SEMINA
Ciências Agrárias

DOI: 10.5433/1679-0359.2025v46n5p1465

Dairy cow behavior in a robotic milking system

Comportamento de vacas leiteiras em sistema de ordenha robótica

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Highlights

Eating and rumination times increased with lactation period in Holstein cows.
Concentrate efficiency (kg milk per kg concentrate) decreases with eating time.
Increase in rumination time led to an increase in concentrate efficiency.
Milk yield was increased by the concentrate intake inside the milking robot.

Abstract

Automatic milking systems (AMS) have been adopted by farmers owing to reduced labor availability on dairy farms and improve welfare of dairy cattle. Considering the lack of knowledge about the relationship of milk yield and production efficiency with cow behavior, this study aimed to evaluate the effect of feeding behavior on milk production in an AMS herd. A total of 20234 data points collected from 52 Holstein lactating dairy cows (body weight = 650 ± 15 kg, parity = 2.3 ± 1.1, and 156 ± 65 days in milk [DIM]) housed in a compost barn were analyzed. One robot (Lely Astronaut A3 – Lely®) was equipped in the barn for all cows. Cows were fed a partially mixed ration in a bunk and received 3 kg of pelleted concentrate per milking inside the robot. Feeding behavior was recorded using an electronic system (QWES HR-LD tag – Lely®) attached to a collar around the neck of the cow. The behavioral variables included the daily time spent eating and ruminating. The productive variables included milk yield, concentrate intake inside the robot, and concentrate efficiency (kg of milk produced per kg of concentrate ingested). Cows were categorized into two classes based on eating time (Low, <270 min day^{-1} and High, ≥270 min day^{-1}) and three classes based on rumination time (Low, <550 min day^{-1}; Medium, ≥550 min day^{-1} and <590 min day^{-1}; and High, ≥590 min day^{-1}). Cows that spent more time eating had reduced milk yield and concentrate

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Received: Apr. 30, 2025 Approved: Sept. 29, 2025

intake inside the robot but increased concentrate efficiency. They also had higher DIM. The rumination time was similar between the eating time classes. The eating time, milk yield, concentrate intake inside the robot, and concentrate efficiency were similar among the rumination time classes. However, cows that spent more time ruminating had higher DIM, and concentrate efficiency was positively correlated with rumination time. The time spent eating by dairy cows in the AMS is positively correlated with DIM and affects milk yield. An increase in rumination time occurs mid-lactation onward and improves concentrate efficiency in terms of milk production.
Key words: Automatic milking system. Concentrate efficiency. Eating time. Milk yield. Rumination time.

Resumo

Devido a diminuição da disponibilidade de mão de obra em propriedades leiteiras e a preocupação com o bem-estar das vacas, sistemas de ordenha robotizada (SOR) têm sido adotados pelos produtores. Considerando o conhecimento limitado sobre a relação da produção de leite e da eficiência produtiva com o comportamento das vacas, o objetivo deste estudo foi avaliar o efeito do comportamento alimentar na produção de leite em rebanho mantido em SOR. Foi analisado um banco de 20234 dados coletados de 52 vacas leiteiras Holandesas em lactação (peso corporal = 650 ± 15 kg, ordem de parto = 2,3 ± 1,1 e 156 ± 65 dias em lactação [DEL]) alojadas em compost barn. Um robô (Lely Astronaut A3 – Lely®) foi instalado no galpão para todas as vacas. Elas foram alimentadas com ração parcial misturada no cocho e receberam 3 kg de concentrado peletizado por ordenha no robô. O comportamento alimentar foi registrado utilizando-se um sistema eletrônico (QWES HR-LD tag – Lely®) acoplado a um colar no pescoço das vacas. As variáveis comportamentais incluíram o tempo diário de alimentação e de ruminação; e as variáveis produtivas incluíram a produção de leite, a ingestão de concentrado no robô e a eficiência de uso do concentrado (kg de leite produzido por kg de concentrado ingerido). As vacas foram categorizadas em duas classes com base no tempo de alimentação (Baixo, <270 min dia^{-1}; e Alto, ≥270 min dia^{-1}) e três classes com base no tempo de ruminação (Baixo, <550 min dia^{-1}; Médio, ≥550 min dia^{-1} e <590 min dia^{-1}; e Alto, ≥590 min dia^{-1}). Vacas que passaram mais tempo se alimentando apresentaram menor produção de leite e menor ingestão de concentrado no robô, mas aumentaram a eficiência de uso do concentrado; elas também apresentaram maior DEL. O tempo de ruminação foi semelhante entre as classes de tempo de alimentação. O tempo de alimentação, a produção de leite, a ingestão de concentrado no robô e a eficiência de uso do concentrado foi semelhante entre as classes de tempo de ruminação. No entanto, vacas que passaram mais tempo ruminando apresentaram maior DEL, e a eficiência de uso do concentrado foi positivamente correlacionada com o tempo de ruminação. O tempo gasto em alimentação por vacas leiteiras em SOR é positivamente relacionado com DEL e afeta a produção de leite. O aumento do tempo de ruminação ocorre do meio para o final da lactação e melhora a eficiência de uso do concentrado para produção de leite.
Palavras-chave: Eficiência de uso do concentrado. Produção de leite. Sistema de ordenha robotizada. Tempo de alimentação. Tempo de ruminação.

Introduction

Milk production (35.4 billion L year^{-1}) is an important pillar of the Brazilian economy (Instituto Brasileiro de Geografia e Estatística [IBGE], 2023). However, the low productivity per cow limits the development of Brazilian dairy production systems. Thus, adopting management practices that improve animal welfare may contribute to improved milk production in the Brazilian dairy industry. Automatic milking systems (AMS) have gained popularity mainly in southern Brazil. These systems provide cows more freedom to express natural individual behavioral activities such as feeding, lying down, and milking (Mattachini et al., 2019), resulting in an increased productivity per cow (Jacobs & Siegford, 2012; Simões et al., 2020). In contrast, cows milked in conventional milking parlors follow specific routines for feeding, milking, and social activities. Furthermore, cows in the conventional herd receive all the nutrients they need from their diets as total mixed rations. In AMS herds, part of the concentrate is provided inside the robot during milking to attract cows to the AMS, which may affect animal behavior (Bach & Cabrera, 2017). According to Jacobs and Siegford (2012), cows in AMS herds have improved welfare, and their milk yield may increase by 12%. These factors are also associated with an 18% decrease in labor costs.

The welfare of dairy cows is an important topic in both the dairy industry and academic community (von Keyserlingk et al., 2009; Nalon & Stevenson, 2019; Leliveld & Provolo, 2020). The assessment of animal behavior is an efficient method to study dairy cow welfare and can be performed in commercial herds using wearable devices. Lying behavior is a useful indicator of health and welfare in dairy cows (Leliveld & Provolo, 2020; Tucker et al., 2021). Furthermore, lying and feeding behavioral patterns are associated with cow productivity. In general, lying behavior is affected by the health status of cows; sick and lame animals tend to spend more time lying down than healthy animals. However, cows with mastitis tend to reduce their lying time owing to pain from the inflamed udder (Fogsgaard et al., 2015; Nalon & Stevenson, 2019). Notably, the lying time varies considerably between cows. Studies have shown that lying time in dairy cows ranges from 6 to 16 h day^{-1} with a daily mean of approximately 11 h day^{-1} (Charlton et al., 2016; Solano et al., 2016; Westin et al., 2016).

Different production systems, such as confinement and pasture, also influence cow lying time with cows in the pasture system exhibiting less lying time compared with those in confinement (Tucker et al., 2021). However, inadequate stall space per cow, floor hardness, stall dimensions, and unfavorable environmental conditions may reduce lying time in confined systems. Winckler et al. (2015) reported that cows in pastures are more likely to lay down at night instead of during the day; however, the diurnal pattern of lying time of cows housed indoors is less apparent. The humidity of the bedding surface also affects the lying behavior. Cows spend more time lying down on dry surfaces (3–5 h more) than on muddy surfaces (Chen et al., 2017).

Rumination is an important digestive process in dairy cattle and other ruminants. According to Beauchemin (2018), ruminants spend 9–12 h day^{-1} ruminating, which is the most pronounced behavior (37.5%–50% per day). In dairy cows, the time spent lying down is associated with rumination (Tucker et al., 2021; McWilliams et al., 2022). A cow in a robotic milking system ruminates between 7 and 9 h per day (Reith & Hoy, 2012) and this activity occurs more frequently at night when the cow lays down.

As suggested by Ben Meir et al. (2018), animal behavioral data, such as lying and rumination durations, can be used to estimate intake and productivity to improve animal efficiency. For instance, Watt et al. (2015) reported that cows under pasture systems with high rumination time are expected to have higher milk and methane production but a lower yield of methane per kilogram of milk. Milk production is positively associated with rumination time (Johnston & DeVries, 2018; Antanaitis et al., 2019). In high-producing Holstein cows, for every 1-h increase in rumination time, milk yield increases by 1.26 kg day^{-1} (Johnston & DeVries, 2018). However, McWilliams et al. (2022) found that in an AMS herd, cows that spent more time ruminating produced milk with higher fat and protein content without changing the milk yield.

Cow behavior in AMS affects milk composition; however, its effects on milk yield and production efficiency remain unclear. Moreover, there remains a gap in the understanding of the relationship between days in milk (DIM) and the time spent eating and ruminating, as well as inside milking robots. Thus, the aim of this study was to evaluate the effect of cow behavior on milk production in an AMS herd.

Material and Methods

All study protocols were approved by the Animal Care and Use Committee (*Comitê de Ética no Uso de Animais – CEUA*) of the Federal University of Parana (*Universidade Federal do Paraná – UFPR*), Palotina Campus, Palotina, Paraná State, Brazil, under protocol no. 015/2022-CEUA/Palotina. The study was conducted from January 10, 2020 to December 20, 2022.

Experimental protocol

The trial was conducted at a commercial dairy farm located in western Paraná State, Brazil. A total of 20234 data points were collected from 52 lactating Holstein dairy cows (15 primiparous and 37 multiparous cows, average body weight = 650 ± 15 kg, parity = 2.3 ± 1.1 parturitions, and DIM = 156 ± 65 days). Behavioral variables included the daily time spent eating and ruminating.

The cows were housed in a compost barn with an average area of 12 m^2 per cow. One robot (Lely Astronaut A3, Lely Industries N.V., Maassluis, Netherlands) was installed in the barn for all cows. The milking area consisted of one AMS unit, and the cows had free access to the robot, except during system cleaning (three times a day at 04:00, 11:00, and 20:00). Cows were fetched for milking if they had not been milked for more than 12 h since the last milking.

The diet was supplied to the bunk (partial mixed ration [PMR]) and inside the robot (pelleted concentrate). The diet composition is described in Table 1. The PMR was offered once a day (08:00), and the daily orts averaged 5.4% of the feed delivered. The AMS was programmed to permit cows to milk at intervals of 6–12 h, depending on milk yield per cow. The maximum amount of pelleted concentrate available per cow per milking session at the robot was 3 kg. The concentrate allowance was programmed based on the milk production of individual cows.

Table 1
Ingredient and nutritional composition of partial mixed ration (PMR), and nutritional composition of pelleted concentrate offered in the automated milk system (AMS) for dairy cows

Item	PMR	Pelleted concentrate
Ingredient (g kg^{-1} DM)		
Sorghum silage	548.9	
Tifton haylage	74.9	
Pelleted concentrate	224.6	
Soybean meal	44.4	
Ground corn	89.8	
Mineral premix	10.0	
Sodium bicarbonate	7.5	
Nutritional composition		
Dry matter (g kg^{-1} as fed)	410.5	870.0
Crude protein (g kg^{-1} DM)	131.0	220.0
Non-protein nitrogen (g kg^{-1} DM)	1.3	5.9
Ether extract (g kg^{-1} DM)	27.0	20.0
Neutral detergent fiber (g kg^{-1} DM)	443.1	250.0
Acid detergent fiber (g kg^{-1} DM)	225.3	100.0
Lignin (g kg^{-1} DM)	34.5	5.4
Non-fiber carbohydrate (g kg^{-1} DM)	333.7	493.8
Ash (g kg^{-1} DM)	72.0	16.2
Total digestible nutrients (g kg^{-1} DM)	633.2	750.0
Net energy for lactation (Mcal kg^{-1} DM)	1.43	1.72

Time spent eating and ruminating was categorized to create class variables, as described below. The productivity variables included milk yield, concentrate intake from the AMS, and concentrate efficiency (kg of milk produced per kg of concentrate ingested).

Behavioral recording

Feeding behavior was recorded during each lactation period according to the parity of each cow using an electronic system (QWES HR-LD tag [Figure 1, Part 6]) attached to a collar around the neck.

The tag was placed on the left side of the cow's neck. A weight (Figure 1, Part 3) was attached to the collar to maintain the tag in its correct position. The QWES HR tag was used to identify and monitor heat activity and rumination. The data were stored in blocks of 2 h in separate tag files. The tag has a storage capacity of 12 blocks (24 h) and sends data every 20 min to an LD receiver. When the tag is read, the stored data are transmitted to T4C and the stored data are overwritten by a new 2-h block. The QWES HR tag (Figure 1, Part 6) has a non-replaceable battery and electronics (tag ID, data storage, activity sensor, and transmitter). The exterior of the tag is transparent to an infrared beam. When the battery is fully drained, the tag loses all its functions and must be replaced. Rumination was assessed using a microphone. Low-frequency noise (e.g., fans, engines, [cooling] compressors, and wind) can interfere with the proper measurement of rumination.

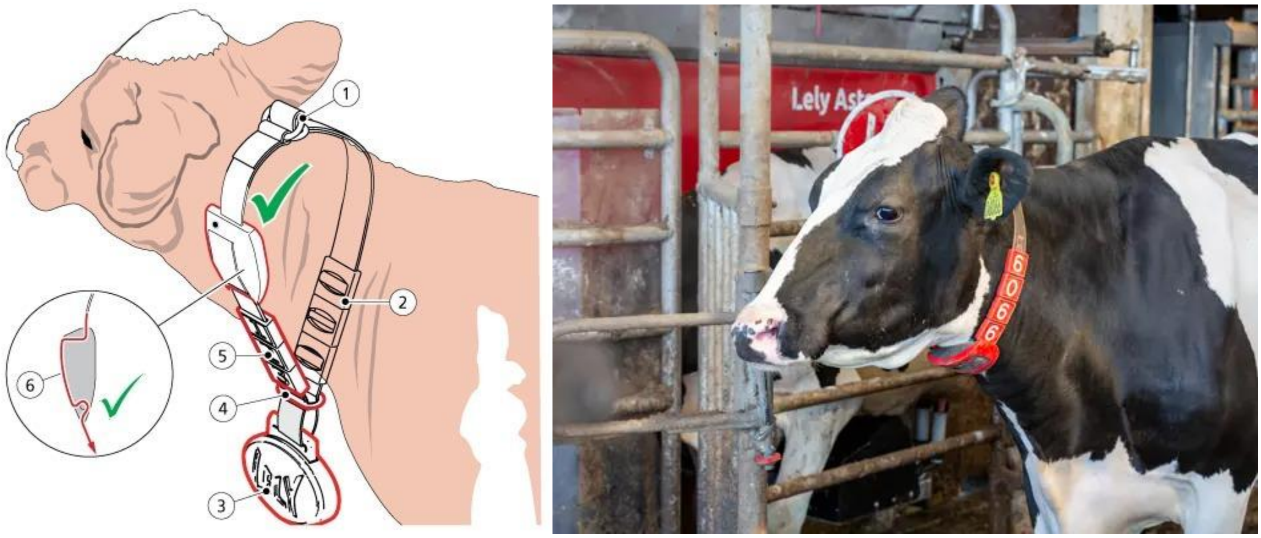

Figure 1. Automatic disposal to measure rumination and eating times. Item:
1. Double ring buckle; 2. First number set; 3. Weight; 4. Ring; 5. Second number set; and 6. QWES HR-LD tag.
Source: Lely® - https://www.lely.com/

At the end of the recording period, the complete dataset (n = 21628 data points) was analyzed for inconsistencies, such as failure or absence of data recording, short recording period (less than 120 d), and lactation duplicity for each cow. These inconsistencies were analyzed using the dynamics sheet tool in Microsoft Excel®. The presence of outliers in the dataset of each cow was analyzed using the Statistical Analysis System (SAS) software, version 9.0 (SAS Institute, Cary, NC, USA). Outliers were identified using the PROC UNIVARIATE and Shapiro-Wilk tests. After inconsistencies and outliers were identified and eliminated, the complete dataset contained 20234 data points (93.6% of the total recorded data).

The average time spent ruminating and eating, milk yield, concentrate intake, and concentrate efficiency were calculated for each cow during each lactation period. Next, rumination and eating times were categorized into different classes based on data distribution, and homogeneous groups were formed based on the number of cows per group. Considering eating time, class Low was defined as time spent eating < 270 min day^{-1} (n = 51; data points = 10729), and class High was defined as time spent eating ≥ 270 min day^{-1} (n = 38; data points = 9505). Rumination time was categorized into three classes: Low, rumination time < 550 min day^{-1} (n = 23; data points = 4955); Medium, rumination time ≥550 min day^{-1} and < 590 min day^{-1} (n = 39; data points = 9531); and High, rumination time ≥ 590 min day^{-1} (n = 27; data points = 5748).

Statistical analyses

Statistical analyses were conducted using SAS software, and statistical significance was set at $p < 0.05$.

Data were subjected to analysis of variance (ANOVA using PROC GLM), in which eating or rumination time classes were the independent variables, and DIM and parity were included as covariates. Both factors may have affected the dependent variables owing to the variation in milk yield throughout the lactation curve and the difference in milk yield between primiparous and multiparous cows. Thus, DIM and parity were included as covariates to correct for the mean estimation of these effects. Analyses were performed using the following model:

$$\hat{Y}_{ij} = \mu + C_i + \beta_1 DIM + \beta_2 P + \varepsilon_{ij},$$

where: $\hat{Y}_{ij}$ is the value of the dependent variable for the *j*th cow in the *i*th eating or rumination time class, adjusted for their DIM and parity; μ is the mean value of the dependent variable (constant); C_i is the effect of *i*th eating or rumination time class; β_1 is the regression coefficient for DIM; DIM is the days in milk of the jth cow; β_2 is the regression coefficient for parity; P is parity of the *j*th cow; and ε_{ij} is the random error. When the eating class was analyzed, the F-test of ANOVA was adopted to determine significant differences. For the rumination class, the variables that presented significant differences were compared using the Tukey–Kramer test.

Pearson's correlations (PROC CORR) of the time spent eating and ruminating with milk yield, concentrate intake, and concentrate efficiency were also analyzed. The *partial* option was used to adjust the coefficient of correlation to both parity and DIM effects. Simple linear regression analysis (PROC REG) was applied when the correlation was significant and the time spent eating or ruminating was the independent variable.

Results

For eating classes, the time spent eating was 86 min day^{-1} lower ($p < 0.001$) for cows that spent less time eating than for those that spent more time eating (Figure 2). Rumination time was similar ($p = 0.057$) between the two classes, with a mean value of 571 min day^{-1}.

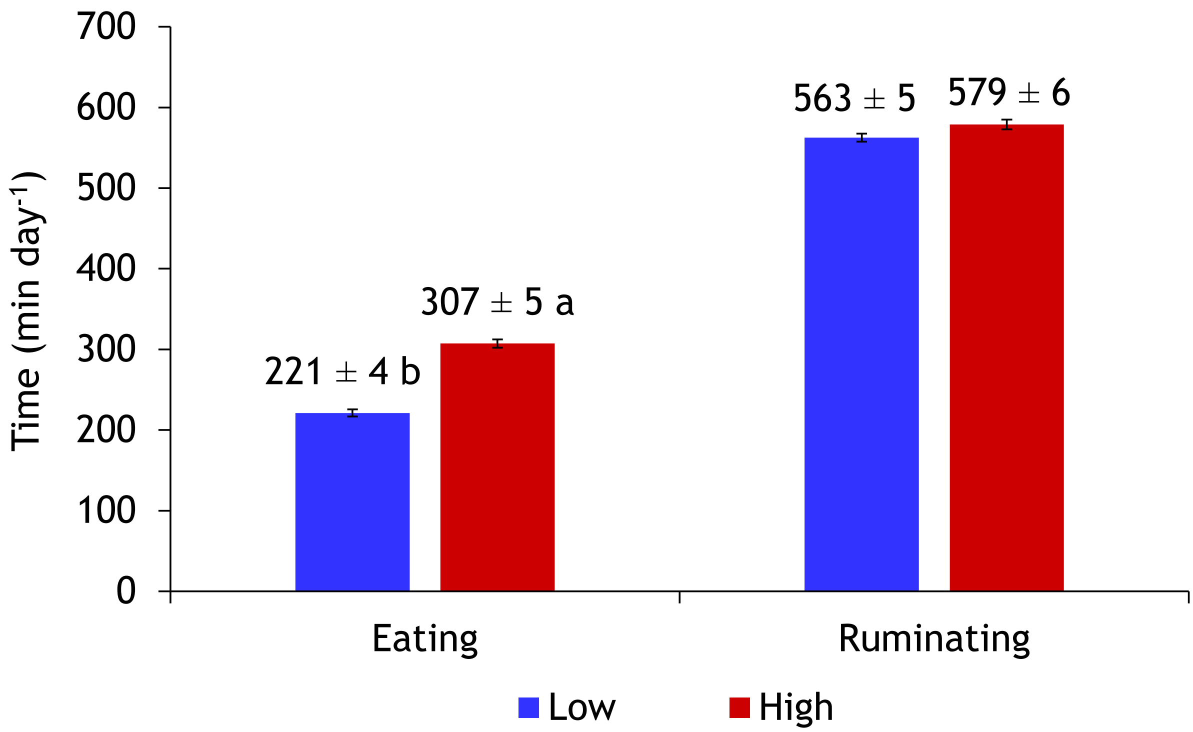

Figure 2. Time spent eating and ruminating by Holstein cows in an automated milk system (AMS) in two classes of eating time.
Values expressed as mean ± standard error.
Lowercase letters in the columns of each variable compare the means by Tukey-Kramer test ($p < 0.05$).

Milk yield was significantly influenced ($p < 0.001$) by the eating time (Figure 3). Cows that spent more than 270 min day^{-1} eating exhibited milk yield reduced by 6 kg day^{-1} compared to cows that ate less than 270 min day^{-1}. Cows that spent more time eating also reduced their concentrate intake inside the robot by 1.41 kg DM day^{-1}. However, the concentrate efficiency was 0.37 kg milk kg DM^{-1} higher in cows that spent more time eating (Figure 4), which represents a 7.5% efficiency increase in relation to cows that spent less time eating.

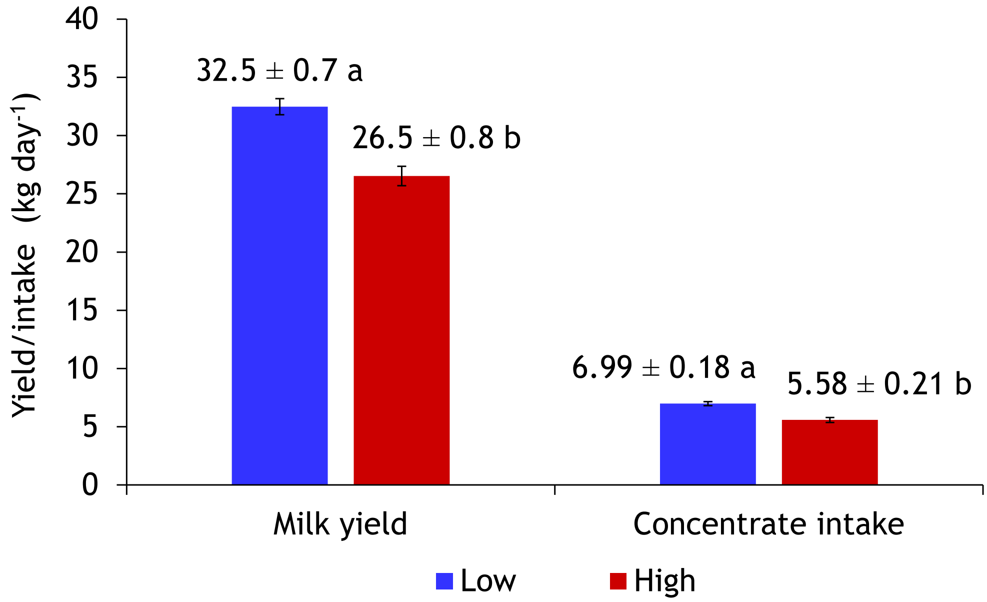

Figure 3. Milk yield and concentrate intake inside the robot by Holstein cows in an automated milk system (AMS) in two classes of eating time.
Values expressed as mean ± standard error.
Lowercase letters in the columns of each variable compare the means by Tukey-Kramer test ($p < 0.05$).

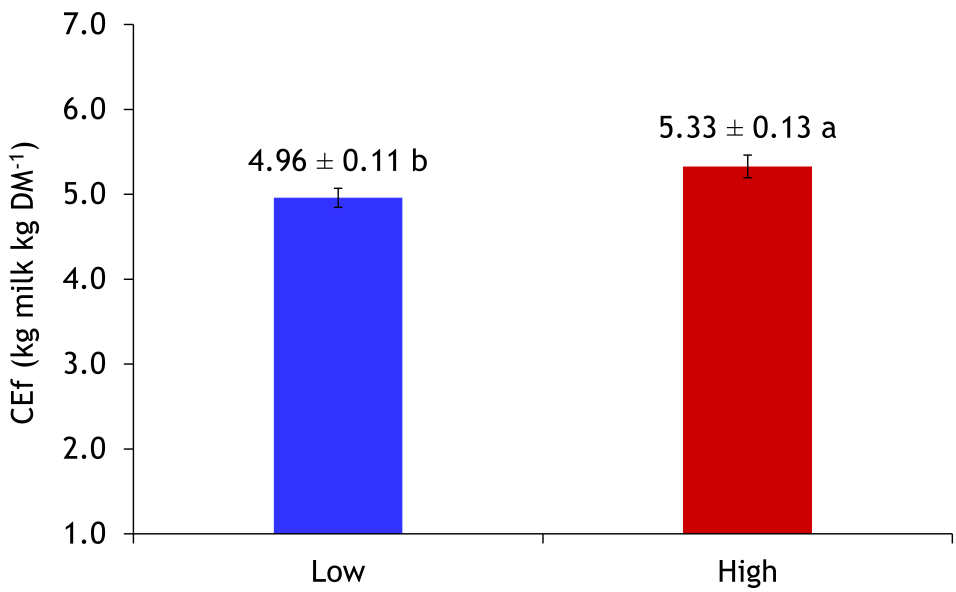

Figure 4. Concentrate efficiency (CEf) by Holstein cows in an automated milk system (AMS) in two classes of eating time.
Values expressed as mean ± standard error.
Lowercase letters in the columns of each variable compare the means by Tukey-Kramer test ($p < 0.05$).

Time spent eating was negatively correlated with milk yield (r = -0.38; $p < 0.001$) and concentrate intake (r = -0.30; $p = 0.004$) but was not correlated with concentrate efficiency ($p = 0.478$). For each minute of increase in eating time, milk yield was reduced ($p < 0.001$) by 0.07 kg day^{-1} and the concentrate intake inside the robot was reduced ($p < 0.001$) by 0.01 kg day^{-1} (Figure 5).

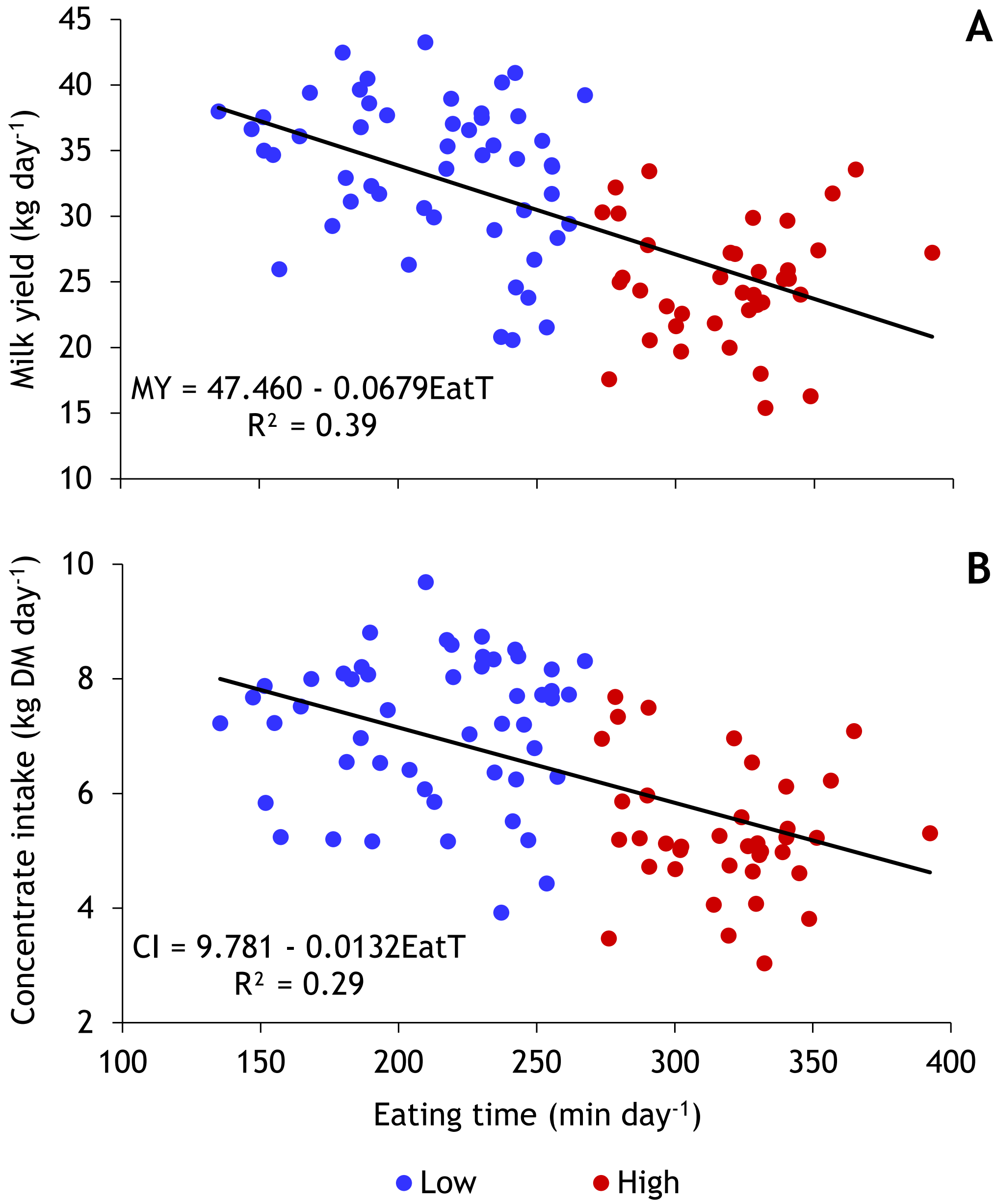

Figure 5. Simple regression of milk yield (A) and concentrate intake inside the robot (B) on eating time of Holstein cows in an automated milk system (AMS).
Low: cows exhibiting low eating time; High: cows exhibiting high eating time; MY: milk yield; CI: concentrate intake; EatT: eating time.

For rumination classes, ruminating time increased ($p < 0.001$) by 43 min day^{-1} between the Low and Medium classes and by 39 min day^{-1} between the Medium and High classes (Figure 6). Eating time, milk yield, concentrate intake inside the robot, and concentrate efficiency were not affected ($p > 0.050$) by the rumination class (Figures 6 to 8). The mean values for these variables were 258 min day^{-1}, 30.0 kg day^{-1}, 6.41 kg DM day^{-1}, and 5.11 kg milk kg DM^{-1}, respectively. Although concentrate efficiency was similar among rumination classes, it was positively correlated with rumination time (r = 0.24; p = 0.027). The regression equation indicated an increase (p = 0.016) of 0.006 kg milk kg DM^{-1} with each minute of increase in rumination time (Figure 9).

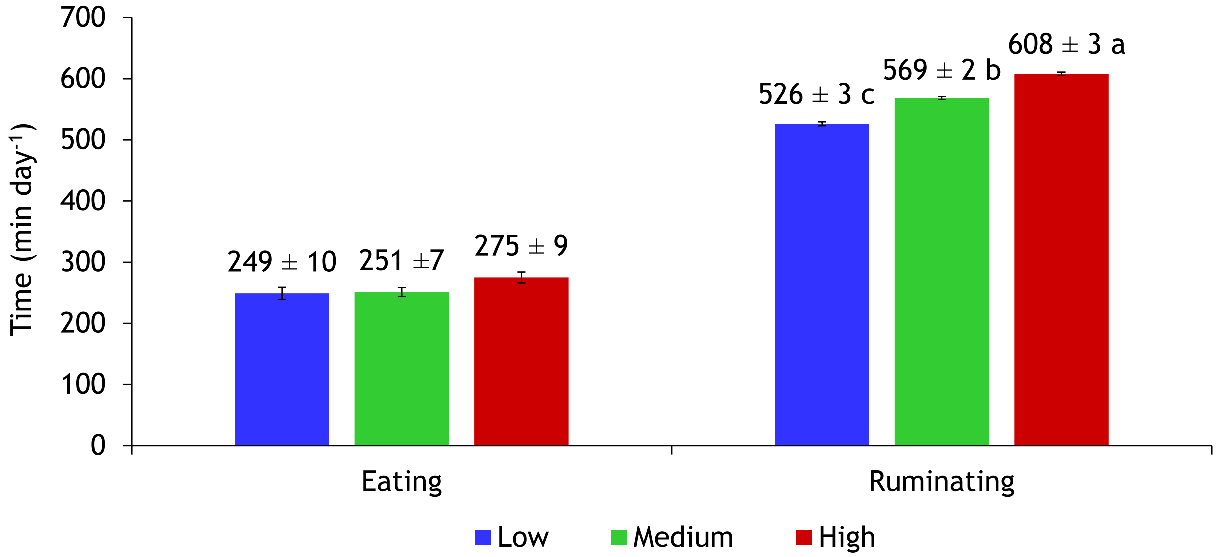

Figure 6. Time spent eating and ruminating by Holstein cows in an automated milk system (AMS) in three classes of rumination time.
Values expressed as mean ± standard error.
Lowercase letters in the columns of each variable compare the means by Tukey-Kramer test ($p < 0.05$).

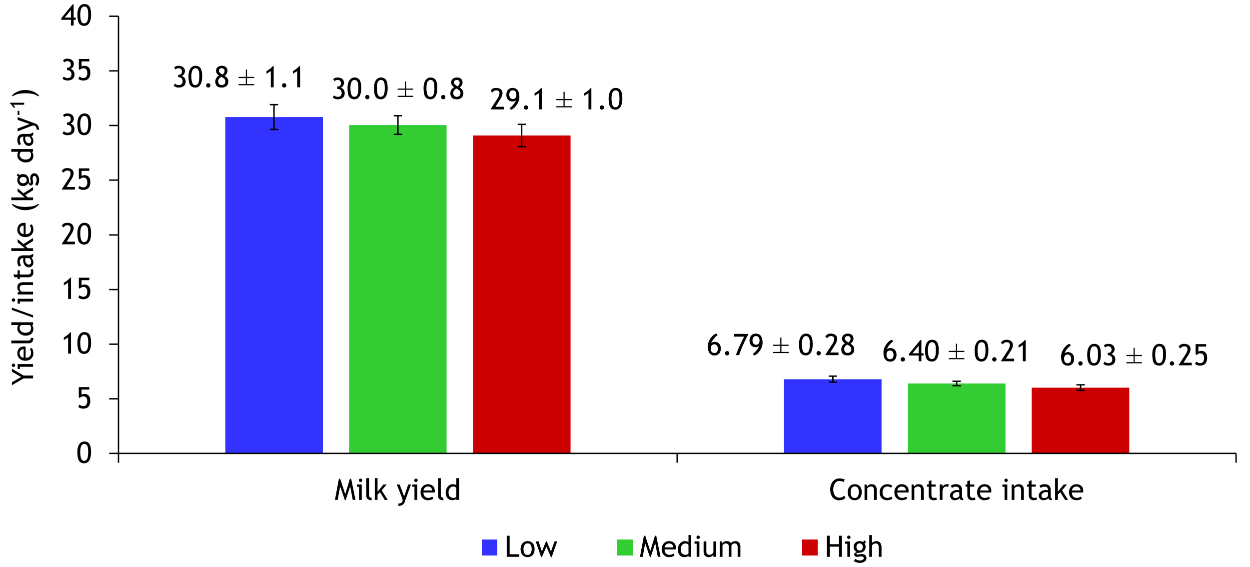

Figure 7. Milk yield and concentrate intake inside the robot by Holstein cows in an automated milk system (AMS) in three classes of rumination time.
Values expressed as mean ± standard error.

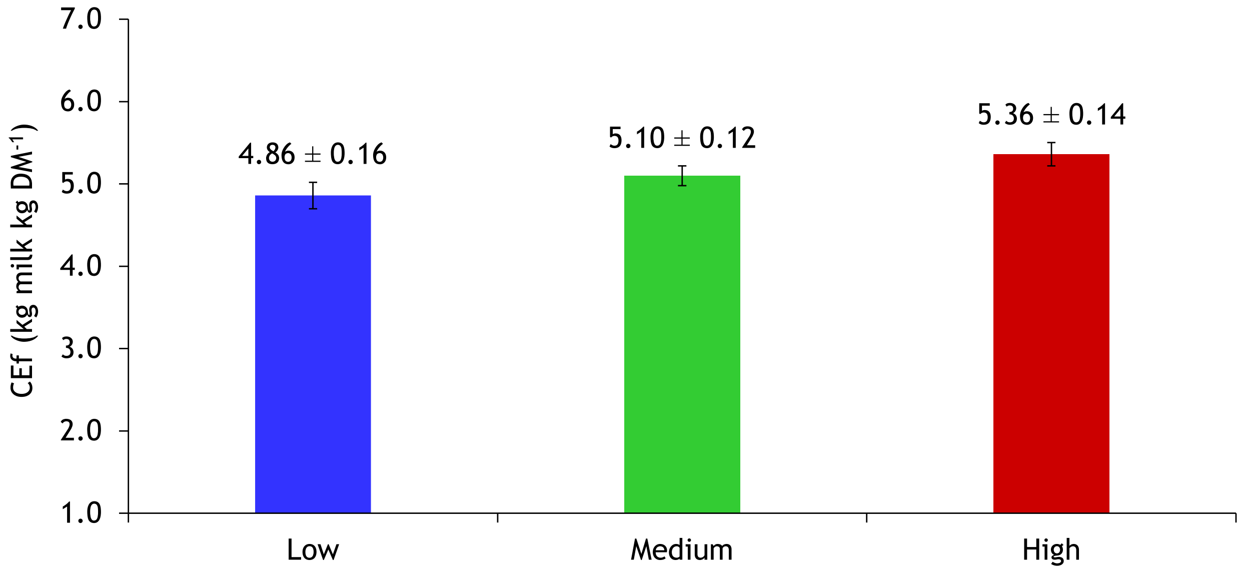

Figure 8. Concentrate efficiency (CEf) by Holstein cows in an automated milk system (AMS) in three classes of rumination time.
Values expressed as mean ± standard error.

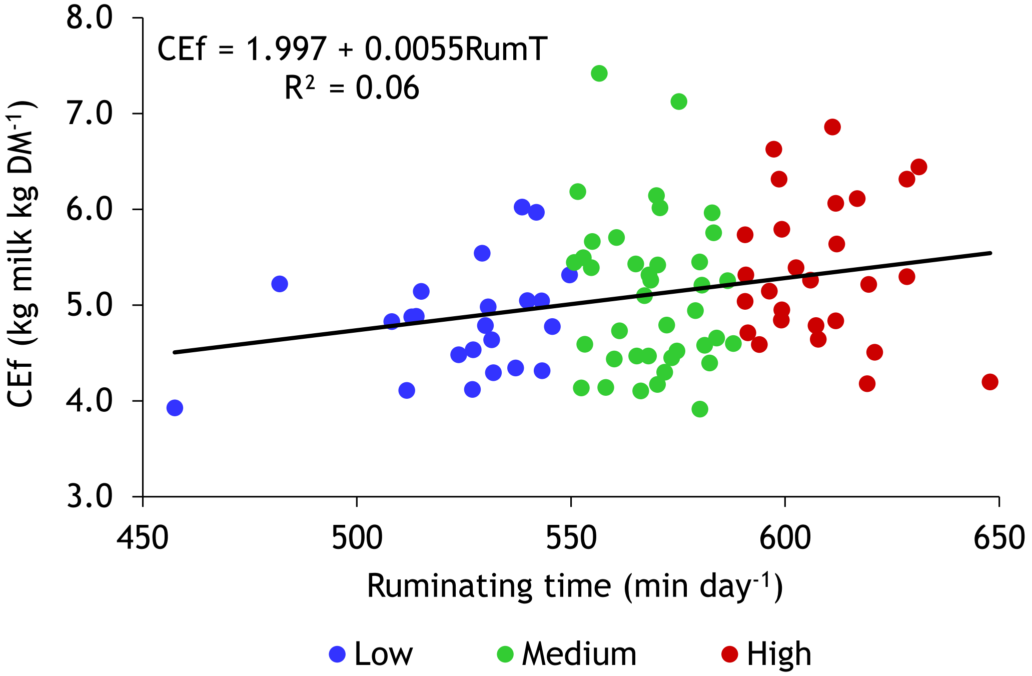

Figure 9. Simple regression of concentrate efficiency (CEf) on rumination time of Holstein cows in an automated milk system (AMS).
Low: cows exhibiting low rumination time; Medium: cows exhibiting medium rumination time; High: cows exhibiting high rumination time; RumT: rumination time.

Discussion

The feeding behavior patterns of lactating cows milked by AMS are reported to be less variable than those of cows housed in a conventional milking parlor (Wagner-Storch & Palmer, 2003), which have less feeding activity at night and early in the morning and more intense feeding-related behavior after milking and diet delivery. The low standard error values for the dependent variables evaluated in this study, both intra- and inter-class, demonstrate the low variability in cow behavior in AMS.

According to Friggens et al. (1998), the dry matter intake (DMI) of cows is influenced by feeding behaviors such as meal size, meal duration, meal frequency, and feeding time. These behavioral traits can be affected by factors such as sanitation patterns (Fogsgaard et al., 2015; Charlton et al., 2016; Solano et al., 2016; Westin et al., 2016; King et al., 2018; Antanaitis et al., 2019), bunk space, climate, tooth condition, age of the animal (Albright, 1993), nature and availability of beds, condition of the floor (Winckler et al., 2015; Chen et al., 2017), and chemical and physical characteristics of the diet (Beauchemin, 2018; Li et al., 2020). Studies examining cow feeding behavior are important because of their strong associations with cow productivity (Johnston & DeVries, 2018). In the current study, more time spent eating was associated with lower concentrate intake inside the robot, lower milk yield (Figure 3), and higher concentrate efficiency (Figure 4). Cows that spent more time eating also had higher DIM (188 vs. 133 days), which suggests that they spent less time milking and more time in other activities, such as eating at the bunk or idleness. The behavioral and productive responses related to changes in the eating time are summarized in Figure 10.

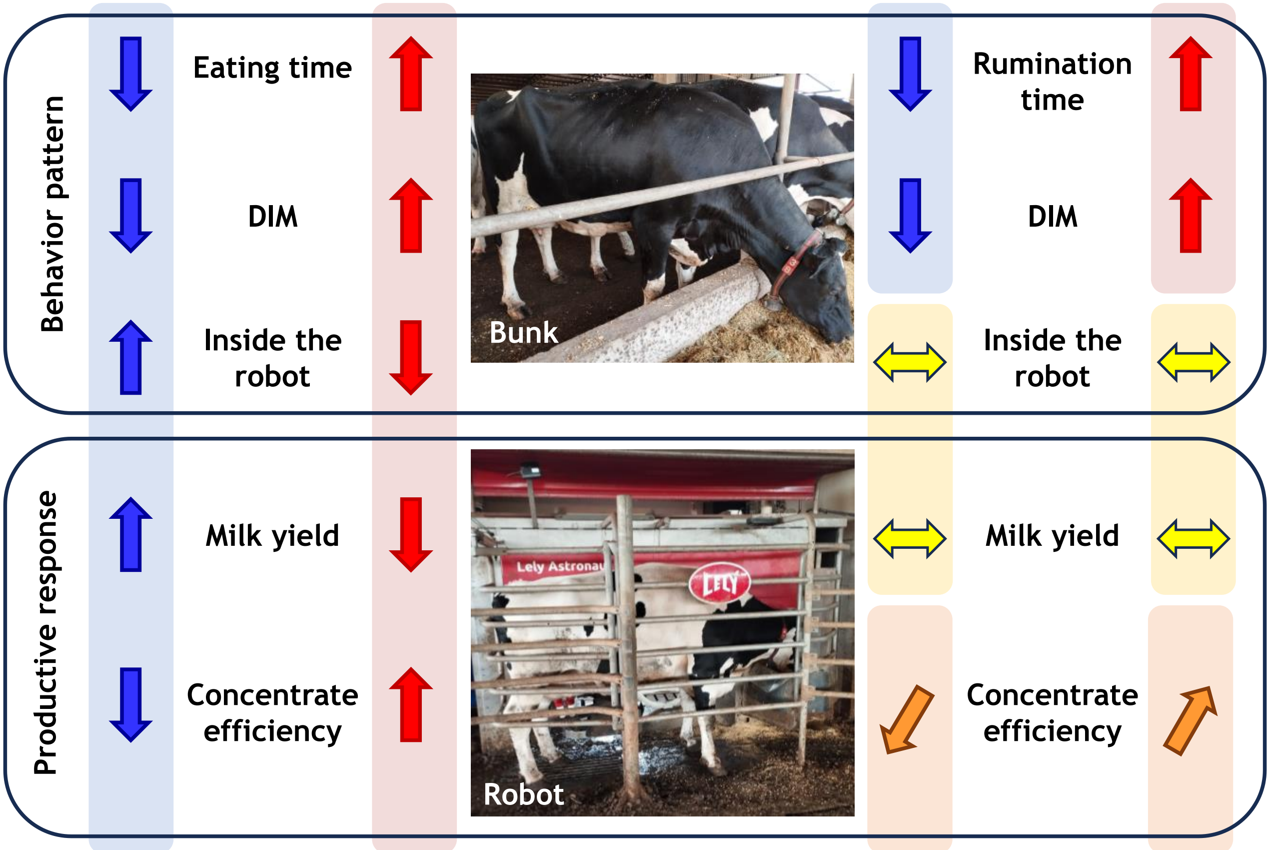

Figure 10. Diagram demonstrating the behavioral and productive responses of lactating Holstein cows to changes in feeding and rumination times.
DIM: days in milk.

As the PMR had a higher content of forage sources (623.8 g kg^{-1} DM, wherein 548.9 g kg^{-1} DM was sorghum silage and 74.9 g kg^{-1} DM was Tifton haylage; Table 1) and the concentrate intake inside the robot was reduced, an increase in eating time occurs naturally owing to increased manipulation and selection of feed in the bunk for dairy cows. The same rumination time between eating time classes (Figure 2) provides evidence that feed selection occurred at the bunk, and a diet with similar physically effective fiber content was probably selected in both classes. Although low, a positive correlation may be found between eating time and forage neutral detergent fiber (NDF) content in the total mixed ration (TMR) provided at the bunk for dairy cows (Beauchemin, 2018).

Conversely, reduced eating time was associated with a high concentrate intake inside the robot, high milk yield (Figure 3), and low concentrate efficiency (Figure 4). Given that cows that spent less time eating presented lower DIM, the greater milk yield in the first half of lactation stimulated them to be milked with higher frequency in the AMS (Simões et al., 2020). This motivation was also associated with the concentrate provided inside the robot, which had a high energy content to meet the high requirements of dry matter and energy intake in early- to mid-lactation (National Research Council [NRC], 2021). Li et al. (2020) reported that cows fed a diet containing 350 g kg^{-1} DM of forage had a greater DMI than those fed a diet containing 600 g kg^{-1} DM of forage (24.85 vs. 22.45 kg/d, respectively). According to these authors, the main factor contributing to the variation in DMI was the forage:concentrate ratio in the TMR. The time spent eating in the low eating time class (220 min day^{-1}; Figure 2) was similar to that reported by Johnston and DeVries (2018) and McWilliams et al. (2022), who found an eating time of 205–230 min day^{-1} in cows fed TMR containing 542–589.4 g kg^{-1} DM of forage sources in the PMR provided in free-stalls with an AMS.

Some studies demonstrated a positive correlation between eating time and DMI (Huzzey et al., 2005; Ben Meir et al., 2018). In addition, milk yield is associated with feeding behavior, such that greater milk yield is correlated with greater DMI (Ben Meir et al., 2018) and eating time (Veerkamp, 1998; Johnston & DeVries, 2018). Johnston and DeVries (2018) reported that cows that spent more time eating had higher milk yields, with a 1.7 kg day^{-1} increase for every 1-h increment in daily eating time. The DMI in the bunk was not measured in our study; however, the linear decrease in milk yield and concentrate intake with an increase in eating time (Figure 5) suggests that total DMI decreased with eating time. Considering the same comparison basis as that of Johnston and DeVries (2018), and according to the linear coefficient of regression equations obtained in the current study, for every 1-h increment in eating time, milk yield reduced by 4.07 L day^{-1} and concentrate intake reduced by 792 g day^{-1}. This can be explained by an increase in DIM with an increase in eating time. According to Holter et al. (1997), DIM is negatively and weakly to moderately correlated with DMI (r = -0.25), grain content in the TMR (r = -0.60), and milk yield (r = -0.66) and positively and moderately correlated with forage NDF content in the TMR (r = 0.58), corroborating our findings. Positive associations between eating time, DMI, and milk yield reported by Ben Meir et al. (2018) and Johnston and DeVries (2018) were related to lower DIM and its lower variation (standard deviation), and the high potential milk yield of the cows evaluated by these authors, at 126 ± 3 and 108 ± 43 days for DIM and 46 and 43 kg day^{-1} for milk yield, respectively.

Rumination is an essential behavior of ruminants, and housed dairy cows fed a TMR spend 434–632 min day^{-1} (7.2–10.5 h day^{-1}) ruminating (Aikman et al., 2008; Beauchemin, 2018; Moore et al., 2020; Tucker et al., 2021). The time spent ruminating in the rumination time classes (Figure 6) was within this range. Variations in daily rumination time can be explained by dietary factors. The amount of long particles (≥19 mm) in the diet and feed restriction significantly affect eating time and NDF intake, and the amount of particles ranging from 4 to 19 mm in the diet can strongly influence rumination time (Beauchemin, 2018).

In the current study, an increase in rumination time by 43–82 min day^{-1} (classes Medium and High, respectively) in relation to cows that spent less time ruminating (526 min day^{-1}; Figure 6) did not affect milk yield (Figure 7). This result is corroborated by that of McWilliams et al. (2022), who evaluated Holstein cows in AMS with a similar pattern of behavior to that of our cows, with 558 ± 41 min day^{-1} spent ruminating. Several studies have reported a positive association between milk yield and rumination time (Watt et al., 2015; Kaufman et al., 2018; Johnston and DeVries, 2018; Antanaitis et al., 2019). Johnston and DeVries (2018) reported an increase of 1.26 kg day^{-1} in milk yield for every 1-h increment in rumination time for high-producing dairy cows.

As observed in the eating classes, DIM also differed among the rumination classes. Cows that spent less time ruminating also had a lower DIM (125 d) than those in the Medium and High time classes (170 and 164 d, respectively). Thus, the lack of effect of rumination class on milk yield may be related to a compensation of rumination activity to the extent that cows increased forage intake at the bunk, and slightly reduced concentrate intake inside the robot (0.76 kg DM day^{-1} between the Low and High rumination classes; Figure 7) with the advance in lactation period. In this case, a low variation in diet digestibility was observed, justifying the similar milk yields among the rumination classes. Mikula et al. (2022) also reported no effect of rumination time classes (Low ≤ 412 min day^{-1}, Medium = 412 to 527 min day^{-1}, and High > 527 min day^{-1}) on milk yield (35.3 kg day^{-1}, on average) of dairy cows.

Concentrate efficiency was similar among rumination classes (Figure 8); however, it was weakly positively associated with rumination time (Figure 9). This demonstrates that chewing during rumination plays an important role in reducing the size of both forage and concentrate particles, and in increasing the surface area for the adhesion and action of ruminal microbiota (Beauchemin, 2018). Consequently, the utilization of an ingested diet is improved, and the production of short-chain fatty acids is increased (Silva et al., 2016), resulting in a greater milk production efficiency. An increase of 2.3%–6.4% in concentrate efficiency with rumination time was also observed in other studies on Holstein cows (Watt et al., 2015; Mikula et al., 2022). We found a greater increase in concentrate efficiency than in milk production; cows that spent more time ruminating had a concentrate efficiency 10.3% higher than those that spent less time ruminating. The behavioral and productive responses related to changes in the rumination time are summarized in Figure 10.

Conclusions

The time spent eating by dairy cows in an AMS is related to the DIM and affects milk yield. Cows that spend more time eating are in mid- to late-lactation, and hence, spend less time in milking and concentrate intake inside the robot, and have a lower milk yield. Conversely, cows that spend less time eating are in early- to mid-lactation and increase their milking frequency and concentrate intake, resulting in a greater milk yield. An increase in rumination time occurs from mid-lactation and improves concentrate efficiency in terms of milk production.

Understanding these behavioral patterns may help improve practices related to feeding management and in monitoring productive performance in response to concentrate intake inside the robot, as well as relative to the lactation curve. Among feeding management practices, the feed supply and feeding frequency of cows are highlighted. Therefore, our results contribute as foundational data for precision dairy farming using free-stall systems.

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