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Teat and udder morphology and pathology of New Zealand dairy ewes

G Chambers ^a, KE Lawrence ^b, AL Ridler ^b and RA Laven ^b

^aEpiVets, Te Awamutu, New Zealand; ^bTawharau Ora – School of Veterinary Science, Massey University, Palmerston North, New Zealand

ABSTRACT

Aims: To describe the morphology and prevalence of teat and udder pathology of New Zealand dairy ewes.

Methods: A repeated cross-sectional study was conducted on 20 commercial New Zealand dairy sheep farms over the 2022–2023 season. Approximately 15 randomly selected ewes were examined on each farm in early, mid, and late lactation. Four udder morphology measures were scored on a 5-point scale: depth (1 = pendulous, 5 = compact udder), suspension (ratio of width at abdominal attachment to height, 1 = low, 5 = high), gland separation (1 = zero, 5 = maximum separation), and teat placement (1 = distally located, vertically oriented, 5 = laterally located, horizontally oriented teats). Teat length and width were measured, and the presence of supernumerary teats, asymmetry, visible teat/udder inflammation, and lesions were recorded. Teats and glands were palpated for consistency, gland-nodules, teat canal thickening, and patency, and teat ends scored for hyperkeratosis. Teat and gland-level pathological variables were converted to ewe-level scores. The presence of involuted, non- or minimally lactating glands was recorded. Data were analysed using descriptive statistics.

Results: Across the three visits, 893 observations were made on 882 unique ewes. Mean teat length and width were 27.5 (95% CI = 27.2–27.7) and 15.8 (95% CI = 15.7–15.9) mm. Udder depth, separation, suspension, and teat placement had modal scores of 4, 3, 3, and 3 respectively, and varied across visits and age groups. Asymmetrical udder prevalence was 39% (95% CI = 35.5–42%) overall and increased with age (27% for 1-year-olds, 38% for two-year-olds, 43% for mixed age ewes). Supernumerary teats were observed in 15% (95% CI = 13–17.9%) of ewes. There was between-farm variation in all udder morphology variables. Ewe-level prevalences of teat end hyperkeratosis (any degree of severity), gland/teat inflammation, lesions, palpable defects, and involuted glands were all < 6%.

Conclusions: Morphological observations resembled those from overseas dairy sheep. Teat dimensions, udder depth, separation, suspension, teat placement, and presence of supernumerary teats varied between farms. Udder depth, separation, and suspension scores decreased with age, while teat placement score and the prevalence of asymmetry increased with age. Teat and udder pathology were rare.

Clinical relevance: This is the first systematic study of teat and udder morphology and pathology in New Zealand dairy ewes. The data will be useful for farmers and industry partners, providing a comparison with their own flocks, identifying areas for improvement, and informing and contrasting with future studies.

Abbreviations: BCS: Body condition score; DIM: Days in milk

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Introduction

The New Zealand dairy sheep industry has experienced rapid growth in the last decade, with an estimated 30 commercial farms milking approximately 30,000 ewes in 2022 (McCoard *et al.* 2023). Modern facilities and equipment are therefore commonplace, and machine milking is standard. In the progression from start-up flocks consisting of mixed breeds to consolidated flocks specialised for dairy farming, farmers may focus on teat and udder conformation because these heritable traits impact milkability (how efficiently and easily milk can be harvested from the ewe), and

consequently productivity, teat and udder health, and milk quality.

The ideal dairy ewe allows milk to be harvested rapidly without manual assistance and has teats that are well-placed for easy application of milking machinery. Milk is stored in two compartments in the ovine udder: the alveolar and the cisternal compartments. In sheep, cisternal milk comprises 25–75% of total milk volume depending on the breed but is typically > 50% in dairy breeds, which is higher than meat breeds (Rovai *et al.* 2004). Moreover, differences in cisternal volume but not alveolar volume have been

CONTACT RA Laven  r.laven@massey.ac.nz

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found between high- and low-producing ewes, suggesting that cistern volume is important for milk production (Rovai *et al.* 2008). The suspensory ligament creates the intermammary groove and therefore visible gland separation. It is also thought to affect the change in udder conformation as milk is drained, and therefore the positioning and angle of the teats during the milking process, and in turn the amount of milk that sits below the level of the teats. This is particularly important in ewes, with the cistern comprising a relatively large proportion of milk volume. Furthermore, ewes with lax suspensory ligaments tend to develop horizontally orientated teats, making machine milking more challenging (McKusick 2000). Sagi and Morag (1974) demonstrated higher milk yields among machine-milked ewes with stronger gland definition and more downward-pointing teats. Ewes with taller cisterns (i.e. a greater udder volume below the level of the teats), while on average producing greater milk yields, also often require manual elevation of the udder to allow that milk to drain into the teats, which increases the time required to milk the ewe and the risk of overmilking (McKusick *et al.* 2003). New Zealand research found that higher udder depth scores (i.e. less pendulous udders), lower separation scores (poorly defined glands), higher attachment scores (udders that are relatively wide in relation to their height), and teats with a backwards angle were negatively associated with some or all of milk, fat, protein, and lactose yields (Marshall *et al.* 2023). Teat and udder morphology therefore clearly impact the productivity and milkability of dairy ewes.

Morphology is also important for udder health. Strong gland separation, well-attached udders, and higher udder depth scores (less pendulous udders) have been shown to be associated with lower somatic cell counts (Huntley *et al.* 2012; Marshall *et al.* 2023).

Teat and udder morphology are heritable, making selection for these characteristics an important tool for farmers. Fernández *et al.* (1997) studied Churra breed ewes and determined heritabilities of 0.16, 0.17, 0.24, 0.18 and 0.24 for udder depth, udder attachment, teat placement, teat size, and udder shape, respectively. However, the same study showed that selection solely for milk yield, without attention to milkability, is likely to have a negative effect on udder conformation because higher milk yields were correlated with teats that were less vertically orientated. Furthermore, while more pendulous udders were positively correlated with milk yield, ewes with very pendulous udders can be harder to milk by machine and carry a higher risk of mastitis (Huntley *et al.* 2012; Marshall *et al.* 2023).

Reliable and practical visual assessment of teat and udder morphology is thus important for genetic selection. Several different systems have been developed including linear scoring systems in which each trait is scored on a numerical scale. The original system

used a 1–9 scale (De la Fuente *et al.* 1996). There are several variations of this system in use around the world, including a 1–9 scale used in New Zealand for dairy sheep by Marshall *et al.* (2023) and a 1–5 scale used for non-dairy sheep by Griffiths *et al.* (2019), both of which were influenced by the system developed by Casu *et al.* (2006).

Teat and udder pathology are also important for milk quality and mastitis control. Teat-end hyperkeratosis, defined as thickening of the teat canal and teat-end skin, is a known risk factor for mastitis in dairy sheep (Vouraki *et al.* 2018). Other observable pathological changes, such as inflammation, lesions, lumps, and udder asymmetry, may be sequelae of mastitis or other conditions. The prevalence of palpable udder defects has been described in non-dairy sheep in New Zealand (Ridler *et al.* 2021; Zeleke *et al.* 2021; Marshall *et al.* 2023), but the prevalence of teat and udder pathology in New Zealand dairy sheep is unknown.

Given the importance of teat and udder morphology, the small amount of published morphology data and the lack of published pathology data for New Zealand dairy sheep, the objectives of this study were to describe teat and udder morphology and the prevalence of visible and palpable teat and udder pathology in New Zealand dairy ewes. Our purpose was to establish a baseline set of data that represents the New Zealand situation at this stage in the industry's development, to understand the variability between flocks, identify areas for improvement, and provide a reference point for future studies.

Materials and methods

All animal manipulations were approved by the Massey University Animal Ethics Committee (application AEC 22/25).

Study design, setting, and participants

A repeated cross-sectional study was conducted on 20 commercial New Zealand dairy sheep farms. The farms were selected to represent a range of locations and systems and were previously described in Chambers *et al.* (2024). Briefly, the farms were in the Waikato ($n = 12$), Wairarapa ($n = 2$), and Canterbury ($n = 6$) regions. All farms lambed entirely in the spring except for one farm that also had an autumn-lambing flock. The median peak number of ewes milked per farm was 790 (min 171, max 1,530). All ewes lambed outdoors except on three farms, where some ewes lambed indoors (e.g. 1-year-old ewe lambs and/or ewes bearing three or more lambs, either routinely or only during inclement weather).

Morphology/pathology assessments were planned on three occasions on each farm during the 2022–

2023 lactation season, at times corresponding approximately to early-, mid-, and late- lactation.

Initially, we aimed to select 30 ewes per visit but, after visiting three farms during visit 1, this was reduced to a minimum of 15 ewes because of concerns about the time taken for the visit and consequently the time the ewes were held off pasture. On the first three farms, at the first visit, the ewes were examined prior to being milked. Thereafter, examinations occurred 2–3 hours after the morning milking to avoid prolonging milking time, except for one farm, where ewes were examined prior to the morning milking at all three visits. The ewes were returned to the milking flock after examination.

All ewes that lambed in the 2022–2023 season and within the milking flock at the time of each visit were eligible. As this was part of a wider study, exclusion criteria were unrelated to the present study: if ewes were (1) under treatment or had been treated within the previous 30 days for illness; (2) were diagnosed with clinical mastitis on the day of sampling (defined as visual or palpable udder changes with clots in the milk); (3) were fractious and could not be safely examined or sampled; or (4) the ewe's teats, udder, or hind-legs were so heavily contaminated with moisture, dirt and/or faeces that the operator deemed it unlikely that milk samples would be uncontaminated.

Ewes were randomly selected using a calculation based on the total number of ewes being milked at the time of the visit. For the first two farms at visit 1, to select 30 ewes, the number of ewes being milked was divided by 30 to calculate the number p . A random number generator was used to select the position of the first ewe to be selected (i.e. a whole number ranging between 1 and the number of milking positions in a rotary parlour or one side of a herringbone shed). Then every p th ewe was selected and examined during milking. If a ewe was excluded, the adjacent ewe in the parlour was selected. For the third farm visited at visit 1, the same process was followed but the ewes were separated at the milking prior to the visit by the farmer. For all other visits, on the day prior to the visit, the number of ewes being milked was divided by 18 to calculate p , and the same process was followed as above. This provided 15 ewes and three spares in case of exclusions since these ewes were examined outside of milking time and adjacent ewes could not be selected. Ewes were presented to the research team and the first 15 eligible ewes were included. The farmers were responsible for selecting and separating ewes.

There were 18 known dairy sheep farms in New Zealand in 2019 (Anonymous 2020), and there were estimated to be approximately 40 commercial dairy sheep farms at the start of the 2022–2023 milking season. We enrolled 20 farms to achieve a study that included approximately 50% of New Zealand dairy

sheep farms. The sample size of the present study was determined by another part of the wider study on mastitis in dairy sheep and was based on being able to estimate the prevalence of a binary variable (subclinical mastitis) with an expected prevalence of 26% (Vasileiou *et al.* 2018) and an intraclass correlation coefficient (the extent of clustering within farms) of 0.06 (Barkema *et al.* 1997). A two-stage sampling method was employed (selection of ewes within farms), so the precision of the estimate when using varying numbers of ewes per farm was calculated with the R package *epiR* (Stevenson *et al.* 2024), based on the formula detailed by Bennett *et al.* (1991):

$$c = \frac{\rho(1 - \rho)D}{s^2b}$$

where c = the number of clusters (farms), ρ = the estimated prevalence, s = the standard error, b = the number of ewes sampled per farm, and D = the design effect, calculated from the formula:

$$D = 1 + (b - 1)\rho$$

where ρ is the intraclass correlation coefficient. The original sample size of 30 ewes per farm (1,800 ewes in total) would have allowed a 26% prevalence to be estimated with a 95% CI that has a precision (half the width of the CI) of 5.9%. Enrolling 15 ewes per visit from 20 farms would allow an assumed 26% prevalence to be estimated with a 95% CI that has a precision of 6.8%.

Study procedures

All procedures were carried out in the milking parlour by trained technicians and/or the lead author, with ewes in a standing position. Ewes were identified by visual ear tags. Body fat reserves were assessed by palpating the spinous and transverse processes of the lumbar vertebrae and assigning body condition score (BCS) on a five-point scale, with increments of 0.5, using the technique described by Kenyon *et al.* (2014). When known, ewe demographic data (age, number of fetuses at pregnancy diagnosis, number of lambs born, lambing date, and first milking date) were subsequently collected from farmers by email and at an in-person interview by the lead author with each farm owner or manager after all ewes had been dried off (May–June 2023).

The number of days in milk (DIM) at each visit was calculated as the number of days between the recorded lambing date (when known) and the visit date. The number of days between lambing and first milking was calculated as the difference between the recorded lambing date and the recorded first milking date (when both were known). Age was categorised into hoggets (1 year of age at lambing), two-tooths (2 years of age at lambing), and mixed age (older

than two-tooth). These variables were left blank when the data were not available.

Assessments of teat and udder morphology

Udders were assessed for depth, suspension, gland separation, teat placement, and symmetry, using the system of Griffiths *et al.* (2019), in which the scores were scaled to a range of 1–5 (Supplementary Figure 1). Udder depth was defined by the distance between the udder cleft (the most dorsal point of the udder skin at the junction between the glands at the apex of the udder when observed from behind the ewe) and the abdominal wall. Depth scores 1 or 2 implied a pendulous udder and were subjectively made in relation to score 3 which was applied when the cleft was level with the hocks, while a score of 5 applied when the cleft was against the belly. Udder suspension was defined as the ratio between the udder width at the abdominal attachment and the udder height. Suspension score 1 implied a narrow attachment compared to the height of the udder, a score of 3 indicated a ratio of 1, and a score of 5 indicated an udder with an attachment width greater than the height. Gland separation was defined as the extent to which the two glands were separated by the cleft, with a score of 1 equating to no separation (a globose udder) and a score of 5 equating to the cleft extending more than half of the udder height. Teat placement was determined from the vertical distance between the teat attachments and the most distal point of the udder, with a score of 1 indicating teats that are placed at the most dependent part of the udder and orientated downward, and a score of 5 indicating teats placed high up the udder and orientated laterally. Symmetry was subjectively appraised by observing the evenness of the position and size of the two glands and coded as either symmetrical or asymmetrical. The presence of supernumerary teats (present or absent) was also noted. Teat length and width (at the attachment to the udder) were measured with Vernier callipers (150 mm Pocket Vernier Calliper; Fuller, Montreal, Canada) to the nearest millimetre (see Supplementary Figure 2).

Assessments of teat and udder pathology

Inflammation, defined as any heat or redness, was recorded as present or absent for each gland and teat. External lesions, categorised as nodules, scabs, scars, or other, were recorded as present or absent for both teats and glands, and a description was entered for the category “other”. Teat-end hyperkeratosis was measured on a four-point scale developed for dairy ewes as described by Vouraki *et al.* (2018): score (1) no keratin ring around teat orifice; score (2) a smooth or slightly rough ring around the orifice and no keratin fronds; score (3) a raised roughened ring with isolated fronds of old keratin extending 1–3

mm from orifice; score (4) a raised ring with rough fronds of old keratin extending >4 mm from the orifice. Glands were palpated for consistency using a categorical scoring system as described by Griffiths *et al.* (2019) and graded from 1 (soft consistency) to 7 (diffuse hard consistency), and the presence of udder nodules (present or absent) was also recorded. Teats were palpated and scored for consistency, from 1 (soft consistency) to 5 (obstructed), and thickening of the teat canal (present or absent), and patency (patent or blocked) recorded. The presence or absence of poorly producing glands (those subjectively judged to be smaller and producing a lower volume of milk compared to the contralateral gland) and involuted, dry glands (“half udders”) was recorded at the ewe level.

Study personnel who performed morphology and pathology assessments for North Island farms attended a training day prior to the study commencing, to calibrate their scoring, and the lead author and lead technician presided at the first three farm visits on South Island farms for calibration. The lead author oversaw visits at random across the study to re-calibrate scoring.

Data management

Raw physical examination data were captured using paper forms and, when mobile reception allowed, by entry directly into a custom smartphone application that stored the data in an online database. Paper forms were transcribed to spreadsheets and online data were exported as spreadsheets (Excel; Microsoft Corporation, Redmond, WA, USA).

We collected data at the gland and ewe levels. Teat morphology, and teat and gland pathology were measured at the gland level. Ewe demographic information, udder morphology, presence of supernumerary teats, and presence of half udders were measured at the ewe level. All gland-level variables were initially explored at the gland level (i.e. for the left and right sides separately) and were then collapsed to the udder (ewe) level for analysis except for teat length and width, which were reported at the gland level. Teat-end hyperkeratosis scores were categorised into three ewe-level groups per the method used by Vouraki *et al.* (2018): group (1) no or mild hyperkeratosis (ewes with both teat-ends scored < 3); group (2) medium hyperkeratosis (ewes with only one teat-end scored \geq 3); and group (3) severe hyperkeratosis (ewes with both teat-ends scored \geq 3). If inflammation was present in at least one teat or glands, the ewe was deemed positive for teat or gland inflammation. Similarly, if any lesion was present in at least one teat or gland, the ewe was deemed positive for lesions of the teats or glands. Udder palpation scores were collapsed into ascending grades “normal,” “lump,” and

“hard” per the methods of Griffiths *et al.* (2019), and teat palpation scores collapsed into “normal” and “abnormal” (any score > 1). The ewe was assigned the worst of the two gland and teat palpation categories.

Statistical analysis

Unless otherwise stated, all statistical tests were two-tailed, and the critical significance level was set at 5%. Data were imported into RStudio using R 4.2.2 for statistical analysis (R Core Team, R Foundation for Statistical Computing, Vienna, Austria). The data were collated and merged in wide format by uniquely identifying each ewe and visit on each farm, then examined for completeness, duplication, consistency, and spurious values.

Exploratory data analysis included generating tables of summary statistics and distributional plots, overall and by farm, age group, and visit. Relationships between pairs of variables were visualised with frequency tables and plots. This was performed separately at the ewe and farm level. Pairwise associations between categorical variables were tested by χ^2 analyses unless expected counts were < 5, in which case Fisher’s test was used with the p-value simulated from 2,000 replicates (calculation of the exact p-value was computationally demanding given the size of the dataset). Associations between categorical and continuous variables were tested by ANOVA (normally distributed continuous variables) or the Kruskal–Wallis rank-sum test (non-parametric continuous and integer variables).

Confidence intervals of summary prevalence statistics were calculated with the Wilson method (Wilson 1927). To test for differences in teat length and width between farms, mixed linear regression models were constructed with a fixed effect for farm and a random intercept for ewe to account for clustering within ewe. The significance of the associations between teat length and teat width and farm were tested by a likelihood ratio test against analogous models without fixed effects for farm.

An association was found between age and the prevalence of gland lesions at the ewe level during the exploratory analysis. To calculate adjusted OR that accounted for clustering within farm, a mixed generalised linear regression was built, with a random intercept for farm to account for clustering. Age was the only predictor variable. OR and their 95% CI were computed which, due to the low prevalences of gland lesions, were approximate to relative risks. The model was tested for overdispersion, goodness of fit, and homoscedasticity by inspection of simulated residual plots, and influential observations by deletion diagnostics. Linearity was not assessed because there was only a single, categorical predictor variable.

Results

Across the three visits, 893 observations were made on 882 unique ewes (11 ewes were examined at two visits by chance, though three of those ewes were missing ear tags and were likely six different ewes). Visits 1, 2, and 3 were conducted on 24 August to 6 October 2022, 7 November to 22 December 2022, and 25 January to 16 March 2023, respectively. Visit 1 was scheduled to occur after the lambing period had ended but was skipped for farms that had not yet started to milk ewes due to a policy of rearing lambs ($n=3$ farms) on the ewes or prolonged adverse weather ($n=1$ farm). The numbers of ewes examined on each farm at each visit are summarised in Supplementary Table 1. Outside the first three visits, more than 15 ewes were examined at six farm visits due to farmer selection errors and sufficient time during the visit to examine and enrol more ewes. Only 12 ewes were examined at one farm visit due to farmer error in separating the ewes from the main flock. No ewes were excluded at the selection or data analysis stages. Complete demographic and examination data were available for 326 observations. The reasons for missing data are presented in Supplementary Table 2.

General ewe information

Because ewes were randomly selected anew at each visit, there were differences between visits in lambing spread of the selected ewes, with medians of 7 August (range 17 July–19 September), 26 August (range 9 July–16 October), and 22 August (range 2 July–15 October) for visits 1, 2, and 3 respectively (Kruskal–Wallis $p < 0.001$). Of the 409 ewes with data on the number of lambs born, there were 138 (34%), 211 (52%), 57 (14%), and 3 (0.7%) ewes with singles, twins, triplets, and quadruplets, respectively. These proportions did not differ between visits (Kruskal–Wallis $p = 0.2$). The distributions of age at lambing, DIM at first milking, and BCS and DIM at the visit, differed between visits (Table 1). The median age was older at visit 1, the median lambing to first milking interval was shorter at visit 1, the median BCS remained the same across visits but the upper quartile increased in visits 2 and 3 compared to visit 1, and the median number of days since lambing increased from visit 1 to visit 3.

Teat and udder morphology

Raw gland-level results and sample images are provided in Supplementary Table 3 and Supplementary Figures 3–6.

Teat-level measurements

Teat length and width were measured for 1,776 and 1,773 teats respectively. Mean teat length was 27.5

Table 1. Median (IQR) age, body condition score, days since lambing, and days between lambing and the first milking of the season, overall and at each of three visits between August 2022 and March 2023, in a study of udder health of randomly selected ewes ($n = 893$) on 20 commercial dairy sheep farms in New Zealand.

Variable	N ^a	Overall	Visit 1 (August–October 2022)	Visit 2 (November–December 2022)	Visit 3 (January–March 2023)	P-value ^b
Age at lambing (years)	659	2 (1, 3)	3 (2, 3)	2 (1, 4)	2 (1, 3)	0.010
Lambing to first milking (days)	438	3 (2, 41)	3 (2, 4)	4 (2, 62)	4 (2, 57)	<0.001
Body condition score	890	2.5 (2.0, 2.5)	2.5 (2.5, 2.5)	2.5 (2.0, 3.0)	2.5 (2.0, 3.0)	<0.001
Days since lambing	479	102 (46, 166)	32 (26, 44)	94 (78, 118)	183 (161, 201)	<0.001

^aNumbers differ because not all farms collect these data or because of missing values (body condition score).

^bKruskal–Wallis rank sum test; significant differences were found despite identical medians and IQR because of differences across the whole range of data.

(95% CI = 27.2–27.7) mm and mean width was 15.8 (95% CI = 15.7–15.9) mm (Figure 1). At the farm level, mean teat length and width both varied significantly between farms ($p < 0.001$), with mean length at the farm level ranging across the 20 farms from 24.9 to 34 mm and mean width ranging from 14.2 to 17 mm (Figure 1).

Udder-level measurements

Udder morphology is summarised overall and by visit in Table 2, and by age group in Table 3. Udder separation, udder suspension and teat placement scores all had modes of 3, while udder depth score had a mode of 4. The distributions of udder depth, separation, suspension, and teat placement, were

statistically different in shape between visits and age groups, but the modes remained the same across visits and age groups. The prevalence of udder asymmetry was 39% (95% CI = 35.5–42%) overall, and it increased with age group (Table 3). A difference between visits was not confirmed (Table 2). Supernumerary teats were found in 15% (95% CI = 13–17.9%) of ewes. No difference in the prevalence of supernumerary teats was confirmed between visits or age groups. Udder depth, separation and suspension scores decreased with age (udders were longer, less separated, and had narrower bases relative to their heights), while teat placement score increased with age (Table 3). There was between-farm variation in all udder morphology variables (Fisher exact test $p <$

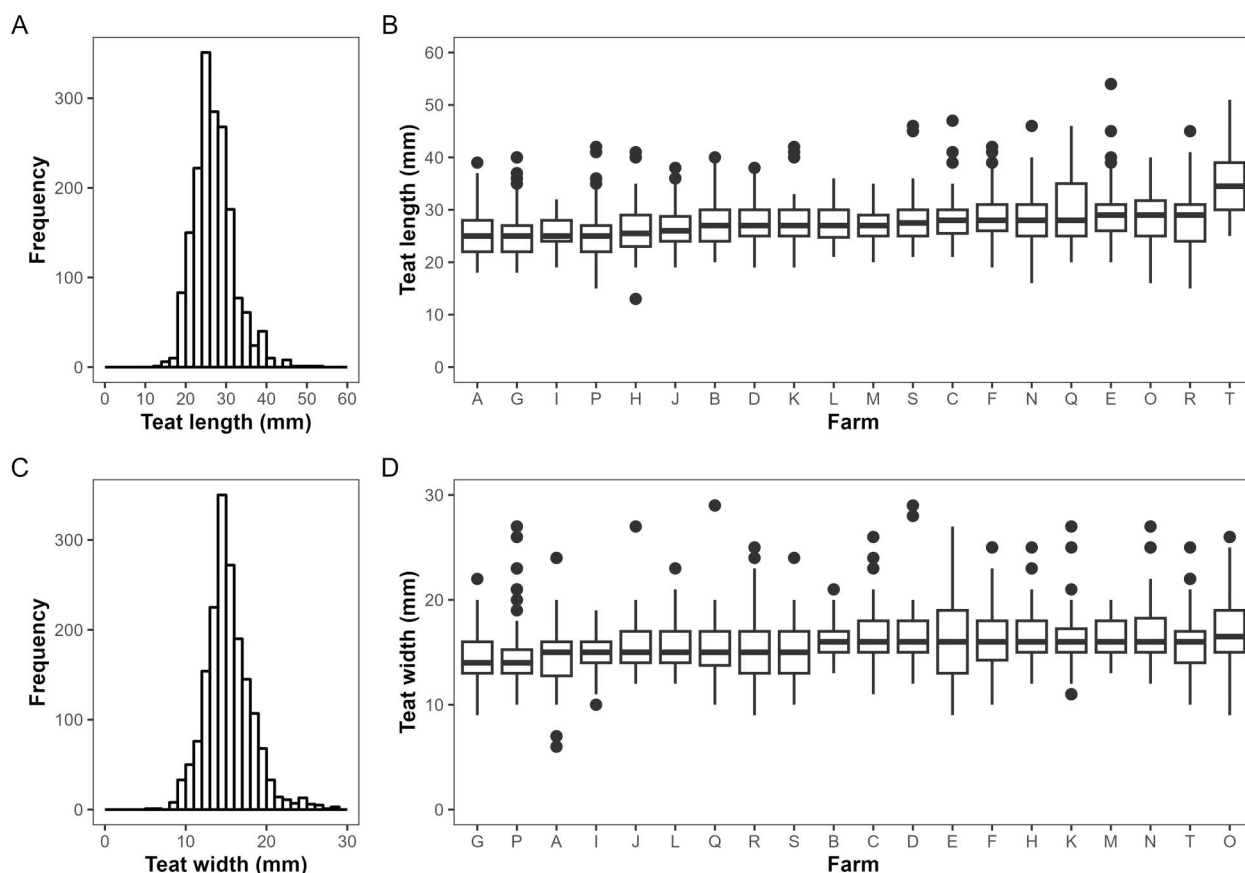


Figure 1. Distributions of teat length overall (A) and by farm (B), and teat width (at the base) overall (C) and by farm (D), in a study of udder health of randomly selected ewes ($n = 893$) from August 2022 to March 2023 on 20 commercial dairy sheep farms in New Zealand. Farms are ordered on their median values. Boxes extend from the 25th to the 75th percentiles, with a line at the median. Whiskers extend to values no more than 1.5 times the interquartile range, and outliers are shown as individual dots.

Table 2. Udder morphology of ewes, overall and at each of three visits between August 2022 and March 2023 in a study of udder health of randomly selected ewes (n = 893^a) on 20 commercial dairy sheep farms in New Zealand.

Variable	Overall	Visit 1 (August–October 2022)	Visit 2 (November–December 2022)	Visit 3 (January–March 2023)	P-value ^b
Udder depth ^c					<0.001
1	0/893 (0%)	0/286 (0%)	0/306 (0%)	0/301 (0%)	
2	8/893 (0.9%)	2/286 (0.7%)	4/306 (1.3%)	2/301 (0.7%)	
3	129/893 (14%)	61/286 (21%)	39/306 (13%)	29/301 (9.6%)	
4	613/893 (69%)	195/286 (68%)	219/306 (72%)	199/301 (66%)	
5	143/893 (16%)	28/286 (9.8%)	44/306 (14%)	71/301 (24%)	
Udder separation ^d					<0.001
1	26/890 (2.9%)	14/284 (4.9%)	8/305 (2.6%)	4/301 (1.3%)	
2	291/890 (33%)	115/284 (40%)	86/305 (28%)	90/301 (30%)	
3	383/890 (43%)	118/284 (42%)	133/305 (44%)	132/301 (44%)	
4	162/890 (18%)	34/284 (12%)	67/305 (22%)	61/301 (20%)	
5	28/890 (3.1%)	3/284 (1.1%)	11/305 (3.6%)	14/301 (4.7%)	
Udder suspension ^e					<0.001
1	39/893 (4.4%)	7/286 (2.4%)	8/306 (2.6%)	24/301 (8.0%)	
2	252/893 (28%)	82/286 (29%)	77/306 (25%)	93/301 (31%)	
3	346/893 (39%)	114/286 (40%)	130/306 (42%)	102/301 (34%)	
4	182/893 (20%)	68/286 (24%)	71/306 (23%)	43/301 (14%)	
5	74/893 (8.3%)	15/286 (5.2%)	20/306 (6.5%)	39/301 (13%)	
Teat placement ^f					0.003
1	0/893 (0%)	0/286 (0%)	0/306 (0%)	0/301 (0%)	
2	76/893 (8.5%)	25/286 (8.7%)	21/306 (6.9%)	30/301 (10.0%)	
3	450/893 (50%)	122/286 (43%)	174/306 (57%)	154/301 (51%)	
4	304/893 (34%)	124/286 (43%)	90/306 (29%)	90/301 (30%)	
5	63/893 (7.1%)	15/286 (5.2%)	21/306 (6.9%)	27/301 (9.0%)	
Udder asymmetry ^g	345/891 (39%)	104/285 (36%)	132/306 (43%)	109/300 (36%)	0.15
Supernumerary teat(s) ^h	135/884 (15%)	32/280 (11%)	53/304 (17%)	50/300 (17%)	0.093

^aDenominators differ because of incomplete data collection and ewes with dry glands.

^bFisher's exact test or Pearson's χ^2 test for differences in the distributions of each variable's scores (1–5) across visits.

^cScored on a scale of 1–5. Depth scores 1 or 2 implied a pendulous udder and were subjectively made in relation to score 3 which was applied when the cleft was level with the hocks, while a score of 5 applied when the cleft was against the belly.

^dDefined as the extent to which the two glands were separated by the cleft and scored on a scale of 1–5 where 1 = no separation and 5 = cleft extending more than half of the udder height.

^eDefined as the ratio between the udder width at the abdominal attachment and the udder height and scored on a scale of 1–5 where 1 = attachment width less than the udder height; 3 = equal udder attachment width and height; and 5 = attachment width greater than udder height.

^fDetermined from the vertical distance between the teat attachments and the most distal point of the udder, and scored on a scale of 1–5 where 1 = teats that are placed at the most dependent part of the udder and orientated downward and 5 = teats placed high up the udder and orientated laterally.

^gSubjectively appraised as symmetrical or asymmetrical.

^hPresent or absent.

0.001 for udder depth, separation, suspension, and teat placement, and presence of supernumerary teats; Fisher exact test $p=0.021$ for udder asymmetry) (Figure 2).

Udder and teat pathology

Raw gland-level results and sample images are provided in Supplementary Table 3 and Supplementary Figures 7–10.

At the level of the individual gland, the most common gland lesion type was “scab” (n = 44 glands), followed by “other” (n = 37 glands), nodules (n = 16 glands), and scars (n = 1 gland). Among the “other” category, pustules (n = 17 glands), skin tags (n = 4 glands), and loose skin (n = 2 glands) were the most common lesions. The most common teat lesion type at the gland level was “other,” observed in 15 teats, followed by “scab” (n = 8 teats), nodules (n = 3 teats), and scars (n = 2 teats). Among the “other” category, pustules (n = 4 teats) and skin tags (n = 4 teats) were the most common lesions.

Overall, the ewe-level prevalence of teat end hyperkeratosis, inflammation of the glands or teats, lesions of the glands or teats, palpable defects of the glands

or teats, and half udders were 6% or lower (Table 4). Group 1 (no or mild hyperkeratosis), group 2, and group 3 hyperkeratosis were diagnosed in 99% (95% CI = 98–99.5%), 0.7% (95% CI = 0.3–1.6%), and 0.3% (95% CI = 0.1–1.1%) of ewes, respectively. Inflammation of the glands and teats were diagnosed in 1.7% (95% CI = 1.0–2.8%) and 0.4% (95% CI = 0.1–1.2%) of ewes respectively, while lesions of the glands and teats were diagnosed in 4.0% (95% CI = 2.8–5.5%) and 2.1% (95% CI = 1.3–3.4%) of ewes respectively. Gland palpation scores of “normal,” “lump” and “hard” were diagnosed in 98% (95% CI = 96.2–98.4%), 2.5% (95% CI = 1.6–3.8%), and 0% (95% CI = 0–0.5%) of ewes, respectively. Abnormal teat palpation findings were diagnosed in 6% (95% CI = 4.6–7.9%) of ewes.

The ewe-level prevalence of inflammation of the glands or teats, gland lesions, and palpable defects of the glands or teats differed between visits (Table 4). Inflammation and palpable lumps of the gland were more prevalent at visit 1, while visible gland lesions were more prevalent at visits 1 and 3. Palpable teat abnormalities were more prevalent at visit 2. Aside from the prevalence of lesions of the glands, which increased with age, no differences were confirmed in

Table 3. Udder morphology of ewes, overall and by age group^a, in a study of udder health of randomly selected ewes (n = 893^b) between August 2022 and March 2023 on 20 commercial dairy sheep farms in New Zealand.

Variable	Overall	Hogget	Two-tooth	Mixed age	P-value ^c
Udder depth ^d					<0.001
1	0/893 (0%)	0/168 (0%)	0/171 (0%)	0/554 (0%)	
2	8/893 (0.9%)	1/168 (0.6%)	0/171 (0%)	7/554 (1.3%)	
3	129/893 (14%)	7/168 (4.2%)	27/171 (16%)	95/554 (17%)	
4	613/893 (69%)	97/168 (58%)	118/171 (69%)	398/554 (72%)	
5	143/893 (16%)	63/168 (38%)	26/171 (15%)	54/554 (9.7%)	
Udder separation ^e					0.021
1	26/890 (2.9%)	1/168 (0.6%)	5/171 (2.9%)	20/551 (3.6%)	
2	291/890 (33%)	38/168 (23%)	60/171 (35%)	193/551 (35%)	
3	383/890 (43%)	81/168 (48%)	75/171 (44%)	227/551 (41%)	
4	162/890 (18%)	41/168 (24%)	27/171 (16%)	94/551 (17%)	
5	28/890 (3.1%)	7/168 (4.2%)	4/171 (2.3%)	17/551 (3.1%)	
Udder suspension ^f					<0.001
1	39/893 (4.4%)	0/168 (0%)	8/171 (4.7%)	31/554 (5.6%)	
2	252/893 (28%)	20/168 (12%)	51/171 (30%)	181/554 (33%)	
3	346/893 (39%)	65/168 (39%)	62/171 (36%)	219/554 (40%)	
4	182/893 (20%)	43/168 (26%)	42/171 (25%)	97/554 (18%)	
5	74/893 (8.3%)	40/168 (24%)	8/171 (4.7%)	26/554 (4.7%)	
Teat placement ^g					0.024
1	0/893 (0%)	0/168 (0%)	0/171 (0%)	0/554 (0%)	
2	76/893 (8.5%)	23/168 (14%)	9/171 (5.3%)	44/554 (7.9%)	
3	450/893 (50%)	92/168 (55%)	81/171 (47%)	277/554 (50%)	
4	304/893 (34%)	46/168 (27%)	65/171 (38%)	193/554 (35%)	
5	63/893 (7.1%)	7/168 (4.2%)	16/171 (9.4%)	40/554 (7.2%)	
Udder asymmetry ^h	345/891 (39%)	45/168 (27%)	64/170 (38%)	236/553 (43%)	0.001
Supernumerary teat(s) ⁱ	135/884 (15%)	24/166 (14%)	27/169 (16%)	84/549 (15%)	>0.9

^aHogget ewes are 1 year old at lambing, two-tooth ewes are 2 years old at lambing and mixed-age ewes are > 2 years old at lambing.

^bDenominators differ because of incomplete data collection and ewes with dry glands.

^cFisher's exact test or Pearson's χ^2 test for differences in the distributions of each variable's scores (1–5) across age groups.

^dScored on a scale of 1–5. Depth scores 1 or 2 implied a pendulous udder and were subjectively made in relation to score 3 which was applied when the cleft was level with the hocks, while a score of 5 applied when the cleft was against the belly.

^eDefined as the extent to which the two glands were separated by the cleft and scored on a scale of 1–5 where 1 = no separation and 5 = cleft extending more than half of the udder height.

^fDefined as the ratio between the udder width at the abdominal attachment and the udder height and scored on a scale of 1–5 where 1 = attachment width less than the udder height; 3 = equal udder attachment width and height; and 5 = attachment width greater than udder height.

^gDetermined from the vertical distance between the teat attachments and the most distal point of the udder and scored on a scale of 1–5 where 1 = teats that are placed at the most dependent part of the udder and orientated downward and 5 = teats placed high up the udder and orientated laterally.

^hSubjectively appraised as symmetrical or asymmetrical.

ⁱPresent or absent.

the prevalence of any of the teat or udder pathology measures between age groups (Table 5). Compared to a hogget, the odds of gland lesions, after adjusting for clustering within farm, were 5.5 (95% CI = 0.6–47.8) times higher for two-tooth ewes, and 10.8 (95% CI = 1.4–81.8) times higher for mixed-age ewes.

There was between-farm variation in the prevalence of teat lesions (Fisher exact test $p = 0.014$) and teat palpation scores (Fisher exact test $p = 0.002$), but such differences were not confirmed for teat end hyperkeratosis, inflammation of the glands or teats, lesions of the glands, palpation of the glands, or the prevalence of half udders (Fisher exact test $p = 0.2, 0.3, 0.5, 0.12, 0.7, \text{ and } 0.2$, respectively) (Figure 3). Group 2 hyperkeratosis was only observed on four farms, with prevalences of 2.2–5.0%, and group 3 hyperkeratosis on three farms, with prevalences of 1.7–2.3%.

Discussion

We present here the first large-scale study of teat and udder morphology and pathology from dairy ewes on multiple farms in New Zealand. The purpose was to establish a baseline set of data that represents the

New Zealand situation at this stage in the industry's development. With that baseline, the variability between flocks can be understood, farmers and industry partners can compare their own flocks to the results in this dataset, areas for improvement can be identified, and future studies can be compared to this one. Approximately 50% of commercial flocks were enrolled, providing a strong representation of the industry at this time.

Teat and udder morphology

There are limited published studies of teat and udder morphology in dairy ewes, and direct comparisons are generally not possible because different scales have been used. A study of primiparous Sardinian breed ewes found the same preponderance of mid-range scores (on a 1–9 scale) for suspension (mean = 5.1), but higher udder depth (less pendulous udders), separation, and teat placement scores (means = 6.4, 6.5, and 7.3 respectively) (Casu *et al.* 2006). These differences may, however, be due to parity. On the other hand, the ewes in the present study had higher udder depth but similar separation, suspension, and

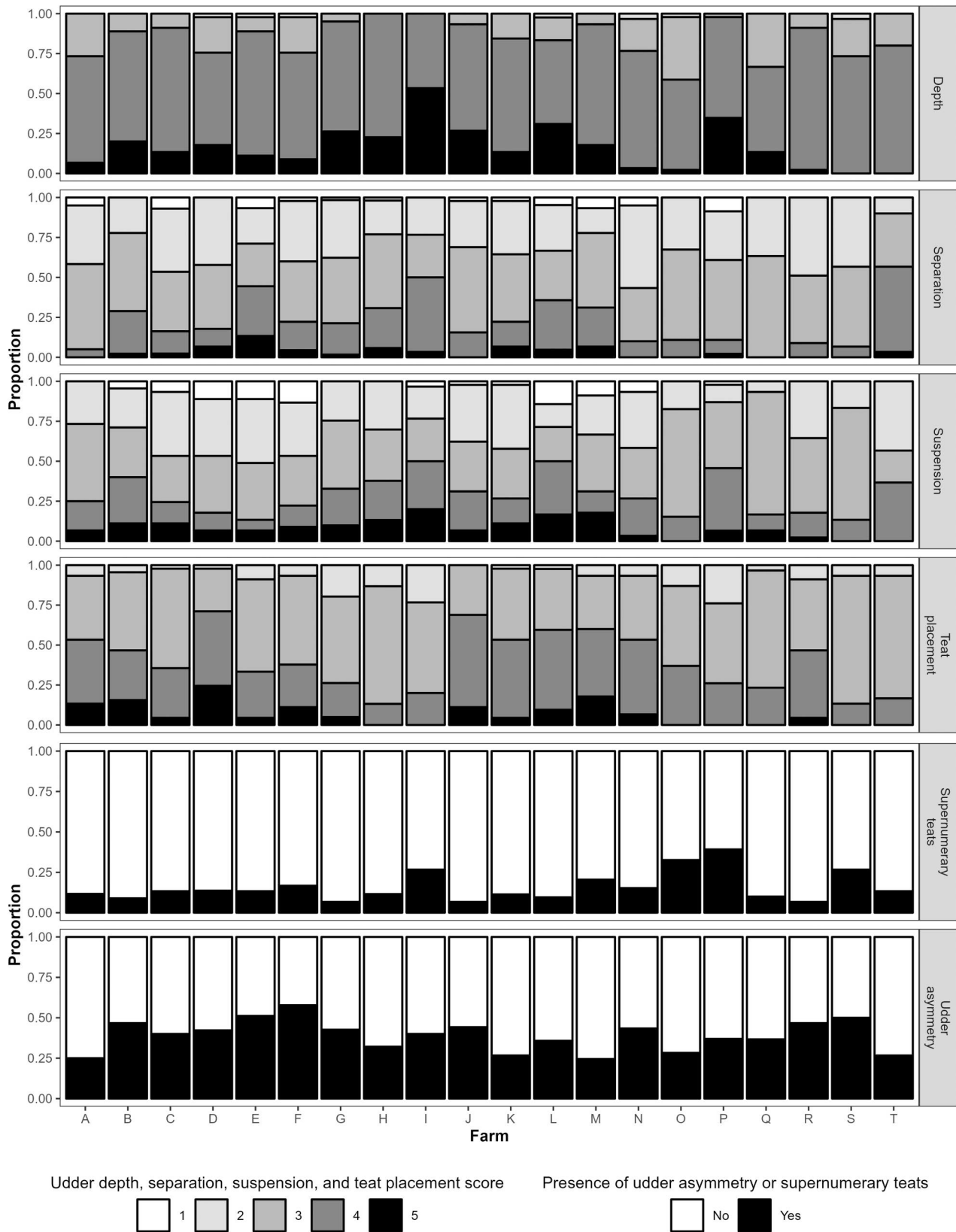


Figure 2. Distributions of udder morphology measures (depth, separation, suspension, teat placement, udder asymmetry and supernumerary teats) on each farm in a study of udder health of randomly selected ewes ($n = 893$) from August 2022 to March 2023 on 20 commercial dairy sheep farms in New Zealand. For an explanation of the scoring system, see main manuscript.

teat placement scores to those observed among East Friesian-cross ewes in the Czech Republic, that recorded means of 3.82, 5.1, 4.8, and 4.1 for depth, separation, suspension, and teat placement respectively

using a nine-point scale (Makovický *et al.* 2024). Among Churra breed ewes in Spain, the udder depth, attachment, and teat placement scores resembled those in the present study, with means of

Table 4. Prevalence of udder and teat pathology, by visit and overall, in a study of udder health of randomly selected ewes (n = 893^a) on 20 commercial dairy sheep farms in New Zealand.

Variable ^b	Overall	Visit 1 (August–October 2022)	Visit 2 (November–December 2022)	Visit 3 (January–March 2023)	P-value ^c
Teat-end hyperkeratosis ^d					0.4
Group 1	874/883 (99%)	281/282 (100%)	298/301 (99%)	295/300 (98%)	
Group 2	6/883 (0.7%)	1/282 (0.4%)	1/301 (0.3%)	4/300 (1.3%)	
Group 3	3/883 (0.3%)	0/282 (0%)	2/301 (0.7%)	1/300 (0.3%)	
Inflammation ^e					
Glands	15/888 (1.7%)	12/283 (4.2%)	1/305 (0.3%)	2/300 (0.7%)	<0.001
Teats	4/889 (0.4%)	0/284 (0%)	4/305 (1.3%)	0/300 (0%)	0.036
Lesions ^e					
Glands	35/883 (4.0%)	13/284 (4.6%)	3/305 (1.0%)	19/294 (6.5%)	<0.001
Teats	19/890 (2.1%)	3/284 (1.1%)	7/305 (2.3%)	9/301 (3.0%)	0.3
Gland palpation ^f					0.020
Normal	871/893 (98%)	273/286 (95%)	303/306 (99%)	295/301 (98%)	
Lump	22/893 (2.5%)	13/286 (4.5%)	3/306 (1.0%)	6/301 (2.0%)	
Hard	0/893 (0%)	0/286 (0%)	0/306 (0%)	0/301 (0%)	
Teat palpation ^f					0.011
Normal	54/893 (6.0%)	11/286 (3.8%)	29/306 (9.5%)	14/301 (4.7%)	
Abnormal	11/893 (1.2%)	5/286 (1.7%)	1/306 (0.3%)	5/301 (1.7%)	
Half udder ^g	11/893 (1.2%)	5/286 (1.7%)	1/306 (0.3%)	5/301 (1.7%)	0.2

^aDenominators differ because of incomplete data collection and ewes with dry glands.

^bVariables measured at the gland level (all variables except half udder) are presented at the ewe level.

^cFisher's exact test.

^dScored at the gland level on a scale of 1–4 (Vouraki *et al.* 2018) then classified at the ewe level into group 1 = no or mild hyperkeratosis (both teat ends < 3); group 2 = medium hyperkeratosis (one teat end ≥ 3); and group 3 = severe hyperkeratosis (both teat ends ≥ 3).

^ePositive if inflammation (heat, redness) or lesions (nodules, scabs, scars, other) were recorded in either or both glands/teats.

^fUdders were scored on a scale of 1–7, then collapsed into normal (1, 2), lump (3–6), and hard (7); teats scored on a scale of 1–5, then collapsed into normal (1) and abnormal (2–5) (Griffiths *et al.* 2019). Ewes were assigned the worst of the teat and gland palpation scores.

^gSubjectively defined as producing a small volume of milk compared to the contralateral gland, or non-lactating.

5.2 (with high scores corresponding to more pendulous udders), 5.1, and 4.5 respectively on a nine-point scale (De la Fuente *et al.* 1996). Differences between New Zealand dairy ewes and dairy ewes in other countries may be partly due to the industry's relative recent establishment in New Zealand, with few farms

or breeders having had many decades to select ewes for milking and milk production. Griffiths *et al.* (2019) used the same scale as the present study for non-dairy New Zealand ewes and found similar scores for suspension (mode = 3–5 depending on the visit), and teat placement (mode = 3), but higher udder depth

Table 5. Prevalence of udder and teat pathology, overall and by age group^a and overall, in a study of udder health of randomly selected ewes (n = 893^b) between August 2022 and March 2023 on 20 commercial dairy sheep farms in New Zealand.

Variable ^c	Overall	Hogget	Two-tooth	Mixed age	P-value ^d
Teat end hyperkeratosis ^e					0.12
Group 1	874/883 (99%)	165/167 (99%)	168/171 (98%)	541/545 (99%)	
Group 2	6/883 (0.7%)	2/167 (1.2%)	3/171 (1.8%)	1/545 (0.2%)	
Group 3	3/883 (0.3%)	0/167 (0%)	0/171 (0%)	3/545 (0.6%)	
Inflammation ^f					
Glands	15/888 (1.7%)	1/166 (0.6%)	3/171 (1.8%)	11/551 (2.0%)	0.6
Teats	4/889 (0.4%)	1/167 (0.6%)	0/171 (0%)	3/551 (0.5%)	0.8
Lesions ^f					
Glands	35/883 (4.0%)	1/168 (0.6%)	5/170 (2.9%)	29/545 (5.3%)	0.016
Teats	19/891 (2.1%)	1/168 (0.6%)	3/171 (1.8%)	15/552 (2.7%)	0.2
Gland palpation ^g					0.2
Normal	871/893 (98%)	167/168 (99%)	166/171 (97%)	538/554 (97%)	
Lump	22/893 (2.5%)	1/168 (0.6%)	5/171 (2.9%)	16/554 (2.9%)	
Hard	0/893 (0%)	0/168 (0%)	0/171 (0%)	0/554 (0%)	
Teat palpation ^g					0.8
Normal	839/893 (94%)	159/168 (95%)	162/171 (95%)	518/554 (94%)	
Abnormal	54/893 (6.0%)	9/168 (5.4%)	9/171 (5.3%)	36/554 (6.5%)	
Half udder ^h	11/893 (1.2%)	0/168 (0%)	3/171 (1.8%)	8/554 (1.4%)	0.2

^aHogget ewes are 1 year old at lambing, two-tooth ewes are 2 years old at lambing and mixed-age ewes are > 2 years old at lambing.

^bDenominators differ because of incomplete data collection and ewes with dry glands.

^cVariables measured at the gland level (all variables except half udder) are presented at the ewe level.

^dFisher's exact test.

^eScored at the gland level on a scale of 1–4 (Vouraki *et al.* 2018) then classified at the ewe level into group 1 = no or mild hyperkeratosis (both teat ends < 3); group 2 = medium hyperkeratosis (one teat end ≥ 3); and group 3 = severe hyperkeratosis (both teat ends ≥ 3).

^fPositive if inflammation (heat, redness) or lesions (nodules, scabs, scars, other) were recorded in either or both glands/teats.

^gUdders were scored on a scale of 1–7, then collapsed into normal (1, 2), lump (3–6), and hard (7); teats scored on a scale of 1–5, then collapsed into normal (1) and abnormal (2–5) (Griffiths *et al.* 2019). Ewes were assigned the worst of the teat and gland palpation scores.

^hSubjectively defined as producing a small volume of milk compared to the contralateral gland, or non-lactating.

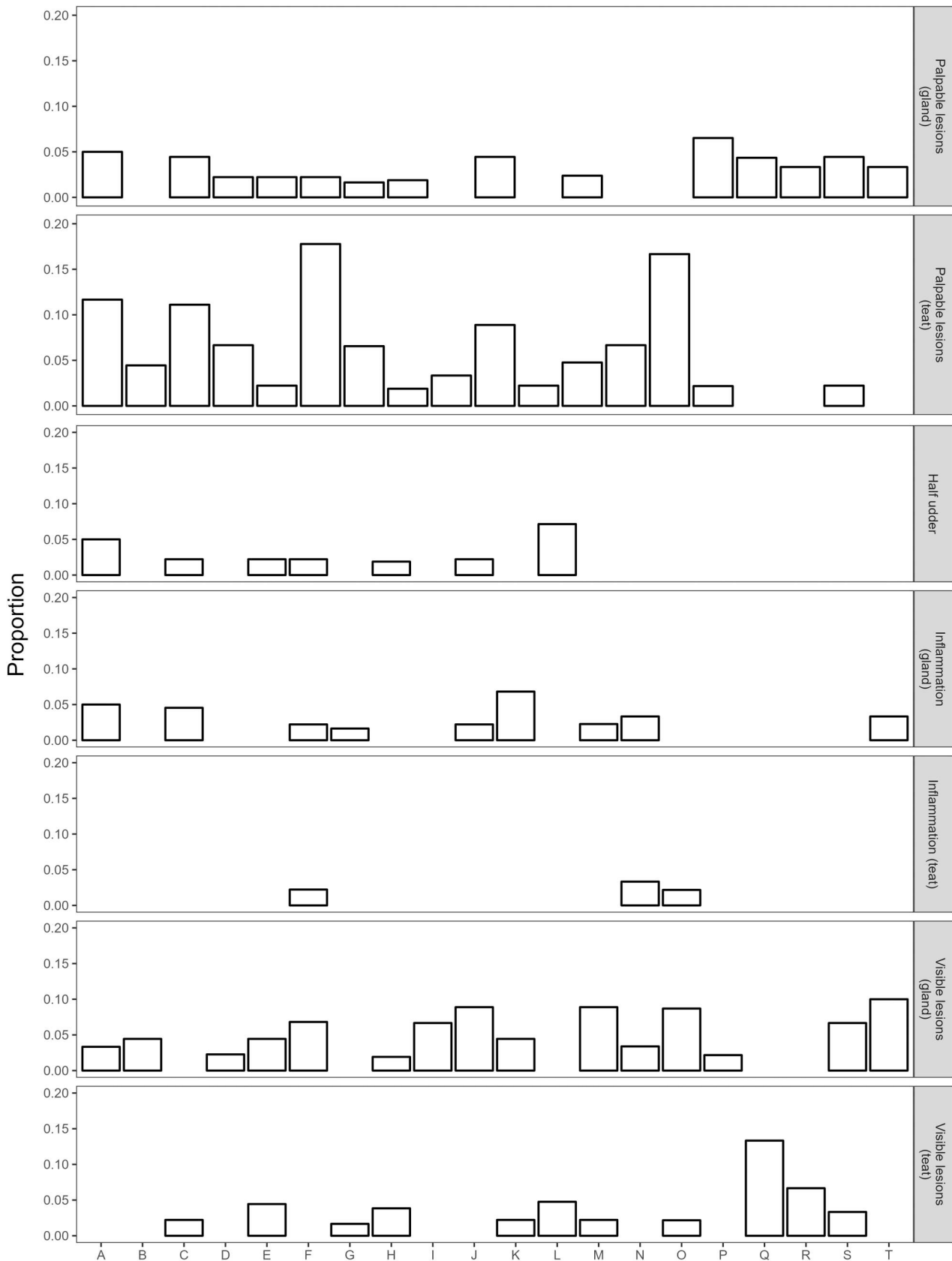


Figure 3. Prevalence of teat and udder pathology measures on each farm in a study of udder health of randomly selected ewes (n = 893) from August 2022–March 2023 on 20 commercial dairy sheep farms in New Zealand. Missing bars indicate a prevalence of zero. For an explanation of the scoring system, see main manuscript.

scores (mode = 3–5 depending on the visit) and lower separation scores (mode = 1). The lower depth scores (more pendulous udders) in the present study were

likely a result of the greater udder volume in dairy ewes compared to non-dairy ewes. The teat dimensions observed in the present study were like those

observed in eight European dairy breeds by Labussière (1988), who reported mean lengths of 26.1–33.3 mm and mean widths of 14.3–17.9 mm from eight studies, but shorter than those of East Friesian-cross ewes in the Czech Republic (Makovický *et al.* 2024), who reported mean lengths of 37.0 mm.

We found differences in udder morphology between visits, although the differences were relatively small, and the modes of each udder morphology measure remained the same throughout the season. We did not sample the same ewes at each visit, so some of the differences are likely to be due to the different ewes sampled at each visit rather than a true change in the population. However, the stage of lactation was shown by Fernandez *et al.* (1995) to affect udder depth, width, and circumference, cistern height, and teat position, angle, length, and width. This may be due to changes in milk volume affecting udder fullness and therefore morphology.

Among older ewes, udders were longer, less separated, had narrower bases relative to their heights, and the teats were more laterally placed. Other researchers have noted changes with parity. Sezenler *et al.* (2016) found udder circumference and width increased with parity, while teat length and diameter were not affected. In a study of Spanish breeds, udder depth increased with parity while suspension, teat angle, and udder shape scores declined, and teat length remained the same (Rovai *et al.* 2004).

Substantial differences in morphology were found between farms. To our knowledge, there are no other published data comparing morphology across farms. Breed, age, and lactation stage may contribute some of the differences between farms, but this descriptive study was not designed to explain such differences. We did not examine associations between breed and morphology due to the incompleteness of breed information and the large number of breeds and cross-breeds on the study farms. In other studies, breed effects on udder length, distance between teats, and teat angle were non-significant (Caja *et al.* 2000).

Udder symmetry was subjectively assessed, considering the relative size and position of each gland. Only one study has been identified that reported udder symmetry as a binary variable (Griffiths *et al.* 2019). That study enrolled New Zealand non-dairy ewes and sampled them at pre-mating (February), pre-lambing (October), docking (November) and weaning (January 2018), and found 5–10% of the (non-dairy) ewes had asymmetric udders depending on the time point. Asymmetry was much more prevalent in the present study, and we noted an increase in asymmetry as parity increased, suggesting an accumulation of damage or pathology. However, the prevalence did not increase across the lactation, although it is possible that farmers removed ewes with more severe asymmetry from the milking flock.

Approximately one in seven ewes had supernumerary teats, with no differences between parities. While they are common and heritable, Spanish research suggests that they do not present a significant problem and need not be removed (Palacios and Abecia 2014).

It is not clear what the ideal udder conformation is for a New Zealand dairy ewe, and it probably depends on the farm system. Farmers who rear lambs on the ewe may require different morphology characteristics, especially teat placement and udder depth (higher teat placement and less pendulous udders being more favourable for suckling lambs) than farmers who remove lambs within a week of lambing. Ewes with more pendulous udders (and therefore higher volume), lower suspension scores (narrower attachments), greater separation scores, and lower teat placement scores, are optimal for production and milkability (Sagi and Morag 1974; Marshall *et al.* 2023), although excessively pendulous udders can be harder to milk. But there are trade-offs between milkability and mastitis, and pendulous udders are more prone to physical injury. For example, lower udder depth scores (more pendulous udders) are associated with higher somatic cell counts (Marshall *et al.* 2023), which are a proxy for mastitis. However, this antagonistic relationship appears to be mitigated by selecting for somatic cell count (Allain *et al.* 2018). In general, moderately low udder depth (moderately pendulous) and teat placement scores, and moderately high suspension and separation scores, are likely to be ideal for farmers who machine-milk ewes and rear lambs artificially. The udder depth, separation, and suspension scores in the present study were all in the mid-range, showing significant potential for improvement of the New Zealand dairy sheep flock by applying selection pressure on these traits across the industry. While the morphology assessment methods we used are subjective, they are rapid and repeatable, with Casu *et al.* (2006) determining repeatability values of 0.70–0.76 for their linear scoring system.

Teat and udder pathology

We found that the prevalence of teat and udder pathology was low (below 6%), such that the variables had to be collapsed into fewer categories.

There is limited information on the prevalence of teat-end hyperkeratosis in dairy ewes. Vouraki *et al.* (2018) found group 2 (mild) teat-end hyperkeratosis in 8.5% and group 3 (severe) teat-end hyperkeratosis in 8.9% of the 1,360 ewes they examined on 60 Greek dairy sheep farms. In contrast, the prevalence of hyperkeratosis in the present study was substantially lower, with group 2 teat-end hyperkeratosis found in 0.7% and group 3 teat-end hyperkeratosis

found in 0.3% of ewes. The prevalence did not change across visits or parities. It is not clear why the prevalence of severe hyperkeratosis was much lower in the present study, but it may reflect shorter milking times (due to lower volume), different vacuum and pulsation settings, different teat cup liners, or different teat sprays.

Inflammation was also rare, but more prevalent for udders at the first visit and for teats at the second visit. The reasons for these differences across time are unknown but may reflect increased blood flow during early lactation (udders), inflammation associated with parturition (udders), or exposure to milking machinery (teats).

Lesions were similarly rare and dominated by warts, skin tags, loose skin, pustules, and scabs. It is not clear why there was a lower prevalence of gland lesions at the second visit (1.0%) than at the first (4.6%) or third visit (6.5%). The increasing prevalence with parity may reflect changes in udder morphology that make the udder more prone to injury.

Minimal published information on the prevalence of palpable teat or udder defects can be found for dairy ewes. Palpable udder defects (hardness or lumps) were found in 5.0–7.4% of ewes, and palpable teat abnormalities (in one or both teats) in 6.4–34.9% of ewes across four visits in a New Zealand study of non-dairy ewes (Griffiths *et al.* 2019). The prevalences were substantially lower in the present study. The higher prevalence among non-dairy ewes may be a function of damage caused by lamb suckling. On the other hand, regular observation and culling by dairy farmers may reduce the prevalence among dairy ewes. Along with inflammation, palpable teat abnormalities were more common at the second visit and udder abnormalities at the first visit. The reasons for these differences are unknown but may reflect the same factors as for inflammation.

Between-farm differences in udder and teat pathology were only confirmed for teat lesion prevalences and udder palpation scores. Teat lesions were only found on 11/20 farms, and on those farms, the prevalence varied from 1.7–13.0%. Similarly, differences in udder palpation scores were small, with prevalences of 0–7% across the farms. Overall, teat and udder pathology did not vary substantially between farms, suggesting that the factors that affect udder and teat health are consistent across the industry.

Large-scale studies on commercial farms have limitations. To determine if morphology and pathology changed across the lactation, the cross sections took place at early, mid, and late lactation, in line with the work of Fthenakis (1994). Ideally, we would have sampled the same ewes at each visit, but this would have necessitated a larger sample size to address losses to follow-up and required more work by the farmers to select the study ewes. Missing demographic

data limited our ability to make some comparisons across age groups and prevented comparisons by other factors such as breed. Many farmers do not routinely record such information at the individual ewe level, as ewes are often managed in mobs. The missing data were not due to the study design but rather to the practicalities of working on commercial farms. Being commercial ventures, the prevalence of pathology at each visit may have been biased by culling.

In conclusion, a baseline set of descriptive teat and udder morphology and pathology data have been provided from 20 commercial New Zealand dairy sheep farms. Morphology resembled observations in overseas dairy sheep but varied across the season and between farms. Teat and udder pathology was rare and consistent across farms, with less pathology than has been observed in New Zealand non-dairy ewes. There is potential to improve milkability across the industry by selection on udder morphology traits, though attention must also be paid to mastitis susceptibility. The data will be useful for farmers and industry partners, providing a comparison with their own flocks, identifying areas for improvement, and informing and contrasting with future studies.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

G Chambers  <http://orcid.org/0000-0001-7864-0057>

KE Lawrence  <http://orcid.org/0000-0002-2453-1485>

AL Ridler  <http://orcid.org/0000-0002-5210-0578>

RA Laven  <http://orcid.org/0000-0002-8938-8595>

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