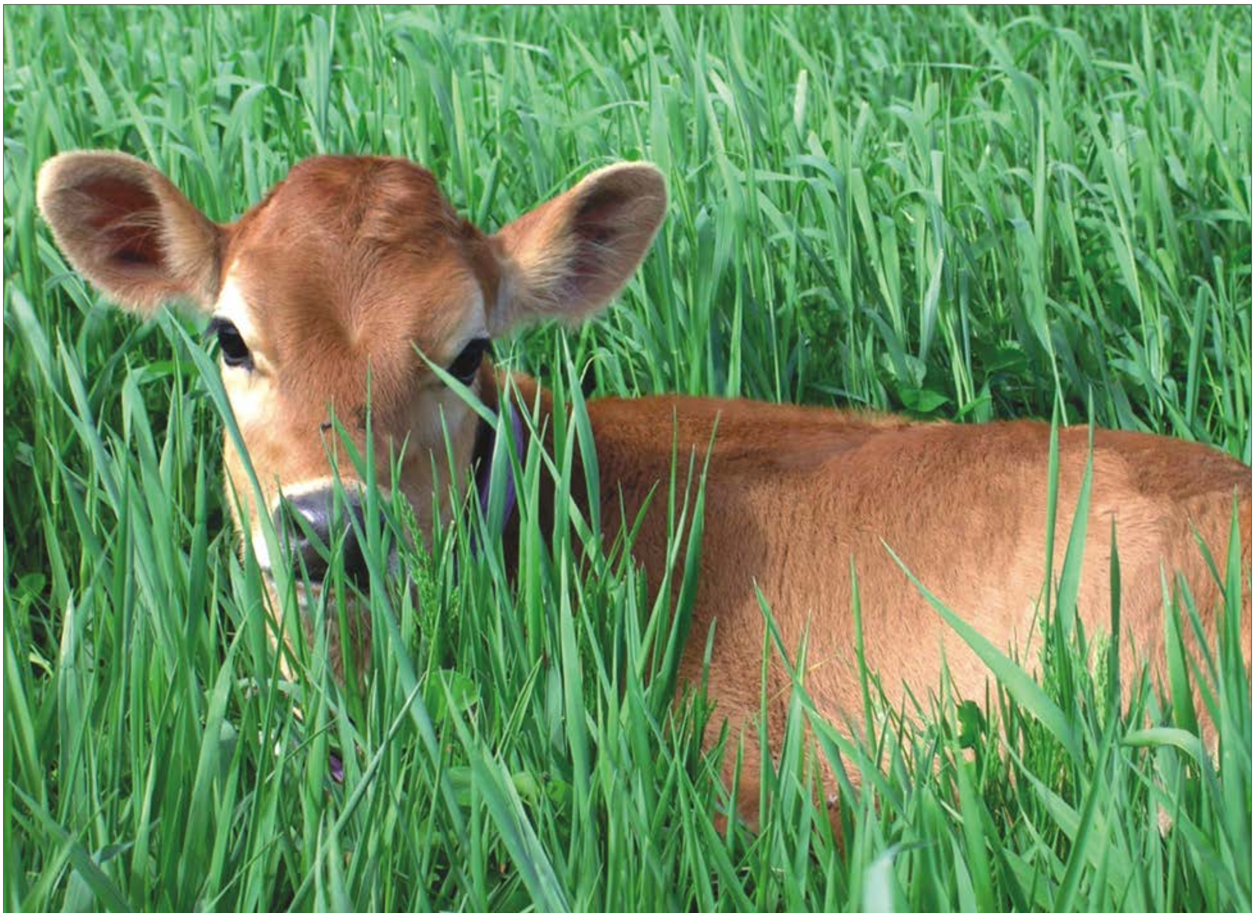

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Research Article

A Study of Nutrient Digestibility, Milk Production and Performance of Lactating Barki Ewes Fed Synchronous Least Cost Ration

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Abstract

Background: Synchronization the rate of which dry matter and crude protein degraded at the rumen significantly affects the synthesis of microbial protein and thus the efficiency of feed utilization. During previous study a new software application “Lacto-sheep” had been developed to facilitate the formulation of the least cost ration considered this important factor. So that formulation of a synchronous least cost ration is possible and not difficult. This study was carried out to investigate the advantages of feeding synchronous least cost ration as an alternative to the traditional least cost ration on nutrients digestibility and milk production and its constituents. **Materials and Methods:** The kinetics of dry matter and crude protein disappearance and approximate analysis were determined for each feed ingredients used. Then, using our feed formulation software “Lacto-Sheep” two diets; traditional least cost and synchronous least cost ration were formulated and fed to two groups of multiparous lactating Barki ewes (5 ewes each), suckling single with an average body weight (35.10±2.50 kg) using completely random design. Experiment started 2 weeks after lambing and lasted 60 days. **Results:** The synchronous least cost ration contained variety of protein sources compared with the least cost ration, which did not contain any rich source of protein (soya bean or cotton seed meal) that’s because the cost of feed is the main limiting factor regardless optimizing feed utilization. Digestion coefficient of crude protein was slightly improved in group fed synchronous least cost ration. In addition, milk production and its components were also slightly higher. However, the differences were not significant. **Conclusion:** Based on the results obtained from this study, synchronous least cost ration seemed to be more practically appropriate ration for feeding lactating Barki ewes.

Key words: Synchronous least cost ration, Barki ewes, milk production, milk constituents

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Feed is considered the major expense for any dairy farm[1]. Reducing feed costs and/or increase feed utilization may be an effective key for increasing the profitability and sustainability. Formulating a least cost ration was commonly and had a marked impact on feeding practices[2] since the mid-1960's. Recently, many computer-assisted applications was offered and have a great benefit for the producers in determining an economically and balanced feeding programs for their herds[3].

Linear programming is the most widely used method for the least cost diet formulation. However, the formulated diet may not be the optimal for animal feeding, especially for ruminants. The least cost method depends on the assumption that nutrients from different feeds are used additively on the basis of their assigned nutritive value. Actually, it does not have a mechanism for taking into account such complications as associative effects of feeds. The least-cost ration may be appropriate for monogastric animals, partly because of their simple system of gastric digestion and partly because of the narrow range of feeds used in their diets but in ruminants that assumption may differ. However, in ruminants, digestion and metabolism depend much on rumen microbial metabolism[4]. Microbial protein synthesis may be maximized, if the fermentable energy availability and that of N not degraded by the microbes in the rumen are synchronized[5]. This increase in microbial efficiency then should translate into an increase in animal performance. Therefore, new parameters should be taken into account to formulate the ration for ruminants. In our previous study, a new software application was developed that could be used to formulate balanced ration at least cost taking into account the degree of synchronization between the rate of release of Organic Matter (OM) and Nitrogen (N) in the rumen after feeding the diet[6]. The optimal ratio between the hourly release of N to OM truly digested in the rumen was recommended to be 25 g of N kg^{-1} of OM[7]. The degree of the nutrient synchronization for any diet could be calculated using the Synchrony Index (SI) described by Sinclair *et al.*[8]. The value of 1.0 represents perfect synchrony between N and OM release throughout the day and values less than 1.0 indicate the degree of asynchrony.

The objective of this study was to investigate the effect of feeding lactating Barki ewes on synchronous least cost ration as an alternative to the traditional least cost ration to lactating Barki ewes and its impact on nutrients digestibility and milk production and its constituents.

MATERIALS AND METHODS

Experiment 1

***In situ* degradability experiment calculation of the degradability and synchrony index:** *In situ* degradability trail was conducted as described by Orskov *et al.*[9] for the examined feedstuffs. About 3-4 g of the ingredients were placed in duplicates polyester bags 7×15 cm with a pore size of 47 µm and incubated simultaneously in the rumen of three rumen-fistulated Barki rams (55±1.9 kg b.wt.) for (2, 4, 8, 16, 24, 48 and 72 h) and (4, 8, 16, 24, 48, 72 and 96 h) for concentrate and roughage samples, respectively. Then, bags rinsed in cold water until the water became clear and then gently squeezed prior to storage at -20°C. After that, bags were frozen, thawed and washed again in running water to eliminate microorganisms attached to the residue, then drained and dried for 72 h at 65°C. The DM and CP contents were then estimated. Two bags were washed in running water for 1 h to determine soluble fraction (a).

The kinetics of DM and CP disappearance were fitted to the equation of Orskov and McDonald[10]:

$$P = a+b\,(1-e^{-ct})$$

Where:
P = Disappearance at time 't'
a = The soluble fraction
b = The degradable fraction
c = The rate of degradation of the degradable fraction

Then, the effective degradability (ED) with rumen outflow rate ($0.05\ ^{h-1}$) were calculated as follows:

$$ED = a+b\,\{c/(c+k)\}$$

where, k is the rate of particulate outflow from the rumen.

Obtained data were inserted into our developed software application "Lacto-Sheep"[6] and the Synchrony Index (SI) for the whole experimental rations were calculated according to Sinclair *et al.*[8]:

$$SI = \frac{25 - \sum_{1-24} \dfrac{\sqrt{(25 - (\sum_{j=1}^{n} \text{hourly}\, N_j / \sum_{j=1}^{n} \text{hourly}\, OM_j))^2}}{24}}{25}$$

Experiment 2

Animals and feeding: Ten multiparous lactating Barki ewes, suckling single with an average body weight (35.10±2.5 kg) were randomly divided after 1 week of parturition into two groups (5 ewes each) using completely random design. The experiment started 2 weeks after lambing and lasted 60 days. Two rations were formulated using our developed feed formulation software "Lacto-Sheep[6]" to cover the animal's nutrient requirements according to NRC[11] allowances. Using linear programing, the Least Cost Ration (LCR) was formulated according to the traditional least-cost procedure for ration formulation. While, Synchronous Least Cost Ration (SLCR) was formulated using non-linear programing and taking into account the synchronization between energy and protein degradation rate in the rumen. The concentrate to roughage ratio was (70:30). The first group fed the LCR, while the second group fed the SLCR. Animals fed the Concentrated Feed Mixture (CFM) twice daily at 9:00 and 14:00. While, roughages were offered once daily at 10:00. Fresh water was available to the animals all the time.

Digestion coefficients: At the end of the lactation period, four animals from each treatment were selected randomly for the digestion trial to evaluate nutrients digestibility, nutritive value of the different experimental rations. The animals were individually housed in a pen for 7 days as a preliminary period followed by 4 days as a collection period. The rations were offered daily and refusals if found, were recorded every day. Grap sample of feces from rectum were daily collected. Feces samples were sprayed with H_2SO_4 10% and dried at 60°C for 48 h and then it was ground and kept for chemical analysis. Silica as an internal marker was applied for determining the apparent digestibility. Total Digestible Nutrients (TDN) were calculated from digestion coefficients such as: TDN (%) = Digestible protein (%)+digestible crude fiber (%)+digestible nitrogen free extract (%)+(digestible ether extract (%)×2.25). Digestible energy (DE) was calculated with the formula of Crampton *et al.*[12] and Swift[13]:

$$\text{DE (Mcal kg}^{-1}\text{ DM)} = \%\text{TDN}\times 0.04409$$

$$\text{ME (Mcal kg}^{-1}\text{ DM)} = 0.82\times\text{DE (Mcal kg}^{-1}\text{ DM)}^{11}$$

Daily milk yield and chemical composition: Lambs were separated from their dams at 3.00 pm till the next day. The ewes were completely hand milked and the daily milk yield was recorded every 2 weeks over the experimental period. Milk contents of fat, protein, lactose, solids-not-fat (SNF) and total solids (TS) were determined using LACTOSCAN SP MILK ANALYZER (Milkotronic Ltd- Bulgaria). Daily milk production was standardized to 4% fat and 3.3% protein using the energy corrected milk (ECM) formula:

$$\text{ECM milk} = \text{Milk production}\times\frac{0.383\times\text{fat (\%)}+0.242\times\text{protein (\%)}+0.7832}{3.1138}$$

Weight of ewes and their lambs: Ewes and lambs were weighted before the morning feeding every two weeks over the experimental period to record changes in body weight and to adjust their nutrient requirements.

Statistical analysis: Data of production performance were statistically analyzed for Two-Way Repeated Measures ANOVA using SPSS[14]. The statistical model was:

$$Y_{ijk} = \mu+R_i+T_j+(RT)_{ij}+e_{ijk}$$

Where:

Y_{ijk} = The kth observation (k = 1⋯ 20) for ration i in time j
μ = The overall mean
R_i = The effect of ration i (i = 1⋯ 4)
T_j = The effect of time j (j = 15, 30, 45, 60)
RP_{jk} = The interaction
e_{ijk} = The experimental error

While, data of nutrients digestibility and growth performance were analyzed using independent T-test as follows:

$$X_{ij} = \mu+R_i+E_{ij,}$$

Where:

X_{ij} = The jth observation (j = 1⋯ 20) for ration i
μ = Overall mean
R_i = The effect ration i (i = 1⋯ 4)
E_{ij} = Experimental error

RESULTS AND DISCUSSION

Experimental rations: The approximate analysis and *in situ* degradability for tested feedstuffs are presented in Table 1. Corn OM had more soluble fraction than beet pulp OM. However, the rate of degradation was considerable higher for beet pulp OM. This may be the result of the pectin-rich content in sugar beet pulp. Often, pectins are associated with the cell wall but they are not covalence linked to the lignified portion of the wall[15]. Furthermore, corn CP had more rapidly soluble fraction and greater ability to be degraded in the rumen but with slower degradation rate compared with beet pulp CP. These results are consistent with the findings of

Table 1: Chemical composition and *in situ* degradability of ingredients

Items	Yellow corn	Sugar beet pulp	Undecorticated cotton seed meal	Soya meal	Coarse wheat bran	Berseem hay	Rice straw
Chemical composition (g kg^{-1} DM)							
OM	990.4	959.4	936.8	938	900.4	833.9	799.8
CP	92.5	102.5	300.6	527.1	167.5	184.4	32.5
CF	25.9	220.8	250.3	80.1	132.5	338.3	389.3
EE	42.8	11	65.3	16.5	43.1	26.1	6.9
NFE	829.2	625.1	320.6	314.3	557.3	285.1	371.1
Ash	9.6	40.6	63.2	62	99.6	166.1	200.2
***In situ* degradability**							
OM							
a (%)	26.1	16	28	35.1	33.2	40.7	13.4
b (%)	73.9	82.5	72	64.9	53.5	42.23	38.6
c (h^{-1})	0.033	0.045	0.008	0.05	0.065	0.032	0.033
ED	51.6	53	40.2	67.1	66.1	57.2	27.2
CP							
a (%)	32.1	13.5	24.5	18.7	30.5	50.5	24
b (%)	67.9	86.5	69.4	81.3	61.8	40.7	0.1
c (h^{-1})	0.002	0.01	0.031	0.034	0.14	0.03	0.02
ED	44.1	36.6	63.4	58.1	73.6	64.4	24

a: Soluble fraction, b: Potentially degradable fraction, c: Rate of degradation of the potentially degradable fraction (fraction per hour), ED: Effective degradability with outflow rate (0.05 fraction per hour)

Table 2: Dietary ingredients and composition (g kg^{-1} DM) used in formulating the concentrate mixture

	Concentrate feed mixture[1]	
Items	LCR	SLCR
Ingredients		
Yellow corn	482	375
Sugar beet pulp	301	292
Undecorticated cotton seed meal	0	105
Soya meal (48%)	0	17
Coarse wheat bran	192	186
NaCL	10	10
Mineral mixture	5	5
Dicalcium phosphate	10	10
AD_3E	1	1
Chemical composition		
OM	947.2	947.1
CP	104.3	126.4
CF	105.1	107.1
EE	23.1	24.3
NFE	714.7	689.3
Ash	52.8	52.9
[2]ME (Mcal kg^{-1} DM)	2.81	2.77

[1]LCR: Least cost ration, SLCR: Synchronous least cost ration, [2]Calculated metabolizable energy[10]

Nocek *et al.*[16] who demonstrated more rapid N disappearance rate within 2 h for corn than beet pulp of the two protein sources, the cotton seed meal OM was less degradable in the rumen and had slower degradation rate compared with soya meal OM. In contrary, cotton seed meal and soya meal have convergent values for CP effective degradability fractions and the degradation rates. For wheat bran OM, the rapidly soluble fraction represented about 50.23% of the ED and the residual degradable fraction was quickly degraded at the rate of 6.5% h^{-1}. In addition, wheat bran CP had the greatest ability to be degraded in the rumen with a considerably high degradation rate (14% h^{-1}). Berseem hay OM had more degradable and soluble fraction compared with rice straw. While, the rate of degradation was approximately the same in both. In addition, berssem hay CP had the greatest value for effective ruminally available fraction compared with other feedstuffs. The most of berseem hay CP was soluble, while all of rice straw CP was soluble (78.42 vs 100%, respectively).

Table 2 shows ingredients, chemical composition and nutritive values of the experimental rations. Although, both rations were formulated to cover nutrients needed by the ewes the SLCR is higher in CP than LCR due to the presence of an addition constraint to ensuring the synchronization between the release of OM:N in the rumen. Furthermore, LCR was formulated on the base of the least cost only and it doesn't contain any high cost protein source (soya or cotton seed meal). Formulated rations is differ in their calculated SI. The LCR was considered as asynchronous compared with SLCR (SI = 0.60 vs 0.87, respectively). In a previous study, Richardson *et al.*[17] classified diets according to their synchrony index to synchronous diet (SI = 0.86) and asynchronous diets (SI = 0.63).

Digestion coefficients and nutritive values: Apparent digestibility coefficients and nutritive values for experimental rations are shown in Table 3. Generally, the differences between the two groups in the apparent digestion coefficients were insignificant. However, group fed SLCR had higher CP and EE digestibility and lower CF digestibility compared with those fed on LCR. This results in line with that observed

Table 3: Digestion coefficients and nutritive values of experimental rations

Items	Experimental ration[1] LCR	SLCR	SEM	p-value
Apparent digestibility coefficients (%)				
OM	72.99	73.24	3.41	0.94
CP	51.91	60.23	7.11	0.31
CF	59.23	54.75	6.38	0.52
EE	52.55	59.27	6.22	0.34
NFE	81.71	80.88	2.36	0.95
Nutritive value (on DM basis)				
[2]TDN (%)	68.14	68.41	3.17	0.94
[3]DE (Mcal kg^{-1})	3.00	3.02	0.14	0.94
[4]ME (Mcal kg^{-1})	2.46	2.47	0.11	0.94
[5]DP (%)	5.56	7.39	0.79	0.82

[1]LCR: Least cost ration, SLCR: Synchronous least cost ration, [2]TDN (%): Digestible CP (%)+digestible CF (%)+digestible NFE (%)+digestible EE (%)×2.25, [3]DE (Mcal kg^{-1} DM) = TDN (%)×0.04409, [4]ME (Mcal kg^{-1} DM) = 0.82×DE (Mcal kg^{-1} DM), [5]DP (%) = CP digestion coefficient×CP (%), SEM: Standard error of mean

Table 4: Milk yield and composition of ewes fed on the experimental rations

Items	Experimental ration[1] LCR	SLCR	SEM	p-value
Yield (g day^{-1})				
Milk	450.50	463.70	56.09	0.87
[2]ECM	481.30	517.70	65.22	0.71
Total solids	62.17	65.85	8.03	0.78
Fat	16.40	18.69	2.89	0.58
Solids-not-fat	45.77	47.16	5.76	0.91
Total protein	21.40	22.03	2.68	0.92
Lactose	20.45	21.10	2.57	0.92
Ash	3.92	4.08	0.50	0.89
Milk composition (%)				
Total solids	13.80	14.20	0.39	0.48
Fat	3.64	4.03	0.45	0.55
Solids-not-fat	10.16	10.17	0.14	0.95
Total protein	4.75	4.75	0.07	0.96
Lactose	4.54	4.55	0.07	0.98
Ash	0.87	0.88	0.01	0.76
Milk urea-N (mg dL^{-1})	35.14	45.83	3.91	0.09

[1]LCR: Least cost ration, SLCR: Synchronous least cost ration, [2]ECM milk = (milk production×(0.383×fat (%)+0.242×protein (%)+0.7832)/3.1138), SEM: Standard error of mean

by Biricik *et al.*[18] who stated that, synchronizing the dietary starch and crude protein degradation in the rumen of sheep did not significantly affect DM, OM, CP and NDF digestibility in the rumen and total tract. Similarly, Kolver *et al.*[19] did not notice any changes in the apparent total tract digestibility of DM, OM, CP and NDF when microbial protein synthesis was increased by the release of carbohydrate rich supplements with availability of pasture N in the rumen. In contrast, ration synchronization by changing feed ingredients resulted in a significant increase in true OM digestibility[20]. In addition, digestibility of low quality rice straw and rumen fermentation end products were improved with supplementation of protein source and adjusting feeding frequency[21].

Numerical increase in CP digestibility in the synchronized ration (SLCR) might be due to: (1) The enhancement in nitrogen utilization in the rumen due to synchronization of the hourly ratios of N:OM release in the rumen[19] and/or (2) The absence of any high digestible protein-rich sources in the diet formulation of LCR.

On the other side, the slight decrease in CF digestibility of the SLCR might be due to the presence of undecorticated cotton seed meal in the ration and the low amount of yellow corn compared with LCR. The high fiber content in undecorticated cotton seed meal is rich in acid detergent lignin[22] and this might decrease CF digestibility. Moreover, corn is a valued energy source with high starch content that might promote the rumen bacteria growth, thus enhancing, rumen digestion, cycling and subsequent feed intakes[23]. Although, increasing the amount of undecorticated cottonseed meal in the ration may have a negative effect on CF[24] digestibility, it could have a positive effect on EE digestibility due to its high EE digestibility being about 90-100%. Finally, no significant differences in TDN%, DE (Mcal kg^{-1}) and ME (Mcal kg^{-1}) were observed. However, R1 had the lower DP ($p = 0.82$) and this might be due to its low CP content and digestibility.

Milk yield and composition: The concomitant effects of experimental rations on daily milk yield and composition are presented in Table 4. Group fed a Synchronous Least Cost Ration (SLCR) showed the highest daily milk yield, ECM and milk fat percentage. However, the results were insignificant. The considerable numerical difference in milk fat percent lead to increase the difference between SLCR and LCR in ECM. The ECM was being 481.3 and 517.7 (g day^{-1}) for LCR and SCLR, respectively. No significant differences were observed in milk total solids, total protein, lactose, ash percentage and their yields. The average daily milk yield of lactating Barki ewes ranged from 385.9-466.1 (ECM, g day^{-1}) with (3.99-4.37%) fat[25,26]. In a previous study using lactating ewes, feeding on synchronous diet increased daily milk protein yield (g day^{-1}), however daily milk or milk fat yield (g day^{-1}) was not affected[27]. However, differences in dietary synchronization did not elicit substantial differences in milk yield, or milk component yield in the study of dairy cows[19].

The improvement in milk production performance might be due to high efficiency of dietary energy use[17]. Witt *et al.*[27] investigated the effect of synchronizing diet with fast or slow degradation rate of OM produced and observed a significant improvement in feed conversion efficiency than asynchronous diets.

Table 5: Milk physical characteristics of animals fed on the experimental rations

Items	Experimental ration			
	LCR	SLCR	SEM	p-value
Density (kg m^{-3})	1040.27	1040.030	0.83	0.85
Freezing point (°C)	-0.572	-0.575	0.01	0.80
pH	6.64	6.700	0.04	0.30

LCR: Least cost ration, SLCR: Synchronous least cost ration, SE: Standard error, SEM: Standard error of mean

Table 6: Changes in ewe's body weight (kg) during experimental period

Experimental period	Experimental ration[1]			
	LCR	SLCR	SEM	p-value
0 days (initial)	36.0	34.2	5.26	0.74
60 days (final)	36.6	34.4	4.60	0.65
[2]Changes (kg)	0.60	0.20	1.00	0.70

[1]LCR: Least cost ration, SLCR: Synchronous least cost ration, [2]Changes: Final body weight-initial body weight, SEM: Standard error of mean

Table 7: Growth performance of lambs suckled their dams which fed on the experimental rations

Items	Experimental ration			
	LCR	SLCR	SEM	p-value
Initial body weight (kg)	4.1	4.0	0.37	0.79
Final body weight (kg)	9.8	11.8	1.17	0.13
Total gain (kg)	5.7	7.8	1.14	0.10
Average daily gain (g day^{-1})	95	130.0	19.0	0.10

LCR: Least cost ration, SLCR: Synchronous least cost ration, SEM: Standard error of mean

Milk urea-N concentrations (MUN) for the experimental groups are presented in Table 4. The MUN is used to monitor the excess of dietary CP and urine N excretion could be predicted using MUN output as a sole predictor or in combination with dietary CP level[28]. So, test-day MUN data could be a suitable way to monitor the efficiency of nitrogen utilization in commercial dairy herds.

Obtained results showed no significant differences between groups (p = 0.09). However, group fed a synchronous ration showed higher concentrations of MUN. Baker *et al.*[29] and Roseler *et al.*[30] found that, milk urea-N concentrations has been shown to be sensitive to concentrations of dietary CP, rumen degradable protein, rumen undegradable protein and protein to energy ratios. The higher protein feeding associated with higher MUN concentrations and production may be due to a combination of factors, including greater amino acid availability for milk protein synthesis, improved availability of energy through deamination of amino acids, improved efficiency of utilization of absorbed nutrients, or improved dry matter intake[31,32].

Milk physical characteristics: Table 5 shows the milk physical characteristics for groups fed on the experimental rations. Data showed that, milk production characteristics were not significantly affected and the obtained values for milk density, freezing point and pH were within the normal ranges that reported by Haenlein and Wendorff[33]. The Specific gravity of milk is affected by the removal of fat and or the addition of water. In industry the determination of freezing point is widely used for detection of adulteration of milk with water. The major milk constituents responsible for 70-80% of the overall depression in the freezing point of milk are lactose and chloride[34]. For milk pH, fresh milk has a pH of between 6.7 and 6.5. Values higher than 6.7 denote mastitic milk and values below pH 6.5 denote the presence of bacterial deterioration[35].

Changes in body weight: Table 6 presents the changes in ewe's body weights during the experimental period. There were no significant differences in the initial and final body weight between experimental groups. Feeding diets differing in their ruminal degradation synchronicity between nitrogen and organic matter did not show marked body weight change, reported by Richardson *et al.*[17].

Table 7 shows the performance of lambs suckling from ewes in respect of average daily gain and total gain. This parameter reflects indirectly the milk production during suckling period or lactation period (60 days). No significant differences between groups were observed, regarding the initial body weight. However, results indicate that, feeding a synchronous ration (SLCR) increased the average daily gain of lambs compared with asynchronous ration (LCR) but the differences were not significant ($p<0.05$). The average daily gain of lambs were 130 and 95 (g day^{-1}) for SLCR and LCR groups, respectively. The average daily gain of lambs in SLCR group is near to that reported by Abdalla *et al.*[25] who found that, the average daily gain for Barki lambs suckled from dams received 100% of allowances was 140.1 g day^{-1}. While, lambs in LCR group had lower average daily gain than that reported.

CONCLUSION

Based on the results of the present study, it can be concluded that, incorporating the concept of synchronizing ruminal release of OM:N into the least-cost ration procedure may help to produced more practically appropriate rations for feeding lactating Barki ewes.

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