rubio et al., 2016) and milk intakes (Davis et al., 1998), however, this sex difference is not clear-cut as early castrated male kids (our kids were castrated in order to be rehoused) have lower ADG than intact males (Louca et al., 1977; Murray et al., 2001) and sex does not significantly impact weight in both dam and artificially reared kids studied up until 28 days old (Delgado-Pertíñez et al., 2009). It would be useful for future research to study female kids to investigate feeding behaviour differences and future productivity, as dairy calf research shows that early growth rates impact conception and milk yields (reviewed by Khan et al., 2011). Understanding how to achieve optimal growth rates is essential to rearing healthy and productive animals, which has wider environmental impacts (faster growing animals capable of conceiving younger have a lower overall carbon footprint: Bell et al., 2015).

Regarding social meals, our threshold value was lower than David et al., (2014) (3 min 10 s versus 22 min 30 s) as our criterion used the amount of time the feeder spent empty, from the end of one visit to the start of the next, whereas David et al., (2014) calculated start to start time intervals. This could explain why we saw less evidence of 'social' meals compared to David et al., (2014) who observed that 65% of lambs wanted to access milk during the same meal, however their study had a slightly higher number of individuals per teat (8–15 versus 7–9 in our study) and provided no solid feed, which could have increased milk competition. No other research is available on social meal criterions of milk-feeding for comparison. Interestingly whilst only 42% of 'social' meals had > 2 kids in attendance, 74% of milk was consumed during these meals, showing that kids drank more when attending a social meal versus feeding alone which suggests that feeding competition does not detrimentally impact milk intake for the kid to teat ratio used in our study. This is supported by the small number of observed displacements from the milk station, and minimal amounts of time spent queueing for milk access (average: 19.63 s/six-hour observation), evidencing that the generous stocking density allowed for our kids likely minimised feeding competition.

Our goat kids reared on ad libitum milk had low solid feed intakes at weaning which likely impacted their rumen development and ability to compensate for the loss of milk nutrients at weaning; however, a noticeable growth check was not observed, and we were unable to directly measure rumen development. Most artificially reared kids are weaned at 56 days of age (UK, Anzuino et al., 2019; Canada, Belanger-Naud et al., 2021) so this study weaned at the same age, to ensure comparability to commercial conditions. Early weaning is common in artificial systems due to the high cost of milk replacement and the labour-intensive nature of the milk-feeding period. Young ruminants who are slow to transition to solid feeds show impaired growth (lambs: David et al., 2014; goat kids: Warmington and Kirton, 1990), as solid feed intakes are positively correlated with rumen development (goat kids: Hamada et al., 1976). Hart and Delaney (2016) suggest a kid must have concentrate feed intakes of > 250 g day at weaning; a widely used industry guideline for lambs that is commonly transferred to goat kids (Lamlac, 2019). Yet at the industry standard weaning age, our kids were only spending 6.2 min within six hours at the creep feeder and consuming 64 g/d of creep feed, which rapidly increased by > 600% to 392 g/d when milk access was removed. Social learning plays a significant role in the development of ruminant feeding behaviour (Launchbaugh and Howery, 2005); for example naïve calves show increased grazing when with an older, experienced companion (Hessle, 2009). Research shows that feed intakes are affected by individual behaviour (von Keyserlingk and Weary, 2010), that develops early in life (Provenza and Balph, 1987), and rearing goat kids in groups of naïve individuals is likely to impact solid feed intake.

5. Conclusions

Kids showed marked differences in their milk feeding behaviour and understanding this individuality would be beneficial and could inform further research that aims to provide management information regarding reducing weight gain variability, improving productivity and individual kid welfare. There was little evidence of close, consecutive feeding however, kids consumed more milk in 'social' meals, and combined with behavioural evidence this suggests that milk-feeding competition was not problematic with 7–9 kids per milk teat. Solid feed intakes and time spent solid-feeding pre-weaning were concerningly low and could have been impacted by a lack of experienced social models, yet goat kids reared on ad libitum milk achieved weight gains comparable to those reported in kids reared with their dams. Whilst this study should be interpreted with caution since it was small-scale and used only male mixed dairy breed kids, it utilises formerly unused technology to provide previously unknown information that has established an important baseline for future work in this understudied species.

Ethics approval

Ethical approval was granted by the University of Reading, School of Agriculture, Policy, and Development (reference number 001561) and Dalhousie University (reference number 2021–010).

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CRediT authorship contribution statement

Holly Vickery: Conceptualization, Funding acquisition, Methodology, Investigation, Writing – original draft preparation, Formal analysis. **Rebecca Meagher**: Methodology, Supervision, Writing – review & editing. **Sokratis Stergiadis**: Methodology, Supervision, Writing – review & editing. **Rachael Neal**: Methodology, Funding acquisition, Supervision, Writing – review & editing.

Conflict of Interest statement

The authors declare that there is no conflict of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2023.105898.

References

Anzuino, K., Knowles, T.G., Lee, M.R.F., Grogono-Thomas, R., 2019. Survey of husbandry and health on UK commercial dairy goat farms. Vet. Rec. vetrec. https://doi.org/10.1136/vr.105274 vetrec–2018–105274.

Appleby, M.C., Weary, D.M., Chua, B., 2001. Performance and feeding behaviour of calves on ad libitum milk from artificial teats. Appl. Anim. Behav. Sci. 74, 191–201. https://doi.org/10.1016/S0168-1591(01)00171-X.

Belanger-Naud, S., Cinq-Mars, D., Julien, C., Arsenault, J., Buczinski, S., Levesque, J., Vasseur, E., 2021. A survey of dairy goat kid-rearing practices on Canadian farms and their associations with self-reported farm performance. J. Dairy Sci. 104, 9999–10009. https://doi.org/10.3168/jds.2020-18663.

Bell, M.J., Garnsworthy, P.C., Stott, A.W., Pryce, J.E., 2015. Effects of changing cow production and fitness traits on profit and greenhouse gas emissions of UK dairy systems. J. Agric. Sci. 153, 138–151. https://doi.org/10.1017/S0021859614000847.

Borderas, T.F., de Passillé, A.M.B., Rushen, J., 2009. Feeding behavior of calves fed small or large amounts of milk. J. Dairy Sci. 92, 2843–2852. https://doi.org/10.3168/jds.2008-1886.

David, I., Bouvier, F., Ricard, E., Ruesche, J., Weisbecker, J.-L., 2014. Feeding behaviour of artificially reared Romane lambs. Animal 8, 982–990. https://doi.org/10.1017/S1751731114000603.

Davis, J.J., Sahlu, T., Puchala, R., Tesfai, K., 1998. Performance of Angora goat kids fed acidified milk replacer at two levels of intake. Small Rumin. Res. 28, 249–255. https://doi.org/10.1016/S0921-4488(97)00093-X.

Day, M., Imakawa, K., Clutter, A., Wolfe, P., Zalesky, D., Nielsen, M., Kinder, J., 1987. Suckling Behavior of Calves with Dams Varying in Milk-Production. J. Anim. Sci. 65, 1207–1212. https://doi.org/10.2527/jas1987.6551207x.

De Paula Vieira, A., Guesdon, V., Marie de Passille, A., von Keyserlingk, M., Martin Weary, D., 2008. Behavioural indicators of hunger in dairy calves. Appl. Anim. Behav. Sci. 109, 180–189. https://doi.org/10.1016/j.applanim.2007.03.006.

Delgado-Pertíñez, M., Guzmán-Guerrero, J.L., Mena, Y., Castel, J.M., González-Redondo, P., Caravaca, F.P., 2009. Influence of kid rearing systems on milk yield, kid growth and cost of Florida dairy goats. Small Rumin. Res. 81, 105–111. https://doi.org/10.1016/j.smallrumres.2008.12.007.

de Haer, L.C.M., de Vries, A.G., 1993. Feed intake patterns of and feed digestibility in growing pigs housed individually or in groups. Livestock Production Science 33, 277–292. https://doi.org/10.1016/0301-6226(93)90008-6.

Hamada, T., Maeda, S., Kameoka, K., 1976. Factors influencing growth of rumen, liver, and other organs in kids weaned from milk replacers to solid foods. J. Dairy Sci. 59, 1110–1118. https://doi.org/10.3168/jds.S0022-0302(76)84330-5.

Hammell, K.L., Metz, J.H.M., Mekking, P., 1988. Sucking behaviour of dairy calves fed milk ad libitum by bucket or teat. Appl. Anim. Behav. Sci. 20, 275–285. https://doi.org/10.1016/0168-1591(88)90052-4.

Hammon, H.M., Schiessler, G., Nussbaum, A., Blum, J.W., 2002. Feed intake patterns, growth performance, and metabolic and endocrine traits in calves fed unlimited amounts of colostrum and milk by automate, starting in the neonatal period. J. Dairy Sci. 85, 3352–3362. https://doi.org/10.3168/jds.S0022-0302(02)74423-8.

Hart, S., Delaney, C., 2016. Husbandry of dairy animals – goat: replacement management, 00822–00822 Ref. Modul. Food Sci. B978–0-08–100596-5. https://doi.org/10.1016/B978-0-08-100596-5.00822-2.

Hempstead, M.N., Lindquist, T.M., Shearer, J.K., Shearer, L.C., Plummer, P.J., 2021. Health and welfare survey of 30 dairy goat farms in the Midwestern United States. Animals 11, 2007. https://doi.org/10.3390/ani11072007.

Hessle, A.K., 2009. Effects of social learning on foraging behaviour and live weight gain in first-season grazing calves. Applied Animal Behaviour Science 116, 150–155. https://doi.org/10.1016/j.applanim.2008.08.004.

Jasper, J., Weary, D.M., 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85, 3054–3058. https://doi.org/10.3168/jds.S0022-0302(02)74391-9.

von Keyserlingk, M., Weary, D., 2010. Review: Feeding behaviour of dairy cattle: Measures and applications. Canadian Journal of Animal Science 90, 303–309. https://doi.org/10.4141/CJAS09127.

von Keyserlingk, M.A.G., Brusius, L., Weary, D.M., 2004. Competition for teats and feeding behavior by group-housed dairy calves. J. Dairy Sci. 87, 4190–4194. https://doi.org/10.3168/jds.S0022-0302(04)73563-8.

Khan, M.A., Weary, D.M., von Keyserlingk, M.A.G., 2011. Hay intake improves performance and rumen development of calves fed higher quantities of milk. J. Dairy Sci. 94, 3547–3553. https://doi.org/10.3168/jds.2010-3871.

Khan, M.A., Lee, H.J., Lee, W.S., Kim, H.S., Ki, K.S., Hur, T.Y., Suh, G.H., Kang, S.J., Choi, Y.J., 2007. Structural Growth, Rumen Development, and Metabolic and Immune Responses of Holstein Male Calves Fed Milk Through Step-Down and Conventional Methods. J. Dairy Sci. 90, 3376–3387. https://doi.org/10.3168/jds.2007-0104.

2019 Lamlac., 2019. URL ⟨https://www.lamlac.co.uk/latest/view,weaning-lambs_22.htm⟩ (accessed 5.4.22).

Launchbaugh, K., Howery, L., 2005. Understanding landscape use patterns of livestock as a consequence of foraging behavior. Rangel. Ecol. Manag. - Rangel. Ecol. Manag. 58, 99–108. https://doi.org/10.2111/03-146.1.

Louca, A., Economides, S., Hancock, J., 1977. Effects of castration on growth rate, feed conversion efficiency and carcass quality in Damascus goats. Anim. Sci. 24, 387–391. https://doi.org/10.1017/S0003356100011892.

Lu, C.D., Potchoiba, M.J., 1988. Milk feeding and weaning of goat kids — A review. Small Rumin. Res. 1, 105–112. https://doi.org/10.1016/0921-4488(88)90025-9.

Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., Bates, D., 2017. Balancing Type I error and power in linear mixed models. Journal of Memory and Language 94, 305–315. https://doi.org/10.1016/j.jml.2017.01.001.

McGraw, K.O., Wong, S.P., 1996. Forming inferences about some intraclass correlation coefficients. Psychol. Methods 1, 30–46. https://doi.org/10.1037/1082-989X.1.1.30.

Munro, J., 1956. Observations on the suckling behaviour of young lambs. The British Journal of Animal Behaviour 4, 34–36. https://doi.org/10.1016/S0950-5601(56)80014-2.

Murray, P., Sumarmono, J., Pratiwi, N., Taylor, D., 2001, Growth of goats for meat production: effect of breed and castration. Asia Pacific Journal of Clinical Nutrition.

NFCC, 2022, Goats - Codes of Practice for the care and handling of Goats [WWW Document], n.d. URL ⟨https://www.nfacc.ca/codes-of-practice/goats⟩ (accessed 2.6.23).

Nicol, A.M., Sharafeldin, M.A., 1975, Observations on the behaviour of single-suckled calves from birth to 120 days. Proc N Z Soc Anim Prod.

Palczynski, L.J., Bleach, E.C.L., Brennan, M.L., Robinson, P.A., 2022. Youngstock Management as "The Key for Everything"? Perceived Value of Calves and the Role of Calf Performance Monitoring and Advice on Dairy Farms. Frontiers in Animal Science 3.

Provenza, F.D., Balph, D.F., 1987. Diet learning by domestic ruminants: Theory, evidence and practical implications. Appl. Anim. Behav. Sci. 18, 211–232. https://doi.org/10.1016/0168-1591(87)90218-8.

Reinhardt, V., Reinhardt, A., 1981. Natural sucking performance and age of weaning in zebu cattle (Bos indicus). The Journal of Agricultural Science 96, 309–312. https://doi.org/10.1017/S0021859600066089.

Rojo-Rubio, R., Kholif, A.E., Salem, A.Z.M., Mendoza, G.D., Elghandour, M.M.M.Y., Vazquez-Armijo, J.F., Lee-Rangel, H., 2016. Lactation curves and body weight changes of Alpine, Saanen and Anglo-Nubian goats as well as pre-weaning growth of their kids. Journal of Applied Animal Research 44, 331–337. https://doi.org/10.1080/09712119.2015.1031790.

Rushen, J., 2016. Using automated feeders to wean calves fed large amounts of milk according to their ability to eat solid feed. Journal of Dairy Science 99. https://doi.org/10.3168/jds.2015-10259.

Rutten, C.J., Velthuis, A.G.J., Steeneveld, W., Hogeveen, H., 2013. Invited review: Sensors to support health management on dairy farms. J. Dairy Sci. 96, 1928–1952. https://doi.org/10.3168/jds.2012-6107.

Searle, S.R., Casella, G., McCulloch, C.E., 2009, Variance Components. John Wiley & Sons.

Teke, B., Akdağ, F., 2011, The effect of age, lactation number, sex and birth type on suckling and nursing behaviour of Karayaka lambs. undefined.

Veissier, I., Stefanova, I., 1993. Learning to suckle from an artificial teat within groups of lambs: Influence of a knowledgeable partner. Behavioural Processes 30, 75–82. https://doi.org/10.1016/0376-6357(93)90013-H.

Vickery, H.M., Neal, R.A., Meagher, R.K., 2022. Rearing goat kids away from their dams 1. A survey to understand rearing methods. Animal 16, 100547. https://doi.org/10.1016/j.animal.2022.100547.

Warmington, B.G., Kirton, A.H., 1990. Genetic and non-genetic influences on growth and carcass traits of goats. Small Rumin. Res. 3, 147–165. https://doi.org/10.1016/0921-4488(90)90089-O.