The effects of manual and automated milk feeding methods on group-housed calf health, behaviour, growth and labour

Livestock Science

Sinnott, Alison M.; Kennedy, Emer; Bokkers, Eddie A.M.

https://doi.org/10.1016/j.livsci.2020.104343

Livestock Science xxx (xxxx) xxx

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

The effects of manual and automated milk feeding methods on group-housed calf health, behaviour, growth and labour

Alison M. Sinnott [a], Emer Kennedy, Conceptualisation [a,*], Eddie.A.M. Bokkers [b]

[a] Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland
[b] Animal Production Systems group, Wageningen University & Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands

HIGHLIGHTS

- Automatic calf feeding systems are 39% more labour efficient than manual systems
- 98% of calves were classified as healthy with no difference between feeding systems
- Calves expressed normal behavioural patterns regardless of feeding system
- The plane of nutrition offered was the same between treatments so there was no difference in weight gain

ARTICLE INFO

Keywords:
Calf
Feeding Systems
Labour
Automation
Health
Welfare

ABSTRACT

It has been suggested that the integration of automatic feeding systems into calf rearing programmes has the potential to improve calf behaviour, growth and the associated labour. Thus, the objective of this study was to compare the effects of automatic and manual feeding systems on calf health, behaviour, growth and labour. A population of 60 dairy heifer calves was used: 44 Holstein-Friesian (HF) and 16 HF x Jersey (JE), balanced for birth weight (33 ± 4.1 kg), birth date (26 January ± 3.2 days) and breed. The experiment was a randomised block design including two treatments; i) automated calf feeding system (AFS) and ii) manual calf feeding system (MFS). Each treatment was replicated once, so a total of four balanced groups of 15 heifer calves were created. Milk replacer was offered at a rate of 6 L per calf/day (reconstitution rate 15%), with fresh water, *ad-libitum* concentrates and hay offered from three days old. Calves were weaned based on weight (90 kg for HF and 85 kg for HF x JE). Total labour input/day was consistently less for AFS compared to MFS (-00:01:06 per calf/day). Automatic feeding systems had a higher labour requirement for health inspections and training to the system (+00:00:15 per calf/day and +00:02:06 per calf/day, respectively), on a per calf basis, compared to MFS. The MFS-calves had an increased likelihood of experiencing faecal scores > 0 (Odds Ratio (OR) = 2.009; Confidence Interval (CI) = 1.463 – 2.759). The MFS-calves were also more likely to defecate and urinate (OR= 1.450; CI = 1.080-1.945), eat (OR= 1.281; CI = 1.140 – 1.439) and socially interact (OR= 1.300; CI = 1.111 – 1.521), compared to standing. There was no difference in number of days from birth to weaning (80.8 days) and weight at weaning (92.9 kg); average daily gain in both the pre (81 days) and post weaning (79 days) periods was similar between the two treatments (0.74 and 0.70 kg/day, respectively). Patterns for behaviours such as lying and playing were similar and low levels of abnormal behaviours were found in both treatments. Calves in both treatments exhibited good health and normal behavioural patterns as well as similar growth rates. Thus, when managed appropriately, the saving of labour is a distinct advantage automated feeding systems have over their manual counterparts when rearing group-housed calves.

Introduction

In response to global demand, milk production quotas were abolished across Europe in April 2015, which resulted in a sharp increase in expansion of dairy herds throughout many EU countries. In Ireland alone, dairy cow numbers have increased by almost 20% since

* Corresponding author
E-mail address: emer.kennedy@teagasc.ie (E. Kennedy).

https://doi.org/10.1016/j.livsci.2020.104343
Received 20 July 2020; Received in revised form 10 November 2020; Accepted 11 November 2020
Available online 12 November 2020

Please cite this article as: Alison M. Sinnott, *Livestock Science*, https://doi.org/10.1016/j.livsci.2020.104343

2015 (ICBF, 2019). However, post-quota expansion is threatening the social sustainability of dairy farming in Ireland, due to the increased labour demand associated with a large increase in herd size. Adapting farming practices to facilitate social sustainability is an important step in ensuring that farming is seen as an attractive career in terms of work life balance (Kelly et al, 2017).

Calf rearing is labour intensive, particularly on seasonal calving dairy farms (Gleeson et al, 2008), such as those that predominate in Ireland and New Zealand. Within these systems, the majority of cows calve within a 12-week period, which in conjunction with increasing herd sizes, places amplified pressure on an already labour intensive period (Deming et al, 2018). A recent study on 38 labour efficient Irish dairy farms, pre-determined by previous interaction with the farmers, has shown that labour inputs for calf rearing can vary greatly among farms (from 0.48 h/cow/yr to 2.85 h/cow/yr (average 1.4 h/cow/yr)) (Deming et al., 2018). In addition, sourcing labour has been identified as one of the most limiting factors affecting expansion of the Irish dairy sector (Kelly et al, 2017). Consequently, alternatives such as automation of various tasks e.g. calf feeding, need to be considered as their increased use is perceived as an efficiency investment for farmers (Medrano-Galarza et al, 2017). Traditionally, Irish dairy farms manually feed group-housed calves through multi-teat feeders (Barry et al, 2019). However, as the dynamic of the Irish dairy industry changes, it is possible that the introduction of automatic calf feeders may become more common. Before adopting automated feeding technology, the needs of the calf must be considered to ensure that calf health, behaviour, growth and over-arching welfare are not affected in a negative way.

Automatic feeders offer a number of advantages in a calf rearing system. It can be a useful tool to detect illness in calves (Johnston et al, 2016) and track animal growth performance (Moran, 2012). A healthy calf is imperative for any successful cattle production system, with subsequent performance in later life impacted by its health status as a calf (Lorenz et al., 2011). Effective management practices are of paramount importance to minimise and control health complications to safeguard the welfare of calves (Sumner & von Keyserlingk, 2018). Furthermore, it affords calves an opportunity to express behaviour that mimics natural suckling behaviour most closely (Medrano-Galarza et al, 2017), satisfying behavioural needs. However, the successful inclusion of an automatic feeder in a calf rearing system is often influenced by management practices used on the farm, rather than the feeder itself. Studies have shown that group-size (Maatje, 1993; Svensson et al, 2003; Svensson and Liberg, 2006), age of introduction to the feeder (Jensen, 2007), quality of milk fed to calves and separation of older and younger stock (Medrano-Galarza et al. 2018) dictates a calf's health status rather than the feeding system that is implemented.

Automatic feeders may also offer additional benefits for calf growth. Research has shown that the speed by which milk moves through the digestive tract is stimulated by the frequency of consumption, whereby emptying occurs quicker in the abomasum allowing for entrance of new matter (Mylrea, 1966). Although large volumes of milk have been fed to calves with reasonable efficacy (e.g. once-a-day feeding (Saldana et al. 2019)), it is also suggested that the greater the volume of milk offered at each feeding, the longer milk will remain in the abomasum (Bergstaller et al, 2017) and prolonged abomasal emptying may increase rates of digestive disorders (Songer and Miskimins, 2005). For this reason, provided a feeder is programmed to do so, it is possible that automatic feeding systems may utilise milk more efficiently due to the smaller portions being consumed more often, stimulating the movement of milk through the digestive system more quickly, perhaps resulting in a higher ADG (average daily gain).

To date, studies regarding labour efficiency in calf rearing have relied on commercial farmers to record (Deming et al, 2018) or recall information (O'Donovan et al., 2008; Cummins et al, 2016). They have also been either based off estimates (Bostad et al, 2010), or snapshot data collection (Gleeson et al, 2008). Furthermore, the majority of these studies have examined the dairy enterprise as a whole instead of focusing solely on examining the labour associated with calf rearing (Gleeson et al, 2008, Bostad et al, 2010). Although it has been suggested that the costs associated with automatic feeders can be mitigated within two to three years through savings in labour, detail pertaining to this finding is limited (Kung Jr et al, 1997). Previous studies have singularly evaluated the impact of calf feeding systems on health (Maatje, 1993; Svennson et al, 2003; Svennson and Liberg, 2006), welfare (Sutherland et al, 2018) and growth (Kung Jr. et al, 1997; Fujiwara et al, 2014). However, a controlled study which collectively examines how group-housed calf health, behaviour, growth and labour are influenced by feeding system has not been carried out.

To establish modern sustainable farming practices, it is essential to take a balanced approach and ensure that progress is not made at the expense of either the animal or human. Thus, the objective of this study was to compare the effects of automatic and manual feeding systems on calf health, behaviour, growth and labour. We hypothesised that feeding calves using automatic feeders would be more labour efficient and provide greater average daily gains than manually feeding calves.

Materials and Methods

The study was conducted from January 24 to June 27, 2019 at Teagasc Moorepark Research Farm, County Cork, Ireland. The study population consisted of 60 dairy heifer calves: 44 Holstein Friesian (HF) and 16 HF x Jersey (JE) (HF x JE). Calves were balanced for birth weight (33 ± 4.1 kg), birth date (26 January ± 3.2 days) and breed. Ethical approval to undertake the study was approved by the Teagasc Animal Ethics Committee (TAEC201-2018). Experiments were undertaken in accordance with the European Union (Protection of Animals Used for Scientific Purposes) Regulations 2012 (S.I. No. 543 of 2012).

2.1. Pre-experimental Management

All births were supervised. Following birth, calves were immediately removed from the cow, as a biosecurity procedure. Calves were weighed (TruTest XR 3000, TruTest limited, Auckland, New Zealand), placed in an individual pen and fed 8.5% of birth bodyweight (BW) of colostrum from a single cow (not specifically their own dam) via bottle and teat. A stomach tube was used if calves refused to consume the colostrum feed using a bottle and teat. Calves were fed colostrum with a quality of ≥22% Brix (>50 g/L IgG), determined using a Brix refractometer (Milwaukee Instruments MA871 Digital Brix Refractometer), which should sufficiently accommodate passive transfer (Bielmann et al, 2010). Following colostrum feeding, calves were offered five feeds of transition milk, which was pooled from the second milking post calving of recently calved cows. Calves were fed two 3 L feeds of transition milk per day using an individual bucket and teat. From approximately three days of age, calves were moved to a group pen, offered milk replacer and fed according to their respective experimental treatment group.

2.2. Experimental Treatments and Calf Management

The experiment was a randomised block design which included two treatments; i) automated calf feeding system (AFS) and ii) manual calf feeding system (MFS). Each treatment was replicated once. A total of four balanced groups of 15 heifer calves were created. Each group was assigned to one of two treatments. There was no more than a six day difference in date of birth between calves within each group. At approximately three days of age, calves were assigned to their respective treatment.

Two different locations/houses were used – each location contained both treatments. Treatment groups were located adjacent to one another within each house. No physical contact was possible between the treatment groups, but auditory and olfactory cues could be exchanged.

Each calf was offered 26% crude protein (19.7 ME MJ/kg DM) milk replacer (Volac Heiferlac Instant, Volac, Hertfordshire, United Kingdom) at a rate of 6 L/calf/day. Milk replacer was reconstituted at a rate of 150 g/L. Concentrates (20% crude protein; ingredients: barley, soya meal, sugar beet pulp, distillers grains, rape seed meal, and maize; (Sweet Start Calf Starter Pencils, Southern Milling, Cork, Ireland)), water and hay were offered to all calves for *ad-libitum* consumption from three days old. Water was provided using automatic filling drinking bowls and hay was offered in a rack.

Group pens were 35.3 m^2 (2.4 m^2/calf) and contained a concrete feeding area and a lay back area bedded with straw (1.8 m^2/calf). The feeding area of each pen was cleaned in the morning (9:30-10:00) and evening (16:30-17:00) using water and detergent. The lay back area was cleaned, disinfected and re-bedded with fresh straw, to a depth of 15 cm, twice weekly (Monday and Thursday).

2.3. Automatic Calf Feeding System

Each AFS group pen was equipped with an automatic milk and concentrate feeder (Volac Förster Technik Vario, Germany). The automatic milk feeder was computerised, receiving information regarding milk feeding from the RFID in a calf's ear tag. The feeder then mixed milk replacer automatically and distributed it, according to the individual's threshold allowance. A common feeding programme was devised for the AFS calves. Upon entering the treatment pen, milk allocation was increased from 5 to 6 L, remaining at this level until weaning. Each calf was allocated four feeds of 1.5 L spaced evenly throughout the day (24 hr); access to the feeder was granted until the 1.5 L threshold was reached, after this time calves had to wait for four hours until access was allowed for the next 1.5 L to be consumed. Milk was prepared by the machine in units of 750 ml at a temperature of 37°C. The teat for the automatic feeder was located 68 cm from ground level for each pen, respectively.

Calves assigned to AFS were taught how to use the automatic feeder over a 24-hour period and this was repeated thereafter if necessary. Calves were initially guided to the teat by hand, with the process repeated if the calf broke away from the teat. Training was considered successful after two consecutive days of unassisted feeds were consumed from the feeder. A calf was not required to consume its full allocation in one visit, however, a calf needed to demonstrate its ability to revisit the feeding station voluntarily without human assistance. All calves were monitored twice-a-day after this time to ensure that further training was not required.

The automatic concentrate feeder granted *ad-libitum* access to concentrate for each calf. A fixed quantity of concentrate was manually placed in the feed dispenser. Records were taken of the date, number of calves per pen and the quantity of concentrate, to determine an estimate for concentrate dry matter intake (CDMI). The RFID tag in the feeding station is registered by a computer and stimulates an auger in the dispenser, which automatically distributes small 200g quantities of concentrate into the feeding bowl. Small quantities minimises wastage and increases the accuracy of distribution. Once all concentrate was consumed, the distribution of concentrate into the feeding bowl was repeated again. Calves were not trained to the concentrate feeder.

2.4. Manual Calf Feeding System

The MFS consisted of three plastic compartmentalised five-teat feeders (Wydale, Somerset, England) per group. These feeders were equipped with side partitions between calves and chin protection to minimise the occurrence of bullying. Feeders were not shared between groups. A common feed plan was devised for MFS calves. The milk allocation for manually fed calves was increased from 5 L to 6 L, upon entry into the treatment pen, remaining at this level until weaning. Calves on the MFS were given two feeds of 3 L per day (08:00 and 16:00). When feeding the MFS-calves, the correct volume of warm water (35-38°C) was measured before adding the powder. A whisk was used to mix the milk replacer and water to ensure a homogenous consistency. Milk was fed to calves no more than five minutes after mixing. As each calf moved from their individual pen to the group MFS treatment pen, it was trained to drink from the manual unit. This involved guiding calves to an available teat by hand during milk feeding, with the process repeated if the calf broke away from the teat. The teats were located at 65 cm from ground level for replicate one and two.

Concentrates were offered on an *ad-libitum* basis from three days old with one open meal bar concentrate feeder (Birdproof Meal Bar, Milk Bar, McInnes Manufacturing, New Zealand) per group, which allowed up to four calves to feed at any one time. Concentrate consumption was also monitored (as outlined for the AFS above) to determine an estimate of CDMI.

2.5. Weaning

Calves were weaned based on weight; the HF calves were weaned once they attained a minimum of 90 kg and the HF x JE calves were weaned once they reached a minimum weight of 85 kg. When a calf on the AFS achieved the minimum target weaning weight, the feeding plan on the computer system was changed. Milk allocation was adjusted to reduce gradually over a period of four days from 6 L to 0 L. This reduced the milk allowance by 1.5 L per day for the calf over the course of the weaning period. Once a calf was fully weaned off milk for one day i.e. 0 L consumed for 24 h, it was moved from the treatment pen (AFS) to a larger group pen. This indoor pen was 79 m^2 and bedded with straw.

When a calf on the MFS achieved the minimum target weaning weight, the calf was removed from the treatment group and placed in a separate group pen with calves at the same stage of weaning. A calf's milk allocation was reduced by 1.5 L per day, from 6 L to 0 L, over the course of four days, similar to AFS.

2.6. Measurements

Labour evaluations were completed for three non-consecutive days per week, until all calves were weaned (final calf weaned 14 weeks after introduction to treatment based on weight). Individual tasks associated with calf rearing were assessed including: training calves to drink from teat feeder or AMS, feed preparation, feeding/ feed inspection ensuring all calves drank milk allocation, cleaning feeding equipment, cleaning pen (wash down in the morning and evening), bedding, and health observations. Each measurement was repeated in the morning and evening and timed using a stopwatch (SW; time is expressed as hh:mm:ss)). The farm tasks related to calf care and start/stop cues for the SW are defined in Table 1. The sum (total hh:mm:ss) of each labour task quantified per day was then divided by the number of calves in the pen on that day.

Individual animal health scores were assigned to calves on a twice-weekly basis. This was carried out independently of routine daily health inspections, which were completed as part of the labour evaluation. For this reason, the labour associated with health scoring twice-weekly was not recorded. The calf health scoring criteria was developed using a modified scoring system (Supplementary File 1) developed from the Calf Welfare Assessment Protocol published by Barry et al. (2019). Health factors used from the protocol included the following: overall demeanour, nasal discharge, ocular discharge, ear position, attitude, coughing, faecal hygiene, dehydration, and mobility. An additional factor was included to account for hind quarter cleanliness from faecal matter. Calves were assigned a score on the aforementioned traits from zero to three; zero representing normal and three representing the most severely affected. This meant that numerous health scores were recorded for each health factor related to a calf throughout the study period.

Behavioural observations were undertaken weekly during the pre-weaning period. Prior to data collection, specific behavioural patterns were defined, referring to the calf ethogram reported by Barry et al. (2019). Individual calf behavioural measurements were taken by a

Table 1
Catalogue of definitions and cues used during labour evaluations to differentiate between tasks involved with automated calf feeding system (AFS) and manual calf feeding system (MFS).

Task	Definition of action	MFS Stopwatch (SW) Cues	AFS Stopwatch (SW) Cues
Training Calves	All treatments: Guiding calf to find drinking teat	SW started when calf was aided to find teat. SW stopped when calf correctly latched to teat.	SW started when calf was aided to find teat. SW stopped when calf correctly latched to teat.
Milk Preparation	MFS: ensuring correct water temperature, adding milk powder, whisking to remove lumps. AFS: Emptying bag of milk replacer into the hopper.	SW started when water first entered bucket. SW stopped when milk allocation for the whole pen was fully prepared (milk powder mixed with water).	SW started when bag was opened. Hopper cover was removed. Bag was emptied into the hopper. SW stopped when the hopper cover was replaced.
Feeding/ Feeding Inspection	All treatments: Monitoring consumption of milk allocation.	SW started when the first bucket of milk was poured into the manual feeders. Calves observed until all milk was consumed. SW stopped when the last calf finished drinking.	SW started when hand-held automatic feeding monitor attached to feeder was inspected for calf drinking history. SW stopped when all calves' information had been checked.
Cleaning Pen/ Equipment	All treatments: Cleaning of concrete, feeding units and area	SW started when entered pen. Water and detergent used to clean surfaces. SW stopped when pen and respective feeding unit within the pen were clean.	SW started when entered pen. Water and detergent used to clean surfaces. SW stopped when pen and each compartmentalised calf feeder was clean.

single observer using a scan sampling method for each group once every one minute for a duration of 15 minutes, five times per day (10:30, 11:30, 12:30, 14:30, 16:30). A five minute adjustment period before each observation period commenced was adhered to thereby ensuring calves were accustomed to the observer's presence. The observer stayed in one position outside of the pen to ensure minimal interference with expressed behaviour. Behaviours related to the ethogram are defined in Table 2.

Live-weight was measured at birth, weekly until weaning and fortnightly post-weaning (weighing scales described above) until six-months of age.

Table 2
Ethogram adapted from Barry et al (2019), which categorises and defines various behaviours, used for behavioural observations.

Category of behaviour	Behaviour	Definition
Posture	Standing	Calf is in a static upright standing position with weight placed on all four legs
	Lying	Calf is resting either sternally or laterally with all four legs hunched close to body either awake or asleep.
General	Walking	Calf is actively moving from one point in the pen to another in an active walking motion
	Not visible	Behaviour of the calf is not visible
	Defecating/Urinating	Calf defecates or urinates
Feeding Behaviour	Drinking water	Calf is drinking water
	Eating	Calf eats concentrates or roughage, or other solid feed (proximity of head to feed)
Comfort behaviour	Scratching/Rubbing/ Stretching	Calf scratches itself with one of their legs (generally hind legs). Calf rubs itself on pen structure. Calf stretches itself.
Abnormal behaviour	Tongue playing/rolling	Calf makes repeated movements with its tongue inside or outside its mouth
	Urine drinking / oral manipulate prepuce / cross sucking	Calf drinks the urine of another calf. Calf attempts to suck the naval area of another calf. Calf attempts to suck any body part of another calf.
	Orally manipulating pen structure	Calf licks, nibbles, sucks, or bites at the pen structure (barriers, walls, buckets, troughs etc.)
Play behaviour	Play behaviour/ Mounting/ Head butting	Calf runs, jumps, changes direction suddenly, bucks, kicks hind legs, twists or rotates body. Calf mounts, or attempts to mount, a pen mate. Calf is engaged in head to head pushing with another calf.
Social behaviour	Social interaction	Calf licks another calf in the same area multiple times. Calf nudges another calf with its nose

2.7. Data Editing

Labour, behaviour and health data was divided into two periods; period one (P1) which was early pre-weaning from week one to seven and period two (P2) which was late pre-weaning from week eight until weaning. This was completed to reflect differences which were observed and associated with calf age during the experimental period. Weight data was not divided into two periods, as it was reported based on age (days). However, the following ages relate to each period; Period 1 = 0-42 days; Period 2 = 43-81 days (based on averages).

Preliminary analysis of labour data showed skewed data from week 13 to 15. Upon investigation it was realised that the labour input was divided among a fewer number of animals towards the end of the study which was incorrectly increasing the time associated with various tasks (week 13 between 39% and 85% of calves weaned depending on replicate and treatment). Furthermore, by only reporting data from week three of the experiment onwards, when all calves were assigned to treatment, a critical period of labour input would have been overlooked, whereby training time would not have been included. Consequently, when analysing labour data, the threshold for inclusion of data points was when 70% of calves were taken off treatment (due to weaning). The resulting labour dataset included measurements that were taken from week one to week 12. Training time to teach the calves to drink from their respective feeding system was recorded on a per calf basis, due to calves being assigned to treatment on an individual basis, based on date of birth, over a period of two weeks. Training time is also omitted from the figure for total labour input, due to its infrequent occurrence at the beginning of the trial period.

Relating to behavioural data, in order to get an accurate representation of the group behaviour, it was important that each treatment group was at full capacity (15 calves). For this reason, behavioural data was analysed from week three to week 11.

Bodyweight data were arranged based on a calf's age rather than by a calendar date. As all calves were not born on the same date and were weighed every Friday, differences in calf age arose. The ADG of each calf was calculated based on the difference between weighing dates and weight values on each respective date. For example, the difference in weight of a calf recorded at 21 days (± 3 days) and 28 days (± 3 days) is taken and divided by the number of days between weighings to get an ADG for that period. Average daily gain data was divided into pre and post weaning on a per calf basis. The pre and post weaning periods were each approximately 80 days in length. The number of days to achieve weaning weight was calculated by subtracting a calf's birth date from their weaning date.

To create binary data for analysis, health scoring categories were condensed individually, for each health factor, from four possible categories (0, 1, 2, 3) to two categories; category one are calves that scored zero and are of excellent health for a specific health factor, and category two are calves that score anything greater than zero, so have a health issue (mild or severe) related to a specific health factor.

Milk powder intake was calculated on a per calf basis, based on the number of days to achieve weaning weight (accounting for colostrum and transition milk consumption, and a reduction in milk powder consumption during weaning) multiplied by a calf's daily milk powder allocation. Seven days (accounting for three days of colostrum and transition feeding and a four-day weaning period) was subtracted from the number of days to achieve weaning, which resulted in the number of days calves received milk replacer. Calves received 900 g of milk replacer per day (reconstitution rate of 15%), which was multiplied by the number of days receiving milk replacer. To account for the milk replacer consumed over the four-day weaning period (9 L x 150 g) 1.35 kg was added to the resulting figure.

2.8. Statistical Analysis

Statistical analyses were conducted using SAS software (Version 9.4, SAS Institute Inc, 2002). Linear mixed models (PROC MIXED) were used to determine whether treatment had an effect on the labour, growth (BW and ADG) and CDMI of rearing calves. Dependent variables used in this procedure followed a normal distribution pattern. Significant associations were confirmed at $P<0.05$; least square means assessed and interactions were examined between significant variables in each model. Treatment, breed, calf number, Economic Breeding Index (EBI; single figure profit index related to production, used to identify most profitable dairy herd replacements) and replicate were included as categorical variables. Fixed effects were considered as treatment, replicate, week of treatment (WOT) and period for procedures regarding labour and CDMI. Week of treatment was nested within period due to their close association. When analysing animal variables (i.e. body weight and ADG) WOT and period were not included as fixed effects and instead replaced with birthweight, date of birth and breed. To account for the difference in age (days) between the calf's actual age and the mean age of the group on each respective weighing date , a covariate was included in the model. Time of measurement was the repeated measure used in the model.

The frequency procedure (PROC FREQ) was used to report the non-normal distribution of categorical variables related to health scoring including; demeanour, nasal discharge, ocular discharge, ear position, attitude, coughing, faecal consistency, dehydration, mobility and presence of faecal matter. Logistic regression (PROC LOGISTIC) was used to determine the associations between the independent variables treatment, breed, replicate and period (each of which were dichotomous variables) on the dependent health scores (binary data). The AFS treatment was designated as the reference category (odds ratio (OR) = 1). The HF x JE breed, replicate one and period two were also designated as the reference categories. The frequency procedure (PROC FREQ) was used to establish the distribution of the data. A multinomial logistic regression (PROC LOGISTIC) was used to determine the associations between treatment, replicate and period on the fifteen calf behaviours (non-binary data). The AFS treatment was designated as the reference category, alongside replicate two and period two. 'Standing' was the designated reference category for the dependent variable, behaviour. Oral manipulation and tongue rolling occurred too infrequently to be statistically analysed.

Results

3.1. Labour

An interaction was found between treatment and period in terms of total labour input ($P < 0.01$). Total labour for AFS decreased from P1 to P2 (00:09:42 per pen/day ± 00:00:28 and 00:08:56 ± 00:00:25 per pen/day, respectively). Total labour for MFS also decreased from P1 to P2 (00:28:19 ± 00:00:27 per pen/day and 00:21:07 ± 00:00:25 per pen/day, respectively). Labour input for MFS was consistently greater (+00:15:12 per pen/day) than for AFS (Table 3). The labour demand per pen per day for feed preparation, feed inspection and cleaning was higher for the MFS compared to the AFS. However, the labour required for health inspection (+00:03:23 per pen/day) and training (+00:02:06 per calf/day during introduction to treatment), on a per calf basis, were significantly higher for AFS compared to MFS.

3.2. Health

Table 4 shows the distribution frequencies for each of the health scores recorded throughout the study period. For all health scores, regardless of treatment, the majority of calves were scored as 0, i.e. healthy. More calves were categorized as having poor faecal cleanliness than any other health score. Compared to calves in the AFS, calves were more likely to be allocated a faecal score greater than zero in the MFS group (OR = 2.009; CI = 1.463 – 2.759).

Looking at the frequency distribution of health scores, the number of health scores greater than zero reduced in occurrence in P2, compared to P1, with the exception of eyes, cough and interest, which increased during P2 (+1 %, +1.7 % and +0.1 %, respectively).

There were three incidences of illness over the course of the experiment which required medical treatment, one incidence of septicaemia (unrelated to experimental treatment) was found in the MFS, while there were two incidences of digestive bloat, one in each of the two treatments.

3.3. Behaviour

Calves in the MFS had an increased likelihood of defecating and urinating, eating and having (or engaging in) social interactions (Table 5). Calves in the AFS had an increased likelihood of walking. Calves were more likely to lie than stand in P1, compared to P2 (OR= 1.387; CI= 1.301–1.480). Oral manipulation (cross-suckling/urine drinking or manipulation of prepuce) and tongue rolling occurred too infrequently to be statistically analysed. There were nine incidences of oral manipulation (two MFS, seven AFS). This behaviour ceased after week three of treatment. There were three reports of tongue rolling recorded between week six and eight (one MFS, two AFS).

3.4. Calf Weight

There was no interaction between feeding system and breed. Weaning weight was similar between feeding systems (92.9 kg) and no differences between breeds were observed (92.9 kg). There was no effect of feeding system on the number of days taken to achieve target weaning weight (80.7 days).

There was no effect of treatment on BW at 14 (39.0 kg ± 1.03 kg), 63 (74.3 ± 1.05 kg), 118 (116.0 kg ± 1.05 kg) or 160 (147.5 kg ± 1.05 kg) days of age. There were no significant differences in ADG between treatments ($P = 0.277$).

3.5. Dry Matter Intake

Milk powder intake per calf was approximately 67.7 kg over the course of the study period. The concentrate dry matter intake (CDMI) per calf/ day was significantly higher for MFS-calves than AFS-calves over the course of the study (1.09 and 0.87 ± 0.070 kg/calf/day, respectively; $P<0.05$). The CDMI per calf per day increased from P1 to P2 (0.37 kg/calf/day and 1.60 ± 0.072 kg/calf/day, respectively; $P < 0.01$).

Table 3
Mean total labour input (±S.E.) and labour input per calf per day (hh:mm:ss) regarding tasks associated with calf rearing for Automatic (AFS) and Manual (MFS) Feeding Systems.

(hh:mm:ss)	AFS	MFS	SE	P-value	P1	P2	SE	P-value
per pen/day								
Total time (excl. training)	00:09:33	00:24:46	00:00:21	0.001	00:19:04	00:15:02	00:00:22	0.001
Feed Preparation	00:02:13	00:04:57	00:00:07	0.001	00:03:35	00:03:31	00:00:07	0.674
Feed Inspection	00:01:16	00:15:40	00:00:19	0.001	00:10:13	00:06:28	00:00:19	0.001
Cleaning (incl. pen & equipment)	00:02:41	00:04:09	00:00:06	0.001	00:03:24	00:03:31	00:00:07	0.485
Health Inspection	00:03:23	00:00:00	00:00:04	0.001	00:01:52	00:01:33	00:00:05	0.003
per calf/day								
Total Time (excl. training)	00:00:45	00:01:50	00:00:02	0.001	00:01:17	00:01:17	00:00:03	0.879
Feed Preparation	00:00:11	00:00:22	00:00:01	0.001	00:00:15	00:00:18	00:00:01	0.005
Feed Inspection	00:00:05	00:01:10	00:00:01	0.001	00:00:42	00:00:32	00:00:02	0.001
Cleaning (incl. pen & equipment)	00:00:13	00:00:19	00:00:01	0.001	00:00:14	00:00:19	00:00:08	0.001
Health Inspection	00:00:15	00:00:00	00:00:01	0.001	00:00:07	00:00:08	00:00:01	0.361
Training	00:02:14	00:00:08	00:00:24	0.001	00:01:11	NA	00:00:21	NA

Table 4
Distribution frequencies (%) of health scores for automatic (AFS) and manual (MFS) feeding systems and early pre-weaning (P1) and late pre-weaning (P2).

	Health Score per Feeding System (%)				Health Score per Period (%)			
	AFS		MFS		P1		P2	
Health Factor	0	(≥1)	0	(≥1)	0	(≥1)	0	(≥1)
Demeanour	99.8	0.2	100	0.0	99.9	0.1	100	0.0
Ears	99.5	0.5	99.3	0.7	99.9	0.1	98.9	1.1
Eyes	96.8	3.2	97.5	2.5	95.1	4.9	100	0.0
Nasal	99.0	1.0	98.6	1.4	98.6	1.4	99.1	0.9
Cough	99.0	1.0	98.7	1.3	99.6	0.4	97.9	2.1
Dehydration	100	0.0	100	0.0	100	0.0	100	0.0
Mobility	99.8	0.2	100	0.0	99.9	0.1	100	0.0
Interest	99.8	0.2	100	0.0	99.9	0.1	99.8	0.2
Faecal Hygiene	92.6	7.4	86.4	13.6	85.7	14.3	94.6	5.4

Table 5
Liklihoods of automatic (AFS) and manual (MFS) feeding systems exhibiting various behaviours (reference treatment and behaviour are AFS and standing).

Behaviour	Odds Ratio	Confidence Interval		P-Value
Lying	1.055	0.991	1.123	0.162
Walking	0.795	0.683	0.925	0.012
Defecating/ Urinating	1.450	1.080	1.945	0.037
Drinking Water	1.185	0.867	1.620	0.372
Eating	1.281	1.140	1.439	0.005
Scratching/Rubbing/Stretching	0.903	0.760	1.072	0.327
Manipulating Pen	0.935	0.758	1.154	0.599
Playing	0.940	0.769	1.150	0.615
Social Interaction	1.300	1.111	1.521	0.006

Discussion

4.1. Labour

In this study we compared the effects of automatic and manual feeding systems on group-housed calf health, behaviour, growth rates and labour. For the duration of the experiment, the total labour input per pen per day was consistently higher for MFS than AFS; this was mainly attributable to time required for feed inspection, which was also found to be the case in a study by Bostad et al. (2010). Feed inspection for the AFS was the time spent checking the automatic feeding monitor attached to the feeder for the drinking history of each calf within the pen. For MFS, feed inspection was the time spent pouring milk into the compartmentalised feeders and observing all calves until the last calf in the group finished drinking. The measurement in the present study was done in an experimental setting. On a commercial farm, this figure for feeding inspection is not expected to be as high (Gleeson et al, 2008), because it is likely that farmers would distribute milk to calves and move on to another task while calves are consuming the milk. Although time that is saved by the farmer in doing this may be spent in a positive way towards carrying out other tasks related to calf care, such as cleaning equipment, farmers cannot be sure that each calf has received its full allocation of milk. It is important to note there was an opportunity to overlap tasks with the MFS. Health inspections could be carried out for the MFS in tandem with feeding time (Medrano-Galarza et al, 2017). In order to achieve the same level of health inspection for AFS, it would be necessary to enter the pen at a separate time point during the day, which is advised in association with the inspection of feeding behaviour on the computerised system (Johnston et al., 2016). On a number of occasions, measurements were recorded to evaluate the time required to inspect feeding and leaving when sufficient health inspection had occurred for the MFS. This data indicates that if this practice is used, a labour reduction of approximately 88% could be achieved in time spent inspecting feeding in this study.

Cleaning is another task associated with calf rearing that contributed to the total labour input per pen. The proportion of time spent cleaning was higher for MFS than AFS, because it was necessary to clean the pen as well as each of the compartmentalised feeders used in the MFS. In pens with AFS, only pen cleaning is required because cleaning of the feeding equipment (i.e. teat) is done automatically. Cleaning is an essential management practice that influences calf health (Barry et al., 2019). It is necessary as it aids in the control of pathogen levels on equipment used for rearing calves (Bazeley, 2003).

Training time was higher for AFS than MFS. There is no clear explanation for this difference in time. However, in the period before being moved into their treatment pen, all calves were fed manually with an individual bucket and teat, which could have lead calves to associate humans with the positive reward of milk (Krohn et al, 2001). When calves were moved to their respective treatments, this principle remained the same for MFS at feeding time, whereas with the AFS calves, the human factor was reduced significantly. Furthermore, the difference could be related to a time lag which occurred with the AFS between the feeding unit and the transfer of milk to the teat. When a calf in an AFS pen enters the feeding unit, it is identified through its RFID tag. The system then begins mixing the milk allocation for the calf. Once mixed, milk is transferred through pipes to the feeding station (Hnatiuc & Caracostea, 2017). The difference may also be a result of the ability of calves to learn from each other socially. Social learning has been shown to benefit calves, whereby they learn from one another regarding how to act (Fukasawa et al, 1999). The AFS is an individual feeding system, so as a result, calves may not stimulate or learn from one another as quickly, perhaps, as the MFS calves, who have the ability to carry out feeding in groups.

Although a calf's milk intake was controlled in this study, it is important to note that, if desired, automatic feeders allow farmers to increase the amount of milk given to calves without adversely increasing the labour required (with the exception of increased labour associated with a higher frequency of re-filling the automatic feeder with milk powder).

4.2. *Calf Health*

It was seen from this study that there was a low rate of illness for both treatments. This outcome was potentially reflective of the hygiene management practices used on the farm, whereby emphasis was placed on maintaining high levels of sanitation for feeding equipment and housing (McGuirk, 2004).

Although, calves in the MFS were more likely to have faecal matter on their hindquarters, it is unclear why this occurred. It is believed that hindquarter cleanliness in this study is a result of loose faecal material, rather than pathogenic diarrhoea, which has been highlighted as an important distinction (Jorgensen et al., 2017). As calves in the MFS had a greater CDMI, it suggests that a higher quantity of food matter may be moving through the digestive tract of the calf. This in turn may have caused these calves to either defecate and urinate more frequently, which behavioural data has shown in this study, or have higher levels of faeces and urine to expel from their bodies, compared to their counterparts.

Increased faecal matter on a calf's hindquarters occurred more frequently in the early pre-weaning period. This finding has not been associated with pathogenic infection, which may indicate that this could be due to the ruminal development of a calf. Solid feed intake is a key component in the transition from a pre-ruminant animal to a functioning ruminant (Coverdale et al, 2004). Forage and concentrate consumption is required in a calf's diet for many things including muscular and papillae development in the rumen (Coverdale et al, 2004). The transition process of developing a rumen begins at four weeks and can take up to week 12 to develop fully (Teagasc, 2017). Therefore, although calves in this study had the opportunity to consume forage and concentrates from a young age, their digestive system may not have been developed enough to digest these feedstuffs effectively. This could then have resulted in calves having looser faecal matter in the early pre-weaning period, leading to a hindquarter with a higher level of faecal matter on it. However, this did not result in a greater incidence of diarrhoea.

4.3. *Weight Gain*

Research has shown that the speed by which milk moves through the digestive tract is stimulated by the frequency of consumption, whereby emptying occurs quicker in the abomasum allowing for entrance of new matter (Mylrea, 1966). Although large volumes of milk have been fed to calves with reasonable efficacy (e.g. once-a-day feeding (Saldana et al. 2019)), it is also suggested that the greater the volume of milk offered at each feeding, the longer milk will remain in the abomasum (Bergstaller et al, 2017) and prolonged abomasal emptying may increase rates of digestive disorders (Songer and Miskimins, 2005). For this reason, it was expected that AFS would utilise milk more efficiently due to the smaller portions being consumed more often, reducing the risk of milk in the rumen and stimulating the movement of milk through the digestive system more quickly, resulting in a higher ADG. However, results from this study show that ADG and the number of days taken to achieve target weaning weight were the same for both treatments. The aforementioned findings could support Mylrea's research (1966) because, although MFS calves had a greater concentrate DMI compared to AFS calves, it was not reflected in the ADG of calves in that treatment. This may be explained by a study which found that large infrequent volumes of milk feeds can have negative effects on calf metabolism and insulin sensitivity (Bach et al, 2013). However, it is important to also consider a study (MacPherson et al., 2016) which found that insulin sensitivity was not negatively affected by two large feeds of milk replacer per day (4 L/feed; 15% reconstitution rate).

1.4. *Behaviour*

Behavioural observations are reported on a group level in this study. Although social structure is typically accounted for in behavioural analysis, it is believed that in this circumstance, the treatment has a larger effect compared to calf effect. Treatment differences are large in relation to feeding behaviour. Feeding is at a common time in MFS leading to synchronised feeding behaviour, whereas calves assigned to the AFS system could choose their own individual feeding time. The stocking rate of the AFS was 50% less than the manufacturer's recommendation (Volac Förster Technik Vario, Germany), resulting in a lower demand for the feeding station. It is possible that other behaviours may be affected by these differences in feeding practices. Furthermore, solid dividers were used between treatment pens ensuring behaviour was not influenced by visual stimulation.

The expression of normal behaviour, such as the time spent lying, recorded in this experiment corresponds with behavioural profiles of calves in previous studies, which found calves had increased frequency of lying in early life (Neja, 2013; Calvo-Lorenzo et al, 2016). Normal behaviour is believed to be actions that allow a calf to satisfy its maintenance needs (Webster et al, 1985). Both feeding systems were offered the same plane of nutrition in terms of milk allowance (6 L/day; approx. 15% of birth body weight), concentrates and forage, which was deemed a sufficient amount to satisfy a calf's needs in a previous review (Lorenz et al., 2011). This sufficiency may be reflected by the normal behavioural profile exhibited in this study. Furthermore, the occurrence of abnormal behaviours, such as tongue rolling and oral manipulation, are almost absent in both treatments. The absence of these behaviours suggests that calves in this study had the ability to cope well in their respective environment (Broom, 1991).

As expected, there was a reduction in lying behaviour between P1 and P2 (Neja, 2013). This reduction may be a result of a decrease in the need for low energy expenditure as a calf's digestive system develops to consume solid feed, as well as the desire for fulfilment of other behavioural needs such as play and social interaction (Calvo-Lorenzo et al., 2016; Jensen & Khyn, 2000; Tapki et al, 2006).

Suckling is an important behaviour for calves to express (Margerison et al., 2003), however MFS calves had restricted opportunity to perform this behaviour. Research has shown that calves compensate for lack of suckling by either developing abnormal behaviours or consuming other feedstuff such as concentrates and forage (Margerison et al., 2003; Borderas et al., 2009). The latter was seen in our study whereby, eating behaviours, including concentrate and forage intakes, were seen more often in MFS-calves than AFS-calves. Furthermore, calves in the MFS also had higher CDMI than their AFS counterparts. This could be due to calves in the MFS experiencing longer intervals between feeds, which may have encouraged them to consume concentrates between feeds. Research carried out on automatic feeders has shown that when milk intake is controlled, it can result in an increased frequency of unrewarded visits to the feeder (Hammon et al., 2002; Vieria et al, 2008). However, taking into consideration that calves in the MFS do not have an opportunity to carry out un-rewarded suckling, it is possible that this behaviour was instead re-directed towards other feed related behaviours, such as consuming concentrates.

The AFS-calves were more likely to walk than their manual counterparts, this may be due to the feeding system itself. It has been established that calves in each treatment were most likely to be lying compared to standing in this study. Irrespective of treatment, milk was offered at the front of the pen, meaning that a short walk was required to reach the feeders. Once MFS-calves were fed, feeders were removed from the pen, consequently there may have been a reduced incentive for calves to walk from the lying area to the front feeding area. In comparison, the AFS-calves had the opportunity to access the automatic feeder for both rewarded and unrewarded visits at multiple points throughout the day. This, in turn, may have translated into an increase in walking behaviours in the AFS-calves. Alternatively, a study that looked into calf behaviour around restricted and ad-lib feeding using an automatic feeder found that calves with restricted milk allowance (approx. 4 L) had increased levels of unrewarded visits to the feeder, which could be linked to hunger and calf satiety (Vieira et al, 2008). Calves in the AFS were fed smaller volumes of milk more frequently compared to MFS-calves, which may have resulted in calves experiencing hunger more often than their manual counterparts. The AFS-calves may have expressed lower levels of satiety by walking towards the feeder to carry out non-rewarded suckling of the teat. Urination and defecation were higher for the MFS than AFS. It is possible that this correlated with the poorer faecal hygiene scores of the hindquarters found in MFS calves.

Conclusion

Our results showed that calves assigned to both the AFS and MFS exhibited good health and normal behavioural patterns as well as similar growth rates. Automatic feeding systems were consistently more labour efficient than manual feeding systems, despite having higher labour requirements for training and health inspections. Thus when managed appropriately, the saving of labour is a distinct advantage automated feeding systems have over their manual counterparts when rearing group-housed calves.

Author Statement

All authors have seen and approved the final version of the manuscript being submitted. This article is the authors' original work, hasn't received prior publication and isn't under consideration for publication elsewhere.

CRediT authorship contribution statement

Alison M. Sinnott: Investigation, Methodology, Data curation, Formal analysis, Writing - original draft. **Emer Kennedy:** Funding acquisition, Project administration, Supervision, Formal analysis, Writing - review & editing. **Eddie.A.M. Bokkers:** Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgements

The authors would like to thank Prof. Imke J.M. de Boer for comments on the initial manuscript. The authors would like to acknowledge support given by the Teagasc, Walsh Scholar funding scheme. We also thank the farm staff at Teagasc, Moorepark for their care of the animals and assistance during the study.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.livsci.2020.104343.

References

Bach, A., Domingo, L., Montoro, C., Terré, M., 2013. Insulin responsiveness is affected by the level of milk replacer offered to young calves. Journal of Dairy Science 96 (7), 4634–4637.
Barry, J., Kennedy, E., Sayers, R., de Boer, I.J.M., Bokkers, E.A.M., 2019. Development of a welfare assessment protocol for dairy calves from birth through to weaning. Animal Welfare 28, 331–344.
Bazeley, K., 2003. Investigation of diarrhoea in the neonatal calf. In Practice 25, 152–159.
Bielmann, V., Gillan, J., Perkins, N.R., Skidmore, A.L., Godden, S., Leslie, K.E., 2010. An evaluation of Brix refractometry instruments for measurement of colostrum quality in dairy cattle. Journal of Dairy Science 93 (8), 3713–3721.
Borderas, T.F., De Passillé, A.M.B., Rushen, J., 2009. Feeding behavior of calves fed small or large amounts of milk. Journal of Dairy Science 92 (6), 2843–2852.
Bostad, E., Swensson, C., Pinzke, S., 2010. Labour use in Swedish production of red veal. Journal of International Farm Management 5 (3), 1–23.
Broom, D.M., 1991. Needs and welfare of housed calves. New trends in veal calf production. (52), 23–31.
Burgstaller, J., Wittek, T., Smith, G.W., 2017. Invited review: Abomasal emptying in calves and its potential influence on gastrointestinal disease. Journal of Dairy Science 100 (1), 17–35.
Calvo-Lorenzo, M.S., Hulbert, L.E., Fowler, A.L., Louie, A., Gershwin, L.J., Pinkerton, K. E., Ballou, M.A., Klasing, K.C., Mitloehner, F.M., 2016. Wooden hutch space allowance influences male Holstein calf health, performance, daily lying time, and respiratory immunity. Journal of Dairy Science 99 (6), 4678–4692.
Coverdale, J.A., Tyler, H.D., Quigley III, J.D., Brumm, J.A., 2004. Effect of various levels of forage and form of diet on rumen development and growth in calves. Journal of Dairy Science 87 (8), 2554–2562.
Cummins, C., Berry, D.P., Sayers, R., Lorenz, I., Kennedy, E., 2016. Questionnaire identifying management practices surrounding calving on spring-calving dairy farms and their associations with herd size and herd expansion. Animal 10 (5), 868–877.
Deming, J.Gleeson, D. O'Dwyer, T., Kinsella, J., O'Brien, B., 2018. Measuring labour input on pasture-based dairy farms using a smartphone. Journal of Dairy Science 100 (10), 9527–9543.
Fujiwara, M., Rushen, J., de Passillé, A.M., 2014. Dairy calves' adaptation to group housing with automated feeders. Applied Animal Behaviour Science 158, 1–7.
Fukasawa, M., Sato, S., Sugawara, K., 1999. Influence of early social learning on later feeding behaviour for novel food in calves. Nihon Chikusan Gakkaiho 70 (5), 356–359.
Gleeson, D., O'Brien, B., O'Donovan, K., 2008. The labour input associated with calf care on Irish farms. Livestock Science 16, 82–89.
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. Journal of Dairy Science 85 (12), 3352–3362.Vancouver.
Hnatiuc, M.Caracostea, 2017. Automatic Calf Feeder System. International Journal of Modeling and Optimization 7, 218–223.
ICBF. (2019). Dairy Cow Population by County 2016 - 2019. Available: https://www.icbf.com/wp/?p=14603#:~:text=Total%20dairy%20cow%20numbers%20for,1.6%25%20from%201%2C496%2C232%20in%202018.. Last accessed 17 June 2020.
Jensen, M.B., Kyhn, R., 2000. Play behaviour in group-housed dairy calves, the effect of space allowance. Applied Animal Behaviour Science 67 (1-2), 35–46.
Jensen, M.B., 2007. Age at introduction to the group affects dairy calves' use of a computer-controlled milk feeder. Applied Animal Behaviour Science 107 (1-2), 22–31.
Johnston, D., Kenny, D.A., McGee, M., Waters, S.M., Kelly, A.K., Earley, B., 2016. Electronic feeding behavioural data as indicators of health status in dairy calves. Irish Journal of Agricultural and Food Research 55 (2), 159–168.
Jorgensen, M.W., Adams-Progar, A., de Passille, A.M., Rushen, J., Godden, S.M., Chester-Jones, H., Endres, M.I., 2017. Factors associated with dairy calf health in automated feeding systems in the Upper Midwest United States. Journal of Dairy Science 100 (7), 5675–5686.
Kelly, P, Shalloo, L, O'Dwyer, T, Beecher, M, Horan, B, French, P, Dillon, P, 2017. The People in Dairy Project. Teagasc 6–29.
Krohn, C.C., Jago, J.G., Boivin, X., 2001. The effect of early handling on the socialisation of young calves to humans. Applied Animal Behaviour Science 74 (2), 121–133.
Kung Jr, L., Demarco, S., Siebenson, L.N., Joyner, E., Haenlein, G.F.W., Morris, R.M., 1997. An evaluation of two management systems for rearing calves fed milk replacer. Journal of Dairy Science 80 (10), 2529–2533.
Lorenz, I, Mee, J.F., Earley, B, Moore, S.J., 2011. Calf health from birth to weaning. I. General aspects of disease prevention. Irish Veterinary Journal. 64 (10), 1–8.
Maatje, K., Verhoeff, J., Kremer, W.D.J., Vruijsen, A.L.M., van Ingh, T.S.G.A.M., 1993. Automated feeding of milk replacer and health control of group-housed veal calves. Veterinary Record 133, 266–270.
MacPherson, J.A.R., Berends, H., Leal, L.N., Cant, J.P., Martín-Tereso, J., Steele, M.A., 2016. Effect of plane of milk replacer intake and age on glucose and insulin kinetics and abomasal emptying in female Holstein Friesian dairy calves fed twice daily. Journal of dairy science 99 (10), 8007–8017.

Margerison, J.K., Preston, T.R., Berry, N., Phillips, C.J.C., 2003. Cross-sucking and other oral behaviours in calves, and their relation to cow suckling and food provision. Applied Animal Behaviour Science 80 (4), 277–286.

McGuirk, S.M., 2004. Trouble shooting calf health concerns. In: Proceedings of the 23rd World OAPFall Seminar, pp. 33–40.

Medrano-Galarza, C., LeBlanc, S.J., Jones-Bitton, A., DeVries, T.J., Rushen, J., de Passillé, A.M., Haley, D.B., 2017. Producer perceptions of manual and automated milk feeding systems for dairy calves in Canada. Canadian Journal of Animal Science 98 (2), 250–259.

Medrano-Galarza, C., LeBlanc, S.J., Jones-Bitton, A, DeVries, T.J, Rushen, J., Marie de Passillé, A., Endres, M.I., Haley, D.B., 2018. Associations between management practices and within-pen prevalence of calf diarrhea and respiratory disease on dairy farms using automated milk feeders. Journal of Dairy Science 101 (3), 2293–2308.

Moran, J., 2012. Milk feeding the calf. Rearing young stock on tropical dairy farms in Asia. 91–108.

Mylrea, P.J. (1966). Digestion of Milk in Young Calves: I.—Flow and Acidity of the Contents of the Small Intestine. Research in Veterinary Science, 7(3), pp. 333-341.

Neja, W., (2013). Behaviour of calves in the first weeks of life. Journal of Central European Agriculture, 14(1), pp. 0-0.

O'Donovan, K., O'Brien, B., Ruane, D.J., Kinsella, J., Gleeson, D., 2008. Labour input on Irish dairy farms and the effect of scale and seasonality. Journal of Farm Management 13 (5), 38–53.

Saldana, D.J., Jones, C.M., Gehman, A.M., Heinrichs, A.J., 2019. Effects of once-versus twice-a-day feeding of pasteurized milk supplemented with yeast-derived feed additives on growth and health in female dairy calves. Journal of Dairy Science 102 (4), 3654–3660.

Songer, J.G., Miskimins, D.W., 2005. Clostridial abomasitis in calves: Case report and review of the literature. Anaerobe 11 (5), 290–294.

Sumner, C.L., von Keyserlingk, A.G., Weary, D.M., 2018. Perspectives of farmers and veterinarians concerning dairy cattle welfare. Animal Frontiers 8 (1), 8–13.

Sutherland, M.A., Lowe, G.L., Huddart, F.J., Waas, J.R., Stewart, M., 2018. Measurement of dairy calf behavior prior to onset of clinical disease and in response to disbudding using automated calf feeders and accelerometers. Journal of Dairy Science 101 (9), 8208–8216.

Svensson, C, Liberg, P., 2006. The effect of group size on health and growth rate of Swedish dairy calves housed in pens with automatic milk-feeders. Preventative Veterinary Medicine 71 (1), 43–53.

Svensson, C., Lundborg, K., Emanuelson, U., Olsson, S.O., 2003. Morbidity in Swedish dairy calves from birth to 90 days of age and individual calf-level risk factors for infectious diseases. Preventative Veterinary Medicine 58 (3), 179–197.

Tapkı, İ., Şahin, A., Önal, A.G., 2006. Effect of space allowance on behaviour of newborn milk-fed dairy calves. Applied Animal Behaviour Science 99 (1-2), 12–20.

Teagasc, 2017. Development of a calf digestive system. Teagasc Teagasc Calf Rearing Manual. Ireland: Teagasc, pp. 59–62.

Vieira, A.D.P., Guesdon, V., De Passille, A.M., von Keyserlingk, M.A.G., Weary, D.M., 2008. Behavioural indicators of hunger in dairy calves. Applied Animal Behaviour Science 109 (2-4), 180–189.

Webster, A.J.F., Saville, C., Church, B.M., Gnanasakthy, A., Moss, R., 1985. The effect of different rearing systems on the development of calf behaviour. British Veterinary Journal 141 (3), 249–264.

Further reading

Sayers, R.G., Kennedy, A., Krump, L., Sayers, G.P., Kennedy, E., 2016. An observational study using blood gas analysis to assess neonatal calf diarrhea and subsequent recovery with a European Commission-compliant oral electrolyte solution. Journal of Dairy Science 99 (6), 4647–4655.