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Relationship of Udder Morphometric Traits with Milk Production in Dairy Cattle and Buffaloes

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ABSTRACT

Pakistan's dairy industry depends on cattle and buffaloes for milk production. Subclinical Mastitis (SCM), on the other hand, is a serious restriction that lowers milk quality and quantity. **Objective:** To examine the udder and teat morphometric characteristics of cattle and buffaloes and evaluate how they relate to Somatic Cell Count (SCC), milk output, composition, and mineral content. **Methods:** A total of 150 lactating animals (75 cattle and 75 buffaloes) were sampled from five farms in Faisalabad. Milk yield was recorded over three consecutive mornings using a digital meter, while composition and SNF were analyzed. with a Lactoscan SLP SCC was quantified, and minerals were measured by atomic absorption spectrophotometry. Udder and teat dimensions were taken using a Vernier caliper, tape, and visual observation. **Results:** The findings showed that, funnel/cylindrical teats and pendulous udders had significantly higher width and depth ($p < 0.05$), as well as significantly larger teat diameter and length ($p<0.05$). Pendulous and spherical udders ($p <0.01$) and funnel, pear, and cylindrical teats ($p <0.05$) were substantially linked to higher SCC. While several teat measurements, such right front teat length and left front teat diameter, exhibited moderately negative relationships ($r = -0.31$, $p = 0.02$, $r = -0.26$, $p = 0.04$), there was a positive link between milk yield andudder width ($r = 0.45$, $p = 0.003$). Additionally, morphology had a significant impact on the mineral content and composition of milk ($p < 0.05$). **Conclusion:** These results suggested that, selecting dairy animals with favorable udder and teat characteristics could improve udder health and milk productivity.

INTRODUCTION

Milk is a vital source of nourishment and a vital commodity in the cattle industry. However, mastitis negatively impacts milk composition and processing qualities, which frequently compromises milk supply and quality [1, 2]. While buffaloes can have up to ~300,000 cells/mL before being deemed infected, healthy cattle usually have SCC <200,000 cells/mL, whereas SCM, which is a common and expensive constraint, lacks obvious indications but boosts SCC [3]. Although SCC testing and the California Mastitis Test (CMT) are crucial for the diagnosis of SCM, they are still reactive procedures that are employed after infection symptoms manifest [4, 5]. According to recent research, udder shape (globular, pendulum, or bowl) and teat conformations (conical, pear, funnel, or cylindrical) affect milking efficiency and hygiene and are also associated with increased susceptibility to mastitis and SCC [6, 7]. The early identification of these anatomical risk factors would enable farmers to implement preventative measures or targeted screenings programs. However, there are few studies in Pakistan that integrate diagnostic markers with

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morphometric and visual features. Few research has examined the relationship between udder and teat morphometric features and milk yield, composition, mineral levels, and udder health, despite their practical significance. It may be possible to improve early identification of SCM, guide selection methods, and increase dairy yield in field settings by combining visual morphology with measurements and biochemical diagnostics [8, 9]. This study aims to investigate the relationship between udder and teat morphometric traits (visual categorization. and physical measurements) and milk yield, composition, mineral content, and SCC in dairy cattle and buffaloes. Therefore, by integrating anatomical, biochemical, and mastitis related data, this research evaluate the morphological indicators of udder health and milk productivity, thereby addressing a critical knowledge gap and offering tools for improved selection, early diagnosis, and management in Pakistan's dairy sector.

METHODS

The study was approved by the ethical review committee, Department of Clinical Medicine and Surgery, Faculty of. Veterinary Science, University of. Agriculture, Faisalabad (Ref No: Approval No/Diary No 1483). All research. procedures complied with institutional animal care guidelines. Five dairy farms were purposively selected across intensive and semi-intensive systems in Faisalabad, and total 150 lactating animals, comprising 75 cattle and 75 buffalo were selected. Within each farm, 15 lactating cattle and 15 buffalo were randomly selected using simple random sampling. Farms were stratified by management, and animals were randomly chosen via random number tables. To control for environmental variation, housing conditions, temperature, and humidity were recorded at sampling time. **Milk Sampling:** Animals were rested for at least 12 hours and sampled early in the morning (07:00–09:00), under standardized SOPs on three consecutive days to standardized timing, and reduced circadian variation in milk composition and SCC. This ensure the consistent sampling and aligns with study showed pronounced variation in milk yield, fat, and SCC between morning and evening milking [10]. **California Mastitis Test (CMT):** CMT was conducted with. standard kits, labeling quarters A–D. Approximately two milk strips (~2 mL each) were collected per teat, mixed with equal volume of CMT reagent, and gently swirled for. 10 seconds. Results were scored after. 20 seconds as Negative (no reaction), Trace. (slight slime), 1 (distinct slime), 2 (light gel), and 3 (strong gel). Grades ≥1 were considered indicative of SCM [11]. **Udder and Teat Morphometry:** Udder shape (bowl, goaty, pendulous, round. and globular) while teats shape (cylindrical, bottle, funnel, pear, conical) were categorized based on standardized visual scoring system, noting symmetry, attachment, and teat orientation. Categories followed prior morphometric study.Physical measurements were obtained using a flexi-tape and. Vernier caliper (precision ±0.01cm). Measurements included Udder Length (UL), Udder Depth (UD), Udder Width (UW), Teat Length (TL), Teat Diameter (TD), Distance between Fore Teats (DBET), Distance between Hind Teats (DBHT), and Distance between Fore-Hind Teats (DBFHT) [12]. **Milk Yield Measurement:** Milk yield was recorded using a calibrated electronic meter during the morning milking. Daily yield for each animal was averaged over three consecutive sampling days to minimize variation due to milking time or environmental factors [13].Milk **Composition and SCC Analysis:** Milk samples from healthy and. SCM-affected animals were analyzed at NIFSAT, University of Agriculture, Faisalabad. Milk sample were analyzed using a Lactoscan SLP. Milk Analyzer (Milkotronic Ltd., Bulgaria; Catalogue. **No.13070102)** which utilized ultrasonic biochemical detection to quantify fat, protein, lactose, and. SNF level. Daily milk yield was recorded using a calibrated electronic meter, averaged over three consective morning (07:00-9:00) milking sessions to minimize variability SCC was quantified using the SCC kit (PortaCheck, USA)., validated with ~80–90% agreement against standard lab counters and cross-checked against. CMT results. SCC <100,000cells/mL was considered normal, but the threshold for SCM include, SCC >200,000cells/mL in cattle and >280,000cells/mL in buffaloes indicated SCM [14]. **Mineral Analysis:** Milk aliquots.(10mL) were acid-digested, and concentrations of. Ca, and Mg were determined by atomic absorption spectrophotometry. Procedures followed published methods with certified standards [15]. Primary outcomes included physical udder and teat morphometric measurements, milk yield. (L/day), milk composition (fat, protein, lactose, SNF), mineral concentrations. (Ca, Mg), and SCC (cells/mL). Secondary variables included visual shape classification and CMT grade. Data were analyzed using SPSS v26. Associations between categorical traits. (udder/teat shape vs SCM status) were tested using chi-square tests, while continuous trait differences (e.g. udder dimensions, milk yield, composition, SCC) among groups were evaluated by one-way ANOVA with Tukey's post-hoc test. Pearson correlation and multivariate regression accounted for farm, breed, and lactation stage. Statistical significance was set at. $p<0.05$.

RESULTS

Udder Morphometry and Shape Distribution

The majority of cattle had round udders (50%), followed by bowl (17.1%) and globular (15.7%) shapes at moderate rates, and goaty and pendulous forms were less common. 8.6% apiece. The most prevalent udder style in buffaloes was

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bowl-shaped (28.5%), followed by round (22.9%), globular (20.0%), and pendulous (11.4%). Significant differences in the distribution of udder shapes between the two species were confirmed by chi-square analysis (χ^2 test, $p < 0.001$), revealing different morphological patterns (see Fig. 1a–b). The most common teats in cattle were cylindrical (67.1%), followed by conical (1.4%), funnel (7.1%), bottle (4.3%), and pear (20.0%). According to Fig. 1c–d, funnel teats were the least common in buffaloes, while cylindrical teats were the most common (29.0%). Significant interspecies variations in the distribution of teat shapes were validated by chi square analysis. (χ^2, $p<0.001$).

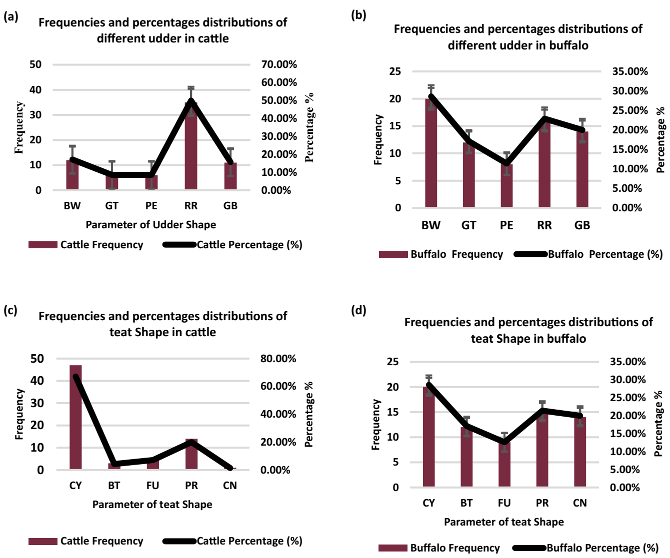

Figure 1: Percentages and frequencies distributions of different udder and teat shapes in cattle and buffalo, BW= Bowl, GT= Goaty, PE= Pendulous, RR= Round, GB= Globular, CY= Cylindrical, BT= Bottle, FU=Funnel, PR=Pear, CN=Conical

Morphometric Evaluation of Udder Dimensions Across Different Udder Shapes in Cattle and Buffaloes

Morphometric analysis revealed that pendulous and round udders exhibited the largest dimensions, with mean udder widths of 35.2 ± 3.2 cm vs 34.8 ± 3.0 cm. ($p = 0.02$) and depths of 29.5 ± 2.8 cm vs 29.0 ± 2.7 cm ($p = 0.03$), respectively.In contrast, goaty (cattle) and globular (buffalo) udders had the smallest measurements (udder width: 28.1 ± 3.4 cm; udder depth as 24.8 ± 2.5 cm, $p < 0.01$ compared to pendulous). These differences were statistically significant via ANOVA with Tukey's post-hoc ($p < 0.05$), illustrating clear morphometric variations across shape categories (Figure2a–b).Mean udder dimensions were UL= 32.4cm (SD 3.5), UW =31.2 cm (SD 3.2), and UD=27.1cm (SD2.8). ANOVA showed significant differences among udder shapes ($p<0.01$).Specific p values are indicated in Figure 2 and 3.

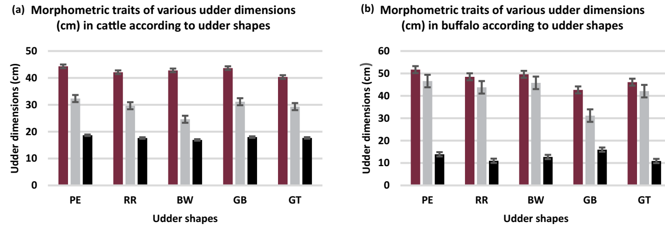

Figure 2: According to udder shapes, morphometric characteristics of different udder dimensions (cm) in cattle and buffalo are as follows: UD = udder depth, UL = udder length, UW = udder width, PE = pendulus, RR = round, GB = globular, and BW = bowl

Morphometric Evaluation of Teat Traits and Their Association with Teat Shapes in Cattle and Buffaloes

Buffalo teats were markedly longer and wider than cattle teats. For bottle-type buffalo teats, mean length was. 9.02 ± 0.7 cm and diameter 3.82 ± 0.4 cm, significantly larger than cattle bottle teats (6.50 ± 0.6 cm length, 3.90 ± 0.3 cm diameter as $p < 0.001$). Additionally, cylindrical teats remained the most common in both species (cattle .67.1%, buffalo .29%), with significant interspecies. distribution differences (χ^2, $p < 0.01$)(see Figure 3a–b).

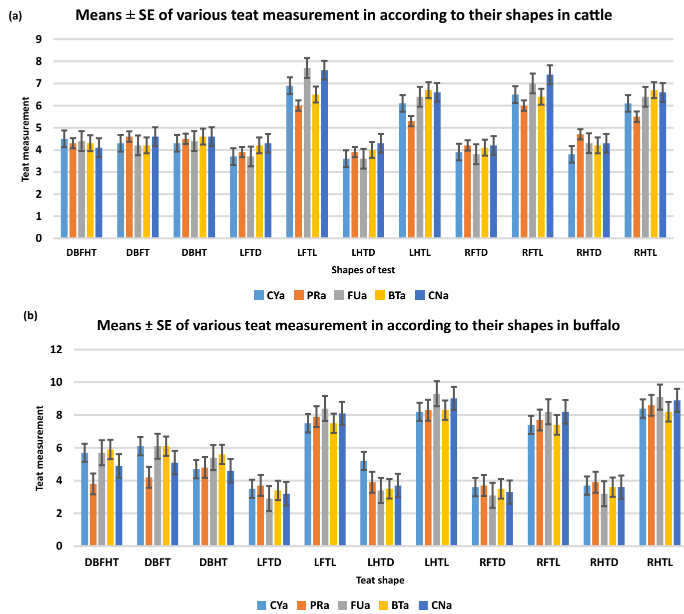

Figure 3: Means ± SE for different teat measurements based on their morphologies DBHFT= Distance between fore and hind teat, DBFT=Distance between fore teats, DBHT=Distance between hind teats, LFTD=Left for teat diameter, LFTL=Left for teat length, LHTD=Left hind teat diameter, LHTL=Left hind teat length, RFTD=Right for teat diameter, RFTL=Right for teat length.

Milk Composition Analysis of Healthy and SCM Milk

In both species, SCM markedly changed the content of milk. In cattle, mean fat percentage decreased from 4.20 ±0.30% to 3.60 ± 0.40% ($p < 0.001$), protein declined from 3.50 ± 0.20% to 3.00± 0.30% ($p < 0.001$), and lactose dropped from 4.50 ± 0.20% to 3.98 ± 0.25% ($p < 0.001$). SNF also decreased ($p = 0.005$) from 7.05 ± 0.40% to 6.50 ±

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0.45%.In buffaloes, fat fell from 5.80 ± 0.50% to.5.20 ± 0.60% (p = 0.002), protein from 3.10 ± 0.30% to 2.60 ±0.40% (p < 0.001), while lactose slightly decreased from 4.10 ± 0.20% to 4.03 ± 0.22% (p = 0.04). SNF change was minimal and non-significant (p = 0.12). These results underscore the detrimental impact of SCM on key milk constituents (Figure 4a–b).

Somatic Cell Count by Udder and Teat Morphology

Buffaloes with round and pendulous udder shapes exhibited significantly higher. SCC levels compared to bowl and globular udders (p < 0.01, Fig.4c).Similarly, pear, conical ,and cylindrical teat morphologies were associated with elevated SCC (p < 0.05) (Figure 4d).

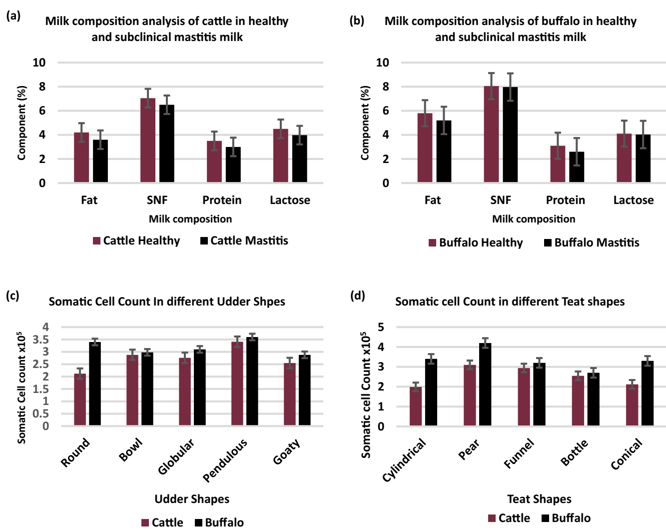

Figure 4: Analysis of the composition of SCM and healthy milk, as well as SCC in various udder and teat shapes

Correlations: Morphometry, Milk Yield, Composition, Minerals, and SCC

Table 1: Association of Morphometric Traits of Udder and Teats with Related Factors

Variables	Udder			Teats Length				Teat Diameter				Milk Composition					Mineral		SCC
	UL	UW	UD	RF	LF	RR	LR	RF	LF	RR	LR	Yield	Protein	Fat	lactose	SNF	Ca	Mg	
Udder Length	1.0	0.35	0.39	0.06	0.03	0.02	0.01	01	0.35	0.03	0.10	-0.24 *	-0.13	0.21*	-0.11	-0.08	0.1*	0.20*	0.2*
	1.0	0.43	0.29	0.06	0.07	0.04	0.05	0.2	0.52	0.05	0.24	-0.31*	-0.15	-0.31	-.021	-0.05	-0.2	0.26	0.8
Udder Width	-	1	0.46	0.22	0.01	0.24	0.31	0.34	0.27	0.09	0.133	-0.61*	-0.019	0.102*	-0.027	-0.0.8	-0.02	-0.10	0.12
	-	1	0.42	0.32	0.03	0.34	0.33	0.42	0.11	0.05	0.	-0.053	-0.023	-0.021	-0.032	-0.02	-0.04	-0.23	0.6
Udder Depth	-	-	1	0.18	0.01	0.01	0.07	0.01	0.00	0.10	0.15	-0.60*	-0.169	0.107	-0.122	-0.08	0.19*	0.09	0.2*
	-	-	1	0.46	0.22	0.01	0.24	0.31	0.34	0.27	0.09	-0.133	-0.61*	-0.019	0.102*	-0.02	-0.08	-0.02	-0.10
Right Front Teat Length	-	-	-	1	0.31	0.103	0.558	0.72	0.416	0.05	-0.20	-0.097	-0.165	-0.49	0.181	0.149	-0.01	-0.18	0.23*
	-	-	-	1	0.42	0.672	0.10	0.26	0.31	-0.26	-0.06	-0.083	-0.06	0.114	0.21	0.132	-0.06	-0.2	0.5
Left Front Teat Length	-	-	-	-	1	0.452	0.672	0.10	0.266	0.31	-0.26	-0.064	-0.083	-0.06	0.114	0.083	0.04	-0.14	0.26*
	-	-	-	-	1	0.73	0.73	0.62	0.41	0.21	0.221	-0.063	-0.04	0.116	0.181	0.149	-0.07	-0.4	0.43
Right Rare Teat Length	-	-	-	-	-	1	0.262	0.05	0.194	0.013	0.315	-0.32	-0.032	-0.207	0.047	0.016	0.20	0.12	0.06
	-	-	-	-	-	1	0.145	0.02	0.11	0.085	0.106	-0.435	-0.015	-0.154	-0.169	-0.05	-0.07	-0.2	0.23
Left Rare Teat Length	-	-	-	-	-	-	1	0.11	0.085	0.106	0.435	-0.015	-0.154	-0.169	-0.05	-0.07	0.27	0.21*	-0.13
	-	-	-	-	-	-	1	0.32	0.078	-0.06	-0.04	-0.044	-0.05	0.2.2	0.17	0.04	-0.07	-0.2	0.32
Right Front	-	-	-	-	-	-	-	1	0.012	0.059	-0.31	-0.231	-0.063	-0.054	-0.05	-0.1	0.09	0.04	0.02
	-							1	0.021	-0.06	-0.04	-0.044	-0.05	0.22	0.17	-0.05	-0.08	-0.32	0.31

Pearson correlation analysis demonstrated a moderate positive association between udder width and milk yield. (r = 0.45, p = 0.003), and a weaker negative association with udder length. (r = –0.24, p = 0.06, not significant). Right front teat length and left front teat diameter were negatively correlated with yield. (r = –0.31, p = 0.02; r = –0.26, p = 0.04, respectively).Udder width positively correlated with milk fat. (r = 0.22, p = 0.03), lactose. (r = 0.21, p = 0.04), and SNF. (r = 0.27, p = 0.02).Udder length showed a. statistically significant positive correlation with lactose concentration (r = 0.21, p = 0.04), indicating that increased udder length may enhance lactose content in milk. Although not with calcium, a comparable modest connection was found with magnesium (r = 0.20, p = 0.03). (r = –0.10, p = 0.12), so confirming the association between milk composition and udder morphology. Finally, udder length and right front teat length both showed weak positive correlations with SCC. Table 1 indicates morphological markers of inflammation risk (r = 0.20, p = 0.03; r = 0.23, p = 0.02). Breed, feeding practice, climate and health status all significantly interacted (p<0.05) to influence milk quality parameters affecting milk yield, composition (fat, protein, SNF), and SCC highlighting the multifactorial nature of milk traits in dairy cattle and buffaloes. However, this correlation is based on morphometric associations and milk samples, not direct daily/total production records. Therefore, further studies with actual production data are required to validate this inference. Pearson correlation was used to assess associations between udder and teat traits and other factors. Values range from +1 to –1, indicating positive or negative relationships.

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Left Front	-	-	-	-	-	-	-	-	1	0.129	-0.31	-0.13	-0.014	-0.032	0.024	0.08	-0.09	-0.09	0.13
	-								1	0.072	0.061	-0.032	-0.056	0.047	0.086	0.02	-0.06	-0.23	0.42
Right Rare	-	-	-	-	-	-	-	-	-	1	0.322	-0.172	-0.06	-0.041	0.044	0.005	0.22	0.17	-0.16
	-									1	0.129	-0.312	-0.13	0.014	-0.032	0.024	-0.03	-0.43	0.38
Left Rare	-	-	-	-	-	-	-	-	-	–	1	-0.192	-0.04	-0.141	0.056	0.014	0.11	0.08	0.11
	-									–	1	-0.067	-0.031	-0.042	0.061	0.03	-0.03	0.05	0.21

DISCUSSION

This study comprehensively evaluated udder and teat morphometric traits in cattle and buffaloes, establishing associations with milk yield, composition, and somatic cell count (SCC). The predominance of round udders in cattle and bowl-shaped udders in buffaloes supports prior research suggesting that udder conformation is species- and breed-specific [16]. Cylindrical teats were the most frequent across both species; however, the variation in less common shapes such as funnel and bottle teats highlights potential breed-related or anatomical predispositions. These differences may be functionally significant, affecting milking efficiency and mastitis risk, as discussed by Bansal and Sharma *et al* [7, 8].The statistically significant interspecies variation in teat shape distribution (χ^2, $p < 0.001$) aligns with earlier reports on Murrah and Surti buffaloes further supporting the anatomical distinctions that influence udder functionality and health [16].The finding that pendulous and round udders had significantly larger morphometric dimensions is consistent with previous work by Saleh *et al.*, in 2023 who linked udder shape with production traits in Friesian cows [17].These larger udder types may accommodate greater milk storage capacity, but they are also more prone to mastitis due to their proximity to the ground, which increases exposure to pathogens [12, 6].Teat morphometry also showed distinct differences: buffalo teats were generally longer and wider, particularly in the bottle-shaped group.These findings concur with Kaur *et al.*, (2018), who found an association between larger teat dimensions and subclinical mastitis in buffaloes [18].Subclinical mastitis (SCM) significantly reduced key milk constituents such as fat, protein, lactose, and SNF in both species, as supported by Batavani *et al.*, and Tommasoni *et al* [19, 5].These compositional losses not only diminish the nutritional and economic value of milk but also reflect underlying inflammatory responses in the udder.Moreover, buffaloes with round and pendulous udders and those with cylindrical, pear, or conical teats exhibited significantly higher SCC values.These morphological characteristics may be indicative of poor drainage or increased susceptibility to bacterial entry, supporting prior findings by Khalid *et al.*, and Sinha *et al* [3, 12]. Moderate positive correlations between udder width and milk yield, and between udder length and lactose content, emphasize the predictive value of morphometric traits for milk production and composition [20, 1]. Negative associations between teat length/diameter and yield may indicate inefficiencies in milk flow or potential for mastitis-related ductal changes [10, 13].The variation in SCC and composition also suggests the need for incorporating morphological assessments into herd health and selection programs. This strategy has been previously proposed by researchers emphasizing the integration of udder health indicators into breeding goals [9, 4]. A key limitation of this study is the restriction to morning milking samples. Previous studies have shown that fat and SCC levels fluctuate diurnally suggesting that evening or nighttime milk may present different profiles 13, 14].Additionally, while morphometric parameters showed correlations with milk yield and quality, actual daily or total yield records were not included, limiting the ability to generalize production predictions. Future research should include longitudinal monitoring of milk yield and composition throughout the day and across lactation stages.

CONCLUSIONS

This study showed the considerable differences in udder and teat morphometric features connected to dairy cattle and buffaloes' milk supply, composition, mineral content, and SCC. These findings suggest that, the incorporating morphometric evaluation into selection criteria could improve milk productivity and udder health, supporting mastitis control strategies. In this study sampling was limited to morning milking, these results mainly reflect morning. SCC and milk composition but evening and nighttime milk may differ significantly due to diurnal variations in fat, protein, and SCC.

Authors Contribution

Conceptualization: MAYA, GM
Methodology: MHK, ASQ, AN, AZ
Formal analysis: MKS, ASQ, AN, AZ
Writing, review and editing: MAYA, FD, MHK, ASQ, AN, AZ

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

All the authors declare no conflict of interest.

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