Udder morphology and milk yield of Lacaune dairy sheep

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Eutermorphologie und Milchleistung von Lacaune-Milchschafen

Diese Studie analysiert Eutermessungen bei Lacaune-Mutterschafen. Die Auswirkungen der Laktationsreihenfolge während den Kontrolljahren von 2022 und 2023 auf verschiedene Eutermerkmale wurden untersucht. Die Anzahl der in die Studie einbezogenen Lacaune-Mutterschafe lag für verschiedene Parameter zwischen 57 und 86 Tieren, während die Anzahl der Kontrollmessungen zwischen 49 und 111 lag. Es wurden erhebliche jährliche Schwankungen bei der Zitzengrösse und -position beobachtet, wobei die Zitzengrösse im Allgemeinen mit zunehmendem Alter abnahm. Das Kontrolljahr hatte einen erheblichen Einfluss auf Euterlänge, -breite und -tiefe sowie auf Zitzenlänge und -winkel. Unsere Ergebnisse zeigen, dass optimale Zitzenwinkel zum Melken bei etwa 45° liegen. Die Laktationsreihenfolge (Parität) hatte einen erheblichen Einfluss auf die Eutergrösse, insbesondere auf die Eutertiefe und -länge, die ab der dritten Laktation zunahmen. Die älteren Mutterschafe wiesen längere Zitzen und eine horizontalere Zitzenposition auf, was auf grössere Euterzisternen deutet. Die Euterzisternenmessungen wurden mit verschiedenen Methoden durchgeführt und zeigten, dass die Zisternengrösse mit zunehmendem Alter tendenziell zunimmt. Grössere Zisternen gehen mit einer höheren Milchleistung und einer schnelleren Milchabgabe einher. Obwohl der Einfluss der Laktationsreihenfolge auf die Zisternenmessungen statistisch nicht signifikant war, erwies sich die Methode «von unten» als effektiver für die Beurteilung der Zisternengrösse. Es gab erhebliche Unterschiede bei den Melkbarkeitsparametern, einschliesslich maschinell gemolkener Milch und Gesamtmilchleistung. Der Zusammenhang zwischen der Euterbefestigung und der Milchproduktion war signifikant, was die Bedeutung einer starken Euterbefestigung für eine effiziente Milchleistung unterstreicht. Eine bemerkenswerte positive Korrelation zwischen Euterbreite und Milchproduktion weist darauf hin, dass breitere Euter in kürzeren Zeiträumen mehr Milch liefern. Grössere Euterzisternen, insbesondere auf der linken Seite, sind mit einer höheren Milchproduktion verbunden. Mit zunehmendem Alter der Mutterschafe und fortschreitender Laktation verbessert sich die Eutermorphologie, was eine bessere Melkbarkeit ermöglicht. Diese Ergebnisse liefern eine wissenschaftliche Grundlage für die

Summary

This study analyses udder measurements in Lacaune ewes, with a particular focus on the effects of the control year (2022–2023) and lactation order on various udder traits. The number of Lacaune ewes included in the study ranged from 57 to 86 for various variables, while the number of control measurements was between 49 and 111. Significant year-on-year variations were observed in teat size and position, with teats generally decreasing in size with age. The control year had a significant impact on udder length, width, and depth, as well as teat length and angle. Our findings indicate that optimal teat angles for milking are around 45°. The order of lactation (parity) had a significant impact on udder size, particularly udder depth and length, which increased by the third lactation. The older ewes exhibited longer teats and a more horizontal teat position, indicative of larger udder cisterns. The results of the udder cistern measurements taken using different methods showed that cistern size tends to increase with age. It was found that larger cisterns correlate with higher milk yields and faster milk letdown. Although the impact of lactation order on cistern measurements was not statistically significant, the 'from the bottom' method proved more effective for assessing cistern size. There was considerable variation in the milkability parameters, including machine-milked and total milk yield. The correlation between udder attachment and milk production was significant, which highlights the importance of a strong udder attachment for efficient milk yield. A notable positive correlation between udder width and milk production indicates that wider udders yield more milk in shorter periods. The study findings indicate that larger udder cisterns, particularly on the left side, are associated with greater milk production. As ewes age and progress through lactations, udder morphology improves, facilitating better milkability. These findings provide a scientific basis for the use of specific udder traits in the selection of ewes with enhanced milk production potential for the Lacaune breed.

Keywords: Dairy sheep, Mammary gland, Udder, Ultrasonography

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Verwendung spezifischer Eutermerkmale bei der Auswahl von Mutterschafen mit erhöhtem Milchproduktionspotenzial für die Lacaune-Rasse.

Schlüsselwörter: Milchdrüse, Milchschafe, Euter, Ultraschall

Introduction

The French Lacaune dairy sheep is one such breed exported worldwide and is utilized in both pure breeding and crossbreeding to enhance the milk yield of domestic sheep populations.[3]

In Slovakia, breeders face significant challenges due to the scarcity of human resources in sheep-raising areas, which has led to a growing interest in machine milking in dairy sheep and, consequently, in udder conformation and machine milking ability.

Milk within the udder can be divided into the following two fractions: cisternal and alveolar milk. The cisternal fraction is available before oxytocin is released from the posterior pituitary gland, triggering milk ejection.[7,13,24] Bruckmaier and coworkers[8] found that in dairy cows, the presence of cisternal milk prior to milk ejection makes teats firm and rigid for teat cup attachment. Otherwise, the applied vacuum on an empty teat and gland cistern can cause the collapse of milk ducts, inhibiting milk ejection during milking and resulting in incomplete emptying of the udder. In dairy ewes and goats, after a normal 12-hour milking interval, the cisternal milk represents between 50 and 80 %.[19] These larger cisterns play an important role in milk collection and storage and have a significant influence on milk ejection during milking. The cisternal milk fraction is available for machine milking or suckling before the occurrence of milk ejection. In animals in which the mammary glands do not have the capacity to store milk (e.g., rodents), the milk let-down reflex is necessary to maintain the secretory function, while in ruminant animals, excluding parts of the innervation of glandular sinuses has no effect on the end of lactation.[18.] In the past, residual milk has been considered a substrate for the multiplication of pathogens in udder tissue.[9] Milk removal from the udder is a determining factor in stimulating milk secretion; consequently, milk removal enhances milk yield.[5] Milk yield depends on many factors, including milking frequency, degree of udder emptying, stage of lactation,[2,8] time since last milking,[8,12,26] breed, and nutrition. If there is incomplete emptying of the udder due to suboptimal milking technique, failure to attach the teat cups, or lack of milk ejection, the milk yield is negatively affected.[2] It is also commonly known that with higher days in milk (DIM), the milk yield will decrease.[8] At the start of the lactation period, milk yield rapidly increases until peak lactation, after which it will begin to decrease.

Anatomically, mammary glands in ewes and goats differ slightly; however, in ewes, the outlet duct of the teat is not always located on the edge of the mammillary part of the cistern, from which, proportionally to the amount of milked milk, the stripping fraction is obtained.[6,16] This anatomical peculiarity is the cause of obtaining a large quantity of milk from machine stripping. On the other hand, the apparent latency in the release of oxytocin in ewes results in a situation where the curves have two milk peaks, with the second peak referring to the alveolar fraction of milk, which is not always milked due to the short time of milking.[7] In small ruminants, milk is readily transferred from the alveoli to the cistern during the period between milkings. This phenomenon of milk transfer during the periods between milkings is not fully understood.[19]

Ewes with a considerable cistern volume tolerated milking once a day well but were not adapted to the increased frequency of milkings.[16] More recent data indicate that an accumulation of proteins synthesized in the gland (FIL – feedback inhibitor of lactation) reduces the synthesis of milk in the alveoli. The inhibition of milk ejection may occur as a result of emotional stress. In most species (except for cattle), ß-endorphin plays an important role. The milk ejection rate is regulated by the adrenergic system, and peripheral inhibition of milk ejection may be caused by adrenergic receptor stimulation or an oxytocin receptor blockade.[28] An increased frequency of milking in ewes positively affected the secretion of milk.[14,16,21]

The present study aims to investigate, in Lacaune ewes, the relationship between linear descriptions of the udder, cistern size detected by ultrasonography, and indicators of their milking performance under machine milking conditions.

Material and methods

Functional and morphological characteristics of the sheep udder were evaluated in a selected population of sheep (in one experimental flock of dairy sheep). The number of purebred Lacaune ewes included in the experiment ranged from 57 to 86 for various variables, while the number of control measurements was between 49 and 111. Ewes in the 1st to 3rd lactation were included in the experiment. During the milking period, two milk control measurements (MCM) were performed, where MCM is defined as an evening milking followed by a morning milking. At the 1st MCM, the ewes were on average on day 124 of lactation, and at the 2nd MCM, ewes were on average on day 157 of lactation. At the MCM, we used installed flow meters to detect milk letdown (milk yield) at 10-second intervals to determine the amount of milk milked in 60 seconds (MY60s), the total amount of milk milked by machine (machine milk yield – MMY), the amount of milk obtained by machine stripping (MS), the amount of milk obtained by machine milking and stripping (total milk yield – TMY), the proportion of machine milk yield to total milk yield (MMY/TMY), and the proportion of milk (from TMY) milked in 30 and 60 seconds (MY30s and MY60s respectively). Sheep were not hand-stripped after machine milking.

We assessed udder morphology (including linear assessment) at morning milking and then used ultrasonography to measure udder cisterns. Linear descriptions of the udder of all ewes included in the experiment were performed using a 9-point scale. We evaluated the following parameters:

The linear assessment scheme contained 7 udder and teat traits: udder depth (1 – low, 9 – high), cistern depth below the teat level (1 – none, 9 – high), teat position (1 – vertical, 9 – horizontal), teat size (1 – short, 9 – long), udder cleft (1 – not detectable, 9 – expressive), udder attachment (1 – narrow, 9 – wide), udder shape (1 – bad, 9 – ideal). Statistical analysis was performed using the restricted maximum likelihood (REML) methodology using a MIXED procedure from the SAS statistical package.[25]

The following statistical model with fixed and random effects was applied:

$yijklm = \mu + Yi + LSj + GENk + Pl + anm + a^{*}DIMijklm + eijklm$

where:

- yijklm is an observed trait (see above for details);
- Yi – year (a fixed effect with 4 to 7 levels);
- LSj – lactation stage, a fixed effect with 4 levels (from 40th to 99th lactation day, from 100th to 129th lactation day, from 130th to 159th lactation day and from 160th to 210th lactation day);
- GENk – genotype (breed group; a fixed effect with 9 levels);
- P1 – parity (a fixed effect with 3 levels; first, second and third);
- anm – animal (random effect);
- DIMijklm – days in milk (covariate; 40 to 210 days in milk);
- eijklm – the random error.

The differences were statistically significant at $p < 0,05$, or less.

External udder measurements of six traits[20] were made by at least two technicians using a ruler, measuring tape, and protractor, and they included: udder length (UL), udder width (UW), rear udder depth (RUD), cistern depth (CD), teat length (TL), and teat angle from the vertical (TA) (Figure 1).

Ultrasound images of the left and right udder cisterns were recorded using a portable ultrasonography device with a 3,5 MHz convex sector probe, as previously described.[23] The procedure involved applying contact gel and placing the probe directly against the upper part of the median suspensory ligament in the inguinal abdominal fold. The operator performed an equal-axis scan of the opposite side of the udder to obtain a sonographic image with the largest cistern size (from the side method). Milkability variables were measured immediately during the milking process. Following this, the udder was left to rest for 12 hours to allow it to naturally fill with milk without any interventions. After this 12-hour resting phase ultrasound images were captured once for each half of the udder for measuring linear udder dimensions and exact udder dimensions.

On the sonographic images, the length of the left (LLC1) and right (LRC1) cisterns, as well as the width of the left (WLC1) and right (WRC1) cisterns (in millimetres), were measured from the cross-sectional scans. Using digital technology, the areas of the left (ALC1) and right (ARC1) cisterns (in mm^2) were measured, along with the sum of the areas in both cisterns (SLRC1). For some control measurements, in addition to scanning the udder cisterns using the from-side method, the sizes of the left and right udder cisterns were also investigated by scanning the entire ventral udder using the from-bottom method. Udders were measured while immersed in water, with the probe held against the udder wall in the water, as described.[4,6] Sonographic images obtained from the bottom produced equal measurements for the udder cisterns as sonography from the side (LLC2, LRC2, WLC2, WRC2, ALC2, ARC2, SLRC2). Control measurements refer to a specific set of results obtained simultaneously. These individual control measurements can be compared with each other (for instance, when monitoring changes over time).

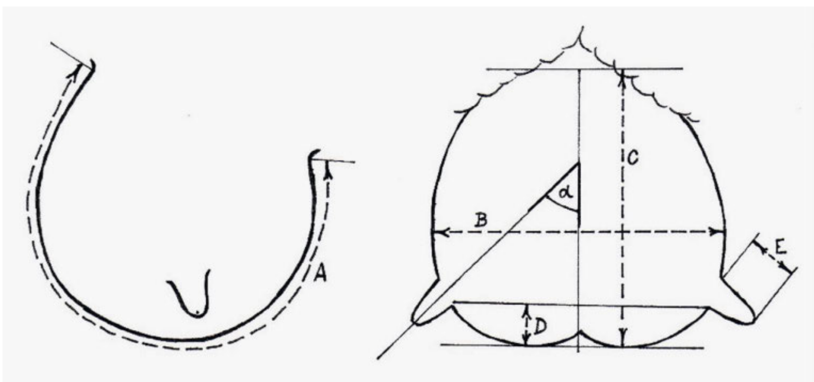

Figure 1: Morphological parameters measured on the udder and teats in French Lacaune dairy sheep.
A: udder length (UL); B: udder width (UW); C: rear udder depth (RUD); D: cistern depth (CD); E: teat length (TL); α: teat angle from the vertical (TA).

Significance levels were tested as follows: P<0,001 (+++); P<0,01 (++); P<0,05 (+); P≥0,05 (ns – non-significant).

Results

Udder measurements and morphological traits

Tables 1 and 2 present the results of the analysis of the observed udder measurements, including linear measurements and measurements detected by tape measure and protractor, of the Lacaune ewes.

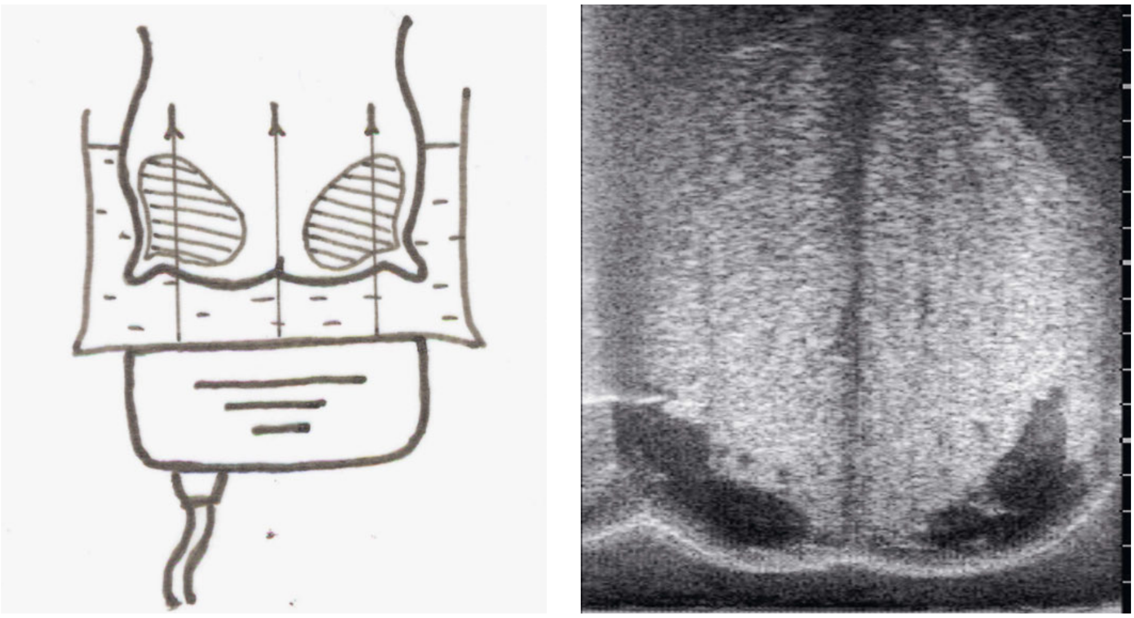

Figure 2: Ultrasonic scan of French Lacaune dairy sheep udder 'from bottom' (sum of cistern areas – BCA).

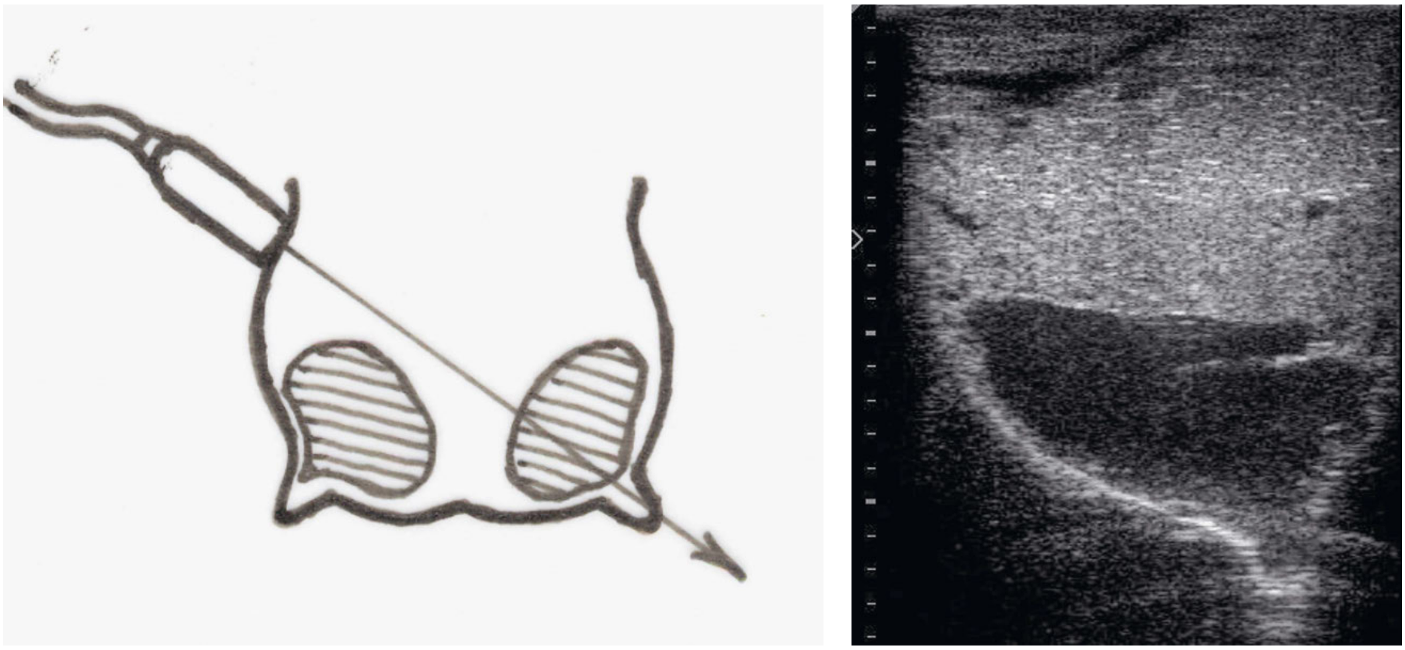

Figure 3: Ultrasonic scan of French Lacaune dairy sheep udder 'from side' (sum of both cistern areas – SCA).

Table 1: Linear evaluation of the udder of French Lacaune dairy ewes depending on the breed group.

Source of variation	Measurement						
	Udder depth [cm]	Cistern depth [cm]	Teat position	Teat size	Udder cleft	Udder attachment	Udder shape
Number of control measurements	111	111	111	111	111	111	111
Total average	5,98	5,97	5,78	4,38	4,36	5,52	5,87
Standard deviation	1,19	1,67	1,58	1,05	1,64	1,24	1,49
Coefficient of variation	19,84	27,97	27,33	23,92	37,53	22,49	25,32
Minimum	2	2	2	2	1	3	2
Maximum	9	9	9	7	8	9	9
Control Year							
2022 (n = 86)	6,13	5,65	5,45	4,79	4,33	5,48	5,77
2023 (n = 80)	5,99	6,33	6,10	4,01	4,33	5,48	5,94
F test value	0,31 ns	3,84 ns	4,02 +	12,97 +++	0,00 ns	0,00 ns	0,31 ns
Parity							
1st (n = 86)	5,16a	5,92	5,89	3,79a	4,70	5,99a	6,06
2nd (n = 80)	6,03b	5,71	5,46	4,15a	4,42	5,67a	5,88
3rd (n = 80)	6,99c	6,34	5,98	5,25b	3,88	4,78b	5,62
F test value	22,47 +++	1,15 ns	0,80 ns	19,27 +++	2,41 ns	9,38 +++	0,84 ns
Milking control measurement							
Evening milking (n = 86)	6,41	5,78	5,51	4,71	4,45	5,24	5,64
Morning milking (n = 80)	5,72	6,26	6,04	4,08	4,21	5,72	6,06
F test value	1,76 ns	0,33 ns	0,60 ns	1,84 ns	0,11 ns	0,81 ns	0,42 ns
Covariance							
Days in milk (F value)	0,15 ns	0,00 ns	0,01 ns	0,89 ns	1,02 ns	2,47 ns	1,31 ns

+++ P<0,001; ++ P<0,01; + P<0,05; ns – non significant (non-significant effect); a, b – differences in means marked with an unequal letter are statistically significant.

Table 2: Exact udder measurements of French Lacaune dairy ewes (using tape measure and protractor) depending on breed group.

Source of variation	Measurement					
	Udder depth [cm]	Udder width [cm]	Rear udder depth [cm]	Cistern depth [cm]	Teat lenght [cm]	Teat angle [°]
Number of control measurements	109	109	109	109	109	109
Total average	32,05	13,48	18,90	46,36	3,51	3,27
Standard deviation	5,04	1,61	2,77	14,39	0,49	1,53
Coefficient of variation	15,71	11,92	14,63	31,04	13,97	46,83
Minimum	18	8	11	2	10	0
Maximum	57	19	31	5,5	90	7
Control Year						
2022 (n = 86)	34,35	14,51	20,45	45,62	3,64	2,94
2023 (n = 80)	29,95	12,33	17,36	46,73	3,40	3,60
F test value	17,74 +++	42,90 +++	29,05 +++	0,14 ns	5,57 +	4,33 +
Parity						
1st (n = 48)	29,13a	13,34	17,34a	45,38a	3,28a	3,17a
2nd (n = 57)	32,39bc	13,69	18,42a	42,20ab	3,40a	2,69a
3rd (n = 61)	34,94c	13,23	20,95b	51,94a	3,87b	3,94b
F test value	12,23 +++	0,60 ns	16,21 +++	4,22 +	14,53 +++	5,12 ++
Milking control measurement						
Evening milking (n = 86)	31,16	13,75	18,85	42,01	3,68	2,94
Morning milking (n = 80)	33,15	13,09	18,96	50,34	3,36	3,59
F test value	0,81 ns	0,88 ns	0,01 ns	1,75 ns	2,32 ns	0,94 ns
Covariance						
Days in milk (F value)	4,54 +	0,59 ns	0,67 ns	0,01 ns	0,61 ns	0,30 ns

+++ P<0,001; ++ P<0,01; + P<0,05; ns – non significant (non-significant effect); a, b – differences in means marked with an unequal letter are statistically significant.

The 'control year' indicator had a statistically highly significant effect on teat size (r=12,97, P=+++), and teat position (4,02+), while the mean teat size was 4,38 cm. Specifically, it was 4,79 cm and 4,01 cm in 2022 and 2023, respectively, showing a tendency for the teats to shrink with age. The control year had no significant effect on UC and UA. Thus, the F value of the test was 0,00 ns. For udder shape traits detected by the exact test, the effect of the indicator 'control year' was statistically highly significant on udder length (17,74+++), udder width (42,90+++), exact udder depth (29,05+++), as well as right teat length (5,57+) and teat angle (4,33+). The teat angle (46,83°) was close to the optimum for machine milking (45°). Regarding the influence of the indicator 'order of lactation' on udder morphology, the results show that the udder size increases by the third lactation. The differences were statistically significant, especially when comparing udder depth and udder length at the 1st lactation (5,16 and 29,13, respectively) and at the 3rd lactation (6,99 and 34,94, respectively). On the contrary, teat length was statistically significantly greater in older ewes (3,87) than in primiparous ewes (3,28) in most cases. Teat position tended to deteriorate with age, although not statistically significant. The teats of older ewes are more horizontal than those of younger ewes, indicating that older ewes have a larger udder cistern. Regarding udder cleft and udder attachment, our results are in agreement with those of the above-mentioned authors, who state that both udder cleft and udder attachment deteriorate with the age of the ewes (4,7 and 5,99 in the first lactation and 3,88 and 4,78 in the third lactation, respectively).

Cistern measurements

Tables 3 and 4 display the results of the analysis of variance for the observed left and right udder cistern measurements of ewes detected by the 'from the bottom' and 'from the side' methods. Measurements obtained from the bottom were consistently smaller than those from the side. For example, the length of the left udder cistern from the bottom (LLC1) was 79,26 mm, whereas the same measure from the side (LLC2) was 91,51 mm.

Table 3: Analysis of variance of the observed left and right udder cistern dimensions of Lacaune ewes detected by the 'from the bottom' method.

Source of variation	Measurement						
	Length of left cistern 1 [mm]	Width of left cistern 1 [mm]	Area of left cistern 1 [mm²]	Length of right cistern 1 [mm]	Width of right cistern 1 [mm]	Area of right cistern 1 [mm²]	Sums of both cross-section areas 1 [mm²]
Number of control measurements	107	107	107	107	107	107	107
Total average	79,26	46,92	2834,55	81,82	48,85	2943,05	5777,59
Standard deviation	17,22	12,62	1160,83	13,86	9,93	966,79	1710,78
Coefficient of variation	21,74	26,62	40,95	16,94	20,33	32,85	29,61
Minimum	12	7	137	39	21	360	2219
Maximum	124	104	7560	118	79	5552	12900
Control Year							
2022 (n = 86)	82,29	51,79	3235,72	81,26	49,94	3026,77	6262,48
2023 (n = 80)	75,84	41,29	2390,19	83,49	48,16	2909,11	5299,30
F test value	3,24 ns	15,98 +++	12,25 +++	0,59 ns	0,75 ns	0,34 ns	7,32 ++
Parity							
1st (n = 47)	78,95	46,96	2790,59	78,11a	47,07	2739,98	5530,57
2nd (n = 56)	77,38	46,50	2641,53	82,74a	49,64	291,74	5558,27
3rd (n = 59)	88,86	46,16	3006,74	86,28b	50,44	3247,10	6253,84
F test value	0,29 ns	1,38 ns	0,72 ns	3,09 +	1,09 ns	2,49 ns	1,90 ns
Milking control measurement							
Evening milking (n = 83)	80,10	48,91	3038,18	82,55	49,55	3197,66	6235,84
Morning milking (n = 79)	78,03	44,16	2587,73	82,15	48,55	2738,22	5325,94
F test value	0,07 ns	0,73 ns	0,77 ns	0,01 ns	0,05 ns	1,16 ns	1,45 ns
Covariance							
Days in milk (F value)	0,00 ns	0,01 ns	0,01 ns	0,12 ns	1,07 ns	0,03 ns	0,03 ns

+++ P<0,001; ++ P<0,01; + P<0,05; ns – non significant (non-significant effect); a, b – differences in means marked with an unequal letter are statistically significant.

In the Lacaune breed, a statistically highly significant effect of the 'control year' indicator on the width and area of the left cistern, as well as a significant effect on the sum of the areas of the two cisterns (detected by both the 'from the bottom' and 'from the side' methods) and the length of the left cistern detected by the 'from the side' method, can be observed.

The factor 'order of lactation' did not have a statistically highly significant effect on the observed left and right udder cistern measurements. However, the length and width of the right cistern measured 'from the bottom' (78,11 mm and 47,07 mm at 1st lactation and 86,28 mm and 50,44 mm at 3rd lactation, respectively) confirmed the expected assumption that older ewes generally have larger cisterns. Although the differences between ewes at 1st, 2nd, and 3rd lactations were not statistically significant, a tendency for udder cisterns to increase with age was observed in all parameters.

Tables 3 and 4 show that the area of the right udder cistern, regardless of the method of detection (for both APC1 and APC2 methods), was higher in sheep in their second and third lactations than in ewes in their first lactation.

Milkability parameters

Table 5 provides the parameters characterizing milkability. These include milk milked in 60 seconds (ml), machine-milked milk (ml), machine-stripped milk (ml), total milk yield (ml), proportion of machine-stripped milk (%), and proportion of milk milked in 30 and 60 seconds (%).

For the entire population of LC ewes under control, the average amount of milk obtained by machine milking (MMY) was 305,80 ml, and the total milk yield was 454,00 ml, with a relatively large range (240 to 740 ml). Consequently, the amount of milk obtained by machine stripping (MS) was 148,20 ml, representing a machine-stripped milk proportion of 35,97 %. On average, the

Table 4: Analysis of variance of the observed left and right udder cistern dimensions of Lacaune ewes detected by the 'from the side' method.

Source of variation	Measurement						
	Length of left cistern 2 [mm]	Width of left cistern 2 [mm]	Area of left cistern 2 [mm²]	Length of right cistern 2 [mm]	Width of right cistern 2 [mm]	Area of right cistern 2 [mm²]	Sums of both cross-section areas 2 [mm²]
Number of control measurements	107	107	107	107	107	107	107
Total average	91,51	42,42	2946,08	94,11	46,76	3229,04	6175,05
Standard deviation	15,36	11,53	1068,10	13,24	12,36	1030,33	1724,81
Coefficient of variation	16,78	27,18	36,26	14,07	26,44	31,91	27,93
Minimum	29	7	166	36	22	623	1936
Maximum	132	77	6731	131	134	7832	12 065
Control Year							
2022 (n = 86)	95,96	47,19	3322,69	97,44	48,73	3380,58	6703,13
2023 (n = 80)	85,76	37,20	2541,39	91,04	44,76	3121,22	5662,60
F test value	10,12 ++	17,21 +++	12,26 +++	5,34 +	2,36 ns	1,45 ns	8,34 ++
Parity							
1st (n = 47)	93,05	42,24	2908,17	91,06	45,70	2981,71	5889,86
2nd (n = 55)	85,45	40,83	2712,19	96,96	48,71	3423,30	6135,44
3rd (n = 59)	94,07	43,52	3175,76	94,70	45,83	3347,69	6523,29
F test value	2,43 ns	0,38 ns	1,38 ns	1,47 ns	0,48 ns	1,65 ns	1,21 ns
Milking control measurement							
Evening milking (n = 82)	91,78	45,28	3298,97	91,84	44,77	3190,30	6489,22
Morning milking (n = 79)	89,94	39,12	2565,10	96,64	48,72	3311,50	5876,51
F test value	0,07 ns	1,41 ns	2,33 ns	0,65 ns	0,51 ns	0,07 ns	0,62 ns
Covariance							
Days in milk (F value)	0,13 ns	0,02 ns	0,26 ns	7,55 ++	6,93 ++	5,76 +	1,26 ns

+++ P<0,001; ++ P<0,01; + P<0,05; ns – non significant (non-significant effect); a, b – differences in means marked with an unequal letter are statistically significant.

Table 5: Analysis of variance of parameters characterizing milkability of Lacaune ewes.

Source of variation	Measurement						
	Milk yield in 60 s [mL]	Machine-milked milk [mL]	Machine-stripped milk [mL]	Total milk yield [mL]	Machine stripping ratio	Milk yield ratio in 30s	Milk yield ratio in 60s
Number of control measurements	49	49	49	49	49	49	49
Total average	299,00	305,80	148,20	454,00	35,97	45,64	62,54
Standard deviation	123,20	126,31	67,34	114,69	18,39	14,46	17,51
Coefficient of variation	41,20	41,30	45,44	25,26	51,12	31,67	28,00
Minimum	0	0	40	240	9,8	0	0
Maximum	600	600	360	740	100	84,62	90
Parity							
1st (n = 48)	382,95 a	384,66 a	140,45	525,11 a	28,04 a	54,85 a	71,60 a
2nd (n = 53)	272,55 bc	287,35 bc	139,30	426,64 bc	36,62 ab	40,76 bc	60,12 ab
3rd (n = 59)	212,12 c	211,98 c	177,87	389,85 c	47,68 b	39,88 c	52,32 b
F test value	6,91 ++	6,42 ++	1,36 ns	5,32 ++	3,80 +	5,10 +	4,23 +
Milking control measurement							
Evening milking (n = 80)	374,75	378,46	150,10	528,56	34,35	44,05	64,84
Morning milking (n = 80)	203,67	210,87	154,98	365,85	40,54	46,28	57,86
F test value	3,72 ns	3,39 ns	0,01 ns	3,88 ns	0,22 ns	0,05 ns	0,31 ns
Covariance							
Days in milk (F value)	0,12 ns	0,08 ns	0,66 ns	0,61 ns	0,6 ns	0,41 ns	0,58 ns

+++ P<0,001; ++ P<0,01; + P<0,05; ns – non significant (non-significant effect); a, b – differences in means marked with an unequal letter are statistically significant.

Table 6: Correlation coefficients between linear udder dimensions and milkability of Lacaune ewes.

Measurement	Udder depth	Cistern depth	Teat position	Teat size	Udder cleft	Udder attachment	Udder shape
Milk yield in 30 s	0,189 ns	0,229 ns	0,076 ns	-0,239 +	0,177 ns	0,501 +++	0,382 ++
Milk yield in 60 s	0,072 ns	0,109 ns	-0,023 ns	-0,292 +	0,230 ns	0,543 +++	0,373 ++
Machine milk yield	0,081 ns	0,101 ns	-0,038 ns	-0,305 +	0,226 ns	0,553 +++	0,385 ++
Machine stripping	0,237 ns	0,225 ns	0,208 ns	0,148 ns	-0,106 ns	-0,207 ns	0,055 ns
Total milk yield	0,219 ns	0,236 ns	0,065 ns	-0,279 ns	0,208 ns	0,537 +++	0,478 +++
MS/TMY	-0,011 ns	0,023 ns	0,126 ns	0,320 +	-0,172 ns	-0,460 +++	-0,289 +
Milk yield ratio in 30s	0,069 ns	0,128 ns	-0,025 ns	-0,342 +	0,051 ns	0,413++	0,272 ns
Milk yield ratio in 60s	-0,004 ns	0,001 ns	-0,100 ns	-0,299 +	0,184 ns	0,456 +++	0,281 +

experimental ewes milked 62,54 % of the total milk in 60 seconds, indicating a rapid milk letdown after the teat cups were attached. This proportion is rather high, suggesting efficient milk yield in ewes. We observed a wide range in the indicators of the proportion of machine-stripped milk and the proportion of milk milked in 30 and 60 seconds.

Evening measurements showed higher MMY and TMY, while morning measurements had higher MS proportions. In ewes from the 1st to the 3rd lactation, the differences were statistically less significant, but the best proportion of milk at 30 and 60 seconds was observed in the 1st lactation, while PSD was highest in the 3rd lactation.

The milk obtained by machine milking and the total milk yield, depending on the order of lactation, showed a decreasing tendency (e.g., MMY at 1st lactation was 384,66 ml, at 2nd lactation 287,35 ml, and at 3rd lactation only 211,98 ml). The milk obtained by machine stripping showed a different pattern, with a decreasing tendency at 1st and 2nd lactations (140,45 ml and 139,30 ml, respectively) and an increasing tendency at 3rd lactation (177,87 ml).

Correlations between udder traits and milkability

Table 6 shows the correlation coefficients between the observed linear udder measurements of purebred LC ewes and their milkability. UA strongly correlated with MMY and TMY (r = 0,553+++), while poor UA reduced MS/TMY (r = -0,460+++). The value of the correlation coefficient between UA and MMY was the highest (0,553). Another linear measure that was statistically significantly correlated (P<0,001) with TMY was the 'total udder shape' indicator (TUS) with a correlation coefficient value of 0,478+++ and also TUS was found to be correlated with MY30s, MY60s, MMY, MYR60s and negatively correlated (P<0,05) with MS/TMY (−0,289+). A negative correlation with MY30s, MY60s, MMY, TMY, MYR30s and MYR60s can also be observed for the 'teat size' indicator, i.e. very long teats cause low milk production obtained by machine milking. Medium sized teats are considered optimal within the breed. The other parameters (UD – udder depth, CD – cistern depth, TP – teat position, UC – udder cleft) had almost no effect on the observed parameters. The correlation coefficients were close to zero, i.e., milk production obtained by machine milking cannot be predicted based on them.

Table 7 shows the correlations between udder shape characteristics detected accurately by tape measure and protractor and milk yield of Lacaune ewes. This table shows that the udder shape trait 'udder width' (UW), measured exactically, had a statistically highly significant effect (P<0,001) on milk production. The values of the correlation coefficients ranged from 0,465 to 0,597, i.e. a moderate to significant relationship. The highest value of the correlation coefficient was between UW and TMY, i.e. total milk yield (0,597+++).

UW was negatively correlated (−0,308+) with MS/TMY (P<0,05). This means that the wider the udders of ewes, the more milk they will deliver in 30 and 60 seconds, the greater the machine-milked milk and total milk yield, and the smaller the proportion of machine-stripped milk to total milk yield. Slight correlations (P<0,05) can be observed between CD (cistern depth measured with a ruler from the lower edge of the right side of the udder to an imaginary line running from the inside of the right teat perpendicular

Table 7: Correlation coefficients between exact udder dimensions and milkability of Lacaune ewes.

Measurement	Udder lenght	Udder width	Rear udder depth	Cistern depth	Teat lenght	Teat angle
Milk yield in 30 s	0,183 ns	0,465 +++	0,180 ns	0,337 +	-0,184 ns	-0,085 ns
Milk yield in 60 s	0,115 ns	0,471 +++	0,114 ns	0,223 ns	-0,168 ns	-0,184 ns
Machine milk yield	0,124 ns	0,477 +++	0,111 ns	0,204 ns	-0,187 ns	-0,184 ns
Machine stripping	0,290 +	0,075 ns	0,282 +	0,201 ns	0,124 ns	0,309 +
Total milk yield	0,297 +	0,597 +++	0,278 ns	0,344 +	-0,153 ns	-0,052 ns
MS/TMY	0,007 ns	-0,308 +	0,035 ns	-0,075 ns	0,238 ns	0,237 ns
Milk yield ratio in 30s	-0,003 ns	0,216 ns	-0,009 ns	0,212 ns	-0,273 ns	-0,089 ns
Milk yield ratio in 60s	-0,020 ns	0,303 +	-0,032 ns	0,117 ns	-0,212 ns	-0,228 ns

to the udder axis) to MY30s and TMY (0,337+ and 0,344+, respectively). Also, between TA (right teat angle measured as the deviation from the vertical udder axis, with 90° representing the horizontal position of the teats with the assumption of larger teats) and MS (0,309+), as well as between RUD (the exact depth of the udder in relation to the heel joint measured from the base of the udder below the vulva to the inferior edge of the udder) and MS (0,282+). There was also a non-significant correlation between udder length (UL) to both machine-stripped milk (0,290+) and total milk yield (0,297+), with udder length negatively correlated with the proportion of milk milked in 30 and 60 seconds (MYR30s and MYR60s, respectively). LC ewes were found to have good milkability, which is probably related to their relatively good udder morphology (especially teat position).

The correlation coefficients between the selected measures of the two udder cisterns detected by the 'from the bottom' and 'from the side' method in relation to the amount of milk yielded in machine milking and milkability in purebred Lacaune ewes are shown in Tables 8 and 9. It can be seen from both indices that all the observed measures of both udder cisterns had a statistically highly significant effect (P<0,001 and 0,01, respectively) on MY30s, MY60s, further on MS and TMY. The values of correlation coefficients were moderately high (r = 0,275 to 0,559). In the case of the amount of milk obtained by machine milking, the results were not so clear-cut, the values were much lower and statistically insignificant. The results presented in Table 8 indicate that ewes with larger cisterns had a higher proportion of milk milked in 30 and 60 seconds. The values of the correlation coefficients were statistically significant, especially when the individual udder cisterns measures detected by the 'from the bottom' method were correlated with the indicators conditioning milkability of ewes. Of note, WLC1 (width of the left cisterns detected by the 'from the bottom' method) was statistically significantly correlated (P<0,001) with TMY, with a correlation coefficient value of r = 0,559. Left cistern width was also positively correlated with other milk production conditioning indicators (MY30s, MY60s, MMY, MS) and negatively correlated with MS/TMY. Statistically significant correlations were also found between ALC1 (left cistern area) and TMY (0,507), and it also correlated with MY30s, MY60s and MS. Left cistern length (LLC1) did not have such a significant effect on milk production. On the contrary, MY/TMY was statistically insignificantly correlated with the observed left cistern measurements in most cases. For example, the correlation coefficient between WLC1 and MS/TMY was r = −0,080; between ALC1 and MS/TMY r = −0,017. Larger cisterns were associated with higher MMY and faster milk letdown. From this it can be concluded that if one of the measures we found (length, width, or left cistern area) could be used in selection, milk production could be increased under machine milking conditions and at the same time the milkability of ewes could be improved. Interestingly, the indicators determining the size of the right cistern (length, width, area) had almost no effect on milk production. SLRC1 (sum of left and right cistern areas, as determined

Table 8: Correlation coefficients between the dimensions of both udder cisterns detected by the 'from the bottom' method and the milkability of Lacaune ewes.

Measurement	Length of left cistern 1	Width of left cistern 1	Area of left cistern 1	Length of right cistern 1	Width of right cistern 1	Area of right cistern 1	Sums of both cross-section areas 1
Milk yield in 30 s	0,333 ++	0,410 ++	0,383 ++	0,065 ns	0,091 ns	0,164 ns	0,330 +
Milk yield in 60 s	0,231 ns	0,374 ++	0,292 +	-0,378 ns	0,083 ns	0,118 ns	0,248 ns
Machine milk yield	0,216 ns	0,352 +	0,277 ns	-0,048 ns	0,074 ns	0,105 ns	0,232 ns
Machine stripping	0,320 +	0,281 +	0,348 +	0,321 +	0,169 ns	0,042 ns	0,013 ns
Total milk yield	0,421 ++	0,559 +++	0,507 +++	0,113 ns	0,175 ns	0,265 ns	0,464 +++
MS/TMY	-0,005 ns	-0,080 ns	-0,017 ns	0,127 ns	0,032 ns	0,043 ns	0,013 ns
Milk yield ratio in 30s	0,165 ns	0,159 ns	0,156 ns	-0,067 ns	-0,092 ns	-0,059 ns	0,065 ns
Milk yield ratio in 60s	0,037 ns	0,124 ns	0,048 ns	0,116 ns	-0,014 ns	-0,025 ns	0,016 ns

by the 'from the bottom' method) was statistically significantly correlated with TMY (0,464+++), partially influenced MY30s (0,330+) and had almost no effect on MS/TMY (0,013ns).

Of the indicators determining the size of the cisterns measured by the 'from the side' method, the influence of the length, width and area of the left tank (LLC2, WLC2, ALC2) on the total milk yield was again statistically highly significant. The values of their correlation coefficients ranged from 0,456 to 0,463. This implies that the larger the udder cistern size, the greater the total milk yield, i.e. higher milk production in machine milking and of course lower MS/TMY (indicated by the negative values of the correlation coefficients). The length and width of the left cistern were statistically correlated with MY30s and MS, the area of the left cistern only influenced MS (0,405++). Again, the influence of the right cistern was negligible, of note is the correlation between the length, width and area of the right cistern detected by the 'from the side' method and TMY, where the correlation coefficients reached values ranging from 0,279 to 0,328 with a significance of $P<0,05$. Statistically highly significant effect was for SLRC2 (sum of left and right cistern areas detected by the 'from the side' method), where the value of its correlation coefficient in relation to the total milk yield was considerably high (0,464), and it also had a significant effect on MY30s (0,350+), MY60s (0,350+) and MS (0,328+). The negative correlation of this indicator was logically evident for MS/TMY (−0,031ns). From Tables 8 and 9, it can be seen that almost all indicators conditioning the size of the left and right udder cisterns were statistically significantly correlated with the total milk yield, regardless of whether the size of the cisterns was detected by the 'from the bottom' or 'from the side' method. In most cases, this was a weak to moderate dependence. In contrast, the proportion of machine-stripped milk correlated statistically significantly negatively (weak to moderate dependence) with the observed measures of both udder cisterns in most cases, which seems to be related to the greater inhomogeneity of the biological material studied.

Discussion

Lactation stage significantly influences the dimensions of the udder in small ruminants.[11] On the other hand, the impact of breed on the length of the udder and the distance between the teats was not significant; similarly, there was little effect of lactation on the teat angle and length of the udder. Breed and parity of animals are significantly associated with the length of teats, as well as the width and height of cisterns.[16] Positive and significant correlations between morphology traits of the udder are included in the evaluation of the udder and selection of animals.[11] The evaluation of udders is performed as part of testing in ewes of the following breeds: Churra, Manchega, Latxa, and Lacaune.[17] Cisternal size and udder morphology traits are correlated with milk secretion rate and milk emission kinetics during machine milking in dairy ewes.[1,16,19]

Table 9: Correlation coefficients between the dimensions of both udder cisterns detected by the 'from the side' method and the milkability of Lacaune ewes.

Measurement	Length of left cistern 2	Width of left cistern 2	Area of left cistern 2	Length of right cistern 2	Width of right cistern 2	Area of right cistern 2	Sums of both cross-section areas 2
Milk yield in 30 s	0,410 ++	0,326 +	0,360 ns	0,275 +	0,237 ns	0,198 ns	0,350 +
Milk yield in 60 s	0,244 ns	0,266 ns	0,229 ns	0,221 ns	0,258 ns	0,191 ns	0,350 +
Machine milk yield	0,232 ns	0,250 ns	0,214 ns	0,222 ns	0,259 ns	0,193 ns	0,250 ns
Machine stripping	0,349 +	0,319 +	0,405 ++	0,051 ns	0,047 ns	0,102 ns	0,328 +
Total milk yield	0,456 +++	0,460 +++	0,463 +++	0,286 +	0,328 +	0,279 +	0,464 +++
MS/TMY	0,005 ns	-0,008 ns	0,044 ns	-0,129 ns	-0,184 ns	-0,109 ns	-0,031 ns

The length, width, and area of the left cistern showed the strongest correlations with total milk yield, with values of 0,559 and 0,507 using the 'from the bottom' method and 0,460 and 0,463 using the 'from the side' method, whereas the values for the right cistern were significantly lower or not statistically significant. Several factors could explain this asymmetry. One possibility is that anatomical differences between the left and right cisterns in individual ewes influence milk storage and release, leading to a more efficient milk letdown on one side. It is also possible that sheep develop a dominant udder side due to genetic or physiological predispositions, resulting in a greater milk ejection capacity. Additionally, the left cistern may have been more effectively stimulated during previous machine milkings or favored by lambs during suckling, reinforcing its role in milk production over time. Blood circulation and hormonal differences between the two udder halves could also contribute to this discrepancy, as increased blood perfusion and higher levels of lactogenic hormones are known to enhance milk output. Similar findings have been reported in the literature,[22] where studies on different sheep breeds, such as Sarda and Awassi, suggest that udder volume and cistern capacity play a crucial role in milk production, and that when cisterns exceed a certain filling threshold, a local inhibitory effect may suppress further milk secretion.[22] This could explain why one side of the udder may produce more milk than the other, as blood perfusion and hormonal conditions influence milk synthesis and ejection. Furthermore, research has shown that increased blood flow to the mammary glands and elevated lactogenic hormone levels are key factors in milk production, further reinforcing the idea that physiological mechanisms may contribute to the observed differences between the left and right udder cisterns.[27] Taken together, these findings suggest that the left cistern plays a dominant role in milk production in our ewes population, highlighting the importance of understanding anatomical and physiological asymmetries when optimizing dairy sheep breeding and milking strategies.
As stated by Ayadi et al.,[1] Sicilo-Sarde ewes in Tunisia are adapted to machine milking in terms of the morphological traits of the udder because of their medium-sized cisterns and teats. According to those authors, udder morphology traits showed positive correlations with milk yield. Another study also showed a moderate association between the udder measurements and milk production in Frizarta dairy sheep.[15]

The Lacaune udder is relatively large and well-developed, with long teats at a small angle to the horizontal axis (wide vertically), making it convenient for machine milking. The increase in the number of lactations significantly affects the increase in udder morphological characteristics, while the duration of lactation affects the reduction of udder morphological characteristics in ewes. In general, as ewes age and lactation progresses, the udder undergoes changes. Older ewes have larger udders, and as lactation progresses, there is an improvement in the udder morphological characteristics that determine milkability. Our findings specifically highlight that teat length increases with advancing lactation periods, a trend that is more pronounced in older ewes compared to primiparous ewes. This reflects the natural progression of udder development and functional adaptation over time. These results align with the findings of De la Fuente et al., who reported similar trends in udder morphology changes with lactation stages.[10]

Conclusion

This study highlights the influence of udder traits, lactation order, and control year on milkability and udder morphology in Lacaune ewes. Significant year-to-year variations were observed, particularly in teat size and position, with teat size decreasing over time. Linear udder measurements, such as udder depth, width, and length, increased significantly with higher lactation orders, while udder cleft and attachment deteriorated with time. Cistern size, particularly the left cistern's length, width, and area, showed a significant positive correlation with total milk yield, which may be driven by a combination of anatomical, hormonal, and genetic factors. Although older ewes generally had larger cisterns, not all measurements showed statistically significant increases with age. Milkability parameters revealed that machine-milked milk yield and total milk yield decreased with higher lactation orders, while machine-stripped milk increased in the third lactation. Ewes with better udder attachment and medium-sized teats produced more milk during machine milking, while long teats and poor udder attachment negatively affected milkability.

These findings underscore the importance of udder morphology, particularly traits like udder attachment and cistern dimensions, in enhancing milkability in Lacaune ewes. The relationships identified between udder traits and milk yield provide valuable insights for breeding strategies aimed at improving milk production and machine milking efficiency. Future research should focus on expanding sample size and genetic diversity to strengthen the generalizability of these findings.

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Morphologie de la mamelle et rendement laitier des brebis laitières Lacaune

Cette étude analyse les mesures de la mamelle des brebis Lacaune, avec un accent particulier sur les effets de l'année de contrôle (2022–2023) et du nombre de lactations sur les différents caractères du pis. Le nombre de brebis Lacaune incluses dans l'étude variait de 57 à 86 pour différentes variables, tandis que le nombre de mesures de contrôle était compris entre 49 et 111. Des variations significatives d'une année sur l'autre ont été observées dans la taille et la position des trayons, la taille des trayons diminuant généralement avec l'âge. L'année de contrôle a eu un impact significatif sur la longueur, la largeur et la profondeur de la mamelle, ainsi que sur la longueur et l'angle des trayons. Nos résultats indiquent que l'angle optimal des trayons pour la traite se situe autour de 45°. Le nombre de lactations (parité) a eu un impact significatif sur la taille de la mamelle, en particulier sur sa profondeur et sa longueur, qui ont augmenté à partir de la troisième lactation. Les brebis plus âgées présentaient des trayons plus longs et une position plus horizontale, ce qui indique des citernes plus grandes. Les résultats des mesures de la citerne de la mamelle effectuées à l'aide de différentes méthodes ont montré que la taille de la citerne tend à augmenter avec l'âge. Il a été constaté que des citernes plus grandes sont en corrélation avec des rendements laitier plus élevés et une descente de lait plus rapide. Bien que l'impact de l'ordre de lactation sur les mesures de la citerne ne soit pas statistiquement significatif, la méthode «à partir du bas» s'est avérée plus efficace pour évaluer la taille de la citerne. Les paramètres d'aptitude à la traite, y compris la traite mécanique et le rendement laitier total, varient considérablement. La corrélation entre l'attachement de la mamelle et la production de lait était significative, ce qui souligne l'importance d'un attachement solide de la mamelle pour un rendement laitier efficace. Une corrélation positive notable entre la largeur de la mamelle et la production laitière indique que des mamelles plus larges produisent plus de lait sur des périodes plus courtes. Les résultats de l'étude indiquent que des citernes de mamelle plus larges, en particulier du côté gauche, sont associées à une plus grande production de lait. Au fur et à mesure que les brebis vieillissent et progressent dans leurs lactations, la morphologie de la mamelle s'améliore, ce qui favorise une meilleure aptitude à la traite. Ces résultats fournissent une base scientifique pour l'utilisation de caractères spécifiques de la mamelle dans la sélection de brebis ayant un meilleur potentiel de production laitière pour la race Lacaune.

Mots clés: Brebis laitière, mamelle, échographie, glande mammaire

Morfologia della mammella e produzione di latte nelle pecore da latte Lacaune

Questo studio si concentra in particolare sulle misurazioni della mammella nelle pecore Lacaune, con particolare attenzione sull'impatto dell'anno di controllo (2022-2023) e dell'ordine di lattazione su vari tratti della mammella. Il numero di pecore Lacaune incluse nello studio variava da 57 a 86 per le diverse variabili, mentre il numero di misurazioni di controllo si trovava tra 49 e 111. Sono state osservate variazioni significative da un anno all'altro nella dimensione e posizione dei capezzoli, con i capezzoli che generalmente decrescevano di dimensione con l'età. L'anno di controllo ha avuto un impatto significativo sulla lunghezza, larghezza e profondità della mammella, nonché sulla lunghezza e l'angolo dei capezzoli. I nostri risultati indicano che gli angoli ottimali dei capezzoli per la mungitura sono attorno ai 45°. L'ordine di lattazione (parità) ha avuto un impatto significativo sulla dimensione della mammella, in particolare sulla profondità e la lunghezza della mammella, che aumentano con la terza lattazione. Le pecore più anziane mostravano capezzoli più lunghi e una posizione dei capezzoli più orizzontale, indicativa di cisterne mammellari più grandi. I risultati delle misurazioni delle cisterne mammellari, ottenute utilizzando metodi diversi, hanno mostrato che la dimensione della cisterna tende ad aumentare con l'età. È stato osservato che cisterne più grandi sono correlate a rese di latte più elevate e un più rapido rilascio del latte. Sebbene l'impatto dell'ordine di lattazione sulle misurazioni delle cisterne non fosse statisticamente significativo, il metodo «dal basso» si è rivelato più efficace per valutare la dimensione della cisterna. C'era una considerevole variazione nei parametri di mungibilità, inclusi i rendimenti di latte delle mungiture meccaniche e totali. La relazione tra l'attacco della mammella e la produzione di latte era significativa, il che evidenzia l'importanza di un attacco mammellare forte per una resa di latte efficiente. Una notevole correlazione positiva tra la larghezza della mammella e la produzione di latte indica che mammelle più larghe producono più latte in periodi di tempo più brevi. I risultati dello studio indicano che cisterne mammellari più grandi, in particolare sul lato sinistro, sono associate a una maggiore produzione di latte. Con l'avanzare dell'età delle pecore e con l'andamento delle lattazioni, la morfologia della mammella migliora, facilitando una migliore mungibilità. Questi risultati forniscono una base scientifica per l'uso di tratti specifici della mammella nella selezione di pecore con maggiore potenziale di produzione di latte per la razza Lacaune.

Parole chiave: Pecore da latte, mammella, ecografia, ghiandola mammaria

Udder morphology and milk yield of Lacaune dairy sheep

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