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Estimating performances of dairy buffaloes in a new model of automated milking system

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Abstract

Background In recent years automatic milking systems (AMS) have emerged as a technology that can improve traditional milking routine. AMS offer several benefits, such as regular milking routine, health of the mammary glands and labour efficiency, higher milk yield (MY), and quality. In contrast with dairy cows, the application of AMS in dairy buffalo herds remains underexplored. This study aimed to extend the current knowledge regarding AMS and evaluate for the first time the efficiency of new AMS models in buffalo species on a wide dataset, by focusing on MY and quality. Two sources of data were analysed: data collected at each milking by the AMS software for a duration of 22 months, and monthly milk yields and quality traits. The statistical analysis was performed through the R software. A mixed model for repeated measures was adopted, using days in milk (DIM) and parity as fixed factors and the visit/day of sampling as repeated measure. A linear regression model was also used to study the relationship between the number of milking per buffalo per day (as independent variable), lactation persistency, DIM, parity, somatic cell score (SCS), and MY (as dependent variables).

Results The effects of parity, DIM and their interaction were significant for all milk quality traits (monthly recordings), except for their interaction on somatic cell count (SCC) and SCS. An average of 2.35 milkings/buffalo was recorded, with a mean milking duration of 7.36 min. The average MY was 9.15 kg/day, with 7.97% and 4.81% fat and protein content, respectively and the lactation peak occurred at 38.17 ± 1.31 DIM. The difference between multiparous and primiparous was clear in terms of both MY and energy-corrected milk (ECM). Also, parity and DIM significantly influenced both average milk flow rate (1.49 kg/min on average) and peak milk flow rate (2.68 kg/min on average): these showed a comparable trend describing higher values during the first days in milk followed by a decrease throughout the lactation, along with a decreased milk production.

Conclusions The present study was the first to investigate new model of AMS in buffalo species in a large dataset providing insight into the new model of AMS as an effective milking system for buffalo species. Still, further research is encouraged to confirm these findings, as well as to compare the performances of different automatic milking systems, possibly under different management practices and environmental conditions.

Keywords Precision livestock farming, Italian mediterranean buffalo, Milk quality, Milking performance, Buffalo husbandry

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Background

The dairy industry is constantly evolving and in recent years automatic milking systems (AMS) have emerged as one of the most common innovative technologies that can implement traditional milking practices. As from the use of the first milking robot in 1992 in Netherlands [1], the technology has been widely investigated and improved by using sensors, lasers and cameras in dairy farming. AMS offer several benefits such as consistent milking routine, health of the mammary gland, and labour efficiency [2–4]; in addition, some studies have been reporting higher milk yield and quality [5]. Therefore, the use of AMS seems to improve the overall efficiency of the industry (6–7).

While the use of AMS in dairy cows has been extensively studied, its use in dairy buffalo herds still needs to be expanded and requires further investigation. Dairy buffalo breeding is a steadily growing sector in the Italian dairy industry, especially due to the raising importance of traditional dairy products such as "Mozzarella di bufala Campana PDO" [8]. For this reason, as for dairy cattle, great attention is being paid to milking, which is pivotal in the management of these animals. The first AMS was installed in a buffalo farm in southern Italy in 2008 [9], and currently only four buffalo farms in Italy are equipped with AMS. Previous studies on buffaloes indicate that AMS improves the productive performance of Italian Mediterranean buffaloes in both quantitative and qualitative traits and increases animal welfare thanks to voluntary milking [9]. The buffaloes milked with robots showed higher concentrations of proteins in milk, especially casein, and lower somatic cell count values [9]. However, factors hindering the widespread adoption of AMS in dairy buffalo herds include limited research into suitable milking techniques for this species [10] and inadequate selection for mammary gland morphology, which differ significantly from bovine udder and is critical for efficient teat attachment (11–12). To address this challenge, recent advances have been developed in AMS technologies, such as teat position detection mechanisms; as a matter of fact the latest generation of milking robots is equipped with a digital camera and a laser triangulation sensor system to accurately determine teat position [13].

Furthermore, unlike dairy cows, buffaloes have been described to be very sensitive to environmental and milking routine changes and differences in milking equipment [10]. As a matter of fact, sensitivity to environmental stimuli of buffalo species throughout the milking procedure has been linked to interrupted milk ejections and unstable blood oxytocin levels [12]. Since AMS systems are still not widely investigated in Italian Mediterranean buffaloes, this study aimed at extending the existing knowledge on the use of AMS in dairy buffalo and to evaluate for the first time the efficiency of new AMS models in buffaloes using a large dataset, focusing on milk quantity and quality traits, and milking performance, namely AMS labour parameters.

Methods

Ethics approval and consent to participate

The approval of the Animal welfare and use Committee was not required for this study. All data were collected from pre-existing databases during routine animal recording procedures and standard controls of milking. Written informed consent was obtained from the owner of the animals.

Animals and farm management

Animal welfare approval was not needed for this study because data came from pre-existing databases. Data were collected during a 22-months period (January 2021 to October 2022) at an organic buffalo farm (40°27′N, 15°01′E, 31 m above sea level) in Campania region (southern Italy). The buffaloes were maintained in a stall divided into 4 sectors (40 × 32 m), each provided with a robotic milking machine (De Laval VMS300, De Laval, Tumba, Sweden) as follows: AMS1 serving 40.84 ± 1.86 buffaloes/day, AMS2 30.91 ± 2.81 buffaloes/day, AMS3 44.29 ± 2.49 buffaloes/day, AMS 4 40.40 ± 2.14 buffaloes/day. A selection gate between pen and milking robot allowed buffaloes to be milked if a minimum time interval of 7 h elapsed between 2 consecutive milkings, otherwise, animals were redirected to the feeding area. Dairy buffaloes were housed in mat-lined free stalls barns with concrete floors and were fed ad libitum a total mixed ration (TMR) provided once a day (07.30 to 09.00 h) and pushed into the feeding trough twice a day. The buffaloes that were allowed to be milked could enter the waiting area facing each AMS and then moved to the milking box; otherwise, they were rejected and directed to the feeding area. The AMS used the standard configuration for dairy cows: the working parameters were 42 kPa vacuum, 60 cycles/min, and 60% pulsation ratio, as reported by Caria et al. [14]. The concentrate feed administered in the milking station to each buffalo ranged between 0.5 and 3.0 kg/day based on daily milk yield.

Data collection

Two sources of data were available: D1) data collected during each milking by the AMS herd management software (DeLaval DelPro, DeLaval), and D2): monthly milk yields (measured using milk metres) and milk quality traits (determined by mid-infrared spectroscopy using a MilkoScan FT6000 (Foss Electric A/S, Hillerod, Denmark)) provided by the official milk recording service of the Italian Breeders Association (AIA, Associazione Italiana Allevatori). Then, two datasets were analyzed.

D1 included: buffalo identification number (RFID), parity, date of calving, days in milk, date and time of buffalo identification, refusals (non-milking visit to the AMS as no./buffalo/day, namely events when the system refuses to milk a buffalo that entered the milking box), milk yield (MY; kg/milking), milking duration (time between the buffalo identification and the last teat-cup detachment (min), milking interval (time between the beginning of 2 consecutive milkings for the same buffalo, h); average milk flow rate (kg/min), peak milk flow rate (kg/min). The last two parameters were recorded per single quarter and the sum of the four quarter was calculated by adding the single values. The initial dataset (D1) was edited for missing information and implausible data (values lying 3 standard deviations below/above the average working parameters of the AMS): a milking interval of < 1 h or > 24 h was discarded [15], as were data for yields of < 0.5 kg, or a milking duration of < 60 s. Finally, only milking sessions including a successful attachment of 2 or more teat-cup were considered. The final AMS dataset consisted of 244,536 milking records from 448 buffaloes.

D2 consisted of monthly milk quantity and milk quality traits collected as test-day and included milk yield, fat and protein content (expressed both as percentage and effective yield in kg), energy corrected milk, somatic cell count (SCC), and somatic cell score (SCS). Also, in this case the initial dataset was edited for missing information and implausible data (values lying 3 standard deviations below/above the average buffalo milk traits), and the final dataset consisted of 4,403 records from 448 buffaloes. Both datasets were also edited by restricting from 5 to 300 DIM and first to seventh parity.

Energy corrected milk (ECM = 740 kcal) was calculated according to the formula from Campanile et al. [16]:

$$ECM = milk\ yield \times \{[fat\ (g/kg) - 40 + protein\ (g/kg) - 31] \times 0.01155\} + 1 \quad (1)$$

SCC was log-transformed into SCS using the formula proposed by Ali and Shook [17]:

$$SCS = \log_2\left(\frac{\mathrm{SCC}}{100}\right) + 3 \quad (2)$$

Statistical analysis

The distance from calving was expressed as 10 classes based on 30 days in milk (DIM) intervals (class A from 1 to 30; class B from 31 to 60; class C from 61 to 90; class D from 91 to 120; class E from 121 to 150; class F from 151 to 180; class G from 181 to 210; class H from 211 to 240; class I from 241 to 270; class L from 271 to 300). Parity was grouped into 5 classes, where 5 + parity included animals that were in their 5th or greater parity (maximum parity number 7). Descriptive statistics (n, arithmetic mean, standard deviation) were calculated for all the variables included in the model. The compliance of the data with the assumption of normality and homogeneity of variances were assessed via Shapiro-Wilk and Levene's tests, respectively. The statistical analysis was performed with the R vers. 3.4.0 for Windows 11 and the packages car, lmer, lmerTest [18], lme4, emmeans [19], ggplot2 were used. D1 was studied adopting a linear mixed model for repeated measures where the class (DIM) and parity were considered between subject factors and the visit was the repeated measure. Similarly, quantity and quality parameters included in D2 were analysed by a linear mixed model for repeated measures where the class (DIM) and parity were between subject factors and day of sampling was the repeated measure. In both models the animal was the random factor, the interaction between classes of DIM and parities was also studied and the Tukey's test was used to adjust the comparison. The lactation persistency was calculated as the rate of decline in daily yield after the peak of lactation [20] and a linear regression model was used to study the relationship between the number of milkings per buffalo per day (as independent variable), the lactation persistency, DIM, parity, SCS and MY (dependent variables). Unless otherwise stated the results are expressed as estimated marginal means ± standard error. Significant statistical differences were declared at $p \leq 0.05$.

Results

The descriptive statistic of the parameters recorded by the AMS as the sum or average of the values of the 4 quarters and milk quality traits are summarised in Table 1. Specifically, the lactation peak occurred at 38.173 ± 1.310 days of lactation and the average number of refusals per day was 1.221 ± 0.001.

The effects of parity and days in milk, and their interaction were significant for all the variables included in D1 and are reported in Table 2. In particular, peak milk flow rate and average milk flow rate were strongly influenced by parity and DIM.

The number of milking per buffalo per day and the milk yield (kg/day) according to parity are reported in Table 3, the highest values were recorded for third and fourth parity buffaloes.

The trend of the number of milking per single buffalo per day across the classes of DIM and parities is displayed in Fig. 1, with primiparous buffaloes showing the lower trend, particularly from class E (150 DIM) onwards.

The following equation describes the relationship between milkings (number of milkings per buffalo at the test day), milk yield (kg/day), lactation persistency (%), DIM, parity, and SCS:

Table 1 Descriptive statistic of the functioning parameters of the AMS for all the milking sessions considered in the trial and monthly quality traits recorded throughout the trial

Variables	Mean	SEM[1]
D1) Data collected during each milking by the AMS herd management software		
DIM[2]	131.864	0.170
Parity	2.723	0.003
Lactation peak (day)	38.173	1.310
Average milk flow rate (kg/min)	1.493	0.001
Milking duration (min/milking)	7.366	0.005
Milkings (no./buffalo per day)	2.352	0.003
Refusals (no./buffalo/day)	1.221	0.001
Peaks milk flow rate (kg/min)	2.679	0.001
Milk yield (kg/milking)	3.970	0.004
D2) Monthly milk quantity and milk quality traits collected as test-day		
Milk yield (kg/day)	9.147	0.065
Fat content (%, day)	7.978	0.030
Protein content (%, day)	4.813	0.008
SCS[3]	1.929	0.006
SCC ($\times 10^3$ cells/ml) [4]	105.595	4.414
Energy Corrected Milk	14.614	0.093
Effective milk yield (kg)	1648.784	15.209
Effective fat content (%)	7.095	0.015
Effective fat content (kg)	120.926	1.179
Effective protein content (%)	4.611	0.005
Effective protein content (kg)	76.423	0.7118

[1]SEM= Standard error of the mean

[2]DIM= Days in milk

[3]SCS= Somatic cell score

[4]SCC = Somatic cell count

Table 2 The F-value and significance of fixed effects are included in the analysis for the functioning parameters of the AMS

Trait	Parity	DIM[1]	Parity × DIM
Peak milk flow rate (kg/min)	1473.955 ***	3010.873 ***	46.417 ***
Average milk flow rate (kg/min)	2415.375 ***	5890.733 ***	58.777 ***
Milk yield (kg/milking)	927.130 ***	8595.632 ***	180.722 ***
Milking duration (min/milking)	2532.927 ***	191.272 ***	35.556 ***
Milkings (no./buffalo per day)	170.600 ***	469.492 ***	12.858 ***
Refusals (no./buffalo/day)	434.872 ***	33.550 ***	60.078 ***

[1]DIM= Days in milk

***= $p < 0.001$

Milkings (no./day/buffalo) = 2.024 + 0.004 (lactation persistency) + 0.072 (Milk yield)– 0.010 (Days in milk) + 0.004 (Parity)– 0.027 (SCS);

$$R^2 = 0.310 \tag{3}$$

Table 3 Descriptive statistic of the number of milking per Buffalo per day and milk yield according to parity throughout the trial

Parity	Milkings no/buffalo/day	SEM[1]	Milk yield (kg/day)	SEM
1	2.122	0.005	6.560	0.019
2	2.234	0.005	9.568	0.028
3	2.352	0.005	10.173	0.034
4	2.487	0.008	10.186	0.049
5^+	2.281	0.027	9.80	0.715

[1]SEM= Standard error of the mean

Since parity and DIM significantly influenced both average milk flow rate and peak milk flow rate, the average trend for average milk flow rate and peak milk flow rate across the classes of DIM and the parities are showed in Fig. 2: these parameters showed a comparable trend describing higher values during the first days in milk followed by a decrement later in the lactation, along with a decreased milk production. Moreover, higher average milk flow rate values were observed in multiparous buffaloes.

The effects of parity and days in milk, and their interaction on all the variables included in D2 are reported in Table 4. The interaction between the two effects was significant for most of the milk quality and quantity traits but SCC, SCS, effective fat, and protein contents (as percentages).

The average trend for milk yield (kg/day), ECM, fat and protein content (%), and SCS across DIM and parity can be observed in Fig. 3. Multiparous buffaloes had higher daily milk yields than primiparous in each class of days in milk except for the last one (L). Also, fat content increased across lactation and the trend for protein content was specular to milk yield with a nadir around 60 DIM and highest values from class H on. The energy-corrected milk overlapped the trend of the milk yield, with a zenith between 60 and 90 DIM and a decreasing pattern afterwards (Fig. 3).

Discussion

Previous research indicated that milking robots in buffalo farms perform comparably or better than traditional milking systems [9]. Recently, the discovery of new and more innovative sensors with better performances has enabled further development of more sophisticated AMS [21]. In particular, a preliminary study [13] conducted over a seven-month period in an Italian Mediterranean buffalo farm in southern Italy, highlighted significantly higher daily milk yield after switching from an older model of DeLaval® milking robot (DeLaval Classic) to a more recent one (the DeLaval VMS300). However, to our knowledge, there is little information available on Mediterranean buffaloes milked through the new AMS. So,

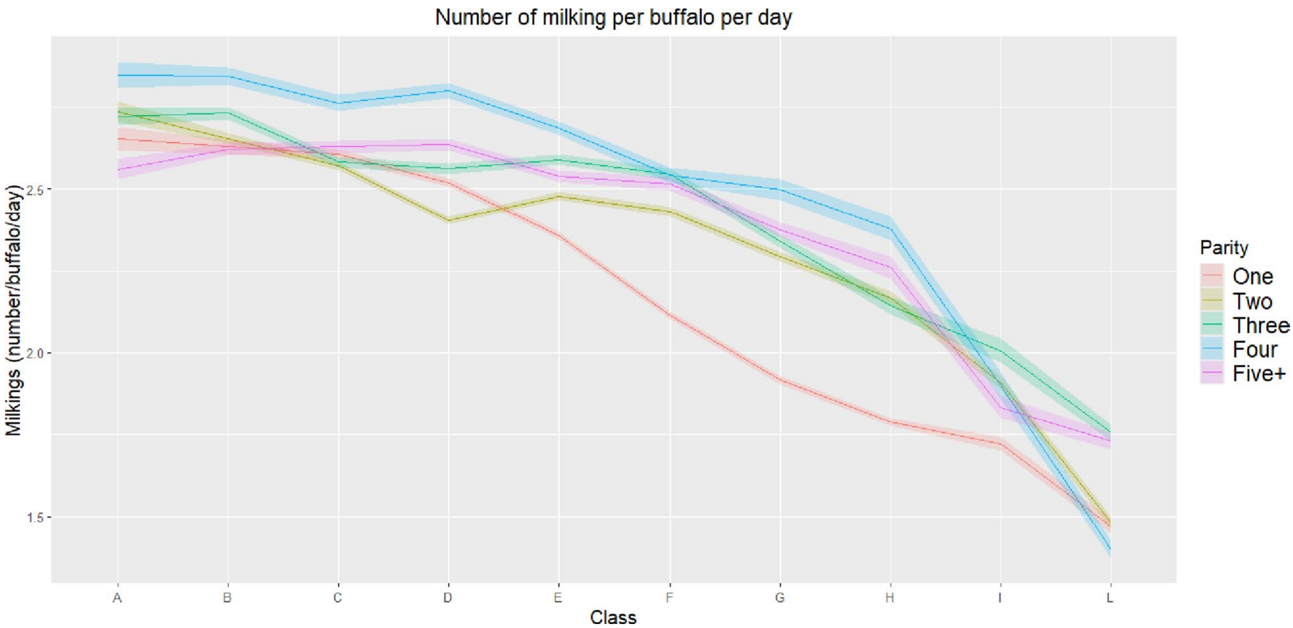

Fig. 1 Trend for the number of milkings (arithmetic means, no./buffalo per day) across classes of days in milk (DIM) and parity (1–5+) in the Italian Mediterranean Buffaloes ($n = 244{,}536$). Class A from 1 to 30; class B from 31 to 60; class C from 61 to 90; class D from 91 to 120; class E from 121 to 150; class F from 151 to 180; class G from 181 to 210; class H from 211 to 240; class I from 241 to 270; class L from 271 to 300 DIM

the present study focused on a new model of AMS and dairy buffaloes' productivity.

The number of animals per automated milking system per day complied with the standard milking capacity of the robot [22], as a matter of fact, a single robot has been reported to have a milking capacity of about eight milkings/hour [23]. The average number of refusals/buffalo/day recorded in the present study was also in line with what has been described in other studies on dairy cows (24–25). In general, milk refusals in cows milked by the AMS increase in the first week after calving and decrease gradually reaching a plateau, this may be due to increased activity after calving or increased concentrate intake in the robot to meet productive requirements (25–26). However, since no direct comparison of refusals is available for Italian Mediterranean Buffalo species, this aspect should be further investigated in future research.

As for milk traits, daily milk yield, ECM, and milk composition recorded in the present trial were consistent with the species-specific physiological values reported in previous studies in both the Italian Mediterranean (27–28) and Murrah buffaloes [29], suggesting the reliability of both data recording and editing.

In particular, the effects of parity, DIM, and their interaction were significant for all traits, except for their interaction on SCC and SCS. MY reached the peak at 38.17 ± 1.31 DIM and gradually decreased in the following months. For both MY and ECM, the difference between multiparous, more productive animals and primiparous was evident. In particular, the third-calving buffaloes were the most productive within the multiparous, as also found in other studies conducted in buffalo species (27–28). Conversely, an opposite trend was recorded for fat content and protein content of milk, with higher values observed in primiparous compared to multiparous. It is likely that a dilution effect may have contributed to this result, since primiparous buffaloes are the less productive in terms of milk yield, therefore the higher production of the multiparous end up lowering both protein and fat contents of milk, as previously reported by Costa et al. [27].

According to previous studies, several factors can influence the number of milkings, namely the age of the animals, adaptation to the robot and farm management in general (30–31). In particular, several studies have investigated how a higher number of milkings can lead to an increase in milk production whether a conventional milking system [32], an indoor AMS [33] or a pasture-based AMS [34] were employed. In our study, the average number of milkings per buffalo per day was comparable to the result reported for buffaloes by Caria et al. [14] (2.35 ± 0.0 vs. 2.3 ± 0.2) and slightly lower than other studies on dairy cows (35–36); the latter may be related to the higher milk production of this species compared to buffaloes. In our study, a strong influence of milk yield on the number of milkings was observed. In addition, the number of milkings was also influenced by parity and stage of lactation: it was the highest at the beginning of lactation and decreased subsequently following different trends depending on parity. Namely, third calving animals showed a higher number of milkings per day compared to the first and second-calving animals. The

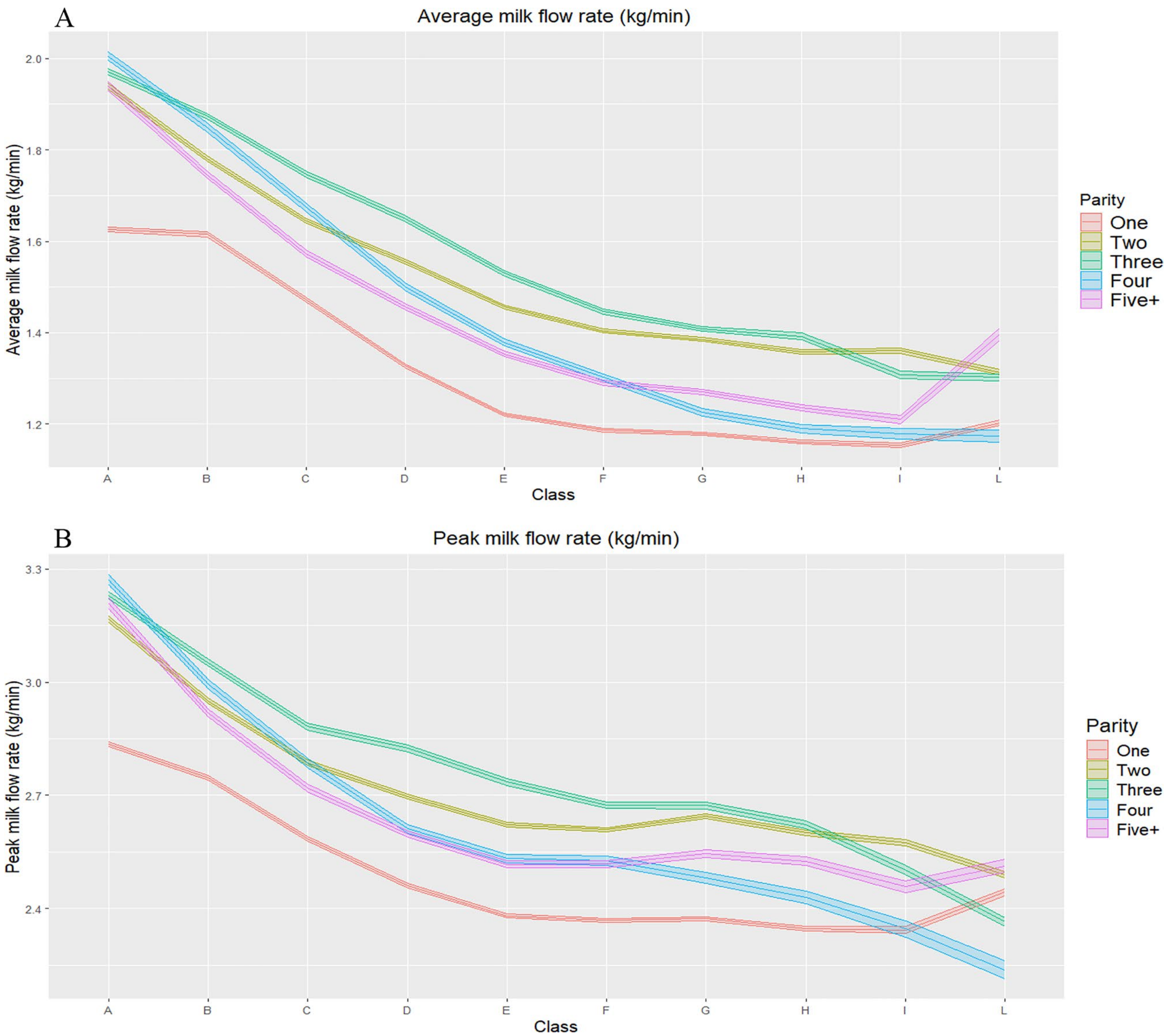

Fig. 2 Trend for milk flow peaks (panel **A**) and milk flow rate (panel **B**) (arithmetic means, (kg/min)) across classes of days in milk (DIM) and parity (1– 5+) in the Italian Mediterranean Buffaloes. Class A from 1 to 30; class B from 31 to 60; class C from 61 to 90; class D from 91 to 120; class E from 121 to 150; class F from 151 to 180; class G from 181 to 210; class H from 211 to 240; class I from 241 to 270; class L from 271 to 300 DIM

decrement in the number of milkings along with DIM could be explained either by the milk yield dropping or by the lower concentrate intake later in the lactation compared to the early stages [30]. Pettersson et al. [37] also observed that a high milking frequency during early lactation was associated with an increased milk production peak, especially in multiparous dairy cows. They also reported an improved lactation persistency, which led to an increment of 21% in milk yield throughout lactation. The positive effect of a higher number of milkings on lactation persistency has also been described in other studies (38–39), supporting the positive effect of the AMS.

Similarly, the average milk flow rate observed in this study was comparable to that observed by Caria et al. [14] in buffaloes and by Zucali et al. [40] in cows. On the other hand, the peak milk flow rate was similar to that reported by Verde et al. [13] in buffaloes and lower than dairy cows (40–41). The latter could be due to the lower production of buffalo species and to the different morphology of the mammary glands. As a matter of fact, the cisternal fraction of milk is lower in buffaloes than dairy cows while the teat is longer and firmer [12–42]. For this reason, average milk flow rate, peak milk flow rate and milk yield could end up being altered when a proper stimulation of the udder didn't occur [10].

In our study, parity and DIM significantly influenced both average milk flow rate and peak milk flow rate. In particular, these parameters showed a comparable trend

Table 4 F-value and significance of fixed effects included in the analysis for the quality parameters of milk

Trait	Parity	DIM[1]	Parity×DIM
Milk yield (kg/day)	133.069 ***	753.032 ***	12.316 ***
Fat content (%, day)	0.561	165.886 ***	1.605 *
Protein content (%, day)	0.915	175.663 ***	2.407 ***
SCC[2]	3.149 *	2.277 *	0.939
SCS[3]	5.505 ***	6.912 ***	1.116
ECM[4]	113.771 ***	376.376 ***	8.557 ***
Effective milk yield (kg)	149.791 ***	3107.404 ***	20.682 ***
Effective fat content (%)	3.188 *	152.511 ***	0.518
Effective fat content (kg)	120.361 ***	3035.267 ***	20.792 ***
Effective protein content (%)	1.193	58.282 ***	0.745
Effective protein content (kg)	143.678 ***	3183.41 ***	20.575 ***

[1]DIM= Days in milk

[2]SCC = Somatic cell count

[3]SCS= Somatic cell score

[4]ECM= Energy Corrected Milk

*= $p < 0.01$

*** $p < 0.001$

describing higher values during the first days in milk followed by a decrement later in the lactation, along with a decreased milk production. Similar effects of DIM on milk flow have been reported for cows [40]. As already observed in other studies on dairy cows [41, 43], higher milk flow values were observed in multiparous buffaloes. This could be explained by the lower secretory and milk storage capacity of primiparous compared to multiparous animals that end up affecting milking flow [44]. Particularly, the highest values were recorded in third parity buffaloes, and lower values in primiparous, as previously reported in Italian Mediterranean buffaloes by Costa et al. [27]. Therefore, it is likely that after third parity udder health issues occur, which is also underlined by the trend of SCS across parities decreasing production and milk flow. The interaction between parity and DIM was previously reported by other studies [41, 45] too. In particular, Bagnato et al. [45] observed a rise of the milk flow peak by about 0.5 kg/min during lactation in Brown Swiss primiparous cows, while multiparous showed a decrease of about 0.85 kg/min between the beginning and end of lactation. On the contrary, the average milk flow rate and peak milk flow rate across the lactation recorded in the present study showed a decrement in both multiparous and primiparous buffaloes, noteworthy the latter were characterized by a smoother trend. Bagnato et al. [45] argued that the difference between different parities across the lactation may be due to several factors, including the stress of first milkings, the adaptation period needed for mammary myoepithelial cells to fully reach their functionality, and oxytocin receptors and their functionality. Hence, further research is encouraged to confirm milk flow trend across lactation in Italian Mediterranean Buffaloes.

Interestingly, the SCS in our study was lower than other studies conducted either on traditional milking systems [27] or AMS [9], but consistent with Verde et al. [13] who reported somatic cells of the buffaloes milked with both the old and new AMS models. The SCC is the most adopted indicator of udder health in livestock worldwide and a strong relationship has been reported between SCC and mastitis in buffaloes [27]. Nevertheless, According to EU Regulation no. 853/2004 [46], an SCC limit exists only for bovine bulk milk, evidencing a lack of threshold in buffaloes.

It must be underlined that several other factors, such as farm management, could influence udder health and milk quality, as already described by Kolenda et al. [5] in dairy cows. In particular, the influence of farm has been reported to influence milk quality regardless of the milking system used [5], therefore the comparison with previous studies must consider the different field conditions. Overall, the effects of AMS on milk quality are very conflicting in the literature. Some studies reported that the cleaning techniques and higher milking frequency associated with AMS would allow a more frequent removal of bacteria and prevent the colonisation of the udder [2]. Conversely, other studies suggest that the increase in the number of milkings could be responsible for udder damage and the increase in SCS [47]. Also, SCS can be influenced by parity and DIM [5]: SCS increases continuously according to lactation and parity, as observed in previous studies on buffaloes [27] and cows [48]. Our results are consistent with the significant influence of parity and days in milk on SCC and SCS, confirming the detrimental effect of these factors on somatic cells of buffalo milk. The reasons may be found in the poorer udder health of multiparous animals compared to their primiparous counterparts, which have been exposed to the stress of the milking procedure over a longer period. Eventually, our study highlighted an appropriate SCS level confirming the potential of automatic milking system in the optimization of milking process and improvement of udder health for buffalo species too.

Conclusion

This was the first study to demonstrate the potential of the new AMS system in buffalo species in a large dataset, recording satisfactory performances and high milk quality. The absence of established reference values for buffalo species implies cautious interpretation of the results and further research should aim at validating and expanding the present findings. In conclusion, the present study provided valuable insights into AMS as a promising system for milking Italian Mediterranean buffaloes.

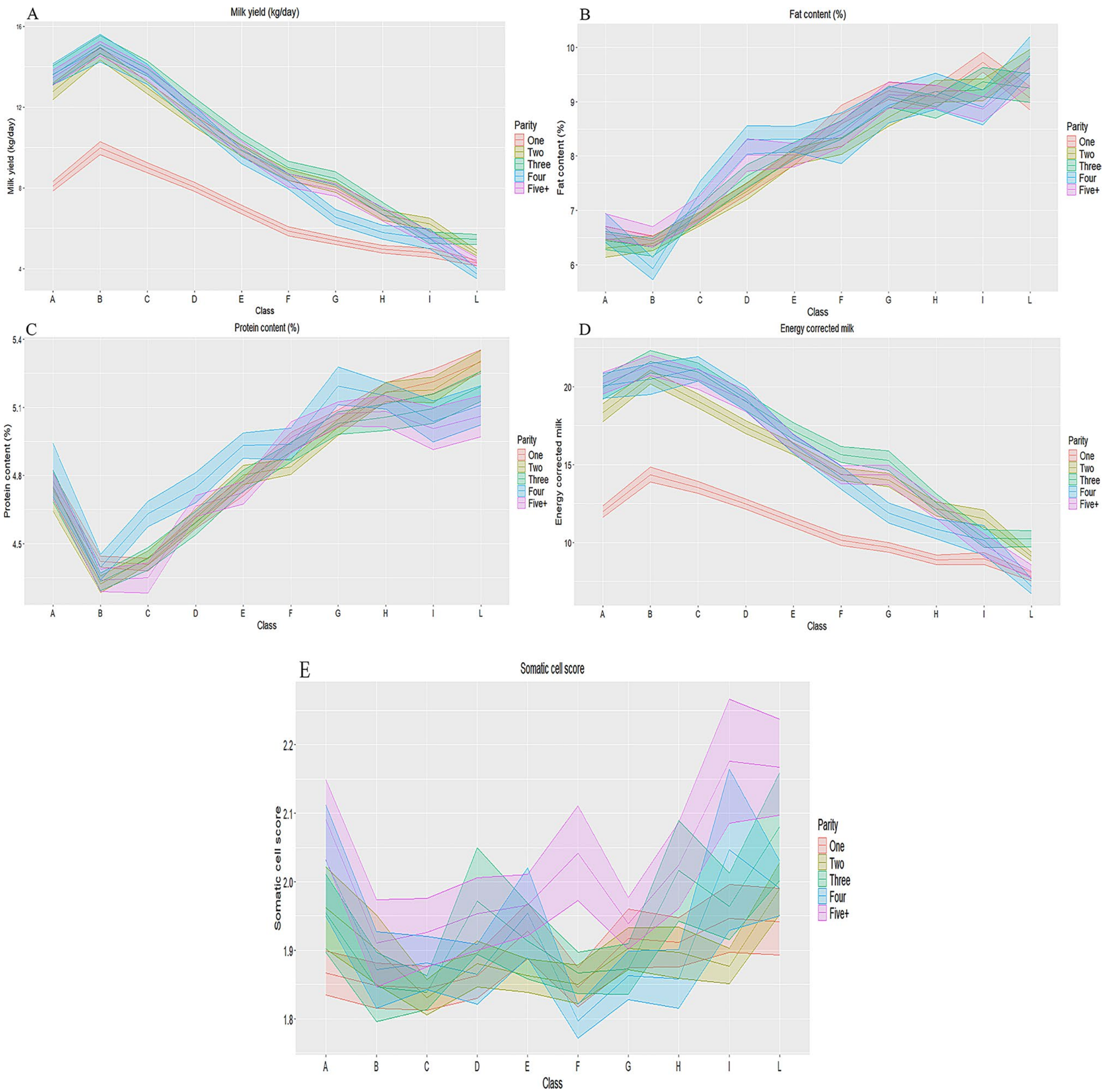

Fig. 3 Trend for milk yield (kg/day, panel **A**), fat and protein content (%, panels **B** and **C**, respectively), energy corrected milk (arithmetic means, panel **D**) and SCS (panel **E**) across classes of days in milk (DIM) and parity (1–5+) in the Italian Mediterranean Buffalo. Class A from 1 to 30; class B from 31 to 60; class C from 61 to 90; class D from 91 to 120; class E from 121 to 150; class F from 151 to 180; class G from 181 to 210; class H from 211 to 240; class I from 241 to 270; class L from 271 to 300 DIM

Abbreviations

AIA	Associazione italiana allevatori (Italian Breeders Association)
AMS	Automated milking system
DIM	Days in milk
ECM	Energy corrected milk
MY	Milk Yield
PDO	Protected designation of origin
SCC	Somatic cell counts
SCS	Somatic cell score

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Author contributions

R.M.: Methodology, Investigation, Writing-original draft. G.B: Investigations, data curation, review and editing. A.C.: Investigations, data curation, data analysis, Writing-original draft. M.T.V.: Investigation, Writing - review and editing. A.C.M.: Conceptualization, Writing - review and editing. G.C.: Conceptualization, review and editing, supervision, funds acquisition. G.N.: Conceptualization, investigations, review and editing, supervision, funds acquisition. All authors reviewed the manuscript.

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Data availability
The dataset(s) supporting the conclusions of this article is (are) available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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