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Effects of different levels of physically effective fibers in diets for cows in early lactation

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Abstract

The study was conducted to investigate the effects of a total mixed ration (TMR) particle size on digestibility and production performances of the high-yielding cows in early lactation. The treatments were TMRs with forage-to-concentrate ratio 43:57 in diet dry matter, with four different mean particle lengths and physically effective fiber (PENDF) content based on different cut length of corn silage and alfalfa haylage. Determined values of PEF (physical effectiveness factor) and PENDF (through original and modified Penn State Particle Separator, PSPS) were considerably higher for forages and TMRs using the modified PSPS. The cut length of forage and particle size of TMRs did not affect dry matter intake. However reduced forage cut length significantly increased the apparent total tract digestibility of NDF (from 53.9 to 58.66%), and crude protein (from 71.56 to 77.90%), with the decrease in the non-fiber carbohydrate digestibility (from 91.99 to 86.80%). The increase in the milk yield (35.62 *vs*. 38.36 kg), and decrease in the milk fat (3.50 *vs*. 3.10%) and protein content (3.11 *vs*. 2.99%) were observed with the reduction of particle size in forages. There was no effect on milk fat daily yield, but the increase of the milk protein yield (1.08 *vs*. 1.15 kg) was determined with the reduced forage cut lengths. The milk fat to protein ratio had tendency to decrease with the reduced forage cut length. Decrease in forage particle size improved feed conversion ratio for milk production, improved digestibility and the milk yield, whereas milk protein content was reduced.

Additional key words: dairy cows; forage; nutrition; particle length; physical effectiveness.

Resumen

Efectos producidos por diferentes fibras físicamente efectivas en la alimentación de vacas en su primera fase de lactación

Se investigaron los efectos producidos por el tamaño de las partículas en una ración total mezclada (TMR) en la digestibilidad y en las características productivas de vacas lecheras de alta producción en su primera fase de la lactación. Los tratamientos fueron TMRs en una proporción forraje:concentrado 43:57, con cuatro diferentes longitudes de partículas y de contenido de fibra físicamente efectiva (PENDF), que varían según la longitud de corte del ensilaje de maíz y de heno de alfalfa. Los valores de PEF (factores de efectividad física) y de PENDF (calculados con el separador de partículas de Penn State, PSPS, tanto original como modificado) fueron mayores para forrajes y TMRs cuando se usó la versión modificada del sistema PSPS. Tanto la longitud de corte del forraje como el tamaño de partícula de la TMR no afectaron al consumo de materia seca, mientras que la reducción del tamaño de partícula del forraje produjo un aumento de la digestibilidad de la fibra neutro detergente y de la proteína bruta, así como una disminución de la digestibilidad de los carbohidratos no fibrosos. Asimismo, se detectó un incremento de la producción de leche y una reducción del contenido de grasa y proteína en la leche. La reducción en la longitud de corte del forraje no afectó a la producción diaria de grasa láctea, pero aumentó la producción diaria de proteínas en la leche. La relación entre el contenido de grasa y proteína en la leche tendió a descender cuando se redujo el tamaño de picado del forraje. La reducción del tamaño de partículas de forraje mejoró el índice de conversión de la materia seca del alimento para la producción de leche (6,8%), mejoró su digestibilidad y la producción, pero redujo el contenido de proteínas.

Palabras clave adicionales: efectividad física; forraje; longitud de las partículas; nutrición; vacas lecheras.

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Introduction

Particle lengths of the forage and total mixed ration (TMR) are significant parameters of the rations for early lactating cows (Kononoff & Heinrichs, 2003a). High-yielding lactating cows are characterized by high energy requirements and limited capacity for dry matter (DM) intake. The concept of physically effective fiber (PENDF) takes into account the dietary particle size and NDF (neutral detergent fiber) content of the diet, and defines physical effectiveness of the diet (Mertens, 1997). Yang & Beauchemin (2006a, 2007) concluded that using Penn State Particle Separator (PSPS) provided a good description of forages and dietary physical effectiveness of the diets.

The exact recommendations of PENDF content for the high-producing cow diets in the early lactation are not precisely defined. The actual values vary because of contradictory results of PENDF effects on digestibility and productive performances for different forages and TMRs with different concentrate to forage ratio (Kononoff & Heinrichs, 2003a). The minimal recommended dietary NDF content is 25 %DM, of which 19% should be from forage, in the rations for lactating cows (NRC, 2001). Moreover, due to the increased requirements for energy concentration, recommendations for minimal concentration of PENDF in the diets for high-producing cows in early lactation are of the special importance.

Reduction of particle size in the lactating cows diets tends to increase DM and organic matter (OM) intake (Einarson *et al.*, 2004*)*, while Rustomo *et al.* (2006) found no effect on the feed intake. Physical characteristics of ration expressed as forage particle length affects ruminal fermentation, rate of passage, postruminal and total digestibility. According to Kononoff & Heinrichs (2003a) the reduction of the dietary particle size increased DM and OM digestibility, whereas decreased intake of PENDF did not affect DM digestibility (Cao *et al.*, 2008). The reduced TMR mean particle length increased CP (crude protein) digestibility (Kononoff & Heinrichs, 2003a), while Yang & Beauchemin (2006b) found no effect on total tract N digestibility. The reduced particle length in alfalfa haylage increased digestibility of NDF (44.7 to 48.1%) and acid detergent fiber (ADF) (52.2 to 54%) according to Kononoff & Heinrichs (2003a). Reduced cut lengths of the corn silage and alfalfa haylage caused lower milk fat percentage, when both feeds were included in ration (Krause & Combs, 2003). Bhandari *et al*. (2007) found no differences in the milk yield, milk fat and protein, also milk fat and protein content with the decrease of cut length of corn silage and alfalfa haylage. Krause & Combs (2003) reported the trend of increased milk production efficiency (kg milk per kg consumed DM) with the reduced forage particle length.

The objective of the following experiment was to determine the effects of the different cut lengths of corn silage and alfalfa haylage on physical effectiveness of forages and TMR, dry matter intake (DMI), digestibility, feed conversion ratio, and production performances of cows in the early lactation. Further objective was to compare the values for PEF and PENDF obtained using modified and original PSPS.

Material and methods

Animals and diets

Forty multiparous Holstein cows in early lactation (10-45 DIM) averaging 60 months of age were randomly assigned to one of four treatments. The experiment was designed as one factorial arrangement with four treatments. The experimental groups were equalized according to the average milk yield. The experimental period lasted for 30 days. The cows were housed in the individual tie stalls and offered a TMR two times a day, at 07:00 and 19:00 h for *ad libitum* intake. Cows were offered one of four diets, which were chemically identical with 57% of concentrate and 43% of forages (DM basis), but different in mean particle size and PENDF level based on different particle length of the corn silage (CS) and alfalfa haylage (AH) (long LG, medium-long MLG, medium-short MSH, and short SH). Whole plant corn (hybrid Rubin, Institute PKB Agroekonomik, Belgrade) was harvested at the moisture content of approximately 70% (at the second/third milk line stage of maturity) using a self-propelled forage harvester (model Jaguar, Claas) set to obtain a theoretical cut length of 22, 19, 16 and 8 mm for LG, MLG, MSH and SH respectively. The chopped mate-

Abbreviations used: ADF (acid detergent fiber); AH (alfalfa haylage); ADL (acid detergent insoluble lignin); CP (crude protein); CS (corn silage); DIM (days in milk); DM (dry matter); DMI (dry matter intake); FCM (fat corrected milk); MP (metabolic protein); NDF (neutral detergent fiber); NE_L (net energy for lactation); NFC (nonfiber carbohydrate); OM (organic matter); PEF (physical effectiveness factor); PENDF (physically effective fiber); PSPS (Penn State Particle Separator); TMR (total mixed ration).

rial was placed in a concrete bunker (capacity 700 t), covered with black plastic, and ensiled for 3 months. First-cut, wilted alfalfa (sort NS Mediana ZMS V, Department of Field and Vegetable Crops, Institute for Forage Crops Novi Sad) was harvested at the early bloom stage using forage harvester (model Jaguar, Claas) to obtain haylage chopped at a theoretical chop length of 22, 19, 16 and 8 mm for LG, MLG, MSH and SH respectively. The chopped material was then ensiled with added inoculants (Sil-All, Alltech) in a concrete bunker (capacity 450t), covered with black plastic, and kept for 7 months before usage. Chemical composition of corn silage and alfalfa haylage is shown in Table 1.

The diets were formulated using the NRC (2001) software to supply adequate net energy for lactation-NE_L and metabolic protein-MP for a 600 kg cow producing 40 kg day^{-1} of milk containing 3.5% fat and 3.1% protein. Composition of the total mixed ration is shown in Table 1.

Physically effectiveness of forages and total mixed rations

Samples of CS and AH were collected once a week during the experimental period, whereas samples of the TMR were collected three times a week, for particle distribution analysis and DM determination, and then grouped by period, frozen (–20^{o}C) and stored for further analysis. The particle size distribution of the CS, AH and TMR were determined using original and new Penn State Particle Separator (PSPS, Lammers *et al*., 1996; Kononoff *et al*., 2003). Physical effectiveness factor (PEF) of both forages and TMR were determined as the proportion of DM retained on two sieves: 19 and 8 mm (PEF_{2s}) or on three sieves 19, 8 and 1.18 mm (PEF_{3s}). The NDF content of the original sample and of all materials retained on the sieves was measured. The $PENDF_{2s}$ and $PENDF_{3s}$ were estimated by multiplying NDF content of the forages and TMR by the

Table 1. Ingredients of the total mixed ration for dairy cows in early lactation, and chemical composition of corn silage, alfalfa haylage and diet

Ingredients	% of dry matter
Corn silage	22.40
Alfalfa haylage	20.97
Sugar beet pulp, dry	1.67
Corn grain, ground	22.05
Extruded soybean	8.82
Sunflower meal	17.40
Wheat middlings	4.22
Limestone	0.7
Dicalcium phosphate	0.5
Salt-NaCl	0.47
Sodium bicarbonate	0.33
Vitamin-mineral mix[1]	0.47

Chemical composition, % of dry matter	Corn silage	Alfalfa haylage	Diet
Dry matter, %	31.45	45.23	54.76
Crude protein	7.45	19.38	17.9
Neutral detergent fiber	47.03	43.63	31.0
Acid detergent fiber	29.79	32.45	20.1
Nonfiber carbohydrate	38.55	23.33	41.1
Ether extract	3.08	3.57	4.5
Ash	3.89	10.09	5.5
Lactic acid	4.15	3.68	–
Acetic acid	2.94	2.38	–
Butyric acid	0.00	0.00	–
pH	4.02	4.85	–

[1] Mixture of vitamins and trace elements, 1 kg contains: Vitamin A-1,000,000 IU, Vitamin D_3-200,000 IU, Vitamin E-5,000 IU, Niacin-2,000 mg, Biotin-50 mg, Fe-2,000 mg, Cu-1,000 mg, Mn-3,000 mg, Zn-5,000 mg, J-100 mg, Se-30 mg, and Co-30 mg.

PEF_{2s} and PEF_{3s}. The $PENDF_{2s\text{-}ndf}$ and $PENDF_{3s\text{-}ndf}$ were calculated as the proportion of NDF retained on two or on three sieves of the PSPS.

Digestibility trial

Apparent total tract digestibility of the nutrients was measured using ADL (Acid Detergent Insoluble Lignin, Official Method 973.18; AOAC, 2002) as suitable internal marker (Sunvold & Cochran, 1991). Five cows (averaged BCS 3.00 ± 0.25 on a 5-point scale) were used from each group for 7 days. Fecal samples were collected for each cow from the rectum twice a day (07:00 and 19:00 h) and stored (–20°C) for analysis. At the end of the experimental period an average sample of feces was formed for each cow, from all gathered samples. Feeds offered and orts were measured for each cow and recorded daily to calculate feed intake. Apparent nutrient digestibility in the total tract was calculated from concentrations of the indicator and nutrients in the consumed diet (feed refusals were taken into account) and feces using the following equation:

$$\text{Apparent digestibility} = 100–[(N_f/N_d)^* (M_d/M_f)]^*100$$

where N_f = concentration of the nutrient in the feces, N_d = concentration of the nutrient in the consumed diet, M_d = concentration of the marker in the consumed diet and M_f = concentration of the marker in the feces.

Analytical procedure

All feeds, TMRs, orts and feces samples were analyzed in the Laboratory for the Animal Nutrition at the Faculty of Agriculture, University in Belgrade. The samples of the corn silage, alfalfa haylage, TMRs, PSPS fractions, orts and feces were dried at 55°C in a forced-air oven for 48 h. Analytical DM content of oven-dried samples and concentrate diet ingredients were determined by drying at 105°C for 5 h. Samples were ground through a 1-mm diameter screen. Ash was determined by combustion at 550°C for 6 h. The OM content was calculated as the difference between DM and ash contents. The CP content was determined by micro-Kjeldahl method (method 988.05; AOAC, 2002) using K_2SO_4/Se catalyst-Kjeltabs S 3.5, on the Kjeltec Auto 1030 Analyzer-Tecator System. Ether extract content was determined by extraction using diethylether in the Soxhlett apparatus (method 920.39; AOAC, 2002). Neutral detergent fiber (NDF) content was determined using heat-stable α-amylase (A3306 Sigma Chemical Co., St Louis, MO, USA) and sodium-sulfite (Official Method 2002:04; AOAC, 2002). The acid detergent fiber (ADF) and acid detergent lignin (ADL) content was determined according to the Official Method: 973.18 (AOAC, 2002).

Milk yield and composition

Milk yield was measured and recorded daily. Cows were milked twice a day (at 06:00 and 18:00 h., DeLaval system Milk Master). Chemical composition of milk was determined once a week, the samples (50 mL) were collected using Waikato MK V apparatus. Milk fat and protein content were analyzed using infrared spectrophotometry (Milk-Scan, Foss Electric, Hillerød, Denmark) in the Laboratory for Quality Managing Eko-Lab DOO, Belgrade.

Calculations and statistical analysis

An ANOVA-procedure using the STATISTICA v.6 (StatSoft, 2003) was conducted to assess the effects of different forage chop length on ration digestibility and milk yield and composition (repeated measurements). Differences among treatment means were tested for significance using Tukey's multiple comparison test. Statistical significance was determined at $p < 0.05$ and $p < 0.01$.

Results

The values for PEF and PENDF of CS, AH and TMRs obtained using new PSPS with three sieves (PEF_{3s}, $PENDF_{3s}$ and $PENDF_{3s\text{-}ndf}$) were higher than those obtained using two sieves (PEF_{2s}, $PENDF_{2s}$ and $PENDF_{2s\text{-}ndf}$ (Table 2). There were wider ranges in PEF when two sieves were used (range of 0.61 to 0.71, 0.51 to 0.61 and 0.47 to 0.65, for CS, AH and TMR, respectively) compared with those obtained using three sieves (range of 0.97 to 0.98, 0.89 to 0.91 and 0.84 to 0.96, for CS, AH and TMR, respectively).

Intake of DM, OM and CP was not significantly affected by the dietary PENDF content, and only slight increases were determined for DM and OM intake

Table 2. Fiber (NDF) content of the Penn State Particle Separator fractions, particle size distribution, physical effectiveness factors and physically effective fiber content of the corn silage, alfalfa haylage and total mixed rations (TMR), in % dry matter (DM)

Item	Treatment			
	Long	**Medium-long**	**Medium-short**	**Short**
Corn silage				
> 19.0 mm	59.93	60.15	61.31	62.14
19.0 – 8.0 mm	49.82	48.25	47.87	48.71
8.0 – 1.18 mm	38.66	43.44	44.51	44.57
< 1.18 mm	29.77	35.88	34.62	34.44
PEF_{3s}[1]	0.98	0.98	0.97	0.97
PEF_{2s}[1]	0.71	0.69	0.68	0.61
$PENDF_{3s}$[2]	46.09	46.09	45.62	45.62
$PENDF_{3s\text{-}ndf}$[3]	46.46	46.42	46.13	46.10
$PENDF_{2s}$[2]	33.39	32.45	31.98	28.69
$PENDF_{2s\text{-}ndf}$[3]	36.06	33.78	33.00	29.70
Alfalfa haylage				
> 19.0 mm	53.99	50.27	57.02	55.80
19.0 – 8.0 mm	44.85	45.10	43.88	44.51
8.0 – 1.18 mm	38.55	42.28	41.05	42.53
< 1.18 mm	33.09	27.58	30.45	30.09
PEF_{3s}[1]	0.90	0.91	0.89	0.89
PEF_{2s}[1]	0.61	0.56	0.54	0.51
$PENDF_{3s}$[2]	39.27	39.70	38.83	38.83
$PENDF_{3s\text{-}ndf}$[3]	40.42	41.12	40.22	40.38
$PENDF_{2s}$[2]	26.61	24.43	23.56	22.25
$PENDF_{2s\text{-}ndf}$[3]	29.01	26.28	25.81	23.92
TMR				
> 19.0 mm	53.33	57.07	57.42	60.69
19.0 – 8.0 mm	28.02	29.05	29.02	32.51
8.0 – 1.18 mm	29.18	29.34	30.64	31.38
< 1.18 mm	14.57	21.66	25.44	11.51
PEF_{3s}[1]	0.96	0.93	0.93	0.84
PEF_{2s}[1]	0.65	0.61	0.60	0.47
$PENDF_{3s}$[2]	29.76	28.83	28.83	26.04
$PENDF_{3s\text{-}ndf}$[3]	30.35	29.43	29.26	28.23
$PENDF_{2s}$[2]	20.15	18.91	18.60	14.57
$PENDF_{2s\text{-}ndf}$[3]	21.41	20.22	19.21	16.80

[1] PEF_{3s} and PEF_{2s} : physical effectiveness factors determined as the proportion of DM retained on three and two sieves of PSPS, respectively. [2] $PENDF_{3s}$ and $PENDF_{2s}$: physically effective fiber determined as NDF content multiplied by PEF_{3s} or PEF_{2s}, respectively. [3] $PENDF_{3s\text{-}ndf}$ and $PENDF_{2s\text{-}ndf}$ physically effective fiber determined as the proportion of NDF retained on three or on two sieves of the PSPS, respectively.

(0.5-1.4% and 1.3-2.1%, respectively). Reduction of the forage particle length significantly increased the NDF intake (4.9-6.8%, $p < 0.01$ (Table 3). There was statistically significant difference for the NFC (non-fiber carbohydrate) intake only between long and medium-short treatment ($p < 0.05$).

Total tract apparent digestibility of DM and OM was not affected by decreased physical effectiveness of ration. The trend of increase in the NDF apparent digestibility was observed (from 53.9 to 58.66%) with the reduced dietary particle length (Table 3), and significant difference ($p < 0.05$) was found between groups fed rations with long and short forage cut lengths. Results of this study indicate the significant effect ($p < 0.01$) of the decrease in forage and the dietary particle lengths on the improvement in total tract digestibility of CP

Table 3. Effects of reducing forage cut length on nutrients intake and total tract apparent digestibility of cows in early lactation

Item	Treatment				SEM[1]	*p*-values
	Long	Medium-long	Medium-short	Short		
Intake, kg day^{-1}						
Dry matter	22.06	22.34	22.17	22.37	0.13	0.800
Organic matter	20.51	20.77	20.77	20.95	0.12	0.629
Crude protein	3.93	4.05	3.91	3.91	0.03	0.144
Neutral detergent fiber	6.74^{ab}	6.62^{a}	6.89^{b}	7.07^{bc}	0.03	≤ 0.001
Nonfiber carbohydrate	8.81^{a}	8.89^{ab}	9.34^{b}	8.97^{ab}	0.06	0.025
Digestibility, %						
Dry matter	70.54^{ab}	68.53^{ab}	71.67^{b}	67.98^{a}	0.53	0.032
Organic matter	72.14^{ab}	70.09^{ab}	72.87^{b}	69.35^{a}	0.51	0.031
Crude protein	73.60^{ab}	71.56^{a}	77.90^{bc}	76.41^{b}	0.68	0.001
Neutral detergent fiber	53.90^{a}	54.40^{ab}	55.01^{ab}	58.66^{b}	0.66	0.027
Acid detergent fiber	52.7	50.66	54.07	54.07	0.66	0.221
Nonfiber carbohydrate	91.99^{b}	89.18^{ab}	86.80^{a}	87.68^{ab}	0.83	0.019
Ether extract	84.17^{b}	73.57^{a}	80.63^{ab}	76.01^{a}	1.18	0.001

[1] SEM: Standard Error of the Mean. [a, b, c] Means in the same row with different superscripts differ ($p < 0.05$).

(from 71.56 to 77.90%). At the same time, the reduction in nonfiber carbohydrate digestibility was determined (from 91.99 to 86.80%) with significant effect ($p < 0.05$) between long and medium-short treatments. The similar trend was also found in ether extract digestibility (from 84.17 to 73.57%, $p < 0.01$).

The actual milk yield was significantly higher (from 35.62 to 38.36 kg, $p < 0.05$) and the 4% FCM (from 31.39 to 34.71 kg, $p < 0.01$) with decrease in the dietary PENDF concentration (Table 4). Milk fat and protein content were decreased (from 3.50 to 3.10%, $p < 0.01$, and from 3.11 to 2.99%, $p < 0.01$, respectively), whereas milk fat yield was unaffected by reduced dietary particle size, and at the same time the milk protein yield appeared to be higher (from 1.08 to 1.15 kg, $p < 0.01$) with reduced forage cut length. A trend for lower milk fat to protein ratio was also observed.

Better feed conversion ratio for milk production was obtained (increased by 6.8%) with reduced forage cutting length, and significant effects ($p < 0.01$) were determined between groups of cows fed diets with short, long and medium-long forage particle length.

Table 4. Effects of reducing forage cut length on yield and composition of milk and feed conversion of cows in early lactation

Item	Treatment				SEM[1]	*p*-values
	Long	Medium-long	Medium-short	Short		
Actual milk, kg day^{-1}	35.62^{a}	35.64^{a}	36.23^{ab}	38.36^{b}	0.39	0.027
4% fat corrected milk, kg day^{-1}	32.82^{ab}	31.39^{a}	31.22^{a}	34.71^{b}	0.40	0.005
Milk fat, %	3.50^{b}	3.21^{ab}	3.10^{a}	3.35^{ab}	0.036	0.001
Milk fat, kg day^{-1}	1.25^{b}	1.14^{a}	1.12^{a}	1.28^{b}	0.013	≤ 0.001
Milk protein, %	3.11^{b}	3.03^{ab}	3.00^{ab}	2.99^{a}	0.013	0.004
Milk protein, kg day^{-1}	1.11^{a}	1.08^{a}	1.09^{a}	1.15^{b}	0.01	≤ 0.001
Milk fat: protein ratio	1.13^{b}	1.06^{a}	1.03^{a}	1.12^{b}	0.013	0.037
Dry matter intake, kg kg^{-1} milk	0.64^{b}	0.64^{b}	0.62^{ab}	0.60^{a}	0.004	0.001
Dry matter intake, kg kg^{-1} 4% fat corrected milk	0.70^{ab}	0.73^{b}	0.73^{b}	0.68^{a}	0.006	0.001

[1] SEM: Standard Error of the Mean. [a, b, c] Means in the same row with different superscripts differ ($p < 0.05$).

Discussion

Higher values for PEF and PENDF of CS, AH and TMRs, and narrower ranges in PEF obtained using new PSPS with three sieves than those obtained using two sieves was due to the relatively large portion of materials retained on the 1.18 mm sieve. The greater differences in the PENDF content of the forages and TMR between treatments were obtained using the original PSPS with two sieves, in both procedures where PENDF is estimated as a proportion of DM or NDF retained on sieves.

These results are in agreement with other studies where PSPS with three or two sieves was used to measure physical effectiveness of CS, AH and TMR. Soita *et al.* (2005) reported that 99% of corn silage retained when 1.18 mm sieve was used, and there was no difference between long (19.1 mm) and short (9.5 mm) cut corn silage. Similarly, no difference in PEF was found for long (22.3 mm) and short (4.8 mm) cut corn silage in the study by Kononoff & Heinrichs (2003b). Yang & Beauchemin (2006a) determined greater range in PEF using original PSPS with two sieves, than those obtained using three sieves (range of 0.41-0.72 *vs.* 0.93 to 0.96, respectively) for three theoretical cut length of corn silage (28.6, 15.9 and 4.8 mm).

There were no significant effects of different PENDF content on DM and OM intake, although a slight increase was observed. The PENDF concentration of the TMR has greater effect on DMI when cows consume low quality forages. Chop length of forages affects the DMI when proportion of concentrate in the TMR is under 40% of the dietary DM (Krause *et al.*, 2002). In this study, proportion of concentrate in the diets for different treatments was approximately 57% in DM basis. Reduced chop length of CS (Kononoff & Heinrichs, 2003b; Yang & Beauchemin, 2006a), and AH (Yang & Beauchemin, 2007) did not affect the dietary DM and NDF intake. It was discussed that the different dietary content of PENDF did not affect the rumen rate of digesta passage and thereby DM intake (Beauchemin & Yang, 2005).

Dry matter intake was not significantly affected by the increased NDF digestibility with reduced cut lengths of CS and AH, which might be attributed to the high-concentrate rations which decreased the effect of higher fiber digestibility, and to the limited dietary DM consumption that is typical for dairy cows in early lactation.

Significant increase of NDF intake with reduced particle length of forages is probably a result of particle selection effect, where cows on the diets with lower particle length consumed a greater proportion of long particles to provide a higher physical effectiveness of the consumed diet. This could be more apparent with the high-concentrate and high-fermentable rations with reduced mean particle size and physically effective fiber concentration, containing high quality and digestible forage with decreased cut length. In the recent study, dietary content of NDF and PENDF for all treatments were above the minimal requirements (25% for NDF, 19% for forage NDF on DM basis; NRC, 2001). Kononoff & Heinrichs (2003b) reported that high-fiber coarse particles of CS were not consumed, and that sorting was the greatest in cows fed diet with longer forage particle length. This could explain the lower NDF intake in cows fed on the diets with longer forage particle length. As particle size of AH decreased there was a significant increase in the effect on DM and NDF intake (Kononoff & Heinrichs, 2003a).

In our experiment DM and OM digestibility were not affected by chop length of forages, which is consistent with earlier studies where no effects of lower PENDF dietary content on DM and OM digestibility was detected (Krause *et al.*, 2002; Cao *et al.*, 2008). Increased NDF digestibility obtained in our research was also documented in some earlier studies and is thought to be due to increased surface area available for microbial attack, which accelerates the cellulolytic processes in the rumen (Kononoff & Heinrichs, 2003a). These authors also reported that decrease in particle length of alfalfa haylage and the TMR increased the NDF and ADF digestibility (from 44.7 to 48.1% and from 52.2 to 54.0%). Total tract digestion of fiber reflects digestion in the rumen. The lower total tract digestibility of NDF (53.2 and 48.2%) and ADF (39.8 and 28.2%) with increased cut length of barley silage was found in an investigation of Yang & Beauchemin (2006b), whereas in other studies digestibility of the NDF and ADF was unaffected by decreased CS cut length (Kononoff & Heinrichs, 2003b) and AH (Krause & Combs, 2003).

Higher digestibility of CP that was found in this experiment could be attributed to the greater availability of the diet protein to proteolytic enzymes of abomasum and small intestine, due to the smaller dietary particles. Those results are in agreement with those of Kononoff & Heinrichs (2003a) who obtained higher apparent digestibility of the CP (from 53.2 to 58.6%) with reduced particle length of AH.

Lower digestibility of NFC with the reduced particle lengths of CS and AH is probably the result of an ab-

sence of shift in starch digestion from the rumen to the intestine, which is typical for rations with longer cut forages (Yang & Beauchemin, 2006a). The reduced dietary particle size might increase the rates of the "small size particle" ruminal passage, reduced ruminal starch fermentation, and increased outflow of starch into intestine. Increased starch delivery decreases the intestinal starch digestion, as a percentage of that is entering the small intestine (Nocek & Tamminga, 1991).

The decrease in ether extract digestibility with finely chopped forage is in agreement with the results of Kononoff & Heinrichs (2003b) who considered the lower total tract digestibility of ether extract a result of shorter cut length of corn silage in the TMR fed to Holstein cows in early lactation.

Milk yield was significantly higher in cows that received the diet with lower dietary PENDF concentration. Robinson & McQueen (1992) and Miller *et al.* (1990) attributed higher milk yield to higher fiber digestibility, as DMI was unaffected. In the study of Oba & Allen (1999), increased NDF digestibility by 1% resulted in 0.25 kg day^{-1} higher FCM (fat corrected milk) yield.

Tendency for lower milk fat percentage in current study is consistent with results of Krause & Combs (2003), who reported decreased milk fat percentage (3.07 and 2.90) with lower cut length of CS and AH when both feeds were ingredients of the TMR. The reduced concentration of the dietary PENDF results in greater decrease of milk fat with rations containing lower PENDF, compared to rations with higher PENDF content (Mertens, 1997).

The decrease in milk protein content with lower PENDF concentration in the diet is probably the result of the lower starch digestibility, because starch is an important source of easy-available energy for microbial protein synthesis (Mackle *et al.*, 2000).

Better feed conversion was obtained with the reduced dietary particle size within the values investigated in this experiment. More effective feed utilization might be the result of the higher NDF and CP digestibility, considering that there were no differences in DM and OM intake between experimental groups. Higher NDF digestibility increases the amount of available energy and NE_L concentration in ration DM. Krause & Combs (2003) reported that reduced forage cut length resulted in the improved milk production efficiency.

As final conclusions, higher values for PEF and PENDF of corn silages, alfalfa haylages, the TMRs, and narrower ranges in PEF were obtained using new PSPS with three sieves compared to the original PSPS. The dietary content of the physically effective fiber and forage particle length affected feed digestibility and production performances in early lactating high-yielding dairy cows. The lower dietary physical effectiveness with reduced chop length of corn silage and alfalfa haylage increased the ration digestibility, milk yield and feed conversion ratio, but also lowered milk protein content. The study demonstrated that the reduced cut length of corn silage and alfalfa haylage in total mixed rations (forage-to-concentrate ratio 43:57) improved the production performances of high-yielding cows in early lactation.

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