https://doi.org/10.17221/228/2022-CJAS

The influence of eating and rumination time on solids content in milk and milk yield performance of cows

Radim Codl, Jaromír Ducháček, Mojmír Vacek, Jan Pytlík, Luděk Stádník, Marek Vrhel*

Animal Husbandry, FAPPZ, Czech University of Life Sciences, Prague, Czech Republic

**Corresponding author: codl@af.czu.cz*

Citation: Codl R., Ducháček J., Vacek M., Pytlík J., Stádník L., Vrhel M. (2023): The influence of eating and rumination time on solids content in milk and milk yield performance of cows. Czech J. Anim. Sci., 68: 161–168.

Abstract: The aim of this study was to evaluate the effect of rumination time, eating time and season on milk yield and on milk component content in the context of milk recording. The experiment was carried out with two breeds – Czech Fleckvieh cattle and Holstein cattle – for one year. Vitalimetr 5P neck responders were used to monitor eating and rumination time. For statistical evaluation, the time of eating and rumination was divided into three groups according to the length of eating and ruminating, with each breed being categorised separately. The highest protein content, which was 3.6%, was calculated for the group with an average eating time. The fat content was highest for the group with a below-average eating time. On the other hand, the highest milk yield was statistically significantly ($P < 0.01$) higher in the group with the longest eating time. In terms of rumination, the trend was similar to that of the eating period. In the evaluation of the effect of rumination time, there was no difference in protein %, fat kg and fat % content. A significant ($P < 0.05$) increase of protein kg was observed with higher rumination time. Changes in milk yield and milk components also occurred throughout the year. During the winter months, the yield decreased, but there was an increase in milk constituent content. During the summer months, the reverse results were obtained. The findings of this study highlight the importance of evaluating eating and rumination time as a potential predictor of milk yield and milk solids content, which are important in milk monetization.

Keywords: dairy cattle; ethology; season

Milk production is affected by many factors. These factors can be divided into environmental factors such as temperature, photoperiod, nutrition and internal factors, i.e. genetic background and, for example, the time of eating or rumination of dairy cows. These factors are interrelated, either directly or indirectly, and can influence both the quantity of the milk produced and its components (Dahl et al. 2000; Bernabucci et al. 2015). With the increasing pressure on milk production and the economics of dairy farming, it is important to keep track of the cash flow of dairy cows in the herd and to use modern automated technologies (Brito et al. 2021).

In addition, systems based on the measurement of the physiological parameters of dairy cows could also help us with milk price prediction based on the estimation of yield and on the content of important milk components, such as fat and protein, for milk monetisation.

Before the invention of automated rumination logging systems, researchers estimated the rumination

Supported from the “S” grant of MŠMT ČR, NAZV Project No. QK1910242, CZU SGS Project No. SV21-6-21320.

https://doi.org/10.17221/228/2022-CJAS

time based on direct visual observations (Stone et al. 2017). Nowadays, modern active sensor systems are used that share information at short intervals directly with the farm management on a device connected to the network (Barker et al. 2018). It is already known from a great deal of previous research (Beauchemin 2018) that eating times are closely related to rumination times, and these longer times are connected with the probability of higher milk yields. Rumination time is also an indicator of welfare, i.e. cow satisfaction (Bernhard et al. 2021).

The literature review described above suggests that monitoring and evaluating eating and rumination times can have a significant relationship with overall yield and milk solids content. Therefore, the objectives of this study were to assess the effect of eating, rumination time and parity in combination with the season on the amount of milk produced, or on milk component content on the day of milk recording.

MATERIAL AND METHODS

Data from two farms were used for the evaluation; 454 Czech Fleckvieh cows on the first one, and 303 Holstein cows on the second one. The trial was performed over the course of one year. The average milk yield of the Czech Fleckvieh herd was 7 247 kg of milk per standard lactation, with fat content of 4.38% and protein content of 3.66%. The average yield in the Holstein herd was 10 063 kg of milk per 305-day lactation, with fat content of 4.12% and protein content of 3.55%. On both farms, the dairy cows were housed in freestall barns during lactation. Milking took place three times per day in a herringbone milking parlour for 24 cows (2 × 12 stalls). The milk recording was carried out according to the standard method of the ICAR by milk performance control. All dairy cows were fed a total mixed ration (TMR) based on maize silage, higher dry matter silage, concentrated grain feed, and mineral feed supplements. The composition of the rations was matched to the lactation stage and the current daily milk yield of the dairy cows.

Both farms used the same system for recording dairy cow activities (eating, ruminating) – Vitalimetr 5P (FARMTEC a.s., Jistebnice, Czech Republic). Data on cow lactation number (NL), milk yield control results (protein %, protein kg, fat %, fat kg, milk yield kg), and calving date were taken from the dairy herd management software FARMSOFT Management (FARMTEC a.s., Jistebnice, Czech Republic).

Compiling and filtering of eating and rumination data

Data on eating and rumination time from nine days prior to the milking records until the actual day of the milking records were selected for evaluation for the observed dairy cows. Records with a very low eating time (< 50 min/day) and rumination time (< 100 min/day) were excluded from the final evaluation. Data were also adjusted for excessive eating (> 500 min/day) and rumination (> 700 min/day) records. Furthermore, data where complete daily milk yield records were missing were not used for evaluation. Finally, dairy cows with two or more days of missing records of eating and rumination were excluded from the evaluation.

Statistical evaluation

Statistical evaluation was performed in SAS v9.4 (SAS Institute, Inc., Cary, NC, USA). The basic statistics of the dataset were calculated using the MEANS and UNIVARIATE procedures. Further evaluation was carried out using the REG procedure to determine the relationship between eating time or rumination time and milk yield parameters. Fat and protein contents in kg were also evaluated and converted to grams in the regressions for better illustration. Main evaluation was performed using the MIXED procedure with a repeated measures design. The STEPWISE method of the REG procedure was used to select the appropriate model to evaluate the indicators. The most appropriate model was selected based on the Akaike information criterion. For the actual evaluation, groups of daily eating and rumination times were created for each of the evaluated breeds separately. The groups were formed based on the arithmetic mean and standard deviation of the values obtained (< $(\bar{x}) - 1/2s$; $(\bar{x}) - 1/2s$ to $(\bar{x}) + 1/2s$; > $(\bar{x}) + 1/2s$). This ensured an even distribution of breeds within the groups while accounting for the metabolic differences between the specialized milking and dual-purpose (cattle) breeds. For the Czech Fleckvieh cows, the daily eating time groups were

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divided into intervals of up to 244 min for group 1, 245 to 314 min for group 2, and over 315 min for group 3. For Holstein cows, the daily eating time groups were divided into intervals of up to 278 min for group 1, 279 to 352 min for group 2, and over 353 min for group 3. For Czech Fleckvieh cattle, the daily rumination time groups were divided into intervals of up to 436 min for group 1, 437 to 493 min for group 2, and over 494 min for group 3. Similarly, for Holstein cattle, the daily rumination time groups were up to 454 min for group 1, 454 to 515 min for group 2, and over 516 min for group 3. For evaluation, the effect of parity was divided into four levels: dairy cows in the first, in the second, in the third, and in the fourth and subsequent lactations. The addition of the breed effect was a matter of course (Czech Fleckvieh, Holstein). The seasons of the year were then entered into the actual model equation: Spring – March, April and May; Summer – June, July and August; Autumn – September, October and November; Winter – December, January and February. Finally, the model equation was augmented with linear regressions for days in milk at milking records, appropriate breeding values for the parameters evaluated, and a random animal effect. A detailed evaluation of the significance of differences between effect levels was performed using the Tukey-Kramer test. The following model equations were used for the actual evaluation:

$$Y_{ijklm} = \mu + GE_i^* \text{ or } GCH_i^* + NL_j + SO_k + BR_l + b_1^*(\text{DIM}) + b_2^*(\text{anim}) + b_3^*(\text{MY}) + e_{ijklm} \quad (1)$$

where:

Y_{ijklm} – monitored parameters from the milk performance control (protein %, protein kg; fat %, fat kg; milk yield kg);

μ – mean value of the dependent variable;

GE_i – fixed effect of eating time group (i = < 244 min and/or < 278 min, n = 1 798; i = 245–314 min and/or 279–352 min, n = 2 077; i = > 315 min and/or > 353 min, n = 1 631);

GCH_i – fixed effect of rumination time group (i = < 436 min and/or < 454 min, n = 1 556; i = 437–493 min and/or 455–515 min, n = 2 321; i = > 494 min and/or > 516 min, n = 1 629);

NL_j – fixed parity effect (j = 1, n = 1 489; j = 2, n = 1 809; j = 3, n = 1 305; j = 4 and subsequent, n = 903);

SO_k – fixed seasons of the year (k = Spring – March, April, May, n = 1 347; k = Summer – June, July, August, n = 1 418; k = Autumn – September, October, November, n = 1 378; k = Winter – December, January, February, n = 1 363);

BR_l – fixed breed effect (l = Czech Fleckvieh cattle, n = 3 093; l = Holstein cattle, n = 2 413);

b_1^*(DIM) – linear regression on days in milk;

b_2^*(anim) – repeated effect of animal (n = 698);

b_3^*(MY) – linear regression on milk yield kg (for fat %, fat kg, protein %, protein kg);

e_{ijklm} – random estimation error.

Significance levels $P < 0.05$ and $P < 0.01$ were used.

RESULTS

The average eating time was 292.94 ± 74.37 min for both breeds evaluated (276.43 ± 70.45 min for Czech Fleckvieh, 314.11 ± 73.91 min for Holstein). For the rumination time parameter an average of 471.8 ± 60.46 standard deviation (SD) min was determined [462.46 ± 57.79 (SD) min for Czech Fleckvieh, 483.76 ± 61.69 (SD) min for Holstein]. The observed animals were on an average of 171 ± 95.93 (SD) days of lactation, and the average parity was 2.29 ± 1.04 (SD) lactations.

The evaluation of the linear regressions using the REG procedure led to the following conclusions. For every extra minute of rumination, a dairy cow increased the milk yield by +0.03 kg, whereas for rumination it was +0.02 kg. From our findings it appears that in one minute of eating, 0.039 kg of milk is produced by Holsteins and 0.035 kg by Czech Fleckvieh cows. Completely opposite results were calculated for protein in kg and %, with a decrease of about 0.001% for each additional minute of eating time. The rumination time showed an opposite but mostly clear tendency for protein content. Almost completely reverse results were then observed when expressing the relationship of the eating time or rumination time to the fat content in % and kg.

In total, two variants of the evaluation were performed, namely with eating time groups and rumination time groups. The model equation with the effect of eating group for the evaluated parameters of milk recording was statistically significant and explained from 18% (% milk fat) to 56% (milk yield kg) of the variability. All effects in the model equation for milk yield and fat content were statistically significant ($P < 0.01$). In the evaluation of the milk protein content parameter, only the effect of animal was not significant.

https://doi.org/10.17221/228/2022-CJAS

Under the variant of the calculation with the effect of rumination group, the model equation was also significant for all evaluations, and an r^2 ranging from 0.183 (fat %) to 0.547 (milk yield kg) was observed. For the milk yield parameter, all effects were statistically significant ($P < 0.01$) in the model equation. Most of the effects for fat content were statistically significant ($P < 0.01$). Lower significance was observed in this model equation for the effects of lactation number and animal ($P < 0.05$). As in the variant evaluation with eating groups, only the effect of animal was statistically insignificant when evaluating milk protein % content.

Table 1 shows the results for the evaluation of the eating and rumination time groups for protein % and kg, fat % and kg content and milk yield. In terms of protein content, the highest protein content was in the group with the longest eating time. The lowest protein content was in the group with the shortest eating time that was lower compared to the group of average eating time. Fat content had a reverse trend of protein. As the eating time increased, the fat content decreased. Milk yield had the same trend as protein, when the highest milk yield was obtained in the group with above-average eating time. In terms of the duration of rumination time, the highest protein content was found in the second group, compared to the lowest value recorded in the first group. A similar trend, but significant, was then recorded for the protein content in kg. In the case of fat percentage, the trend of fat was similar to that of the rumination group where the fat content decreased with the length of rumination time. This was also confirmed in the evaluation of fat content in kg, when the lowest value was in the group with the longest rumination time. Milk yield increased with rumination time. Table 2 shows the evaluation for the lactation number, season and breed effect. In terms of protein content, the trend of the evaluation was not completely clear; in both cases, the highest protein content was in the third lactation and the lowest was in the first lactation. Fat content had a decreasing trend with the number of lactations in both evaluation variants. For the variant with rumination effect, the trend was similar. The same trends in values and significance were confirmed in the evaluation of protein and fat content in kg, see Table 2. With the parity, the daily milk yield increased statistically significantly from the first lactation to the fourth and further lactations ($P < 0.01$) in both calculation variants. The seasons of the year also had a significant effect on milk yield control results. In the case of protein, winter months showed the highest protein content. In contrast, the lowest protein content was observed in summer. In the case of variable eating, the highest milk fat content was found in winter. For the rumination variable, the highest milk fat contents were found in winter and spring. The lowest milk fat was found in summer, both for eating and for ruminating. The protein and fat content per kg were very similar and there was a large number of differences that were statistically significant (at the level of significance $P < 0.01$). The highest values of milk yield were recorded during summer for eating and for rumination. In contrast, the lowest value was measured in spring for milk and rumination time. Numerous statistically significant ($P < 0.01$) differences were observed between the different seasons of the year.

Table 1. Effect of eating and rumination on milk yield and milk solids components

	Eating			Rumination			SEM	*P*-value	
	1	2	3	1	2	3		eating	rumination
C (min)	< 244	245 to 314	> 315	< 436	437 to 493	> 494	–	–	–
H (min)	< 278	279 to 352	> 353	< 454	415 to 515	> 516	–	–	–
Protein (%)	3.53^{A}	3.60^{B}	3.61^{B}	3.57	3.58	3.58	0.21	0.01	0.13
Protein (kg)	0.98^{A}	1.01^{B}	1.01^{B}	0.99^{Aa}	1.00^{B}	1.00^{b}	0.16	0.01	0.01
Fat (%)	4.3	4.3	4.25	4.3	4.29	4.27	0.51	0.05	0.39
Fat (kg)	1.20^{a}	1.20^{a}	1.19^{b}	1.2	1.2	1.19	0.21	0.01	0.42
Milk yield	26.82^{A}	29.55^{B}	30.85^{C}	27.20^{A}	29.15^{B}	30.20^{C}	4.61	0.01	0.01

C = Czech Fleckvieh; H = Holstein; SEM = standard error of the mean

$^{A–C}$Different uppercase superscripts in columns indicate a statistical significance at $P < 0.01$

^{a,b}Different lowercase superscripts in columns indicate a statistical significance at $P < 0.05$

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Table 2. Effect of parity, season and breed on milk yield and milk solids components

		Parity				Season				Breed		SEM	*P*-value		
		1	2	3	4 and more	spring	summer	fall	winter	C	H		season	parity	breed
Eating	protein (%)	3.52^{A}	3.57^{B}	3.61^{C}	3.60^{C}	3.60^{A}	3.44^{B}	3.60^{A}	3.68^{C}	3.68^{A}	3.48^{B}	0.21	0.01	0.01	0.01
	protein (kg)	0.99^{A}	$1.00^{B.a}$	1.01^{C}	1.01^{Cb}	1.00^{A}	0.96^{B}	1.01^{A}	1.03^{C}	1.03^{A}	0.97^{B}	0.16	0.01	0.01	0.01
	fat (%)	4.26	4.3	4.32	4.26	4.37^{A}	4.12^{B}	4.28^{C}	4.37^{A}	4.32^{A}	4.25^{B}	0.51	0.01	0.04	0.01
	fat (kg)	1.2	1.2	1.21^{a}	1.19^{b}	1.21^{A}	1.15^{B}	1.19^{C}	1.22^{A}	1.20^{A}	1.19^{B}	0.21	0.01	0.06	0.01
	milk yield	25.70^{A}	29.52^{B}	30.45^{C}	30.63^{C}	28.62^{A}	30.01^{B}	28.68^{A}	28.99^{A}	25.90^{A}	32.25^{B}	4.55	0.01	0.01	0.01
Rumination	protein (%)	3.54^{A}	3.58^{B}	3.61^{Ca}	3.58^{Bb}	3.59^{A}	3.44^{B}	3.59^{A}	3.67^{C}	3.68^{A}	3.47^{B}	0.21	0.01	0.01	0.01
	protein (kg)	0.99^{Aa}	1.00^{Ab}	1.01^{B}	1	1.00^{A}	0.96^{B}	1.01^{A}	1.03^{C}	1.03^{A}	0.97^{B}	0.16	0.01	0.01	0.01
	fat (%)	4.26^{a}	4.3	4.32^{b}	4.27	4.38^{A}	4.11^{B}	4.28^{C}	4.38^{A}	4.32^{A}	4.25^{B}	0.51	0.01	0.03	0.01
	fat (kg)	1.19	1.2	1.21	1.19	1.22^{A}	1.15^{B}	1.20^{C}	1.22^{A}	1.20^{A}	1.19^{B}	0.21	0.01	0.07	0.01
	milk yield	26.22^{A}	29.67^{B}	30.18^{C}	29.33^{B}	28.21^{A}	30.41^{B}	28.44^{A}	28.35^{A}	25.63^{A}	32.07^{B}	4.61	0.01	0.01	0.01

C = Czech Fleckvieh; H = Holstein; SEM = standard error of the mean

$^{A–C}$Different uppercase superscripts in columns indicate a statistical significance at $P < 0.01$

^{a,b}Different lowercase superscripts in columns indicate a statistical significance at $P < 0.05$

Finally, an evaluation for the effect of breed affiliation can be added. As expected, Holstein cattle had significantly ($P < 0.01$) higher milk yield values, but their milk had lower fat and protein content in % and kg.

DISCUSSION

Our findings for average eating and rumination times were consistent with the values measured for rumination and eating by other authors (Braun et al. 2015; Johnston and DeVries 2018). In the case study (Braun et al. 2015), dairy cows were eating and ruminating for a shorter time on average than in our study, averaging 265 min/day of eating and 441 min/day of ruminating. In the study by Johnston and DeVries (2018), dairy cows were eating for 279.6 min/day on average for a slightly shorter time and ruminating for a longer duration of 516 min/day. Johnston and DeVries (2018) also found a correlation between the milk yield, eating time and rumination time of dairy cows. High-yielding cows tend to have greater feed intake to support energy demand (Krpalkova et al. 2022). Our results of linear regression confirmed that milk production is positively influenced by feed intake (Shabi et al. 2005). Also, milk production is influenced by the behavioural pattern of dairy cattle such as resting time, rumination, eating (Grant 1995). Fregonesi and Leaver (2002) reported that high-yielding dairy cows have higher feed intake, which translates into longer rumination times than in low-yielding cows. Schirmann et al. (2012) confirmed this statement and added that dairy cows with higher dry matter intake also take longer to process the feed received and thus they have longer rumination times. Following this, Krause et al. (2002) found a positive correlation between feed particle length, feed intake and rumination.

The rumination time may also be relatable to milk yield and milk composition (Byskov et al. 2015). In the study of Marino et al. (2021), dairy cows with the longest rumination time had the highest total protein content, but the percentage of protein content decreased from 3.48% to 3.38% with higher rumination time, compared to a 0.18 kg increase in total protein content. In our results, compared to the above-mentioned study, there was a progressive increase in protein content with rumination time and thus a 0.2 kg increase in milk protein compared to the group with the shortest rumination time.

The percentage of fat in milk followed the opposite trend to that of protein, with fat being negatively affected by a longer rumination time in dairy cows. This fact was confirmed by other authors, for example by Andreen et al. (2020). These authors observed a 0.02% decrease in fat per 60 min increase in rumination. The difference in our study was between rumination groups 1

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and 3 ruminating for approximately 70 min and a 0.03% decrease in fat content was the same. The study of Kaufman et al. (2018) also confirmed the negative effect of rumination time on the percentage of milk fat content. In their study, there was a 0.059% decrease in fat content for every 30 min of rumination time. According to the cited authors, a decrease in the percentage of milk fat content was associated with higher milk yield, which was also associated with higher rumination (Kaufman et al. 2018; Andreen et al. 2020).

As the rumination time increased, milk yield increased. Consistent with this finding are the records of Johnston and DeVries (2018) and Marino et al. (2021). Johnston and DeVries (2018) predicted an increase of 1.26 kg of milk for each additional hour of rumination and, in addition, their result shows that there is a difference of 8.7 kg of milk per day between cows with the highest and the lowest rumination times. In the work of Marino et al. (2021) a difference of 6.22 kg of milk per day was found between the highest and the lowest rumination groups. Compared to the data found in our study, the differences were more significant in the authors cited. In our observation, the difference between the longest and the shortest rumination time was 3 kg of milk yield from the regression results, with each additional hour of rumination there was an increase of 1.59 kg of milk in milk production.

Marino et al. (2021) also described the relationship between daily rumination time, milk yield and milk solids content. This relationship may be influenced by two factors: simple dilution effects due to differences in milk yield; or differences in the availability of precursors at the udder level that originate from ruminal activity and absorption. It is clear from their study that milk yield increases with higher average rumination time per 10 days. Additionally, these authors described a higher total fat content in milk, which was slightly lower in percentage terms than in cows with shorter rumination time. A similar conclusion was reached by White et al. (2017), who found that high-yielding dairy cows ruminate close to their physiological maximum.

The amount of milk produced and its composition change throughout the year. These changes were the focus of several authors in the past (Barash et al. 2001; Dahl and Petitclerc 2003; Soriani et al. 2012; Bertocchi et al. 2014). In their studies, these authors attribute a decline in milk production during the winter months to a shorter photoperiod. The opposite is the case in the summer months, when the days are longer and an increase in milk production is observed. Barash et al. (2001) and Bezdicek et al. (2021) reported an average increase of 1.2 kg in milk production for every extra hour of sunlight. They also observed a decrease in milk fat and protein in spring and an increase in autumn again. These times of the year correspond to approximately the same climatic conditions. Thus, the difference in the spring and autumn months is due to the lengthening photoperiod or the stage of lactation rather than to heat stress. In contrast, the large decrease in fat and protein percentage content observed in summer, both in our study and in that of the authors mentioned above, is probably related to the negative effect of the hot conditions on the synthesis of these milk components. Dahl and Petitclerc (2003) also found changes in milk production and milk constituents. They attributed these changes mainly to the dilution of the components in milk due to its increased production. This was confirmed by our work. In a study (Bertocchi et al. 2014) of the effect of seasons on milk production and characteristics, the authors observed a reduction in milk fat and protein concentrations when the average daily temperature was above 14 °C and the average daily temperature-humidity index (THI) was above 55, corresponding to the summer months. Milk composition is affected by both longer days and higher temperatures during the summer season. Acosta-Balcazar et al. (2022) and Park (2022) explain a decrease in milk constituent content by the fact that high temperatures above 30 °C reduce the eating time and the associated milk constituent content. Thus, our calculated milk yield and milk composition values are physiologically justified and agree with the above-mentioned studies.

CONCLUSION

The results of our study confirm the importance of routine monitoring of eating and rumination duration using modern automatic devices. Despite some differences in the milk production of Holstein and Czech Fleckvieh dairy cows, changes in the length of eating and rumination time were similar. The increase in the eating and rumination time

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was reflected in higher milk yield but also in slightly lower milk solids content, on which the milk is monetized. Our work has also confirmed the influence of the season, which, in combination with the results presented earlier, can provide a good basis for predicting milk production based on nutrition, rumination and other factors. Based on this prediction, we will be able to refine models for milk yield and solids content. These models will be the next step in precision animal production and will help farmers to plan cash flows more efficiently.

Conflict of interest

The authors declare no conflict of interest.

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Received: December 31, 2022
Accepted: February 27, 2023
Published online: April 24, 2023