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Effects of Barley Silage Particle Size with Two Levels of Concentrate, Beet Bulp Levels and Grain Levels on Dry Matter Intake, Digestibility, Ruminal Parameters, and Feed Intake Behavior in Sheep

Research Article

M.M. Sharifi-Hoseini[1*], O. Dayani[1] and P. Dadvar[2]

[1] Department of Animal Science, College of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran
[2] Kerman Agricultural and Natural Resources Research and Education Center, Kerman, Iran

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*Correspondence E-mail: mmsharifi@uk.ac.ir

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ABSTRACT

Three experiments were conducted to investigate effects of particle size and levels of barley silage with different levels of concentrate, non-forage fiber, and grain on intake, digestibility, ruminal parameters, and feeding behavior on sheep In all experiments, silages were prepared as the size of large and short particle size (16 and 8 mm, respectively). The barley silage particle size was examined with two levels of concentrate as the first experiment, with two levels of non-forage fiber sources as the second experiment and with two levels of barley grain as the third experiment. In each experiment, eight rams were used in a completely randomized design with a 2 × 2 factorial method in four 21-day periods. In experiment 1, dry matter intake was higher in the diet with 40 percentage concentrate compared to 60 percentage concentrate (P<0.01). Rumen pH decreased in diets with small silage particle size and high concentrate at two and four hours after feeding. Microbial protein synthesis increased in diets with small silage particle size and diet with 60 percentage concentrate (P<0.04 and P<0.02, respectively). In experiment 2, neutral detergent fiber (NDF) intake and digestibility were higher in diets with 20 percentage sugar beet pulp (P<0.05 and P<0.05, respectively). Rumen pH was lower in diets with 20 percentage sugar beet pulp after two and four hours of feeding (P=0.05 and P<0.05, respectively). In experiment 3, rumen pH was lower in diets with 40 percentage barley grain and small particle size silage at two and four hours after feeding. In all three experiments, the time of eating, rumination and chewing activity were higher in diets with large silage particle size. Geometric mean was higher in three experiments in diets with long silage. The results suggest that barley silage shows promise for use in combination with other feedstuffs to potentially enhance animal performance and rumen health.

KEY WORDS barley grain, chewing activity, digestibility, microbial protein synthesis, NH_3-N.

INTRODUCTION

Increasing livestock production requires high levels of concentrate supplementation and producing high quality forage with a tendency to low levels of dietary fiber (March *et al.* 2014). Low levels of fiber can negatively affect rumen metabolism and increase the risk of the metabolic disorders like sub-acute ruminal acidosis (SARA) (Yang and Beauchemin, 2006). Dietary particle size is considered as a key factor along with forage fiber and non-forage carbohydrate concentration in order to ensure a healthy rumen function and maintain animal performance (Zebeli *et al.* 2012). Physically effective NDF (peNDF) can be defined as the fraction of the feed that can stimulate chewing activity (Teimouri-Yansari *et al.* 2004). The peNDF is critical for proper ruminal fermentation and animal production

(Sharifi-Hoseini *et al*. 2018). The peNDF content of a diet is mainly due to forage to concentrate ratio, forage particle size, and their interactions (Li *et al*. 2019). However, some physical properties, such as functional specific gravity, water holding capacity and hydration rate can influence physically effective factor (PEF), but only particle size measurement is central to all effective fiber systems (Teimouri-Yansari, 2016).

Since cereal grains must be limited in diets to avoid SARA, by-product feeds with high fiber content are the alternatives to forages. These by-product feeds are referred to as non-forage fiber sources (NFFS) (Voelker and Allen, 2003). the use of NFFS like beet pulp (BP) in high-starch diet is a method to reduce the dependence on cereals and decrease negative associative effects of high starch, resulting in improved NDF digestibility (NDFD), increased dry matter intake (DMI), and decreased SARA (Nousiainen *et al*. 2009). The NDF in BP is highly fermentable in the rumen and can be used to supply digestible fiber in the diet (Heydari *et al*. 2021). The energy content of the grains is positively correlated with starch content (Aragona *et al*. 2020). There is a positive linear correlation between dietary starch content and dry matter digestibility (DMD) and growth performance (Hu *et al*. 2018).

Since barley silage contains less starch and fiber carbohydrates than corn silage and has a higher buffering capacity, its use instead of corn silage can be effective in reducing dietary non-fiber carbohydrates and preventing a decrease in ruminal pH (Addah *et al*. 2011). However, there is a lack of information on the effects of particle size of grass-silage-based diets (Tayyab *et al*. 2018). To investigate the effects of mixing barley silage of different sizes with various feed ingredients in different proportions, a study was conducted using sheep (*Ovis aries*) as the experimental animals. Two different particle sizes of barley silage were used in the experiment. Additionally, two levels of concentrate, two levels of NFFS, and two types of grain were incorporated into the diets. The main objective was to determine the impact of different factors on DM and NDF intake, digestibility, rumen parameters, and feed intake behavior. The researchers aimed to provide valuable insights into the potential benefits and limitations of incorporating different feed ingredients and varying proportions of barley silage in the diets of small ruminants.

MATERIALS AND METHODS

Silage production and quality

Barley forage was harvested in the field of Faculty of Agriculture, Shahid Bahonar University of Kerman, Kerman Iran (latitude 30° 150 N, longitude 57° 010 E, altitude 1755 m), at late-April 2020. Whole barley forage was chopped by chopper with theoretical length of cut (claas, Jaguar 62 model, 8 blades, Germany) of 8 and 16 mm. The DM of barley forage was 28 ± 3.0 to 34 ± 3.5 percentage at harvest time. Each chopped size of barley forage was separately ensiled in one bunker silo without any additive for 45 days, after that the chemical composition and pH of the silage were determined. The DM (g/kg) and CP (g/kg) contents of the silage were determined according to standard methods of AOAC (2012).

The NDF and acid detergent fiber (ADF) content were analyzed following the methods described by Van Soest *et al*. (1991). NFC value was calculated by DePeters and Arosemena (2000) procedure. The pH of each sample was determined in triplicate using approximately 25 g wet ensilage added to 100 mL of distilled water (Hattori *et al*. 2008). After hydration for 10 min, pH was determined using a digital pH meter (Elmetron-CP 103). The pH values and DM content of the silages were used to calculate the silages Flieg points at the end of fermentation period according to the following equation (Denek and Can, 2006):

$$\textit{Flieg score} = 220 + (2\times\%\mathrm{DM}-15) - 40 \times \mathrm{pH}$$

Diets, animals and experimental design

Three experiments were carried out. In experiments 1, 2, and 3; the two barley silage particle size (SPS) including short and long was examined with two levels of concentrate (high and low); with two levels of NFFS (with or without BP), and with two levels of barley grain (40 and 20%), respectively. The details of the different treatments for each experiment are presented in Table 1. All diets were formulated to meet the sheep requirements (NRC, 2007).

In each experiment, were used eight two years rams (40±2.5 kg live weight). The animals were maintained according to the guidelines of Iranian Council on Animal Care (1995) (file number 22143/granted on 2015/1/1). Each experiment was performed in four 21-day periods, each consisting of the 14 days for the adaptation period and 7 days for sampling and determines the feed intake behavior. Rams were housed in individual metabolic cages (0.75×1.5 m) that allowing separate collection of feces and urine. The animals were fed total mixed ration (TMR) *ad-libitum* twice daily at 08:00 and 18:00 (at least 10 percentage orts). Fresh and clean water was available at all times.

Particle distribution and effectiveness of fiber

Particle size distributions were determined for all diets using the Penn State Particle Separator (PSPS) as described by (Kononoff *et al*. 2003). The PSPS was equipped with 3 screens including 19.0, 8.0, and 1.18 mm and a bottom pan. The PEF values were determined as the proportion of DM retained on three sieves ($PEF_{>1.18}$).

Table 1 Ingredients and chemical composition of the three experimental diets regardless of differing in barley silage particle size (16 and 8 mm) content

Ingredients (g/kg of dry matter)	Experiment 1		Experiment 2		Experiment 3	
	High concentrate	Low concentrate	High NFFS[4]	Low NFFS	High barley grain	Low barley grain
Barley silage	400.0	600.0	400.0	400.0	400.0	400.0
Barley grain	394.8	258.6	200.0	400.0	400.0	200.0
Corn grain	-	-	-	-	-	200.0
Beet pulp	-	-	200.0	-	-	-
Wheat bran	111.1	70.0	80.0	110.0	110.0	80.0
Cottonseed meal	55.6	36.9	60.0	50.0	50.0	50.0
Soybean meal	-	-	40.0	20.0	20.0	50.0
sodium bicarbonate	7.4	7.4	-	-	-	-
Di-calcium phosphate	16.3	13.4	5.0	5.0	5.0	5.0
Crush lime stone	11.1	10.0	10.0	10.0	10.0	10.0
Salt	3.7	3.7	5.0	5.0	5.0	5.0
Chemical composition (g/kg of dry matter)						
Metabolizable energy (MJ/kg)	10.30	10.05	10.51	10.59	10.59	10.59
Crude protein	141.06	141. 06	145.6	141.6	153.0	153.0
Neutral detergent fiber	400.5	402.5	409.5	401.5	373.0	382.0
Ether extract	27.0	28.0	27.0	27.0	27.0	27.0
Ca	7.55	7.50	7.48	7.45	7.035	7.40
P	5.10	5.00	5.50	5.20	5.60	5.50

[1] Diets included (DM basis): 1) long barley silage and 60% concentrate; 2) long barley silage and 40% concentrate; 3) short barley silage and 60% concentrate and 4) short barley silage and 40% concentrate.
[2] Diets included (DM basis): 1) long barley silage diet without beet pulp; 2) long barley silage diet and 20% beet pulp; 3) short barley silage diet without beet pulp and 4) short barley silage diet and 20% beet pulp.
[3] Diets included (DM basis): 1) long barley silage diet and 40% barley grain; 2) long barley silage diet and 20% barley grain; 3) short barley silage diet and 40% barley grain and 4) short barley silage diet and 20% barley grain.
[4] Non forage fiber source

The peNDF > 1.18 of the diets was determined by multiplying the PEF of the TMR by the NDF content (DM basis) of the diet (Yang and Beauchemin, 2004). The geometric mean (GM) of the TMR and its standard deviation were calculated according to ASAE (2002).

Feed intake, digestibility, and microbial protein

The DMI and orts were recorded for each day of the experiment. All the feces was collected and weighed before 08:00 and 10 percentage of the feces were sampled, packed in nylon bags and protected at -20 °C. At the end of the period, feces and feed samples and orts of each sheep were separately mixed, and one sample per animal was considered for chemical analyses. Samples of feed, feces, and orts were first dried at 55 °C for 72 h. The total fecal collection method was used for the calculation of DM and other nutrients digestibility (Beecher *et al.* 2014).

Daily urine production was collected for 5 d and a 100 mL sample was mixed with 10 percentage (V/V) sulfuric acid (Merck, Germany) to prevent bacterial degradation of allantoin and volatile nitrogen (N) losses. Due to the variability in the urine volume produced by rams, the volume of H_2SO_4 was adjusted to ensure that the pH was maintained below 3.0 (Gomes *et al.* 2014). The Microbial protein synthesis was then calculated based on Chen and Gomez (1992) procedure.

Chewing behavior

Eating and rumination activities were visually monitored for a 24-h period at 5 min intervals on day 20 of each experimental period. To estimate time spent eating or rumination per kilogram of DM, the average intake for the period of observations was used.

A period of eating or ruminating was defined as at least 5 min activity. Total time spent chewing was calculated as the total time spent eating and rumination (Sharifi-Hosseini *et al.* 2018).

Ruminal characteristics

At the end of each period, ruminal fluid samples were taken with a stomach tube at 0, 2, 4, 6, and 8 hours after feeding and filtered through four layers of cheesecloth. The ruminal pH was immediately measured using a pH meter (Elmetron, CP130, Poland). A 10 mL sample was mixed with 0.1 mL of sulfuric acid 50 percentage (V/V) for NH_3-N analysis, and kept frozen at -20 °C. The samples were thawed at 4 °C, centrifuged at 12000 rpm for 10 min, and analyzed for NH3-N concentration, using phenol-hypochlorite reaction (Broderick and Kang, 1980).

Statistical analyses

Data on silage characteristics were subjected to analysis of variance (ANOVA) using the GLM procedure of SAS

(2004) as a completely randomized design which can be expressed as (equation 1):

$Y_{ij} = \mu + T_i + e_{ij}$, (equation 1)

Where:
Y_{ij}: dependent variable.
μ: general mean.
T_i: i^{th} effect of the treatments.
e_{ij}: standard error.

Other experimental data were analyzed in a completely randomized design with a 2 × 2 factorial method using the following model (equation 2):

$Y_{ijklm} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \Theta_k + \delta_l + \gamma m + e_{ijklmn}$
(equation 2)

Where:
Y_{ijklm}: dependent variables.
μ: overall mean.
α_i: fixed effect of barley SPS (i=1 and 2).
β_j: fixed effect of concentrate level (j=1 and 2) in experiment 1, NFFS level (with or without BP) in experiment 2, and grain type (barley and corn) in experiment 3.
$(\alpha\beta)_{ijk}$: fixed effect of interaction between α_i and β_j factors.
Θ_l: random effect of the sheep.
δ_k: replication.
γm: block (time) effect (only for ruminal pH and NH_3-N concentration.
e_{ijklmn}: residual error.

Tukey's multiple comparison test was employed to compare the means (P<0.05).

RESULTS AND DISCUSSION

The DM content was higher in long than short barley silages (Table 2, P<0.01). Short barley silage had the higher protein content (P<0.01). The amount of NDF was significantly higher in long barley silage (P<0.01), but ADF was not significantly different between silages. The pH value was lower in short than long barley silages (P<0.01). The NFC value was found to be higher in barley silage with a small particle size (P<0.01). The flieg score was higher in short than long barley SPS (P<0.01).

Long barley SPS diets had more particle retained on 19-mm sieve in experiments 1 and 2, but short SPS had more particle on 1.18-mm sieve in experiments 1, 2 and 3 (Table 3). In experiment 1, short SPS diets had more particle retained on pan (P<0.01), but in experiment 3, long SPS diets had more particle retained on pan (P<0.01).

In the three experiments, GM values were higher in long than short barely SPS diets (P<0.05). Concentrate levels, BP levels and grain types had no effect on particle size distribution and GM value of diets.

In experiment 1, the DMI was higher in 40 percentage concentrate diets compare to 60 percentage concentration diets (P<0.01), but was not affected by barley SPS (Table 4). The NDF intake (NDFI) was affected by SPS and concentrate levels and the lowest NDFI was observed in short SPS and 60 percentage concentrate diet (P<0.05). The DMD was affected by SPS (P<0.05) and concentrate levels (P<0.05) and was higher in short SPS and low concentrate diets (P<0.01). The NDFD was not affected by SPS and concentrate levels. In experiment 2, DMI was not influenced by BP levels and barley SPS, but there was a significant interaction between SPS and BP levels. The NDFI was not affected by SPS, but was higher in BP diets (P<0.01). The DMD was not affected by SPS and BP levels. The highest NDFD was observed in short SPS and 20 percentage BP diet (P<0.05). In experiment 3, the DMI, NDFI, DMD and NDFD were not affected by SPS and barley grain levels.

In experiment 1, the pH value was affected by barley SPS and concentration levels at 2 and 4 hours after feeding (P<0.05 and P<0.01, respectively, Table 5), but no significant interaction was found between them. In experiment 2, the pH value was lower in high BP diets at 2 (P=0.05) and 4 (P<0.05) hours after feeding, but was not influenced by barley SPS. In experiment 3, the pH value was affected by barley SPS and grain type at 2 - 4 hours after feeding, but no significant interaction was found between them.

In experiment 1, the NH_3-N concentration in rumen was not affected by the SPS and concentrate levels at different times after feeding (Table 6). In experiment 2, NH_3-N concentration in rumen was not affected by the SPS and levels of BP at different times after feeding, but interaction effects in short SPS and zero percentage BP diet were significantly lower between treatments at 2 h after feeding (P<0.01). In the experiment 3, NH_3-N concentration in rumen was not affected by the barley SPS and barley grain levels at different times after feeding.

In experiment 1, the production of microbial protein was affected by barley SPS and concentrate levels, but no interaction effect was observed (Table 7). In experiments 2 and 3, the interaction effects of SPS, BP levels, and grain types on the microbial protein synthesis were not statistically significant.

In experiments 1, 2 and 3 the time of eating, rumination and chewing activity (min/day) were higher in long SPS diets (P< 0.01, P<0.05 and P<0.01, respectively, Table 8), but the concentrate levels and grain types had no effect on them.

Table 2 Chemical compositions, pH and flieg score of long and short barley silages (n=4)

Chemical composition	Long silage	Short silage	SEM	P-value
DM (g/kg as fed)	331.4	293.6	4.41	<0.01
OM (g/kg DM)	910.5	915.1	3.52	0.45
EE (g/kg DM)	16.1	17.0	1.6	0.23
Crude protein (g/kg DM)	65.9	83.6	2.45	<0.01
Neutral detergent fiber (g/kg DM)	662.0	585.4	4.60	<0.01
Acid detergent fiber (g/kg DM)	386.7	374.6	8.32	0.09
pH	4.60	4.00	0.02	<0.01
NFC (g/kg DM)	176.5	229.0	13.2	<0.01
Flieg score[1]	86.09	95.62	0.59	<0.01

[1] Flieg score= 220 + (2×%DM-15) – 40 × pH
DM: dry matter; OM: organic matter; EE: ether extract and NFC: non forage carbohydrate.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 3 Penn State Particle Separator and physical characteristics of 2 sizes of barley silage in four diets of three experiments

Silage particle size	Long (16mm)		Short (8mm)		SEM	P-value		
Experiment 1[1] (n=4)						Silage sizes	Concentrate levels	Silage size × concentrate
Concentrate levels (%)	60	40	60	40				
DM retained on sieves								
19 mm (%)	30.57	36.64	20.92	22.83	6.12	0.03	0.81	0.58
8 mm (%)	7.90	8.49	4.46	7.54	1.18	0.14	0.43	0.19
1.18 mm (%)	55.20	53.37	66.52	63.00	6.72	0.03	0.61	0.09
Pan (%)	2.29	0.48	8.07	5.13	1.15	<0.01	0.34	0.07
$peNDF_{>1.18}$ (%)	41.54	40.09	36.96	40.36	0.44	0.08	0.68	0.86
Geometric mean (mm)	13.97	13.91	10.81	10.84	1.22	0.01	0.90	0.87
SDG	1.70	1.63	1.59	1.51	-	-	-	-
Experiment 2[2] (n=4)						Silage sizes	Beet pulp levels	Silage size × beet pulp
Beet pulp levels (%)	0	20	0	20				
DM retained on sieves								
19 mm (%)	59.64	51.36	43.74	40.96	4.73	<0.05	0.36	0.37
8 mm (%)	21.36	24.87	23.89	22.69	4.18	0.96	0.79	0.59
1.18 mm (%)	11.34	25.24	16.99	26.23	2.61	<0.01	0.26	0.11
Pan (%)	7.65[a]	6.77[b]	6.56[b]	7.31[ab]	0.80	0.11	0.70	0.01
$peNDF_{>1.18}$ (%)	43.80	46.44	43.45	45.50	1.84	0.88	0.25	0.79
Geometric mean (mm)	9.23	7.96	6.12	6.14	0.55	<0.01	0.17	0.15
SDG	3.05	5.75	5.13	4.80	-	-	-	-
Experiment 3[3] (n=4)						Silage sizes	Barley levels	Silage size × barley levels
Barley grain levels (%)	40	20	40	20				
DM retained on sieves								
19 mm (%)	43.80	46.44	43.45	43.50	1.84	0.88	0.25	0.74
8 mm (%)	31.78	31.49	22.97	26.65	4.59	0.10	0.87	0.82
1.18 mm (%)	17.54	16.91	27.05	27.99	2.22	<0.01	0.77	0.55
Pan (%)	7.10	5.16	6.53	1.84	1.40	<0.01	0.75	0.19
$peNDF_{>1.18}$ (%)	40.62	42.24	33.82	34.38	1.62	0.08	0.15	0.37
Geometric mean (mm)	8.40	8.16	6.95	6.14	4.70	0.02	0.61	0.98
SDG	2.75	2.65	3.20	3.82	-	-	-	-

[1] Diets included (DM basis): 1) long barley silage and 60% concentrate; 2) long barley silage and 40% concentrate; 3) short barley silage and 60% concentrate and 4) short barley silage and 40% concentrate.
[2] Diets included (DM basis): 1) long barley silage diet without beet pulp; 2) long barley silage diet and 20% beet pulp; 3) short barley silage diet without beet pulp and 4) short barley silage diet and 20% beet pulp.
[3] Diets included (DM basis): 1) long barley silage diet and 40% barley grain; 2) long barley silage diet and 20% barley grain; 3) short barley silage diet and 40% barley grain and 4) short barley silage diet and 20% barley grain.
DM: dry matter; peNDF: physically effective neutral detergent fiber > 1.18 and SDG: standard deviation of the geometric mean.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 4 The effect of four experimental diets in each of the three experiments on nutrients feed intake and digestibility

Silage particle size	Long (16 mm)		Short (8 mm)		SEM	P-value		
Experiment 1[1] (n=8)						Silage sizes	Concentrate levels	Silage sizes × concentrate
Concentrate levels (%)	60	40	60	40				
Intake (kg DM/day)								
Dry matter	1.25	1.43	1.15	1.46	0.10	0.53	<0.01	0.17
Neutral detergent fiber	0.64^{a}	0.68^{a}	0.54^{b}	0.64^{a}	0.02	<0.05	<0.05	<0.05
Digestibility (g/kg DMI)								
Dry matter	578.0^{ab}	579.0^{ab}	531.9^{b}	649.0^{a}	17.1	<0.05	<0.05	0.01
Neutral detergent fiber	166.2	232.4	211.8	217.8	37.2	0.49	0.14	0.28
Experiment 2[2] (n=8)						Silage sizes	Beet pulp levels	Silage sizes × beet pulp
Beet pulp levels (%)	0	20	0	20				
Intake (kg DM/day)								
Dry matter	1.93^{ab}	1.80^{b}	1.80^{b}	2. 09^{a}	0.05	0.10	0.27	0.01
Neutral detergent fiber	0.71^{b}	0.74^{ab}	0.68^{b}	0.86^{a}	0.02	0.08	<0.01	<0.01
Digestibility (g/kg DM)								
Dry matter	771.3^{a}	730.4^{ab}	707.8^{b}	781.1^{a}	24.6	0.80	0.52	<0.05
Neutral detergent fiber	667.3^{b}	659.4^{b}	583.4^{b}	739.7^{a}	35.6	0.90	0.06	<0.05
Experiment 3[3] (n=8)						Silage sizes	Barley levels	Silage size × barley levels
Barley grain levels (%)	40	20	40	20				
Intake (kg DM/day)								
Dry matter	1.74	1.85	1.72	1.86	0.08	0.96	0.06	0.86
Neutral detergent fiber	0.71	0.78	0.70	0.80	0.03	0.83	0.06	0.64
Digestibility (g/kg DMI)								
Dry matter	678.5	762.4	710.4	711.4	26.5	0.99	0.27	0.28
Neutral detergent fiber	448.7	527.4	476.5	482.5	41.7	0.85	0.34	0.40

[1] Diets included (DM basis): 1) long barley silage and 60% concentrate; 2) long barley silage and 40% concentrate; 3) short barley silage and 60% concentrate and 4) short barley silage and 40% concentrate.
[2] Diets included (DM basis): 1) long barley silage diet without beet pulp; 2) long barley silage diet and 20% beet pulp; 3) short barley silage diet without beet pulp and 4) short barley silage diet and 20% beet pulp.
[3] Diets included (DM basis): 1) long barley silage diet and 40% barley grain; 2) long barley silage diet and 20% barley grain; 3) short barley silage diet and 40% barley grain and 4) short barley silage diet and 20% barley grain.
DM: dry matter and DMI: dry matter intake.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

In experiment 2, eating, rumination and chewing activity were significantly higher in 20 percentage BP diets (P<0.01). In this experiment, the interaction effects for eating (P<0.01), rumination (P<0.05), and chewing (P<0.01) activity were significantly higher in 20 percentage BP diets and lower in short SPS and 0 percentage BP diet.

The amount of DM was higher in long than short SPS, which might be due to high seepage in short SPS. Decreasing the size of chopped fodder particles was probably the reason for increasing the surface of fodder and increasing DM loss in the form of silage seepage. The higher DM content in long SPS is in agreement with the study of Soita *et al.* (2000) reporting that the percentage of DM in long and short barley silages was 37.4 and 34.6, respectively. The protein content was higher in short barley than long SPS. As the short fresh forage is ensiled, the more sugars could be available which is accompanied by a rapid reduction of pH and the proteolysis activity declines with reducing the silage pH (McDonald *et al.* 2011). Contrary to our results, it is reported that the chemical composition grass silage chop length was similar (Kononoff and Heinrichs, 2003).

The NDF value was higher in the long SPS. It was reported that lower pH levels had a significant effect on silage cell wall (Jones *et al.* 1992). This result is inconsistent with those reported by Maulfair and Heinrichs (2013), who found that SPS had no effect on NDF and ADF values of corn silages. The pH value was lower in the short barley SPS because the shorter forages were cut, the better it could pack and the more sugars could be available for lactic acid production in the silages (McDonald *et al.* 2011). The lower pH value in the small particle size barley silage can lead to increased breakdown of hemicellulose in the cell wall during the ensiling process. This breakdown of hemicellulose can result in a decrease in the NDF content of the silage, which in turn can lead to an increase in the NFC content of the silage (Yahaya *et al.* 2002).

The flieg score was higher in short barley than long SPS. However, the flieg point in all silages was high because flieg score values between 85 and 100 had very good quality. Flieg's score, based on the pH and DM content, is commonly used as an index to classify the quality of silage (Denek and Can, 2006).

Table 5 The effect of experimental diets in each of the three experiments on ruminal pH after feed intake

Silage particle size	Long (16 mm)		Short (8 mm)		SEM	P-value		
Experiment 1[1] (n=8)						Silage sizes	Concentrate levels	Silage sizes × concentrate
Concentrate levels (%)	60	40	60	40				
Hours after feeding	Ruminal pH							
0	6.66	6.73	6.72	6.72	0.06	0.16	0.32	0.32
2	5.97	6.17	5.92	5.96	0.05	<0.05	<0.05	0.36
4	6.01	6.5	5.80	5.82	0.06	<0.01	<0.01	0.19
6	6.65	6.67	6.63	6.61	0.04	0.91	0.43	0.41
8	6.71	6.72	6.65	6.67	0.15	0.22	0.24	0.82
Experiment 2[2] (n=8)						Silage sizes	Beet pulp levels	Silage sizes × beet pulp
Beet pulp levels (%)	0	20	0	20				
Hours after feeding								
0	6.83	6.87	6.82	6.93	0.03	0.55	0.07	0.33
2	5.84[b]	5.99[ab]	6.15[a]	5.84[b]	0.05	0.54	0.05	0.01
4	6.29	6.20	6.37	6.05	0.09	0.65	<0.05	0.18
6	6.46	6.45	6.51	6.31	0.05	0.42	0.12	0.14
8	6.70	6.66	6.66	6.54	0.05	0.19	0.20	0.48
Experiment 3[3] (n=8)						Silage sizes	Barley levels	Silage size × barley levels
Barley grain levels (%)	40	20	40	20				
Hours after feeding								
0	6.67	6.65	6.80	6.77	0.06	0.08	0.69	1/00
2	5.92	6.30	5.90	6.20	0.16	0.01	0.04	0.39
4	6.17	6.31	6.04	6.28	0.11	0.03	0.04	0.21
6	6.44	6.37	6.45	6.17	0.09	0.34	0.10	0.23
8	6.52	6.62	6.50	6.52	0.12	0.34	0.10	0.23

[1] Diets included (DM basis): 1) long barley silage and 60% concentrate; 2) long barley silage and 40% concentrate; 3) short barley silage and 60% concentrate and 4) short barley silage and 40% concentrate.
[2] Diets included (DM basis): 1) long barley silage diet without beet pulp; 2) long barley silage diet and 20% beet pulp; 3) short barley silage diet without beet pulp and 4) short barley silage diet and 20% beet pulp.
[3] Diets included (DM basis): 1) long barley silage diet and 40% barley grain; 2) long barley silage diet and 20% barley grain; 3) short barley silage diet and 40% barley grain and 4) short barley silage diet and 20% barley grain.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Particle retained on a 1.18-mm sieve are passed out of the rumen slower than those, which are not retained (Yang and Beauchemin, 2006). Therefore, particle size measurement in feeds considering as an important factor in ration formulation is very helpful in ruminant nutrition (Teimouri-Yansari, 2016).

In this study, long barley SPS diets had more particle retained on 19-mm sieve in experiments 1 and 2, but short SPS had more particle on 1.18-mm sieve in experiments 1, 2 and 3.

In agreement with our results, Kmicikewycz and Heinrichs (2015) reported that, a significant difference was observed between long and short corn silages in terms of particle size distribution.

When separated with the PSPS, long corn silage had more particle retained on the 19.0-mm screen similar to amounts on the 8.0-mm screen and pan, and fewer particle on the 4.0 and 1.18-mm screen than short corn silage. The concept of peNDF was developed to reflect the ability of physical characteristics of fiber so as to stimulate chewing and salivary buffering of the rumen, thereby improving ruminal pH status and maintaining a rumen digesta mat (Teimouri-Yansari *et al.* 2004).

The peNDF was not affected by experimental treatments in none of the experiments. In all three experiments, GM values were higher in long than short barley SPS diets as GM was increased with increasing SPS in TMR (Teimouri-Yansari, 2016).

In experiments 1, 2 and 3, DMI was not affected by barley SPS. It is reported that DMI is sensitive to dietary peNDF content as peNDF decreases, passage rate and DMI increase (Teimouri-Yansari *et al.* 2004). There was no significant difference between experimental diets in terms of peNDF levels (Table 3). In their study, Tayyab *et al.* (2018) demonstrated that feeding cows with diets containing a short SPS led to increased DMI, which might due to less time required for chewing before deglutition. In contrast, decreased feed particle size resulted no effect on DMI (Krause *et al.* 2002). However, the effects of grass SPS in based on TMR on intake are inconsistent, which may due to differences in the particle size and peNDF measurement procedure (Tayyab *et al.* 2018). On the other hand, it is reported that a higher acetate content of the long grass silage coupled with its low DM content can be resulted in lower quality and subsequently decreased DMI (McDonald *et al.* 1991).

Table 6 The effect of experimental diets in each of the three experiments on ruminal NH_3-N after feed intake

Barley silage particle size	**Long (16 mm)**		**Short (8 mm)**		**SEM**	**P-value**		
Experiment 1[1] (n=8)						Silage sizes	Concentrate levels	Silage sizes × concentrate
Concentrate levels (%)	60	40	60	40				
Hours post feeding	Ruminal NH_3-N concentration (mg/dL)							
0	9.31	8.24	7.90	7.65	0.69	0.58	0.97	0.36
2	10.70	11.41	11.72	11.97	0.12	0.41	0.84	0.89
4	9.55	11.17	10.42	11.47	0.08	0.57	0.16	0.44
6	11.75	11.28	10.21	11.12	0.10	0.20	0.92	0.17
8	7.61	8.15	7.72	7.07	0.13	0.40	0.53	0.92
Experiment 2[2] (n=8)						Silage sizes	Beet pulp levels	Silage sizes × beet pulp
Beet pulp levels (%)	0	20	0	20				
Hours post feeding								
0	8.44	8.75	8.07	10.80	1.59	0.34	0.58	0.48
2	9.41[a]	7.55[ab]	5.67[b]	9.81[a]	1.20	0.45	0.32	0.02
4	9.36	7.88	8.84	8.52	1.38	0.72	0.72	0.91
6	9.45	7.30	8.57	11.02	1.19	0.28	0.84	0.10
8	9.43	7.34	8.54	11.00	1.19	0.28	0.84	0.10
Experiment 3[3] (n=8)						Silage sizes	Barley levels	Silage size × barley levels
Barley grain levels (%)	40	20	40	20				
Hours post feeding								
0	5.21	5.42	5.37	5.65	0.60	0.39	0.11	0.86
2	6.91	8.16	7.80	6.61	0.52	0.57	0.81	0.94
4	6.22	6.04	7.84	6.68	0.94	0.85	0.47	0.26
6	5.91	5.93	6.47	6.52	0.40	0.65	0.51	0.91
8	5.20	5.57	6.21	6.19	0.40	0.65	0.51	0.91

[1] Diets included (DM basis): 1) long barley silage and 60% concentrate; 2) long barley silage and 40% concentrate; 3) short barley silage and 60% concentrate and 4) short barley silage and 40% concentrate.
[2] Diets included (DM basis): 1) long barley silage diet without beet pulp; 2) long barley silage diet and 20% beet pulp; 3) short barley silage diet without beet pulp and 4) short barley silage diet and 20% beet pulp.
[3] Diets included (DM basis): 1) long barley silage diet and 40% barley grain; 2) long barley silage diet and 20% barley grain; 3) short barley silage diet and 40% barley grain and 4) short barley silage diet and 20% barley grain.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 7 The effect of experimental diets in each of the three experiments on synthesis of microbial protein in the rumen

Barley silage particle size	**Long (16 mm)**		**Short (8 mm)**		**SEM**	**P-value**		
Experiment 1[1] (n=8)	Ruminal microbial protein synthesis(g/d)					Silage sizes	Concentrate levels	Silage sizes × concentrate
Concentrate levels (%)	60	40	60	40				
Protein	69.16	54.99	100.07	91.05	12.93	0.04	0.02	0.11
Experiment 2[2] (n=8)						Silage sizes	Beet pulp levels	Silage sizes × beet pulp
Beet pulp levels (%)	0	20	0	20				
Protein	68.73	77.37	65.31	60.45	10.84	0.53	0.90	0.67
Experiment 3[3] (n=8)						Silage sizes	Barley levels	Silage size × barley levels
Barley grain levels (%)	40	20	40	20				
Protein	55.89	36.06	51.38	37.71	8.26	0.16	0.79	0.77

[1] Diets included (DM basis): 1) long barley silage and 60% concentrate; 2) long barley silage and 40% concentrate; 3) short barley silage and 60% concentrate and 4) short barley silage and 40% concentrate.
[2] Diets included (DM basis): 1) long barley silage diet without beet pulp; 2) long barley silage diet and 20% beet pulp; 3) short barley silage diet without beet pulp and 4) short barley silage diet and 20% beet pulp.
[3] Diets included (DM basis): 1) long barley silage diet and 40% barley grain; 2) long barley silage diet and 20% barley grain; 3) short barley silage diet and 40% barley grain and 4) short barley silage diet and 20% barley grain.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 8 The effects of experimental diets in each of the three experiment on feeding behavior of sheep

Silage particle size	**Long (16 mm)**		**Short (8 mm)**		**SEM**	**P-value**		
Experiment 1[1] (n=8)	**Feeding behavior of sheep (minute/day)**					Silage sizes	Concentrate levels	Silage sizes × concentrate
Concentrate levels (%)	60	40	60	40				
Eating activity	252.5	240.0	187.5	203.8	7.80	<0.01	0.82	0.12
Rumination activity	452.5	452.5	316.3	351.3	31.6	<0.01	0.28	0.19
Chewing activity	705.0	692.5	503.5	555.0	34.5	<0.01	0.23	0.30
Experiment 2[2] (n=8)						Silage sizes	Beet pulp levels	Silage sizes × beet pulp
Beet pulp levels (%)	0	20	0	20				
Eating activity	247.5^{b}	262.5^{a}	190.0^{c}	276.3^{a}	8.10	<0.05	<0.01	<0.01
Rumination activity	420.0^{b}	447.3^{a}	338.8^{c}	442.5^{a}	19.03	<0.05	<0.01	<0.05
Chewing activity	667.5^{b}	708.0^{ab}	528.8^{c}	718.8^{a}	23.70	<0.05	<0.01	<0.01
Experiment 3[3] (n=8)						Silage sizes	Barley levels	Silage size × barley levels
Barley grain levels (%)	40	20	40	20				
Eating activity	232.5	245.0	185.0	188.7	6.04	<0.01	0.23	0.50
Rumination activity	436.3	468.8	330.0	370.0	18.78	<0.01	0.10	0.85
Chewing activity	668.8	713.8	515.0	558.8	27.56	<0.01	0.42	0.49

[1] Diets included (DM basis): 1) long barley silage and 60% concentrate; 2) long barley silage and 40% concentrate; 3) short barley silage and 60% concentrate and 4) short barley silage and 40% concentrate.
[2] Diets included (DM basis): 1) long barley silage diet without beet pulp; 2) long barley silage diet and 20% beet pulp; 3) short barley silage diet without beet pulp and 4) short barley silage diet and 20% beet pulp.
[3] Diets included (DM basis): 1) long barley silage diet and 40% barley grain; 2) long barley silage diet and 20% barley grain; 3) short barley silage diet and 40% barley grain and 4) short barley silage diet and 20% barley grain.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

In this experiment, DMI was increased in 40 percentage concentrate diets due to the higher DMD in these diets. These findings are in disagreement with the study of Yang *et al.* (2001) suggesting that 20 percentage reduction in forage to concentrate ratios had no effects on DMI in cows fed barley silage-based diets.

The lowest NDFI was observed in diets containing short barley SPS and 60 percentage concentrate because they had low NDF content and low DMI. However, in diets with at least 40 percentage concentrate, DMI and NDFI were not reduced by decreasing forage particle size (Nasrollahi *et al.* 2015). On the other hand, increasing dietary peNDF content did not increase peNDF intake as expected by increasing the ratio of forage to concentrate because DMI was decreased due to the filling effect of forages (Li *et al.* 2019).
The DMD was higher in short SPS diets in experiment 1. This could be due to the increase of surface available for microbial attack in short SPS diets (Yang and Beauchemin, 2006). Contrary to our results, Kononoff and Heinrich (2003) reported that DMD tended to be higher in diets containing longer forage particle. However, a significant reduction in forage particle size decreased the retention time of solids in the rumen and reduced DMD (Clark and Armentano, 2002). It has been reported that it takes longer to rumination or chewing due to increasing the hay particle size, which in a diet containing high levels of concentrate is neither effective in increasing ruminal pH nor in improving ruminal fiber breakdown (Zebeli *et al.* 2007). In this experiment, NDFD was not affected by SPS and concentrate levels. In agreement with these results, Knapp *et al.* (2014) reported that, total truck digestibility of NDF was not changed by decreasing the forage particle size, the NDF digestibility was reduced in the rumen, but this reduction was compensated by increasing the hindgut NDFD. Alternatively, decreased rumen pH due to the higher concentration of non-structural carbohydrates in the diets may have a negative impact on the fiber degrading microbiota (Nasrollahi *et al.* 2015). However, feeding a high-concentrate diet with long particle size led to a reduction of the *in situ* fibrolytic capacity of digesta in the rumen, even though the total tract digestibility did not affect (Zebeli *et al.* 2007).

In experiment 2, DMI ranged from 1.80 to 2.09 kg/d and was not affected by BP levels and barley SPS. However, the DMI was higher in short silage and 20 percentage sugar beet pulp diet (P<0.05). Contrary to our results, the substitution of BP for cereal grain decreased (Voelker and Allen, 2003) or increased (Heydari *et al.* 2021) DMI. Munnich *et al.* (2017) reported that DMI was decreased with increasing BP in lieu of corn grain in cows with a higher DMI but not in cows with a lower DMI. Therefore, the effect of BP on DMI depends on the animals' potential to increase their DMI.

The NDFI was not affected by SPS, but it was significantly higher in diets containing BP, because BP had higher level of NDF (McDonald *et al.* 2011). In this experiment, DMD and NDFD were not affected by SPS and BP levels. However, given the significant interaction between SPS and types of grain, it is possible to comparison between the averages of treatments. In their study, Mohsen *et al.* (2021)

demonstrated that DMD was not affected by adding 25-50 percentage BP to dairy cow's diet, but the crude fiber (CF) digestibility was increased. They found that the CF of BP was highly digestible. On the other hand, in the current study, the starch concentration of diets decreased as BP substituted for barley grain. It has been reported that starch concentration reduces as ruminal and total-tract NDFD increases (Ferraretto *et al.* 2013).

In experiment 3, DMI was slightly higher in 20 percentage corn grain diets, but was not statistically significant. Grains with high starch degradability in the diets had greater acidic load potentials in the rumen, thereby requiring greater amounts of peNDF to balance rumen pH (Zebeli *et al.* 2012). Rumen-degradable endosperm for corn starch was lower than that for barley starch. Thus, degradation kinetics and the effective ruminal degradability of starch are lower for corn than barley grain (Knapp *et al.* 2014). Khan *et al.* (2008) reported that lower ruminal pH in the calves fed on barley grain depressed DMI. The DMD and NDFD were not affected by SPS and grain level in this experiment. The DMD and NDFD in the rumen have been reported to decrease with faster degradation of barley starch, but the decrease of ruminal DMD and NDFD is offset by increased hindgut digestibility (Knapp *et al.* 2014).

The pH in the rumen is a key determinant of ruminal digestion (Zebeli *et al.* 2007). It has been shown that short grass particle size results in a reduction in rumen pH (Tafaj *et al.* 2007). In experiments 1 and 3, the pH value was lower in short SPS diets at 2 - 4 hours after feeding. As the average forage particle size reduces, as a result of chewing activity, saliva production and rumen pH decrease (Sharifi-Hoseini *et al.* 2012). Zhao *et al.* (2010) reported that the rumen pH was linearly decreased by reducing the alfalfa particle size and reducing the PEF of goat rations. On the other hand, the pH value was lower in 60 percentage concentrate diets at 2 - 4 hours after feeding. Li *et al.* (2019) reported that increasing dietary NDF concentration and decreasing starch concentration (increase forage to concentrate ratio) may be a more effective means of improving ruminal pH than increasing dietary forage particle size. In their study, Zebeli *et al.* (2007) demonstrated that higher concentrate level in the diet decreased pH. They noted that ruminal fermentation and pH appear to be more affected by the content and degradation rate of the fiber in the hay than by the concentrate level.

In experiment 2, the pH value was lower in 20 percentage BP diets (high NFFS levels) at 2 - 4 hours after feeding, but was not affected by SPS. This result is consistent with the study of Mohsen *et al.* (2021) reporting that the ruminal pH was reduced by supplementing the diet with 25-50 percentage BP. More feed consumption in rations with BP caused more fermentation, followed by a decrease in pH (Aschenbach *et al.* 2011). A significant interaction was observed between SPS and BP levels in terms of ruminal pH at 2 hours after feeding, indicating that their effects were not always incremental. In experiment 3, the pH value was higher in 20 percentage barley grain diets. The pH value could not be predicted only with the peNDF value because the grain types had a greater effect (Maulfair and Heinrichs, 2013). The rate of fermentation of barley starch is higher than that of corn starch in the rumen. Therefore, the diets containing barley grain can more effectively reduce the rumen pH (Yang *et al.* 2001).

In experiment 1, NH3-N concentration in rumen was not affected by the barley SPS and different levels of concentrate at different times post feeding. It appears that the NH3-N concentration in the rumen was not influenced by the particle size of barley silage or the levels of concentrate at various times after feeding. Consistent with our results, Rodriguez-Prado *et al.* (2004) reported that the fiber content and particle size did not affect the NH_3-N concentration or the flow of total NH_3 and nonNH_3-N in continuous culture system. In contrast, Yang and Buchman (2006) found that reducing forage particle sizes increased the NH_3-N concentration in the rumen. However, in their study, Teimouri-Yansari *et al.* (2004) showed that the reduction in forage particle size had no significant effect on concentration of NH_3-N. In experiment 2, NH_3-N concentration in rumen was not affected by the barley SPS and levels of BP at different times after feeding. In agreement with our results, Alamouti *et al.* (2009) reported that cows fed BP instead of corn and barley grain had similar rumen NH_3-N. Contrary to our results, Voelker and Allen (2003) reported that the concentration of NH_3-N was decreased with increasing BP levels in dairy cows' rations, because of the higher rate of conversion of NH_3 for microbial protein synthesis. In the experiment 2, the lowest NH_3-N was observed in diets containing short SPS and without BP for 2 hours after feeding. In the experiment 3, the concentration of NH_3-N in rumen was not affected by the barley SPS and barley grain and corn levels in concentrate. Contrary to this result, it is reported that a lower ruminal concentration of NH3-N in barley grain in comparison with corn grain diets could be an indicator of greater N utilization in calves offered with barley (Kazemi-Bonchenari *et al.* 2020).

In agreement with experiment 1, Yang and Beauchemin, (2006) found that the microbial protein synthesis in the rumen was increased by reducing forage particle size. Reduced particle size leads to increased surface area for microbial attachment and digestion (Bowman and Firkins, 1993) and may enhance energy availability and microbial growth, which may explain the higher microbial protein synthesis observed in short SPS. In contrast, Rodriguez-Prado *et al.* (2004) observed no effects of forage particle size on the microbial protein synthesis. On the other hand, in this study, microbial nitrogen and protein synthesis were higher in 60 percentage concentrate diets. The reduction in ruminal microbial N production with high forage to concentrate diets is consistent with lower organic matter that was truly degraded in the rumen (Li *et al.* 2019). In agreement with our results, Bourquin *et al.* (1994) indicated lower microbial protein synthesis *in vivo* when a 90 percentage vs. 60 percentage forage diet was fed. In contrast, Yang and Beauchemin (2006) reported that low forage diets resulted in lower microbial protein synthesis. In experiment 2, microbial N and protein synthesis was not affected by barley SPS and BP levels. It is reported that the slightly higher sugar and pectin (soluble fiber in BP) content of the low forage to concentrate diet might have contributed to greater microbial protein synthesis compared with the high forage to concentrate diets (Oba, 2011). Our results were in contrast with the studies conducted by Meng *et al.* (1999) and Rodriguez-Prado *et al.* (2004) on the continuous culture suggesting that diets with a high concentration of structural carbohydrates resulted in higher efficiency of microbial protein synthesis than diets with a high non-structural carbohydrate concentration. Some studies reported that in the presence of sufficient concentration of nitrogen in the rumen, the synthesis of the microbial protein is dependent on the availability of the fermentable metabolizable energy (ME). It seems that the availability of the ME was the same among treatments (Table 1). In addition, NH_3-N concentration was the same in all the treatments (Table 6). In the experiment 3, barley SPS and grain types did not affect microbial N and protein synthesis. Availability of energy and protein can be considered as the determinants of ruminal microbial N production and consequently microbial N supply is affected by starch intake (Krause *et al.* 2002).

Contrary to our results, Chen and Gomes (1992) showed that there was more availability of energy in rumen fermentable carbohydrate like barley grain compared to corn grain, and thus there was more synthesis of microbial protein. However, it is possible that the fine milling of both barley and corn grains in current experiment led to similar fermentable energy content, which could have minimized the potential differences in microbial protein synthesis between the two grain sources.

Chewing activity is the first mechanism to reduce particle size in feed. This activity depends on forage particle size, peNDF content, feed quality and amount eaten. Chewing and rumination are known as the accurate measurements of the roughage characteristics for ruminant diets (Teimouri-Yansari, 2016). In experiments 1, 2 and 3, the time of eating, rumination and chewing activity were higher in long SPS diets, which was in agreement with the studies conducted by Tayyab *et al.* (2018) who reported a tendency for a longer daily eating and rumination time when cows received a long versus short SPS. It was reported that the rumination time was increased with increasing corn SPS (Sharifi-Hoseini *et al.* 2012), because of increasing rumen retention time (Beauchemin, 2018). As shown in Table 3, the time of eating was increased by increasing the GM of the forage (Sharifi-Hoseini *et al.* 2012). In experiment 1, levels of concentrate had no effect on the time of eating, rumination and chewing. Zebeli *et al.* (2007) suggested that the measurement of chewing or rumination activity alone may not be sufficient to estimate the physical effectiveness or fiber adequacy in dairy cows, particularly when high-concentrate diets are fed separately. In experiment 2, eating, rumination and chewing activity were higher in diets containing 20 percentage BP. It was reported that the DMI was increased in diets containing 20 percentage BP and also time increased feed intake and eating time (Beauchemin, 2018). The BP has large amounts of pectin and cell wall that gets involved with rumen mat. Therefore, the time of rumination and chewing activity were higher because of lower rate of digesta passage in the rumens (Teimouri-Yansari *et al.* 2004). In experiment 3, the levels of barley and corn grain had no effect on eating, rumination and chewing activity. Our results were in agreement with the study of Maulfair and Heinrichs (2013) reporting that eating time was affected by corn SPS, but grain types had no significant effect. However, Soita *et al.* (2000) found that high rumen fermentable carbohydrate diets had faster rate of passage in rumen and decreased the time of rumination. In this experiment, barley and corn grain were milled finely and their starch degradation was not different.

CONCLUSION

The result of current experiment showed that, by reducing the level of concentrate, the intake and digestibility of DM and NDF increased due to the improvement of rumen conditions. Incorporating sugar beet pulp into diets led to an increase in DMI and extended eating and rumination activity. However, it was associated with a reduction in rumen pH. The levels of barley grain in the diet had no effect on intake and digestibility of DM and NDF and microbial protein synthesis in sheep, regardless of barley silage particle size. Barley silage had great potential to be combined with other Foodstuffs in feeding small ruminants such as sheep.

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