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BRIEF REPORT

Adapting buffalo calves to automated milk feeding: initial observations and future implications

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ABSTRACT
An on-farm observational study evaluated the use of individual automatic milk feeders (AMF) to wean 53 buffalo calves. Analysis of data retrieved from the AMF system over a 4-month period revealed positive indicators for animal adaptation, including rapid self-feeding behaviour, low incidence of feeding refusals, high milk intake, consistent weight gain, and increased frequency of daily feedings. The study identified potential areas for future research, such as determining the optimal number and frequency of feedings and the appropriate milk allowance for different stages of calf development. These findings suggest potential benefits for labour cost savings and emphasise the need to optimise AMF parameters to meet the specific needs of buffalo calves.

HIGHLIGHTS

- Buffalo calves adapted well to an individual automatic milk feeder

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Automatic milk feeder; buffalo calf; precision livestock farming

Introduction

The Italian water buffalo (*Bubalus bubalis*) stands out globally for its milk yield and genetics (Borghese et al. 2022). It is therefore of the utmost importance to ensure the effective rearing of healthy calves in order to maintain the productivity and reproductive efficiency of the herd. During the critical pre-weaning period, buffalo calves are highly susceptible to infectious diseases that contribute to increased mortality and reduced growth rates that can also significantly delay the age at first calving (Lotito et al. 2023). The weaning methods used on most buffalo farms involve the separation of calves from their mothers shortly after birth and individual housing of calves. Milk replacer is manually administered twice a day through open buckets or bottles, and the supply is typically gradually reduced as the calf grows (Mota-Rojas et al. 2022). The feeding practices, demanding in labour for milk replacer preparation, administration, and equipment cleaning, pose additional challenges in Italian buffalo farming due to the uneven distribution of calf births throughout the year. In Italy, the calving of buffalo is concentrated at the beginning of winter due to seasonal anoestrus. Alternatively, if market demand for buffalo mozzarella necessitates, cows are forced to mate during an unfavourable season, such as spring (Gasparrini 2019). In either scenario, a peak in calf births in a short period of time increases the workload for calf care and weaning, potentially increasing the risk of errors or failures in management practices. In addition, manual milk feeding systems (MMFs) makes it difficult to obtain essential feedback on milk intake, feeding times and drinking rates. In contrast, automatic milk feeders (AMFs) are capable of retrieving these indicators, which have been demonstrated to be able to predict disease onset and to assist in the assessment of calf welfare (Svensson and Jensen 2007; Morrison et al. 2021). Furthermore, AMFs can reduce labour requirements and facilitate milk feeding strategies adapted to individual calf needs, thus promoting ideal growth (Costa et al. 2021). However, Fujiwara et al. (2014) found that only 27% of all beef calves

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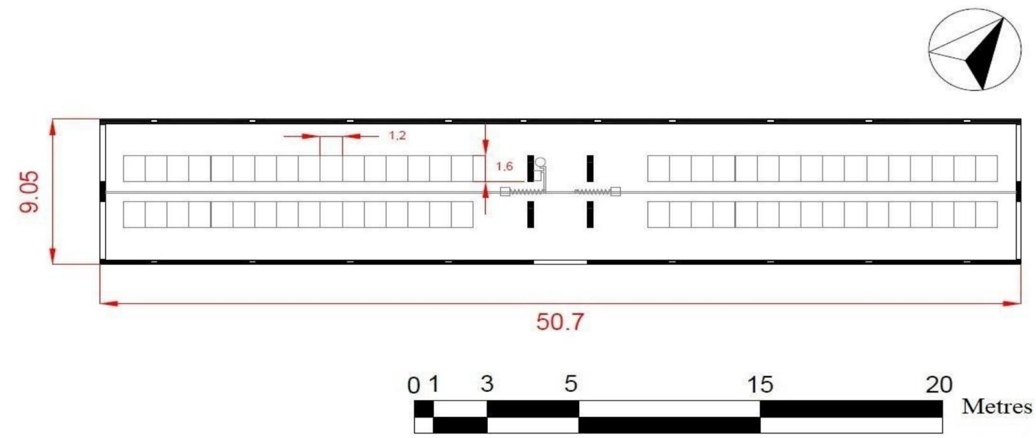

Figure 1. Layout of the pre-weaning facility.

voluntarily drank from the feeder within 24 h. This adaptation period appears to place calves at risk for health problems (Wilson et al. 2018). An additional challenge for small farms may be the significant cost associated with purchasing and maintaining AMFs (Silva et al. 2023). Automated milk feeders are increasingly being used for weaning beef and dairy calves in both individual and group housing systems. However, since the application of precision livestock techniques, including AMFs, is relatively new and uncommon (Sannino et al. 2018), there is a significant need for further research on the use of AMFs specifically for Mediterranean buffalo calves. In this preliminary study, a descriptive observational approach was employed to determine the functional and operational aspects of a single-box AMF system. The objective was to evaluate the adaptation of buffalo calves to the system along with its potential impact on weight gain and health and labour-saving costs, and the further research needed for efficient system use.

Materials and methods

Farm, calf weaning techniques and AMF system

The study was conducted on an organic dairy buffalo farm (130 ha agricultural area, approximately 1200 buffalo heads) in southern Italy (112 asl, 41°16′N 14°11′E) from March to June 2023. On the farm, calves are weaned in three stages. At birth, newborn calves are weighed, fed colostrum immediately and for 24 h, and then placed in individual outdoor weaning cages where they are bottle-fed milk replacer (Sprayfo Bufalino HP65, 24.5% protein, 25% fat) twice a day at 08:00 and 13:00 h. After five days, the calves are transferred to a newly constructed pre-weaning facility where they are fed milk replacer *via* an AMF (Calf Rail Förster-Technik, Engen, Germany) and remain there for 40 days or until their body weight exceeds 80 kg. Subsequently, the calves are relocated to covered outdoor pens and grouped in groups of five, where they are fed a controlled amount of milk replacer *via* teat-equipped buckets, along with *ad libitum* access to starter concentrate. The pre-weaning facility under study is designed to accommodate up to 64 calves in individual 1.6 m x 1.2 m straw-bedded pens constructed of vertical galvanised iron bars (Figure 1). This configuration facilitates visual, auditory, and limited physical interactions between neighbouring calves. Newborn calves entering the nursery are not provided with feeding training. Instead, they are placed in pens adjacent to older calves that are already accustomed to AMF feeding, allowing them to observe the behaviour of the older calves and thereby learn how to approach the feeder. Each pen is equipped with an electronic tag for identification, a freshwater bowl and a trough providing a starter concentrate from few days from entrance. The pens are cleaned and refilled with fresh straw twice a week. The nursery is divided into two identical sectors of 32 pens each. The AMF system in the nursery includes an automatic milk replacer mixer (Vario Smart, Förster-Technik, Engen, Germany), milk transport pipes, two robotic feeding arms equipped with a single teat and management hardware and software wirelessly connected to the robotic arms (Förster Calf Cloud, Förster-Technik, Engen, Germany). The two robotic arms are positioned in the central aisle between two opposing rows of 16 pens. The AMF system operates four times a day starting at 03:00, 09:00, 15:00, and 21:00 h. At the set time, the milk replacer is reconstituted at 180 g/L and heated to 38 °C in the automatic mixer. The milk is then transported through the pipes to the robotic arm, which identifies the pen and delivers a set

Table 1. Milk allowance, consumption, and body weight of calves in the pre-weaning facility.

	Milk allowance, kg			
Period	/Meal	/Day	Milk consumed, kg/d	Body Weight, kg
Days 0–10	1.5	6	5.75 ± 1.16	41.9 ± 2.7
Days 11–25	2	8	6.99 ± 1.19	–
Days 26–35	3	12	7.50 ± 1.20	–
Days 36–dx	2	8	7.33 ± 1.26	85.1 ± 2.9

d0= the 6th day of life of calves; dx = the last day of pre-weaning.

amount of milk according to the feeding schedule set by the farmer in the Calf Cloud software (Table 1). The theoretical waiting time set for the robotic arm is 2.3 min; if the calf does not start feeding, the software registers a refusal and moves on to the next calf. No maximum time is set for feeding duration. The teat on the robotic arm is cleaned with a disinfectant solution (sodium hypochlorite 1.15 g/L) between each calf feeding. There is a 25-minute system cleaning at the end of each feeding cycle and a special 60-minute cleaning twice a month. The milk mixer and the milk transfer system are first rinsed with hot water (60-80 °C) to remove milk residues. An alkaline cleaning solution with a pH of 10-11 is then circulated through the system and left to soak for 25 or 60 min. After soaking, the system is rinsed again with clean water to remove the cleaning solution and dissolved residues. The pre-weaning facility is naturally ventilated by a positive pressure ventilation tube system, and lighting is automatically regulated to ensure that the lights are on when the AMF is operating. The environmental records during the observation period were 18 ± 4 °C for temperature and 60 ± 2% for relative humidity.

Data collection and analysis

Eighteen pens were selected in the pre-weaning facility. Newborn female calves (average body weight 41.9 ± 2.7) were randomly assigned to each selected pen. Data from the Calf Cloud software was collected for three consecutive pre-weaning cycles per pen, resulting in a total of 53 pre-weaning cycles (one pen was unoccupied during the last cycle). The software recorded information continuously throughout the day. Data was retrieved at the same time each day and subsequently exported to Microsoft Excel for further analysis carried out using JMP software (version 10.0.0; SAS Inst. Inc., Cary, NC). The raw variables recorded daily by the management software for each calf, including meal start time, meal end time, and milk quantity per meal, were collected alongside the operational variables of the AMF system, i.e. rejection time, feeding time, and cleaning time.

Upon their initial entrance at the weaning facility and upon their exit, all calves were weighed by a farm scale (WAKM, Meier-Brakenberg GmbH&Co, Germany). The average daily gain (ADG) of each calf was calculated by dividing the total weight gain by the number of days they were in the facility. In the final week of the cycle, the quantity of starter consumed was determined for four days by the difference between the amount offered and the quantity remaining in the feeder. The calves were daily monitored by the farmer for any signs of disease and the length and duration of any health problems detected were recorded. Calves with diarrhoea, signs of respiratory disease, or a decline in general health for more than two days were classified as unwell and were considered recovered after at least two consecutive days without clinical signs of disease. From the raw data set collected, lines with outliers, defined as values at 3 standard deviations from the median, and incomplete entries on the final day of the calves' stay in the facility were excluded. The adaptation of buffalo calves to AMF was evaluated using data collected at 24, 48 and 72 h following their placement in the facility.

Results and discussion

Adaptation to the AMF

Table 2 shows the adaptation indices calculated from data obtained during the initial three days following the calves' introduction into the pre-weaning facility. The total number of rejections amounted to 172, resulting in an acceptance rate of 73.3% to the automatic feeder. Notably, the rejection rates exhibited a consistent decline from the first to the third day subsequent to the calves' entries into the facility. The average number of daily feedings (2.9) was higher than the number of feedings usually provided in MMFs (i.e. 2 meals per day) for an actual milk consumption (3.8 kg/calf/d) equivalent to approximately 9.2% of the average body weight of the calves on entry to the facility (Table 1). All but one calf started eating within 24 h, and all had their first voluntary feeding within 48 h from entries. Additionally, two calves experienced no refusals throughout the adaptation period (specific data not provided). Overall, the data indicate a high capacity of buffalo calves to learn the AMF system, higher than that observed in bovine calves (Fujiwara et al. 2014). This faster rate of adaptation could be due to the individual pen layout with visual interaction between the newly introduced calves in the pre-weaning area and the older calves, in line with research on calf social learning (Miller-

Table 2. Functional variables assessed to evaluate adaptation of buffalo calves ($n = 53$) to the automatic milk feeder during the first 72 h after entering the pre-weaning facility.

Item	Value	Description
Actual feedings, n	466	Number of feedings over 72 h
Milk/feeding, kg	1.30 ± 0.15	Actual quantity of milk consumed per feeding
Feedings/d, n	2.9 ± 0.25	Daily feeding frequency
Milk consumption, kg/d	3.84 ± 0.89	Average daily milk consumption
Feeding time for calf per meal, min	5.95 ± 1.10	Average feeding duration per session
Estimated drinking rate, L/min	0.23 ± 0.05	Amount of milk consumed per minute
Adaptation rate, %	73.3	Consumed to offered ratio
Total refusals, n	170	Number of feeding sessions without milk intake
Feeding refusal rate, %	26.7	Refused to offered ratio
0-24 h	34.0	Refused to offered ratio in the 1st day
24-48 h	24.1	Refused to offered ratio in the 2nd day
48-72 h	22.2	Refused to offered ratio in the 3rd day

Table 3. Functional variables assessed to evaluate the efficacy of the automatic milk feeder for buffalo calves ($n = 53$) from the third day post-entry to leaving the pre-weaning facility.

Item	Value	Definition
Days of occupation, d	41.7 ± 1.6	Average days spent by calves in the nursey facility
Weight increment, kg	43.2 ± 2.8	Average weight increments from the entrance to exit
Average daily gain, kg/d	1.0 ± 0.06	Weight increments divided by the day of occupation
Actual feedings, n	6726	Total number of feedings
Milk/feeding (kg)	2.0 ± 2.21	Actual quantity of milk consumed/feeding
Feedings/d	3.02 ± 0.78	Daily feeding frequency
Milk consumption, kg/d	6.65 ± 1.14	Average daily milk consumption
Adaptation rate, %	80.8	Consumed to offered ratio
Feeding time for calf per meal, min	6.87 ± 0.58	Average feeding duration per session for calves
Estimated drinking rate, L/min	0.30 ± 0.02	Amount of milk consumed per minute
Milk quantity for calf, L	257.4 ± 50	Average daily milk intake
Feeding time for calf per meal (min)	6.87 ± 0.58	Average feeding duration per session
Total refusals, n	1.599	Number of time that calves do not feed
Refusals by feedings, n and percentage		Refused to offered ratio
03:00	342 (21.4%)	1st feeding of the day
09:00	501 (31.3%)	2nd feeding of the day
15:00	380 (23.8%)	3rd feeding of the day
21:00	376 (23.5%)	4th feeding of the day
Four feedings/day, %	28.1	Percentages of four feedings per day recorded

Cushon and DeVries 2015). In addition, the presence of the robotic arm of the AMF approaching the individual calf, as opposed to group AMFs where the calves must approach the machine, may have contributed to faster adaptation of the buffalo calves.

Functional variables

Table 3 presents the indices calculated to evaluate the efficacy of the AMF from the third day after admissions until its end. A total of 1,599 refusals were recorded, resulting in a refusal rate of 19.2%, a figure that is just slightly lower from that observed at the 72-hour mark after admission (22.2%). Nevertheless, while these values confirm the downward trend observed during the adaptation period, no clear temporal trend was identified. In other words, the number of refusals did not vary as a result of calves' growth. This result may further confirm that buffalo calves adapt more quickly to AMF than dairy calves. Unlike Jensen's (2004) study where beef calves increased feeding frequency over time, buffalo calves seem to find the ideal number of meals quickly and maintain it.

In terms of daily distribution, the 09:00 h feeding exhibited the highest frequencies of refusals, comprising 30% of the total refusals. In contrast, the other feeding times demonstrated a lower average refusal rate of 22.9%. One potential explanation for this trend is that social animals have a 'preferred feeding rate', i.e. a rate at which they are most likely to consume feed, and they tend to synchronise their feeding and resting as an adaptive behaviour against predation (Nielsen 1999). However, since cleaning operations were typically conducted during the morning feeding hour, it is possible that the human presence acted as a disturbance, contributing to the observed trends. The calves consumed all four feedings in only 28.1% of the recordings (Table 3), and this finding suggests the need to investigate the technical and economic feasibility of maintaining a four-feedings-per-day program. Instead, adapting the feeding schedule to align with the natural behaviour of the calves could optimise the efficiency of the AMF system. Actual milk consumption was consistently below the

Table 4. Functional variables assessed to evaluate the technical efficiency of the automatic milk feeder for buffalo calves ($n = 53$) from the entrance until leaving.

Item	Value	Definition
Actual feedings, n	7192	Total number of feedings over the preweaning period
Total refusals, n	1769	Number of feeding sessions without milk intake
Feeding time for calf per meal, min	6.82 ± 1.35	Average feeding duration per session for calves
Refusal time for calf, min	2.24 ± 0.86	Actual average refusal time
Total feeding time, h	818.4	Total daily feeding time
Total refusal time, h	66.1	Product of average refusal time and number of refusals during pre-weaning
Total operation time, h	954.2	Sum of the total feeding time, total refusal time and cleaning time that occurred during pre-weaning
Operation time per calf, h	18.0	Total operation time divided by the number of calves ($n = 53$)

permitted daily milk quota (Table 1), indicating that the feeding schedule was essentially designed for *ad libitum* intake. However, with an average of 3.02 feeds per day (Table 3), this quantity was distributed over a greater number of meals compared to the two offered in the manual feeding technique, thereby facilitating more regular feeding intervals. This higher feeding frequency is in accordance with previously observed feeding patterns in bovine calves (Svensson and Jensen 2007; Knauer et al. 2016; Sutherland et al. 2018) and is an indicator of animal welfare, as it meets the natural needs of calves and is associated with higher growth rates (Costa et al. 2016; Shivley et al. 2018). As expected, the daily quantity of milk consumed increased with calves' age ($R^2 = 0.80$, $p < 0.001$; $n = 36$), thereby indirectly confirming that the calves had adapted well to the system (Svensson and Jensen 2007). At the end of the cycle, milk intake was still above 8% of live weight, while the average starter intake was 0.64 ± 0.13 kg per day. In a survey of 70 buffalo farms in southern Italy, De Rosa et al. (2017) reported an average daily milk replacer intake of 4.8 L (range 2-8 L), with hay and concentrate offered starting at around 18 days old. The mean age at weaning was 88 days (range 60-120 days), with calves averaging 77 kg (range 50-115 kg) in weight. The typical practice of separating calves from their mothers at an early age (up to three days old) and limiting their access to milk replacer likely leads to nutrient deficiencies in some calves, which could result in reduced weight gain. This is evidenced by the lower than expected body weights at weaning.The average daily suckling rate per calf was found to be 0.31 ± 0.04 L/min, which increased with animal age ($R^2 = 0.89$, $p < 0.001$; $n = 36$), consistent with findings observed in bovine calves (Jensen 2004). The observed time per feeding, at 5.7 ± 0.60 min/meal, was similar to values reported for bovine calves fed by AMF (Roth et al. 2009). As the average feeding time is longer for calves fed by their mothers than for those fed MMF (Singh et al. 2018), this suggests that AMF more closely aligns with natural feeding behaviours.

The calves spent an average of 41.7 ± 1.6 days in the preweaning facility (Table 3). The average amount of milk consumed per calf (257.4 ± 50 L) and the average daily amount of milk per calf (6.65 ± 1.14 L) were greater than those reported by Abbas et al. (2017) for buffalo calves using the MMFs during an 8-week preweaning period. Although these increases can be attributed to several factors, including the length of the pre-weaning period, calf genetics, milk dose, and daily feeding frequency, they are also indicators of good adaptation of buffalo calves to the AMF system.

Health and growth of calves

No deaths, severe diarrhoea, or severe respiratory disease were recorded for the young buffalo calves during the entire observation period. A total of 97 days with clinical signs were recorded, representing 4.44% of the entire period. This observation further confirms lower disease and mortality rates in individually housed dairy calves during the pre-weaning period compared to group housing, highlighting the importance of considering this approach given typically higher mortality rates on Italian buffalo farms compared to cattle farms (Zucali et al. 2013; Magrin et al. 2021; Lotito et al. 2023). The calves had an average body weight gain of 43.2 ± 2.8 kg and an ADG of 1.0 ± 0.06 kg/day (Table 3), which is consistent with an optimal growth rate for buffalo calves (Vecchio et al. 2013; Mota-Rojas et al. 2022). This rapid pre-weaning growth was likely attributable to the high milk feeding strategy adopted by the farmer with a slow gradual milk reduction as reported in Table 1. In addition, according to Jafari et al. (2021), calves fed at a higher frequency of two meals per day exhibit higher growth due to increased milk intake. Finally, AMF enables milk to be freshly prepared at each feeding time and maintained at a consistent temperature, thereby preventing chemical or biological alterations and preserving milk quality, which is crucial for maintaining calf health and facilitating optimal growth (Jafari et al. 2021).

Efficiency parameters

As illustrated in Table 4, which reports the variables assessed to evaluate system efficiency, the AMF operated for an average of 18 h per calf during the pre-weaning period including feeding time, refusal time, and cleaning cycles. Based on the operational time, the calculated power consumption from the machine specifications of 5 kWh, and the average Italian electricity price (€0.13/kWh in 2023), the estimated electricity cost per calf for the pre-weaning period is approximately €11.70. This relatively low operational cost becomes even more favourable considering that AMFs reduce workload, with labour costs in Italy estimated at €7.30 per hour (Serrapica et al. 2021). This suggests that AMFs could be a cost-effective solution for buffalo calf rearing, offering economic advantages alongside potential benefits for animal feeding, health, and herd management.

Conclusions

Despite being derived from a single on-farm study, the use of AMF during buffalo calf weaning yielded positive results. Calves demonstrated a high adaptation rate to the AMF system, as evidenced by high milk intake (on average 6.7 kg/d), a daily weight gain increase (about 1 kg/d), the shift towards a more frequent feeding pattern (3.02 feedings/day) compared to the traditional manual methods (2 feedings/day), and an absence of significant health issues. Observed increased milk intake and weight gain suggest that AMF systems can effectively support buffalo calf growth during weaning. The more frequent feeding pattern facilitated by AMF may also contribute to rumen development and digestive health in calves, potentially mimicking a natural feeding pattern.

Future studies with larger sample sizes should investigate the optimal number of feedings offered per day and the appropriate milk allowance for the different stages of calf development to maximise the labour-saving benefits of AMF and ensure the systems meet the specific needs of buffalo calves. Additionally, long-term studies are necessary to assess the overall impact of AMF on buffalo heifer welfare and productivity. Finally direct comparison between AMF and MMF would allow for a more comprehensive understanding of AMF's efficacy in buffalo calf rearing.

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Ethical approval

The study did not require Animal Care and Use Committee approval as the data were obtained through remote sensing and routine weighing of calves on the farm. The authors did not have direct control over the care of the animals used in this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Data availability statement

The datasets of this study are available from the corresponding author upon reasonable request.

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