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Original Paper

Nutrition of Dairy Cows: How Starch and Fiber Influence their Overall Activity

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The aim of this study was to show the individual relationships between selected parameters within the groups of high-producing Holstein-Friesian dairy cows in the Early Lactation (EL), Peak Lactation Multiparous (PLM) and Peak Lactation Primiparous (PLP). Firstly, the relationship of individual fractions (Penn State Particle Separator (PSPS) method) retained on Pennsylvanian sieves on dairy cow activity - feed intake time/ eating time (ET); rumination time (RT); time no-active (TN) - was evaluated using BouMatic's RealTime Activity program. It was found that there was a statistically significant difference between the EL group, which intake less amount of fibre retained on the sieve with 8 mm hole size (46.90%) with the PLM (50.19%) and PLP (49.41%) groups (p <0.05). The decrease in fibre intake (8 mm) was related to the fraction intake retained per pad where there was a statistically significant difference between EL (28.02%) and PLP (25.69%); PLM (25.19%) group (p <0.05). The data obtained regarding ET and RT between the groups showed a statistically significant difference where low RT and ET was observed just at higher fraction intake per pad (28.02%) and lower fibre intake (46.90%) in the EL (4:16 h) group compared to PLM (4:41 h) and PLP (5:37 h) (p <0.05), where the percentage intake of fractions contained per pad was lower. The study also evaluated the effect and relationship between selected parameters (starch, lactic acid-LA, fermentation processes-FP, NH_3, acid-detergent fibre-ADF, neutral-detergent fibre-NDF, pad, physically effective neutral-detergent fibre-*pe*NDF) on ET and RT. The starch content of the total mix ration was in medium high negative correlation with RT (p <0.05) and on the other side the *pe*NDF content was characterised by a strong positive correlation with RT (p <0.01). Based on these results, it was found that dairy cows in the EL group preferred a rather higher intake of fractions contained on the pad, which influences the reduced intake of particles retained on the 8 mm average sieve and thus their overall activity (ET, RT, TN) is influenced. Dairy cows in the PLM and PLP groups preferred a higher intake of fiber particles (8 mm) which influenced the increase in activity time (ET, RT).

Keywords: dairy cows, nutrition, fibre, starch, rumination time

1 Introduction

Rumination, a cyclical process characterised by regurgitation, re-mastication and re-swallowing, is also described by authors as a major indicator of welfare, or the overall health of the cow or herd (pH), correct digestion and passage of feed through the dairy cow's digestive tract (Soriani et al., 2012; Cocco et al., 2021). Florit et al. (2023) reported that the terms rumination time (RT) and eating time (ET) are seen as indicators indicative of herd animal health. Bar and Solomon (2010); Paudyal (2021); Ning et al. (2022) state that adequate time spent ruminating is usually between 8 and 9 hours. The rumination process, as described by Beauchemin (2018); Cook et al. (2021); Paudyal (2021); and Ning et al. (2022), is influenced strongly by health status, diet quality, ration composition and structure, and, last but not least, feeding frequency. Dairy cows are bred within a herd with different nutritional requirements in terms of their lactation level and from the reproductive and production cycle phases. Different nutrition in terms of fetal needs and development, growth and high production requires phase-specific nutrition of dairy cows. Often, in order to meet the energy requirements for high milk production in high yielding dairy cows, they are

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fed TMR containing a higher proportion of concentrate at the expense of the fibre component which can be reflected in a negative way in reduced rumination time, reduced salivation and consequently the development of metabolic disorders (acidosis) (Schingoethe, 2017). Rumination time (RT) is an important indicator of the correct structural composition of the TMR, since an adequate particle length of more than 8 mm (*pe*NDF) stimulates the total time spent in food intake, rumination and salivation, or saliva production. The above processes ensure the maintenance of a healthy rumen complex function, to prevent a reduction in milk production and fat content (Beauchemin et al., 2003; Beauchemin & Yang, 2005; Beauchemin 2018).

Monitoring the overall activity (especially ET, RT) of dairy cows can contribute to provide important information to assess the *pe*NDF and easily degradable carbohydrate content of TMR and, based on reduced rumination activity, ensure earlier intervention and minimization of potential risks related to the health status and consequently the economics of the farm (Zebeli et al., 2012; Brandstetter et al., 2019).

2 Material and methods

The experiment concerning the evaluation of the nutritional and structural component of TMR and its influence on ET,RT was carried out on the university farm Kolíňany – farm Oponice, on high-producing Holstein-Friesian dairy cows in Peak Lactation Multiparous (PLM), Peak Lactation Primiparous (PLP) and the group of dairy cows in Early Lactation (EL). The experiment included 4 control periods (15. 2. 2023; 15. 3. 2023; 28. 3. 2023; 4. 4. 2023).

2.1 Evaluation of the structure of the total mix ration (TMR)

The evaluation of the TMR structure was carried out using the Penn State Particle Separator (PSPS) method. Sieves with 19 mm, 8 mm, 4 mm hole diameters and a pad were used. TMR structure evaluation was performed during the given control periods 4 times per 24 h (05:00; 11:00; 17:00; 23:00). The sample taken from the respective group represented a total of 700 grams from the five sampled locations of the feeding table. The sieving and number of sieving movements represented a total of 80 movements (10 times from each side (5 × 2)). Then, the given data from the EL, PLP and PLM groups were individually averaged into a single data.

*2.2 Calculation of physically effective neutral detergent fibre (pe**NDF**)*

To calculate and evaluate the *pe*NDF content in each group, the averaged fractions per control day captured at the 19 and 8 mm diameter sieves were used (pef – physical efficiency factor), which were multiplied by the analytically determined NDF content (using the ANKOM 200 Fiber Analyzer).

2.3 Collection of data on dairy cow activity (ET, RT, NT)

The dairy cows on the farm Oponice are provided with collars from BouMatic, whose task is to monitor and record the total time spent by the cows on eating and then ruminating (24 $h.d^{-1}$). The RT monitoring was carried out using a device on the collar and a digital receiver of this data located in the stall. Data downloads were performed every 24 h throughout the experiment using RealTime Activity software.

2.4 Sampling of TMR

The high producing dairy cows in each group at Oponice Farm were fed a mixed ration (TMR), which was fed to them 1 × daily with the implementation of feeding every 6 hours. TMR collection was carried out together with texture assessment and immediately after putting on the feeding table (5:00). The composition of the TMR together with the content of the selected nutrients for the above groups are given in Tables 1–3.

Table 1 Composition of the mixed ration and content of selected nutrients – peak lactation multiparous

Component	Feed dry matter
Corn silage (%)	31.8
Alfalfa (%)	24
CCM (%)	20.6
Straw (%)	0.70
Feed Mixture (%)	23
Crude Protein (%)	17.4
Fat (%)	2.1
Fibre (%)	15.7
ADF (%)	14.8
NDF (%)	25.3
Starch (%)	29.1
NEL (MJ)	6.80

*CCM – corn cob mix; ADF – aciddetergent fibre; NDF – neutraldetergent fibre; NEL – netto energy lactation; % – percentage; MJ – megajoule

Table 2 Composition of the mixed ration and content of selected nutrients – early lactation

Component	Feed dry matter
Corn silage (%)	31.7
Alfalfa (%)	24
CCM (%)	20.6
Straw (%	0.7
Feed mixture (%)	23
Crude protein (%)	13.9
Fat (%)	1.7
Fibre (%)	12.5
ADF (%)	11.9
NDF (%)	20.2
Starch (%)	23.2
NEL (MJ)	5.44

*CCM – corn cob mix; ADF – aciddetergent fibre; NDF – neutraldetergent fibre; NEL – netto energy lactation; % – percentage; MJ – megajoule

Table 3 Composition of the mixed ration and content of selected nutrients – peak lactation primiparous

Component	Feed dry matter
Corn silage (%)	29.9
Alfalfa (%)	27.2
CCM (%)	19.9
Straw (%)	0.80
Feed mixture (%)	22.3
Crude protein (%)	17.6
Fat (%)	2.1
Fibre (%)	16.2
ADF (%)	15.3
NDF (%)	25.9
Starch (%)	27.8
NEL (MJ)	6.71

*CCM – corn cob mix; ADF – aciddetergent fibre; NDF – neutraldetergent fibre; NEL – netto energy lactation; % – percentage; MJ – megajoule

2.5 Statistical processing

Statistical processing of the results was performed using IBM SPSS ver 26.0. Descriptive statistics (mean, standard deviation, minimum and maximum values) were developed using one-way ANOVA. Statistical significance of differences between groups of dairy cows was expressed by Post Hoc Tukey test (p <0.05). One-way Pearson's correlation coefficient was used to detect the influence between ET, RT and selected parameters.

3 Results and discussion

Table 4 shows the individual relationships between the selected parameters within the groups of dairy cows in early lactation (EL), peak lactating multiparous (PLM) and peak lactating primiparous (PLP) cows. The first indicator, which indicates the mean of the content retained on the first site (19 mm) indicates that there was no statistically significant difference between the groups (EL 8.30%; PLP 8.21%; PLM 7.85%) (p >0.05), and that for the smaller outliers (EL, PLP) the required percentages were met.

The mean at the second site (8 mm) between the groups indicates that there is a statistically significant difference between the EL group (46.90%) and PLP (49.41%), PLM (50.19%) (p <0.05). Which is also indicated by the study of Tafaj et al. (2007) which describes that in dairy cows in the EL group, it is difficult to ensure the intake of sufficient fibre because of the need to maximize energy intake. The mean fraction per pad indicates a statistically significant difference (p <0.05) between the EL group and PLP, PLM. Here, the statement can be confirmed, which is related to the fact that dairy cows that ingested a smaller amount per 8 mm diameter sieve (EL) ingested just a larger amount of more quickly degradable particles. As described by Heinrichs and Kononoff (2013) increasing the concentrate content in the EL group of dairy cows is desirable or necessary to prevent negative energy balance and to ensure that peak lactation is reached. The *pe*NDF content in the individual dairy cow groups, except for a minor deviation in the EL group, satisfied the requirements for the required amount needed to ensure rumen stability (PLP 15.22%; EL 13.85%; PLM 15.22%).

The amount required for the stability of the rumen complex when using Pennsylvanian sieves (19 and 8 mm) should not fall below 14% from a physiological point of view as reported by Yang and Beauchemin (2006). There is no statistically significant difference between the groups (p >0.05).

The group of dairy cows (EL) that received a higher amount of the fraction retained on the pad and thus supported higher requirements at the beginning of lactation also received the required amount of *pe*NDF thus ensuring the prevention of problems such as sub-acute ruminal acidosis (Zebeli et al., 2012; Heinrichs & Kononoff, 2013).

The data in the table in relation to ET indicate a statistically significant difference (p <0.05) between the groups (PLP 5:37 h; EL 4:16 h; PLM 4:41 h). The EL group of cows had the lowest eating time (4:16 h), which is precisely related to the higher intake of the fraction retained on the pad (28.02%) compared to the other groups (PLP 25.69%; PLM 25.19%). The above is also influenced by the results

Table 4 Evaluation of selected factors between groups

Descriptives						
		N	mean	std. deviation	minimum	maximum
Average 1 sieve (%)	EL	8	8.30[a]	0.96	7.41	9.39
	PLP	8	8.21[a]	2.18	4.97	9.97
	PLM	8	7.85[a]	0.45	7.51	8.55
	total	24	8:11	1.35	4.97	9.97
Average 2 sieve (%)	PLP	8	49.41[b]	2.44	47.28	52.72
	EL	8	46.90[a]	1.09	46.23	48.68
	PLM	8	50.19[b]	2.01	47.74	52.99
	total	24	48.84	2.34	46.23	52.99
Average 3 sieve (%)	PLP	8	16.59[a]	1.33	14.71	17.72
	EL	8	16.85[a]	0.51	16.03	17.19
	PLM	8	16.76[a]	1.01	15.57	17.72
	total	24	16.73	0.97	14.71	17.72
Average pad (%)	PLP	8	25.69[a]	2.03	23.59	27.59
	EL	8	28.02[b]	2.07	26.70	31.35
	PLM	8	25.19[a]	1.23	23.93	27.08
	total	24	26.30	2.14	23.59	31.35
*pe*NDF (%)	PLP	8	15.22[a]	1.34	13.47	16.41
	EL	8	13.85[a]	1.65	11.22	15.14
	PLM	8	15.22[a]	0.50	14.52	15.77
	total	24	14.76	1.37	11.22	16.41
ET (h.d^{-1})	PLP	8	5:37[c]	0:07	5:27	5:51
	EL	8	4:16[a]	0:24	3:41	4:58
	PLM	8	4:41[b]	0:09	4:29	4:58
	total	24	4:51	0:37	3:41	5:51
RT (h.d^{-1})	PLP	8	9:05[b]	0:12	8:51	9:26
	EL	8	8:03[a]	0:24	7:42	9:01
	PLM	8	9:03[b]	0:10	8:42	9:14
	total	24	8:44	0:33	7:42	9:26
TN (h.d^{-1})	PLP	8	9:09[a]	0:17	8:41	9:32
	EL	8	11:33[c]	0:34	10:37	12:24
	PLM	8	10:08[b]	0:13	9:52	10:36
	total	24	10:17	1:04	8:41	12:24
Milk yield (l^{-1} daily)	PLP	8	31.04[a]	1.85	28.27	33.40
	EL	8	34.89[ab]	2.97	29.92	40.07
	PLM	8	36.46[ab]	4.04	30.35	40.14
	total	24	34.13	3.76	28.27	40.14

*N – number, EL – early lactation, PLP – peak lactation primiparous, PLM – peak lactation multiparous, *pe*NDF – physically effective neutral-detergent fibre, ET – eating time, RT – rumination time, TN – time no-active, abc – different letters indicate statistical significance (p <0.05), h.d^{-1} – hours per day, % – percentage, l^{-1} daily – litres per day

Table 5 Selected factors in relation to food intake and rumination time

		Starch ($g.kg^{-1}$)	LA ($g.kg^{-1}$)	FP ($g.kg^{-1}$)	NH_3 ($g.kg^{-1}$)	ADF ($g.kg^{-1}$)	NDF ($g.kg^{-1}$)	PAD (%)	*pe*NDF (%)	ET ($h.d^{-1}$)	RT ($h.d^{-1}$)	TN ($h.d^{-1}$)
ET ($h.d^{-1}$)	PCC	-0.105	-0.317	-0.049	0.288	0.227	0.107	-0.218	0.183	1	0.590**	-0.910**
	Sig.	0.313	0.066	0.411	0.086	0.143	0.309	0.153	0.196		0.001	0.000
RT ($h.d^{-1}$)	PCC	-0.469*	0.305	0.412*	0.384*	0.481**	0.424*	-0.656**	0.528**	0.590**	1	-0.868**
	Sig.	0.010	0.073	0.023	0.032	0.009	0.019	0.000	0.004	0.001		0.000

*ET – eating time, RT – rumination time, LA – lactitic acid, FP – fermentation processes, NH_3 – ammonia, ADF – acid-detergent fibre, NDF – neutral-detergent fibre, *pe*NDF – physically effective neutral-detergent fibre, TN – time no-active, $g.kg^{-1}$ – gram per kilogram, $h.d^{-1}$ – hours per day, % – percentage, PCC – pearson correlation

on RT, where the group (EL) that received a lower amount of fraction retained on the second site (8mm) (46.90%) and also the *pe*NDF content was lower (13.85%) had an RT lower by one-hour (8:03 h) compared to the PLP (9:05 h) and PLM (9:03 h) groups (p <0.05).

Overall, it can be evaluated that the increased fraction retained at the second site (8 mm) and the percentage of *pe*NDF in the PLP and PLM group had a positive effect on RT. The same fact is also indicated by the study of Tafaj et al. (2007) describing a positive relationship between feed particle size and RT (p <0.05). Similarly, the statement describing the positive effect of fibre and *pe*NDF on the overall rumination process is also highlighted by Heinrichs and Kononoff (2013), who characterise fibre as an important component for supporting desired rumen functions. An increase in RT based on *pe*NDF was also observed in the study by Zebeli et al. (2006) (R^2 = 0.29) (p <0.05).

Table 5 shows the values regarding the influence and relationship between the selected factors (starch, LA, FP, NH_3, ADF, NDF, pad, *pe*NDF, ET, RT, TN) on the time of food intake and rumination.

The starch content of the total mix ration is moderately negatively correlated with rumination time, indicating that the non-structural component of TMR is rapidly digested and not participating in the rumination process (p <0.05). A similar fact is also pointed out by DeVries et al. (2009) who conducted research when feeding TMR formulated 60 : 40 (feed:concentrate) and TMR formulated 45:55 (feed : concentrate), where they describe that a high intake of concentrate reduced rumination time (from 555 $min.d^{-1}$ to 491 $min.d^{-1}$). Similar results are described by Schmitz et al. (2019), who found that rumination time was reduced (453 to 457 $min.d^{-1}$; p = 0.001) when ruminants consumed TMR that was formulated with a high-energy concentrate component.

Acid-detergent fibre content and the relationship between rumination time is in a medium positive correlation which indicates that ADF content has a positive effect on total time of both eating and rumination time (p <0.01). This is justified by the fact that TMR does not contain forages that were harvested in the late phenological phase (Jung & Vogel, 1989).

Because forages whose harvesting was carried out in the late phenological phase are characterised with higher ADF content, which indicates higher lignin content, which is in negative correlation with ET and RT. As described by Jung and Kenneth (1986), Moore and Jung (2001) lignin are tagged as an indigestible component.

The *pe*NDF content, which thus indicates the particles that were collected at the 1 and 2 Pennsylvanian sites and were plotted analytically by NDV determination, are strongly positively correlated with rumination time (Beauchemin & Yang, 2005; Zebeli et al., 2012), indicating that the higher the fractional content of the fractions collected at the 19 mm hole site, and especially at the 8 mm hole site, the higher the rumination time (p <0.01). The fact with increasing time of food intake and rumination time is also indicated by other studies such as Beauchemin and Yang (2005), where in the studied diets were administered 11.5, 10.3 and 8.9% *pe*NDF which showed an increase in ET (r = 0.41) and RT (r = 0.37) with increasing content. Studies by Yang and Beauchemin (2007) also confirm that increasing the feed : concentrate proportion and increasing the content of longer particles affected rumination activity.

4 Conclusions

The research examined nutritional relationships of high-producing Holstein-Friesian dairy cows with respect to the intake of selected nutrients in relation to the overall activity of dairy cows (ET, RT, TN) in different groups (EL, PLP, PLM). Results of the study revealed the significant differences between the groups in terms of nutrient components TMR and total activity of dairy cows. The composition of TMR, especially the starch to fibre ratio, was found to have a significant effect on the nutritional status of dairy cows and their overall activity (ET, RT, TN). Dairy cows in different groups showed divergent needs and responses to selected nutrients. Dairy cows in the EL

group showed a preference for the energy component of TMR (pad) compared to cows in the PLP and PLM groups, which showed increased intake in the fibre component (8 mm) compared to EL. A significant finding is that dairy cows with higher intake of energy component (EL) showed shorter ET and RT compared to the other groups (PLP; PLM) that had higher intake of fibrous component. These data suggest significant associations between TMR composition, nutritional needs, and behaviour of dairy cows in different groups, which may be a key factor in effective management of high producing dairy cows.

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