

RESEARCH ARTICLE

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# Evolution of udder morphology, alveolar and cisternal milk compartment during lactation and their relationship with milk yield in Najdi sheep

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## Abstract

A total of 30 multiparous Najdi ewes were used to study the evolution of udder morphology traits and milk fractions in the udder during suckling (3<sup>rd</sup>, 6<sup>th</sup>, 9<sup>th</sup> wk) and milking (10<sup>th</sup>, 11<sup>th</sup>, 12<sup>th</sup> wk) periods. During suckling period, daily milk yield was estimated by using the double oxytocin injections method 4-h after milking. During milking period, ewes were hand-milked once daily. Udder and teat morphology traits for all ewes were measured 4-h after milking. Udder compartments were evaluated 8-h after milking by using atosiban and oxytocin; milk samples of each fraction were collected. Najdi ewes had a medium and healthy udders (CMT < 1), with medium sized teats (length, 3.2 ± 0.1 cm and width, 1.7 ± 0.1 cm) attached at 35.7 ± 11° angle. Milk yield averaged 1.88 ± 0.18 and 0.44 ± 0.12 L d<sup>-1</sup> during suckling and milking periods, respectively. A drop in milk yield (-75%, *p* < 0.01) was found in the transition from suckling to milking. Udder traits, teats angle and width, and distance between teats declined (*p* < 0.05) throughout lactation, whereas teat lengths did not show any change. Positive correlations (*p* < 0.05) were observed between milk yield and udder depth (*r* = 0.47-0.49), width (*r* = 0.31-0.39) and distance between teats (*r* = 0.26-0.39). The cisternal milk volumes decreased (*p* < 0.05) after weaning, whilst the corresponding percentages increased (*p* < 0.05). Cisternal milk accounted for 55% and 67% of the total udder milk during suckling and milking periods, respectively. Cisternal milk was positively correlated (*r* = 0.93, *p* < 0.05) with total milk yield. The percentages of protein and total solids in alveolar and cisternal milk increased significantly (*p* < 0.05) after weaning, whilst fat percentages in cisternal milk did not change. In conclusion, the evaluated Najdi ewes showed medium sized cisterns and teats, which considered adequate for machine milking. Udder morphology traits had positive correlations with milk yield and hence, can be utilized in breeding programs.

**Additional key words:** Najdi ewes; suckling; milking; udder traits.

## Introduction

The interest in studying the udder morphology of dairy sheep has been increased in the last few years (Altincekic & Koyuncu, 2011; Ayadi *et al.*, 2011; Gelasakis *et al.*, 2012). Udder and teat morphology have been shown to be related to milk yield (Labussiere, 1988; Fernandez *et al.*, 1995) and milk flow rate (Marie *et al.*, 1999; Marnet & McKusick, 2001). There are

differences between sheep breeds in the proportions of total milk that can be stored within the cisternal compartment (Bruckmaier & Blum, 1992), values of cisternal milk varying from 25 to 70% with an average value greater than 50% in most breeds (Rovai *et al.*, 2008; Ayadi *et al.*, 2011). Several workers found that cisternal size and udder morphology traits were correlated with milk secretion rate during milking in dairy ewes (Marnet & McKusick, 2001; Castillo *et al.*, 2008;

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Ayadi *et al.*, 2011). Teat traits were also related to milk fat (McKusick *et al.*, 2002a) and milk emission during milking (Marie *et al.*, 1999). Therefore, studying the patterns of milk accumulation and storage in the udder during lactation and their relationship with milk yield can help to improve techniques and routines for machine milking in dairy ewes (Rovai *et al.*, 1999; Such *et al.*, 1999).

Sheep has been an integral part of livestock agriculture in Saudi Arabia. The population of sheep is exceeding 7.2 million head (FAOSTAT, 2011) where Najdi breed is fat-tailed and classified as a carpet-wool breed (Abouheif *et al.*, 1989). The Najdi sheep is known for their hardiness and adaptability to the prevailing adverse environment and plays an eminent role in the rural economy. As lamb production is a main source of income in most of flocks, increasing interest in selling manufactured dairy sheep products has emerged as an appealing new agribusiness option. Najdi ewes have been used for milk production under the traditional bedouins rearing conditions, and recently Ayadi *et al.* (2014) reported that this breed has noticeable potentials for milk production under intensive production system. Milk yield and udder morphology traits are influenced by several factors including ewe breed, age, stage of lactation, season, milking system and feeding (Rovai *et al.*, 1999; Ochoa-Cordero *et al.*, 2006; Ayadi *et al.*, 2014). However, few researches were done to study the factors affecting udder and teat morphology traits and their influences on the milk yield in this breed. Hence, an attempt was made to study the evolution of udder morphological traits and milk fractions in the udder during suckling and milking periods of Najdi ewes managed under intensive conditions.

## Material and methods

### Animals and management conditions

A total of 30 Najdi ewes weighing an average of  $62.1 \pm 1.5$  kg and *circa* three years of age, with healthy udders were used in this study. All ewes lambed during December to March 2012 (26°C and 10% RH) in semi-open sheds at the Experimental Animal Farm, King Saud University, Riyadh, Saudi Arabia. Ewes were allotted into homogenous groups according to their weight, managed similarly throughout the study, and fed commercial pellets (DM basis; 14.53% crude pro-

tein, 1.16% ether extract, 24.91% neutral detergent fiber, 14.22% acid detergent fiber, 0.54% Ca, 0.31% P, 7.46% ashes and 2.78 Mcal metabolizable energy  $\text{kg}^{-1}$  DM) in addition to *ad libitum* alfalfa hay to meet their daily energy and protein requirements (NRC, 1985). Fresh drinking water and mineralized salt blocks were freely available.

At lambing time, total lambs weights produced from each ewe (< 5 kg, n = 18; or > 5 kg, n = 12), numbers of born lambs from each ewe ("litter size", single = 19, twins = 11) and gender of each lamb (male = 18, female = 12) were recorded. All lambs were suckling their dams freely throughout the first 9 weeks of lactation (suckling period); thereafter, lambs were weaned and the ewes were hand milked once daily (08:00) up to the 12<sup>th</sup> week of lactation (milking period).

### Milk yield potential

During the suckling period, milk yield potential in 24h-period ( $\text{MY}_{24}$ ) was estimated in the 3<sup>rd</sup>, 6<sup>th</sup> and 9<sup>th</sup> week of lactation; the estimation started after complete udder emptying by hand milking with the aid of an i.m. injection of oxytocin (4 IU ewe<sup>-1</sup>). To ensure complete and total milk letdown, two i.m. injections of oxytocin were given at 4-h interval according to the methodology of Doney *et al.* (1979). Accordingly, at 8.00 am, the suckled lambs were separated and the milk yield in 4-h period ( $\text{MY}_4$ ) was recorded; thereafter, milk yield potential in a 24h-period was calculated ( $\text{MY}_{24} = \text{MY}_4 \times 6$ ). After weaning, milk yield was recorded in the 10<sup>th</sup>, 11<sup>th</sup> and 12<sup>th</sup> weeks of lactation (milking period). The milking routine included hand milking once daily without the aid of oxytocin, udder and teats cleaning, hand striping and teats dipping in 7% iodine solution immediately after milking. Assessment of udder health was performed by California Mastitis Test (CMT) using Bovivet CMT test kit (CMT Bovivet, Kruuse, Germany).

### Udder morphology traits

Measurements of the external udder morphology traits for all studied ewes were performed 4h post hand milking; measurements were made at 3, 6, 9, 10, 11, 12 wks postpartum. The methodology used was based on Labussière (1983) and traits recorded were udder depth (UD, distance between the rear udder attachment

and the base of teat), maximum circumference perimeter and udder width (UW, rear view of the longest horizontal line between the left and right sides of the udder). Teat measurements included: teat angle (TA, inclination with regard to the vertical position), teat length (TL, distance between the teat attachment and the teat orifice), teat width (TW, measured at the middle of the teat using a vernier caliper; ASAHIT, Hamburg, Germany) and the distance between teats (DT, horizontal distance between the bases of the two teats).

### Cisternal and alveolar udder compartments

A subset of 12 ewes was randomly selected from the studied ewes to evaluate the milk partitioning between cisternal and alveolar udder compartments. During the suckling period, the measurements were taken 8 h after complete udder emptying with the aid of an *i.v.* injection of oxytocin (2 IU ewe<sup>-1</sup>) on weeks 3, 6 and 9 postpartum. After weaning, cisternal and alveolar milk were measured 8 h after the a.m. milking on weeks 10, 11 and 12 postpartum. To prevent undesired milk letdown and overestimating cisternal milk, ewes were *i.v.* injected with 10 µg kg<sup>-1</sup> body weight of atosiban (Tractocile, Ferring Middle East, Jordan), as an oxytocin receptor-blocking agent during suckling and milking period. Cisternal milk was evacuated by hand milking and recorded. Approximately 20 min after the atosiban injection and the cisternal milk determination, ewes were received *i.v.* injection of oxytocin (2 IU ewe<sup>-1</sup>) to induce milk letdown in order to determine alveolar milk. Alveolar milk was obtained by hand milking and recorded. Milk samples of each fraction were collected and processed immediately after milking. Fat, protein, lactose and total solids of each fraction were determined using a Milko Scan (Minor Type 78100, FOSS Electric, Denmark).

### Statistical analyses

Data were statistically analyzed using the MIXED procedures for repeated measurements of SAS (version 9.1, SAS Inst. Inc., Cary, NC, USA). All percentage values were transformed to arcsine before the statistical analyses. Preliminary statistical analysis revealed no significant differences ( $p > 0.05$ ) between the values of right and left udder morphology traits and

the volumes of milk partitioning in the udder of each ewe; therefore, values for each trait were averaged and the effect of udder side was removed from the statistical model. Effects of litter size, gender and lamb's birth weight on milk yields, udder morphology traits and milk partitioning in the udder during suckling and milking periods were examined using the following model:

$$Y_{ijklm} = \mu + L_i + G_j + W_k + S_l + LG_{ij} + LW_{ik} + LS_{il} + GW_{jk} + GS_{jl} + WS_{kl} + e_{ijklm},$$

where  $Y_{ijklm}$ : individual value;  $\mu$ : general mean;  $L_i$ : effect of litter size;  $G_j$ : effect of gender;  $W_k$ : effect of lamb's birth weight;  $S_l$ : effect of lactation week;  $LG_{ij}$ ,  $LW_{ik}$ ,  $LS_{il}$ ,  $GW_{jk}$ ,  $GS_{jl}$ , and  $WS_{kl}$ : effects of two way interactions; and  $e_{ijklm}$ : residual error. Analyses of correlations between all the variables were performed. The differences between means were determined by Fischer's least significant difference. The level for statistical significance was set at  $p < 0.05$ .

## Results

The CMT revealed that two lactating ewes developed a clinical mastitis in the 10<sup>th</sup> week of lactation. Intramammary infection was confirmed by milk bacteriology; therefore, their data during milking period were discarded. Analyses of data did not detect any significant interaction effects (not shown in Table 1), thus, only main effects were presented. Litter size and gender of lambs during suckling and milking periods (Table 1) did not produce any effects ( $p > 0.05$ ) on milk yield and teat measurements, but it significantly ( $p < 0.05$ ) affected udder circumference. In addition, lamb's birth weight significantly affected milk yield ( $p < 0.05$ ) and teat length and width ( $p < 0.01$ ).

Milk yield and udder morphology traits changed ( $p < 0.05$ ) throughout the lactation period (Table 2). The estimated daily milk yield reached the maximum (2.13 L) in the 3<sup>rd</sup> wk of lactation and remained unchanged to attain 1.88 L in the 9<sup>th</sup> wk of lactation. After weaning, daily milk yield did not differ ( $p > 0.05$ ) and remained constant throughout the 10<sup>th</sup> to 12<sup>th</sup> wks of milking period with an average daily yield of  $0.43 \pm 0.07$  L. Except for teat length, udder and teat measurements and distance between teats were declined ( $p < 0.05$ ) in values throughout the lactation period; teat lengths did not show any changes with the advancement in lactation period (Table 2).

**Table 1.** Least squares means for the effect of lamb's birth weight, gender and litter size on milk yield and udder morphology traits in Najdi ewes during suckling and milking periods

Factor	No.	DMY <sup>1</sup>	Teat measures <sup>2</sup>				Udder measures <sup>3</sup>		
			TW	TL	To	DT	UC	UD	UW
<b>Suckling period</b>									
<i>Litter size</i>									
Single	19	1.84	1.96	3.4	37.2	13.9	40.2 <sup>b</sup>	20.0	14.2
Twin	11	2.04	1.89	3.2	36.4	13.7	44.6 <sup>a</sup>	19.0	13.8
<i>p</i> value		0.093	0.174	0.312	0.061	0.262	0.001	0.108	0.076
<i>Gender of lamb</i>									
Male	18	1.98	2.01	3.1	37.0	14.8 <sup>a</sup>	43.2 <sup>a</sup>	19.8	14.0
Female	12	1.90	1.85	3.4	36.5	12.7 <sup>b</sup>	41.6 <sup>b</sup>	19.2	13.9
<i>p</i> value		0.424	0.362	0.199	0.114	0.045	0.039	0.511	0.780
<i>Birth weight, kg</i>									
> 5	18	2.17 <sup>a</sup>	2.15 <sup>a</sup>	3.8 <sup>a</sup>	36.9	14.3	42.6	19.3	14.4
< 5	12	1.71 <sup>b</sup>	1.72 <sup>b</sup>	2.7 <sup>b</sup>	36.7	13.4	42.0	19.7	13.6
<i>p</i> value		0.026	0.004	0.001	0.485	0.065	0.128	0.931	0.131
± SEM		0.261	0.292	0.343	4.075	1.811	3.187	2.110	1.902
<b>Milking period</b>									
<i>Litter size</i>									
Single	18	0.43	1.91	3.1	34.1	11.8	35.1 <sup>b</sup>	17.6	10.9
Twin	10	0.44	1.90	3.3	33.5	11.0	37.7 <sup>a</sup>	18.0	12.1
<i>p</i> value		0.112	0.731	0.212	0.315	0.061	0.021	0.201	0.077
<i>Gender of lamb</i>									
Male	16	0.46	1.88	3.2	33.3	11.6	37.3 <sup>a</sup>	18.1	11.8
Female	12	0.39	1.91	3.2	34.2	11.1	35.7 <sup>b</sup>	17.5	11.2
<i>p</i> value		0.076	0.436	0.231	0.086	0.311	0.041	0.541	0.241
<i>Birth weight, kg</i>									
> 5	17	0.52 <sup>a</sup>	2.09 <sup>a</sup>	3.9 <sup>a</sup>	35.0 <sup>a</sup>	12.1	36.3	17.9	11.5
< 5	11	0.34 <sup>b</sup>	1.68 <sup>b</sup>	2.6 <sup>b</sup>	32.6 <sup>b</sup>	10.6	36.5	17.7	11.4
<i>p</i> value		0.045	0.008	0.023	0.046	0.075	0.216	0.645	0.231
± SEM		0.112	0.150	0.312	4.196	0.926	3.017	2.341	1.736

<sup>1</sup> DMY: daily milk yield, L d<sup>-1</sup>; estimated daily milk yield during suckling period: milk yield at 4-h period at 08.00 am × 6; daily milk yield during milking period: milking once a day at 08.00 am. <sup>2</sup> TW: teat width, cm; TL: teat length, cm; To: teat angle; DT: distance between teats, cm. <sup>3</sup> UC: udder circumference, cm; UD: udder depth, cm; UW: udder width, cm. <sup>a,b</sup> Means in same column within a factor carrying different superscripts differ ( $p < 0.05$ ).

Correlation coefficients of udder morphology traits and milk yield during suckling and milking periods are shown in Table 3. Milk yield was positively correlated ( $p < 0.05$ ) with udder depth, width, circumference and distance between teats. Positive correlations were also observed ( $p < 0.05$ ) between udder circumference and udder depth and width, between udder width and udder depth, between teat length and teat width, and between teat angle and distance between teats. Nevertheless, positive correlations ( $p < 0.05$ ) were found between udder circumference and both teat angle and distance between teats, and between udder width and

distance between teats, whereas the correlation between udder depth and teat length was significantly negative ( $p < 0.05$ ).

The volumes of milk fractions changed ( $p < 0.05$ ) with the advancement in lactation weeks (Figs. 1a,b) following the same trend of daily milk yield changes. The corresponding changes for cisternal and alveolar milk as percentages of total milk increased and decreased ( $p < 0.05$ ), respectively with the advancement in lactation weeks. On average, cisternal milk accounted for 55% and 67% of the total udder milk during suckling and milking periods, respectively (Table 4).

**Table 2.** Evolution of milk yield and udder morphology traits in Najdi ewes during lactation periods

Trait	Weeks in lactation						SEM
	3 <sup>rd</sup>	6 <sup>th</sup>	9 <sup>th</sup>	10 <sup>th</sup>	11 <sup>th</sup>	12 <sup>th</sup>	
Milk yield <sup>1</sup> , L d <sup>-1</sup>	2.13 <sup>a</sup>	1.80 <sup>a</sup>	1.88 <sup>a</sup>	0.47 <sup>b</sup>	0.47 <sup>b</sup>	0.34 <sup>b</sup>	0.15
Teat							
Width, cm	2.1 <sup>a</sup>	1.9 <sup>b</sup>	1.8 <sup>b</sup>	1.9 <sup>b</sup>	1.8 <sup>b</sup>	1.9 <sup>b</sup>	0.10
Length, cm	3.4	3.2	3.3	3.2	3.2	3.1	0.13
Angle, °	39.6 <sup>a</sup>	35.7 <sup>b</sup>	35.2 <sup>b</sup>	34.2 <sup>b</sup>	34.6 <sup>b</sup>	32.5 <sup>b</sup>	0.12
Udder							
Circumference, cm	44.9 <sup>a</sup>	41.5 <sup>b</sup>	40.9 <sup>b</sup>	38.4 <sup>bc</sup>	36.0 <sup>cd</sup>	34.7 <sup>d</sup>	1.00
Depth, cm	20.1 <sup>a</sup>	19.4 <sup>a</sup>	18.9 <sup>ab</sup>	18.9 <sup>ab</sup>	17.7 <sup>ab</sup>	16.8 <sup>b</sup>	0.91
Width, cm	14.5 <sup>a</sup>	14.2 <sup>a</sup>	13.4 <sup>a</sup>	12.2 <sup>b</sup>	11.4 <sup>c</sup>	10.8 <sup>c</sup>	0.45
Distance between teats, cm	15.1 <sup>a</sup>	13.6 <sup>ab</sup>	12.6 <sup>b</sup>	12.4 <sup>b</sup>	11.3 <sup>bc</sup>	10.4 <sup>c</sup>	0.62

<sup>a,b,c,d</sup> Means in the same row carrying different superscripts differ,  $p < 0.05$ . <sup>1</sup> Estimated daily milk yield at 3<sup>rd</sup>, 6<sup>th</sup> and 9<sup>th</sup> wks: milk yield at 4-h interval  $\times 6$ ; daily milk yield at 10<sup>th</sup>, 11<sup>th</sup> and 12<sup>th</sup> wks: milking once a day at 08.00.

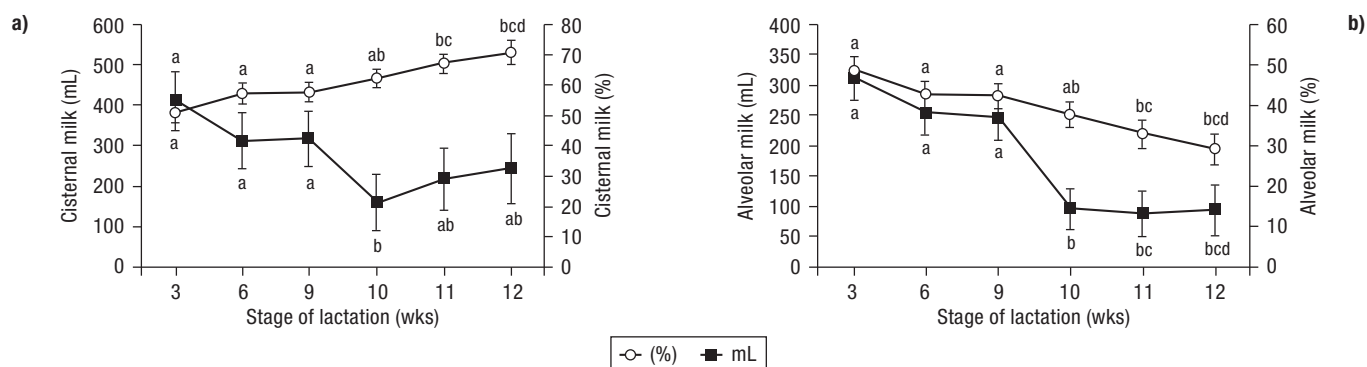
Cisternal ( $r = 0.94$ ,  $p < 0.05$ ) and alveolar milk ( $r = 0.85$ ,  $p < 0.05$ ) were positively correlated with total milk yield. Fat percentages in alveolar milk were 60% and 105% greater ( $p < 0.05$ ) than cisternal milk during suckling and milking periods, respectively. Concurrently, protein, lactose and total solids percentages did not differ ( $p > 0.05$ ) between cisternal and alveolar milk fractions during either suckling or milking periods. The percentages of fat, protein and total solids in

alveolar milk increased significantly ( $p < 0.05$ ) after weaning in the 10<sup>th</sup> week of lactation; thereafter, these values decreased ( $p > 0.05$ ) slightly (Figs. 2a,b,c). Except for fat percentages in cisternal milk, protein and total solids in milk followed the same trends of alveolar milk fraction after weaning; fat percentage remained constant throughout the lactation weeks. On the other hand, lactose percentage of both milk fractions decreased ( $p < 0.05$ ) after weaning

**Table 3.** Correlation coefficients<sup>1</sup> between udder morphology traits and milk yield in Najdi ewes during suckling and milking periods

Traits	DMY	UC	UD	UW	TL	TW	TA
UC	0.47* 0.37*						
UD	0.47* 0.49*	0.33* 0.50*					
UW	0.39* 0.31*	0.62* 0.77*	0.17* 0.41*				
TL	-0.11 0.14	-0.06 0.04	-0.47* -0.19*	0.04 0.13			
TW	0.05 0.22	0.14 0.11	-0.27* -0.07	0.16 0.29*	0.71* 0.66*		
TA	0.14 -0.09	0.33* 0.29*	-0.11 -0.07	0.43* 0.12	0.24* -0.16	0.23* -0.21	
DT	0.39* 0.26*	0.51* 0.60*	0.31* 0.26*	0.58* 0.48*	-0.22 0.12	-0.06 0.04	0.44* 0.51*

<sup>1</sup> Upper and lower values within a trait indicate the coefficients during suckling and milking period, respectively. DMY: daily milk yield; UC: udder circumference; UD: udder depth; UW: udder width; TL: teat length; TW: teat width; TA: teat angle; DT: distance between teats. \*  $p < 0.05$ .



**Figure 1.** Changes in cisternal (a) and alveolar milk (b) in Najdi ewes during lactation.

(Fig. 2d) following the same trend of daily milk yield (Table 2).

## Discussion

Estimated daily milk yield during the suckling period showed a sharp decrease ( $-75\%$ ) at the time of weaning. The milk yields drop was also observed in Manchega ewes (Gargouri *et al.*, 1993), Lacaune and Awassi breeds (Labussière, 1988) and in Sicilo-Srade dairy ewes (Ayadi *et al.*, 2011); the average drop ranged from 30 to 49%. This drop can be explained by the partial disappearance of the stimulus produced by the lamb when suckling. The discrepancies in milk yield dropping rates between the present results and other studies are probably due to breed differences in milk yield and cisternal size, as well as milking management.

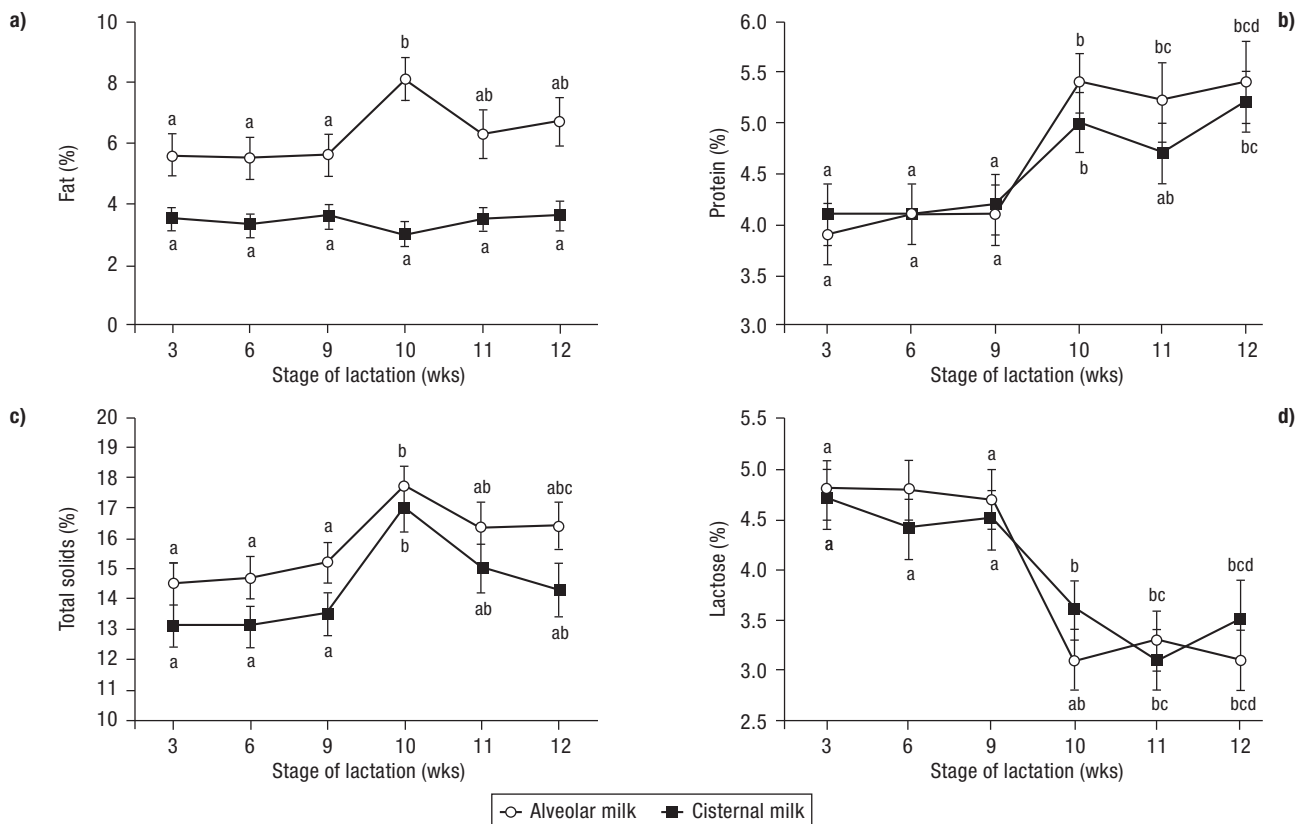
Najdi ewes had shorter teat length than Manchega, Lacaune, Istrian dairy crossbred and Bergamasca ewes (Rovai *et al.*, 1999; Such *et al.*, 1999; Dzidic *et al.*,

2004; Emediato *et al.*, 2008), but in contrary, it had longer teat length than Sicilo-Sarde and Merino Rambouillet dairy ewes (Ochoa-Cordero *et al.*, 2006; Ayadi *et al.*, 2011). The teat lengths of Najdi ewes did not show any change throughout lactation, which is similar to the results reported by Ochoa-Cordero *et al.* (2006) in Merino Rambouillet dairy ewes. Contrariwise, Rovai *et al.* (1999) in Manchega and Lacaune sheep reported an increase in teat length during the lactation period. The discrepancies in results between the latter study and our findings are probably due to their longer milking period, milking with machine and breed differences. The teat width and angle observed in the current study for Najdi ewes were smaller in values than those values reported for Manchega, Lacaune, Merino Rambouillet and Chios dairy breed ewes (Such *et al.*, 1999; Ochoa-Cordero *et al.*, 2006; Rovai *et al.*, 2008; Gelasakis *et al.*, 2012). Teat angle in Najdi ewes was greater than the average value observed in French Rouge de l'Ouest ewes ( $26.5^\circ$ , Malher & Vrayla-Anesti, 1994). The measurements of teat angle and width in Najdi sheep decreased during the

**Table 4.** Least squares means of cisternal and alveolar milk volumes and compositions at 8 h milking interval during lactation in Najdi ewes (n = 12)

Item	Suckling period			Milking period		
	Cisternal	Alveolar	SEM	Cisternal	Alveolar	SEM
Milk volume-8h, L	0.35	0.27	0.05	0.21 <sup>a</sup>	0.09 <sup>b</sup>	0.06
Milk volume-8h, %	55.4 <sup>a</sup>	44.6 <sup>b</sup>	3.20	66.7 <sup>a</sup>	33.3 <sup>b</sup>	3.41
Milk composition, %						
Fat	3.50 <sup>b</sup>	5.62 <sup>a</sup>	0.56	3.40 <sup>b</sup>	6.96 <sup>a</sup>	0.61
Protein	4.12	4.14	0.31	5.01	5.40	0.34
Lactose	4.53	4.78	0.31	3.40	3.16	0.34
Total solids	13.20	14.78	0.72	15.41	16.82	0.82

<sup>a,b</sup> Means in the same row within each period carrying different superscripts differ ( $p < 0.05$ ).



**Figure 2.** Changes in milk fat (a), proteins (b), total solids (c) and lactose (d) in milk fraction during lactation in Najdi ewes.

first 6 wks of lactation; thereafter, these measurement values remained unchanged up to the end of the 12<sup>th</sup> wk of lactation. Arranz *et al.* (1989) and Rovai *et al.* (1999) found no changes in teat angles during lactation. On the other hand, Ochoa-Cordero *et al.* (2006) found that teat width and angle were gradually increased in values during the advancement in lactation period.

Distance between teats did not show any changes in the first 6 wks of lactation, thenceforth it decreased gradually through the end of milking period. Similar results were reported by Arranz *et al.* (1989) and Rovai *et al.* (1999), suggesting that the milk productive capacity in dairy ewes was closely related to the distance between teats. Teat angle correlated positively ( $p < 0.05$ ) with the distance between teats during suckling and milking period, indicating that wide udders furnish a more horizontal teat insertion. Consequently, lamb suckling will be difficult and cluster detaching will occur in some cases during machine milking. This result agrees with those reported in Manchega and Lacuane dairy ewes (Rovai *et al.*, 1999; Such *et al.*, 1999). Except for the distance between teats, no significant

correlations between teat morphology traits and milk production were observed; these results were in accordance to those findings by Labussière (1988), Dzidic *et al.* (2004) and Ayadi *et al.* (2011). The udder depth, width and circumference measurements in this study were greater than the values reported for Sicilo-Sarde dairy ewes (Ayadi *et al.*, 2011), but similar to those reported for Manchega, Lacuane and Merino Rambouillet dairy ewes (Such *et al.*, 1999; Ochoa-Cordero *et al.*, 2006; Rovai *et al.*, 2008). Correlations between udder traits and daily milk yield were positively significant ( $p < 0.05$ ) during suckling and milking periods, which is in agreement with previous reports by Labussière (1988), Arranz *et al.* (1989), Fernández *et al.* (1995), Rovai *et al.* (2008) and Ayadi *et al.* (2011).

The cisternal milk fraction varied according to species, breed, lactation stage, parity and milking intervals (Caja *et al.*, 2004; Salama *et al.*, 2004). Animals that store a large amount of milk in the gland cistern generally produce more milk, milked faster and tolerate extended milking intervals (Ayadi *et al.*, 2003; Castillo *et al.*, 2008). In this study, cisternal milk was positively correlated ( $p < 0.05$ ) with total milk yield

during suckling and milking periods, indicating that cisternal size could be used for predicting milk yield in Najdi ewes.

However, sheep breeds can be classified according to their udder cistern size into large-cisterned ewes that were selected for high milk yield (e.g. Lacaune and Sarda), medium-cisterned ewes, which have been selected as dual purpose (e.g. East Friesian crossbred, Manchega, Sicilo-Sarde) and small-cisterned ewes that resembled unselected or non-dairy sheep. The percentages of Najdi's cisternal milk (55% and 67% during suckling and milking periods, respectively) were similar to the percentages reported in Manchega ewes (Rovai *et al.*, 2002; Castillo *et al.*, 2009), East Friesian crossbred dairy ewes (McKusick *et al.*, 2002b) and Sicilo-Sarde dairy ewes (Ayadi *et al.*, 2011). On the other hand, the percentages of cisternal milk in the current study were lower than those percentages in Lacuane (74-77%, Rovai *et al.*, 2002; Castillo *et al.*, 2009) and Sarda ewes (82%, Nudda *et al.*, 2000). According to the formerly presented results, Najdi ewes can be classified as medium-cisterned breed.

Volumes of cisternal and alveolar milk varied non-significantly ( $p > 0.05$ ) from 420 to 310 and from 320 to 255 mL, respectively during suckling period. After weaning, the cisternal and alveolar milk volumes decreased by 52 and 61% ( $p < 0.05$ ), respectively at the 10<sup>th</sup> week and thenceforth, remained constant ( $p > 0.05$ ) to the 12<sup>th</sup> week of lactation. The corresponding cisternal milk volumes as percentages of total milk in the udder increased ( $p < 0.05$ ) after weaning due to the decrease in total milk yield, whereas the alveolar milk percentages decreased ( $p < 0.05$ ). These results disagree with those previously reported in dairy sheep (Rovai *et al.*, 2002) and dairy goats (Salama *et al.*, 2004), in which volume and the percentage of cisternal milk decreased as lactation progressed. Little information exists in literature on the evolution of the fractional composition of milk throughout lactation in dairy ewes. Fat percentage in alveolar milk of Najdi sheep was greater than in cisternal milk for the 8-h milking interval during suckling and milking periods. This result agreed with those previously reported in sheep (McKusick *et al.*, 2002b; Castillo *et al.*, 2008), goats (Salama *et al.*, 2004), cows (Caja *et al.*, 2004) and dromedary camels (Ayadi *et al.*, 2013). The difference between milk fractions can be explained by the viscosity and large size of fat globules, which are accumulated in the alveolar compartment. No significant differences were observed between milk protein,

lactose and total solid percentages of cisternal and alveolar milk during suckling and milking periods. These results agree in part with those findings in dairy ewes (Rovai *et al.*, 2008), dairy goats (Salama *et al.*, 2004), dairy cows (Ayadi *et al.*, 2004) and lactating dromedary camels (Ayadi *et al.*, 2013).

In conclusion, the indigenous Najdi ewes had acceptable udder morphology traits (medium-sized cisterns and teats) for machine milking. Udder morphology measurements declined throughout lactation and had positive correlations with milk yield. Therefore, udder traits can be adopted in breeding programs. Moreover, further researches with larger numbers of Najdi ewes are required to confirm these results.

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