INFLUENCE OF MODIFICATION THE LENGTH OF STRAW PARTICLES IN TOTAL MIX RATION ON RUMINATION TIME, MILK YIELD, AND MILK COMPOSITION IN THE NUTRITION OF DAIRY COWS

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ABSTRACT

The aim of the experiment was to determine the effect of changing straw length on the behaviour of dairy cows, specifically on activity time (feed intake time, rumination time) or non-activity time (using BouMatic's RealTime Activity program), milk yield (using HerdMetrix program) and milk composition (using True test in 10-day intervals). The 4-week experiment was conducted in a group of high producing Holstein-Friesian dairy cows that were at the peak of their lactation (61-120 days in milk) and were divided into three groups (PLM1;PLM2;PLM3) where they were fed a total mix ration (TMR) with different straw lengths (TMR1;TMR2;TMR3). The group of cows at the peak of their lactation 1 (PLM1) (N=33) were fed TMR1, which

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consisted of straw particles with a length of 3±2 cm. PLM2 (N=29) was fed TMR2 (3±2 cm; 15±2 cm) and the PLM3 group (N=32) was fed TMR3 (15±2 cm). TOMAHAWK Straw mill 404M was used to achieve the desired straw length. The structure of the TMR was also evaluated 3× over the observation period (Penn State Particle Separator method), focusing on the behaviour and selection ability of the dairy cows. TMR structure assessment was performed during the given control periods 4 times/24 h (05:00;11:00;17:00;23:00). The most pronounced selection was observed for PLM3 (TMR3), where the proportion of large particles (+19mm) was as high as 32.92% at 23:00 h., which is 8% higher than the proportion of particles for TMR1 (PLM1) ($p < 0.05$). The results showed that increasing straw length led to an increase in total activity of dairy cows ($p < 0.05$, p-value = 0.000) while non-activity time decreased ($p < 0.05$). There was also a statistically significant increase in milk production (PLM3) with increasing straw length (TMR3), which was an increase of 3.34 kg milk compared to TMR1 (PLM1) ($p < 0.05$, p-value = 0.000). A statistically significant increase with increasing physical structure of TMR was also observed for fat and protein content of milk ($p < 0.05$). Based on the results, it was found that modification of straw length can lead to increased feeding efficiency and consequently higher milk production and quality.

Keywords: dairy cows; sorting; rumination time; milk yield; straw

INTRODUCTION

Nutrition of dairy cows is a key factor influencing the overall performance of dairy cows such as health status, overall activity (feed intake time, rumination time) or non-activity and production ability

(Erickson and Kalscheur, 2020). The performance of dairy cows is not only influenced by the nutritional composition of the total mix ration but also the physical structure of the TMR itself plays a major role (Yang and Beauchemin, 2006a; Yang and Beauchemin, 2006b; Beauchemin, 2018). Yang and Beauchemin (2006b) further describe that the mixing time itself, the type of mixing machine and the cutting machine also influence the total intake or activity and production ability of dairy cows. Miller-Cushon and DeVries (2017) add that forage sorting is also influenced by the frequency of feeding during the day itself, where cows fed twice a day had less selection activity than cows fed once a day. The explanation is that the more a given TMR is available to dairy cows, the more they will select and select for more appetitive particles. Yansari et al. (2004) and Kononoff and Heinrichs (2003) reported that the introduction of so-called physically effective neutral detergent fibre (*pe*NDF) is beneficial for identifying the part of the diet that stimulates the rumination process and is responsible for the formation of the rumen complex (rumen mattress) and for the overall rumen function. Neutral detergent fibre alone only describes the chemical properties of the feed or TMR but not the physical properties (size, density) needed to ensure adequate health status. Yansari et al. (2004) describe that the addition of long particles in TMR provides the desired acetate:propionate ratio, an increase in milk fat concentration and prevention against metabolic disorders (DeVries et al., 2008; Brandstetter et al., 2019; Jurkovich et al., 2019; Shen et al., 2020). Beauchemin and Yang (2005) suggest that to ensure high milk production, it is essential that dairy cows receive energy-rich forages or that sufficient intake of TMR with high energy content is provided. However, an increase in the non-structural carbohydrate content of

TMR, can cause potential problems with decreasing pH values and consequently the development of metabolic disorders (sub-acute ruminal acidosis) which has a negative impact on the microbial representation of fibre-digesting species (cellulolytic bacteria). It is by feeding TMR with sufficient *pe*NDF that the possibility of metabolic disorders will be reduced, as mixing should result in a structure that is sufficiently homogeneous to support minimal selection (Kronqvist et al., 2021). Sova et al. (2013) describe that sorting or selection is an increasing problem in commercial herds. Dairy cows tend to select in favour of smaller particles (pad/starch) and thus take in less fibre (Miller-Cushon and DeVries, 2009; Leonardi et al., 2017). It has been suggested, as Maulfair et al. (2010), that as dairy cows select during the day they ingest different rations, causing fluctuations in the rumen complex (fermentation processes) that can translate in a negative sense into reduced production and poorer health (Miller-Cushon and DeVries, 2009). DeVries et al, (2005) in their research found that the NDF content on the feed table increased during the day, indicating that dairy cows were selecting in favour of finer particles over fibrous components during the day. Also, Leonardi and Armentano (2003) describe that most dairy cows tended to select in favour of finer particles or ingested a higher content of easily fermentable carbohydrates and a lower proportion of fibre than was formulated and supplied. The inclusion of straw in the diets of high producing dairy cows as described by Humphries et al. (2010) may contribute to better activity and consequently productivity of dairy cows. The activity or rumination itself is a mirror result of the effective fibre content in the TMR, which promotes a more stable rumen environment, thus preventing high pH value changes and consequently the development

of metabolic disorders. Yang and Beauchemin (2006b) describe *pe*NDF as the ability of the physical structure of fibre to stimulate the activity of the dairy cow or to activate the process of rumination and then saliva production. Cao et al. (2021) estimate that saliva secreted by the dairy cow can neutralise 30-40% of the volatile fatty acid produced in the rumen environment. In order to maintain proper rumen function, it is necessary to promote salivation, the amount of which depends on the size of the food particles or fibre. The Penn State Particle Separator (PSPS) method is used to determine the *pe*NDF content. It is a tool that provides quantitative determination of feed particle size and total mix ration (Heinrichs and Coleen, 2022). In performing the TMR structure assessment, the focus is not only on the fractions from which the *pe*NDF is determined, but also on the total particle representation on the sieves or on the substrate. The important fact is that in order to make TMR samples objective, the first collection must be secured from the area immediately after TMR establishment or before the cows start to eat and select feed (Heinrichs and Coleen, 2022). Studies by Kononoff and Heinrichs (2003a,b) and Beauchemin and Yang (2005) describe that, based on measurements using the PSPS method, they found that increased *pe*NDF intake was involved in increased rumination time and that it improved overall digestibility. Yang et al. (2001); Kononoff and Heinrichs (2003a) report that the increase in *pe*NDF was also reflected in an increase in milk fat content.

The aim of this experiment was to investigate the effect of changing the length of straw in the total mix ration on the overall activity, production and milk composition of dairy cows. We predicted that different straw lengths would have a significant effect on feed intake time, rumination time and non-activity time, as well as milk production and composition.

MATERIAL AND METHODS

The experiment was realised on the university farm Kolíňany - farm Oponice, where the effect of changing the length of straw in the total mix ration on the overall activity and production ability of high-producing Holstein-Friesian dairy cows was monitored. The experiment was realised in a group of dairy cows that were at the peak of their lactation (61-120 days of lactation). The experiment was carried out for 4 weeks and during these weeks the dairy cows were divided into the following three groups. The group of cows at the peak of their lactation 1 (PLM1) with a head count of 33, where total mixed ration 1 (TMR1) was fed, which consisted of straw cut to an adequate length (3±2 cm). The group of cows at the peak of their lactation 2 (PLM2), with a head count of 29, was fed total mix ration 2 (TMR2), and represented a so-called transitional TMR, meaning that it contained straw particles of 3±2 cm but also straw particles that had a longer cut length (15±2 cm). The third group of dairy cows at the peak of their lactation 3 (PLM3) with a cow number of 32 was fed TMR that contained only particles with a longer chop i.e. 15±2 cm. High producing dairy cows on Oponice farm (PLM1-PLM3) were fed a total mix ration (TMR) which was fed once a day with implementation of feeding every 6 hours. The composition of the TMR together with the content of selected nutrients for the group of cows at the peak of their lactation is presented in Table 1. Straw was cut to the required length using a TOMAHAWK Straw mill 404M. The TMR structure evaluation was realised 3 times during the study period using the Penn State Particle Separator (PSPS) method. Sieves with 19 mm, 8 mm, 4 mm diameter holes and a pad were used. The sample taken from the individual group (PLM1;PLM2;PLM3) was a total of 700±50 grams

from the fifth sampled feeding table locations. The sieving and number of sieving movements represented a total of 80 movements (10 times from each side (5x2). TMR texture assessment was carried out during the given control periods 4x/24 h (05:00;11:00;17:00;23:00). Then, the given data from the PLM1, PLM2 and PLM3 groups were individually averaged into one data for that group. The physically effective neutral-detergent fibre (*pe*NDF) content was obtained from the averaged fractions for the control day (19 mm+ 8 mm=*pef*), which were then multiplied by the analytically determined neutral-detergent fibre content (using the ANKOM 200 Fiber Analyzer). Sampling was always carried out on the day of the structure evaluation, just after TMR establishment (05:00). Daily milk yield data for dairy cows (milked 3 × daily - herringbone type parlour) were recorded and then downloaded using HerdMetrix software. Milk production records included information regarding milking date and time, total milk production (litres), collar number and cow identification number. The True test method (at 10-day intervals) was used to record milk fat and protein content, which allowed milk quality to be monitored accurately and regularly. In this experiment, samples were manually collected by milkers during morning milking into sterile containers, which were then stored at a specific temperature (4°C) and transported to the laboratory for analysis (within 24 hours of collection). The data were used to evaluate the average fat and protein content of the milk of individual cows (subsequently of each group) during the experimental period. The overall activity (feed intake time; rumination time) or non-activity of the dairy cows was also monitored and recorded using BouMatic automated collars (24 h.day-^{1}). Data transmission (between the fitted collar and the receiver installed in the stall) was done at 15-

minute time intervals and then the data were sent at two-hour intervals to the RealTime Activity program. Data downloads were taken every day or every 24 hours throughout the experiment, but in order to increase the accuracy of the results, activity (or non-activity) data from the days closest to the milk sampling date (2 days before; day of sampling; 2 days after; i.e. 5*3=15 days in total/cow) were taken into account. Statistical processing of the results was performed using IBM SPSS ver. 26.0. Descriptive statistics (mean, standard deviation, minimum and maximum values) with one-way ANOVA analysis. Statistical significance of differences between dairy cow groups (PLM1-PLM3) and TMR was expressed using Post Hoc Tukey's test ($p < 0.05$).

Table 1. Composition of the mixed ration and content of selected nutrients

Component	**Total weight of feed (kg)**
Corn silage (%)	47.2
CCM (%)	9.97
Straw (%)	1.23
Rye silage (%)	17.50
Feed Mixture (%)	15.40
Sugar beet strips (%)	8.75
Dry matter intake (kg)	*25.91*
Nitrogenous substances [g]	165.08
Fat [g]	23.37
Fibre [g]	151.41
ADF [g]	189.87
NDF [g]	282.95
Starch [g]	270.86
Total sugars [g]	30.95
NEL [MJ]	7.14

**CCM = Corn Cob Mix, ADF = Aciddetergent fibre, NDF = Neutraldetergent fibre, NEL = Netto energy lactation, kg = Kilograms, g = grams, MJ = Megajoul*

RESULTS AND DISCUSSION

The results showing the selection activity of dairy cows during the period under study are presented in Table 2.

The analysis includes data collected during one month from three groups of peak lactation multiparous 1,2,3 (PLM1;PLM2;PLM3) where different length of straw was fed in each group (TMR1;TMR2;TMR3). Peak lactation multiparous 1 (PLM1) was characterised with TMR1 being fed, with the inclusion of particles or straw that was cut to the desired length (3±2 cm). The second group (PLM2) represented the group where the feed was fed with a transitional ration (TMR2) or fed with a ration that was mixed with short (3±2 cm) and long (15±2 cm) straw particles. The third group (PLM3) was characterised by feeding a diet exclusively with long straw length (15±2 cm). The mean values at 5:00, which represent the average particle content measured immediately after the establishment of the ration, show the variability between the given PLM1-PLM3 groups studied. The feeding ration during the individual measurements during the day (11:00, 17:00 and 23:00) should replicate the values that were measured at 05:00.

Based on the data in Table 2, it can be concluded that in the PLM1 group, where TMR1 was fed (straw length 3±2 cm), dairy cows received TMR more homogenously and selection was less compared to the PLM2 and PLM3 groups ($p < 0.05$). This was particularly indicated by the values measured at the 1st site (19 mm), which varied significantly within the day. In the intermediate ration (TMR2), the addition of longer straw particles increased the selection activity of the cows and the percentage of fractions increased gradually compared to TMR1 ($p < 0.05$, p-value = 0.000).

Table 2. Monitoring intake (/selection) dynamics in peak lactation multiparous groups (PLM1-3)

Evaluated group	Evaluation of structure TMR	Evaluation time	Mean PLM1 (TMR1);N= 12	Mean PLM2 (TMR2);N= 12	Mean PLM3 (TMR3);N= 12	*p*-value
Peak lactation multiparous (PLM)	1st sieve (19 mm)	05:00	12.37[a]	9.01[b]	11.06[c]	0.000
		11:00	14.86[a]	15.89[b]	15.62[c]	
		17:00	21.22[a]	24.45[b]	26.87[c]	
		23:00	24.92[a]	28.51[b]	32.92[c]	
	2nd sieve (8mm)	05:00	48.47[a]	47.97[b]	42.53[c]	
		11:00	48.89[a]	46.37[b]	46.35[c]	
		17:00	48.98[a]	44.42[b]	42.46[c]	
		23:00	51.26[a]	45.74[b]	42.88[c]	
	3rd sieve (4mm)	05:00	12.23[a]	17.84[b]	17.67[c]	
		11:00	12.18[a]	16.41[b]	17.12[c]	
		17:00	10.25[a]	14.31[b]	13.07[c]	
		23:00	9.26[a]	11.44[b]	12.25[c]	
	Pad	05:00	26.93[a]	25.17[b]	28.74[c]	
		11:00	24.07[a]	21.34[b]	20.92[c]	
		17:00	19.55[a]	16.83[b]	17.60[c]	
		23:00	14.20[a]	14.59[b]	11.94[c]	

a-c = Different letters indicate statistical significance ($p<0.05$); TMR1,2,3=total mix ration; PLM1,2,3=peak lactation multiparous groups;N= number of observation.

The most selection was observed at TMR3, where the proportion of large particles (fraction retained on the sieve with a 19 mm hole size) was up to 32.92% at 23:00 h, which is 8% more particles than at TMR1 ($p < 0.05$, p-value = 0.000). The rationale is that after a complete

change in the physical structure of the straw (to longer particles), the dairy cows showed a more pronounced selection in favour of finer particles. A study by DeVries et al. (2005) found that the NDF content gradually increased during the day on the feed table, supporting the fact, as described by Leonardi and Armentano (2003), that dairy cows preferentially select for finer particles, which was also shown in our experiment. A more detailed analysis of the results for sieves with 8 mm and 4 mm diameter holes showed that the percentages of fractions (8 mm - 30-50%; 4 mm - 10-20%) were satisfied for all groups (PLM1-PLM3) ($p < 0.05$, p-value = 0.000). This finding is consistent with that of DeVries et al. (2007), where dairy cows did not show selection towards intermediate particles during the study period ($p = 0.001$). These values indicate that dairy cows mainly selected for particles from 1 sieve (19 mm), which was most affected by the change in straw length ($p < 0.05$). A similar statement is described by DeVries et al. (2007) who describe that in their research they observed dairy cows sorting against long particles or in favour of smaller particles ($p = 0.001$). A large effect of the change in TMR can also be observed on the pad, which had a smaller decrease in fractions during TMR1 feeding compared to TMR2 and TMR3, where the decrease (TMR3) was most evident at 23:00, and the remainder was only 11.94% (PLM3) ($p < 0.05$). These results indicate that the change in total mix ration structure had a significant effect on feed intake by dairy cows ($p < 0.05$). As the total mix ration in the PLM2 group gradually changed (3±2 cm to 15±2 cm), the dairy cows increased their selection, mainly targeting larger particles (+8mm), while decreasing the amount of particles remaining on the pad. This highlights the importance of

proper total mix ration preparation and structure to optimize nutrient intake, efficient feed utilisation and ensure adequate health status.

Table 3. Effect of straw particle size on activity and production ability of dairy cows (mean ±SD)

Parameter	**Group/TMR**			***p*-value**
	PLM1/TMR1 (N^1=495;N^2=99)	**PLM2/TMR2 (N^1=435;N^2=87)**	**PLM3/TMR3 (N^1=480;N^2=96)**	
Total eating time (h.)	4:34:54^a (±1:25:38)	4:44:25^a (±1:22:40)	5:06:09^b (±1:26.52)	
Total rumination time (h.)	7:32:16^a (±1:39:46)	8:08:18^b (±1:39:08)	8:52:11^c (±1:18:41)	
Non-active time (h.)	11:41:51^a (±2:27:19)	11:01:33^b (±2:26:03)	9:58:07^c (±2:01:32)	0.000
Milk yield (kg.day.cow^{-1})	34.35^a (±5.58)	34.86^a (±5.81)	37.69^b (±7.68)	
Fat (%)	3.71^a (±0.61)	3.97^b (±0.81)	3.94^b (±0.63)	
Protein (%)	3.16^a (±0.26)	3.23^b (±0.30)	3.41^c (±0.32)	

a-c = Different letters indicate statistical significance (p<0.05);N1= number of observation;)N2= number of observation for fat anf proteins; TMR1,2,3=total mix ration;PLM1,2,3=peak lactation multiparous; h=hours per day.

In Table 3, we have recorded the average values of total activity and non-activity, and the production ability of dairy cows in the peak group during the study period. Based on these data, a Post Hoc Tukey Test was then used to verify that statistically significant differences existed between the groups. Specifically, the groups (PLM1 and PLM3) were significantly different in selected parameters ($p < 0.05$). The food intake time for TMR1 feeding was 4:34:54 h. which was 0:31:15 h. less

compared to TMR3 (5:06:09 h.) ($p < 0.05$, p-value = 0.000). This difference can be justified by the use of longer particles (15±2 cm) of straw, which caused the dairy cows to select more (see Table 2) and to select smaller and more palatable components from TMR3. Conversely, TMR1 with shorter straw slices (at 3±2 cm) was more readily available, more palatable, which limited the selection process and thus reduced feed intake time. A statistically significant difference in food intake time between PLM2-PLM3 was also identified ($p < 0.05$). Dairy cows fed TMR3 (PLM3) had a significantly longer period of time compared to dairy cows (PLM2) fed TMR2. Analysis of feed intake time between PLM1 and PLM2 indicated a higher p-value (0.136) indicating no statistically significant difference ($p > 0.05$) between the two groups. The reason for this is that since it was an intermediate TMR (TMR2), it contained particles with both smaller section (3±2 cm) and longer section (15±2 cm) and selection was not as necessary as for TMR3 (Table 2). Changes in TMR also had a direct effect on cow behaviour in terms of rumination time ($p < 0.05$, p-value = 0.000). We observed an increase in rumination time when moving from TMR1 (which contained straw particles exclusively with a length of 3±2 cm) to TMR3 (containing longer straw stalks i.e. 15±2 cm). A similar argument is made by Zebeli et al. (2007), where they describe that dairy cows at higher *pe*NDF representation progressively increase rumination time. Rumination time increased progressively for each group based on longer physical structure ($p < 0.05$). Comparison of TMR1 (7:32:16 h.) with TMR3 (8:52:11 h.) showed a difference in rumination time of up to 1:19:54 h. ($p < 0.05$, p-value = 0.000). Changes in total mix ration in terms of increasing rumination time may contribute positively to rumen health and overall digestion in dairy

cows. Increasing the physical structure concentration in the study by Kahyani et al. (2013) increased rumination time, with a 3.7% increase in *pe*NDF content (from 5.7% to 9.4%). We observed a decreasing inactivity time ($p < 0.05$) after introducing longer straw into the TMR, which was related to changes in selection and affected the total time spent ingesting and rumination. Straw of greater length tended to increase the above times due to cows being forced to select more thoroughly and subsequently ruminate longer stalks, as shown in Table 3. The above reductions were observed over the course of each treatment group, with the mean non-active time decreasing by 1:43:43 h from TMR1 (11:41:51±2:27:19) to TMR3 (9:58:07±2:01:32) ($p < 0.05$, p-value = 0.000). There was also a significant increase in milk production between PLM1 and PLM3 groups ($p < 0.05$). In the PLM1 group where TMR1 was fed, the mean milk production was 34.35 kg, where as in PLM3 when TMR3 was fed it went up to 37.69 kg, an increase of 3.34 kg of milk ($p < 0.05$, p-value = 0.000). The increase in milk production suggests that the change in straw length has had a positive effect, but the likely true reason for the higher milk production is indicated in Table 2, where a selection in favour of finer particles (starch) found on the pad can be noted. Starch, being easily digestible, provides a quick source of energy for the cow and the increased intake of these particles improves the overall energy balance of the cow, which is reflected in the higher milk production. The finding that selection against long particles was associated with higher milk production is described by DeVries et al. (2011) ($p = 0.016$). Also, when milk production and fat content were analysed, there was a significant change associated with changes in ration. During TMR1 (PLM1) feeding, milk fat content ranged from 3.71% and in PLM2, fat

content increased to 3.97% during TMR2 feeding, which represented a statistically significant increase ($p < 0.05$). In the PLM3 group, when fed TMR3 the fat content increased mildly (3.94%) but was not statistically significant with PLM2 ($p > 0.05$), indicating a subsequent plateauing and thus that the main increase was between the PLM1 and PLM2 groups ($p < 0.05$, p-value = 0.000). Studies by DeVries et al. (2011); Fish and DeVries (2012) reported that each rejection of long particles (10%) reduced fat content by 0.15% points. Miller-Cushon and DeVries (2017) found a similar association with our results, where milk fat content increased by 0.1% points with the inclusion and benefit of selection for longer particles. The increase in milk constituent content was also evident for protein content and in each group (PLM1-PLM3) ($p < 0.05$, p-value = 0.000). In the TMR1 fed group the protein content of milk was 3.16%, in the intermediate - TMR2 (PLM2) fed group the content increased to 3.23% and in the TMR3 fed group the protein content of milk increased to 3.41% ($p < 0.05$).

CONCLUSION

This study analysed the effect of different straw lengths on the overall activity (feed intake time, rumination time) or non-activity and production ability of dairy cows. The structure of the TMR was also evaluated, where the selection or intake of the different fractions was monitored. The experiment was realised on high producing Holstein-Friesian dairy cows in a peak group, divided into three groups (PLM1;PLM2;PLM3), where each group received TMR with different straw lengths (TMR1;TMR2;TMR3). Food intake time and rumination time increased progressively with increasing straw length and physical structure concentration. PLM3 dairy cows had overall higher activity

compared to PLM1. Statistically significant differences were also observed for milk production and individual milk components, where the greatest increase in production was observed between PLM1 and PLM3 (3.34 kg). Milk fat content increased by 3.97% when fed TMR2 and an increase was also observed in protein content, where it was 3.16% in PLM1 and increased to 3.41% in PLM3 group. When analysing the TMR structure, it was found that as straw length increased, dairy cows selected in favour of finer particles, resulting in a greater percentage of the first sieve. The results suggest that straw length in TMR has a significant effect on the overall behaviour or activity of dairy cows, their milk production ability and milk composition. The PLM3 group of cows showed the most pronounced increase in feed intake time and rumination time, which decreased inactivity time. This increase in activity was related to an improvement in digestive processes and metabolism, which was reflected in increased production and higher fat content in milk. These results are important for the optimisation of TMR in dairy farming because they suggest that adjusting straw length can lead to increased feeding efficiency and subsequently to higher milk production and quality.

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