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RESEARCH ARTICLE

A study on the assessment of milking machine teat cup liner size fitting in indigenous dairy animals

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Abstract: Milking machines aim to efficiently harvest high-quality milk while ensuring animal comfort and protecting against mastitis. The present study focused on 128 and 125 teats of Sahiwal cows and Murrah buffaloes by measuring the teat morphometric parameters and comparing them with the dimensions of the teat cup liner size of the milking machine. The intra-mammary infection status was assessed using thermal imaging and the California Mastitis Test (CMT). Results showed that 37.50% of Sahiwal cows had the best fitting teat sizes for milking machine liners based on upper teat diameter (UTD), while 62.50% had a natural fitting. For Murrah buffaloes, 37.00% had the best-fitting teat size, and 63.00% had normal fitting teat size. In Sahiwal cows, 53.75 and 22.50% of teats were affected by subclinical (SCM) and clinical mastitis (CM) in normal-fitting UTD groups, whereas 43.75% and 18.75% were affected in the best-fitting UTD groups, respectively. In Murrah buffaloes, normal-fitting teat size related to UTD revealed 27.27 and 3.63% of SCM and CM-affected teats, and the mean values of UTD among the various groups based on the CMT score showed a significant difference (p<0.05). The mean UTD values for teats of the best-fitting size showed no mastitis incidences. The mean values of middle and lower teat diameters differed significantly (P<0.05) among both breeds' best and normal fitting groups. These findings present an exciting opportunity for improving milking efficiency and animal welfare in Sahiwal and Murrah breeds by addressing variations in teat size and optimizing teat cup liner fitting with milking machines.

Keywords: Murrah buffaloes, Sahiwal cows, teat diameter, teat liner, teat size

Introduction

Milking machines are designed to maximize milk yield efficiency and quality while prioritizing animal welfare and reducing mastitis risks (Kaskous and Pfaffl, 2023). They offer increased efficiency and consistency in milk extraction, thereby significantly reducing labour intensity and streamlining dairy farming operations. Maintaining udder health during milking is crucial for achieving high yields and milk quality. Improper machine milking settings can lead to adverse teat tissue changes (Stauffer et al. 2021), enabling pathogenic bacteria entry through the teat end's skin (Gasparik et al. 2018). This increases the risk of mastitis infections and elevates somatic cell counts (SCC) in the milk (Gayathri et al. 2024). Teat scoring via visual assessment is carried out to scale the color variations commonly. In addition to the conventional visual assessments and indirect estimation methods, sensor-based techniques have gained prominence for evaluating the teat-liner interface during milking. These methods are ultrasonography, infrared thermography (IRT) and pressure sensors (Tangorra et al. 2019, Rosca et al. 2017). IRT is a simple, effective, non-invasive and contactless method for measuring surface temperatures using specialized cameras that detect infrared radiation emitted from objects and is been utilized in assessing the dairy animal udder health status (Gayathri et al. 2023). Thus, ensuring udder and teat health during milking is essential for optimal milk production and animal welfare.

Selecting the right teat liner is a complex task with significant implications. It's crucial to consider the milking machine, vacuum settings, and the lactating animal's udder anatomy (Vermaak et al. 2022). The massaging function of teat cup liners in machine milking helps move blood and fluids toward the udder's base. However, excessively soft or stiff shafts can affect this function.

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Teat liners come in different shapes, with round liners being the most common worldwide. Studies have shown that liner type significantly impacts keratinization and the frequency of cracked teat ends, with round liners leading to higher keratinization scores compared to square liners (Holst et al. 2021). In practice, there often needs to be more flexibility in liner selection based on teat dimensions, than standard teat cup liners. While most milking equipment manufacturers strive to produce well-fitting teat liners, matching each lactating animal with a custom liner is challenging, resulting in some animals suffering from clinical or subclinical mastitis (Bobic et al. 2018). Thus, an ideal teat liner protects sensitive tissue, provides comfort during milking, adheres securely without causing noise, and helps prevent injuries, significantly improving animal welfare and health (Kaskous and Pfaffl, 2023). Owing to the scenario, the present study attempts to understand the effectiveness of the commercial standard teat liners used among indigenous breeds of Sahiwal cows and Murrah buffaloes. In addition, the present study aimed to assess udder health status via IRT while using standard milking machines' teat liners in varied teat shapes and sizes of Sahiwal cows and Murrah buffaloes.

Materials and methods

One hundred twenty-eight teat quarters of Sahiwal cows and one hundred twenty-five teat quarters of Murrah buffaloes belonging to different parity (1-6) were analysed separately for the present experiment during the autumn season. The investigation was carried out at the Livestock Research Centre (LRC), located in the ICAR-National Dairy Research Institute, Karnal, Haryana, India. The temperature-humidity index (THI) was calculated using the formula established by McDowell in 1972: $THI = 0.72(T_{db} + T_{wb}) + 40.6$ to assess the environmental conditions. In this formula, T_{db} represents the dry bulb temperature in ºC, and T_{wb} denotes the wet bulb temperature in ºC. The morphometric measurements of the teats were taken one hour before Sahiwal cows and Murrah buffaloes were milked. The teat diameter (upper, middle, lower) was measured using vernier callipers. The teat length, distance from the teat end to the floor and length of the teat cup liner were measured using measuring tape and the diameter of the teat cup with liner was measured with a vernier calliper. The cross-section of the teat cup with liner was taken as a model, and images of individual teats were captured against the cross-section of the teat cup. The attachment of the teat cup was assessed based on measurements and images captured using a Nikon camera. The teat size was measured in terms of teat diameter to the teat cup liner of the milking machine and classified the teats as the best fitting (Group 1) and normal fitting (Group 2) groups. The inner diameter of the metallic sheath of the milking machine's teat cup–teat cluster was 38.73 mm. The teat liner 1 (29 cm length, bore size 24 mm) used for Sahiwal cows had an upper, middle, and lower inner diameter (mm) of 28.65, 22.68, and 20.92, respectively. In Sahiwal cows, the teat size that falls in the range of 23.75 to 33.55 mm, 18.03 to 27.54 mm and 19.22 to 20.27 mm, respectively for upper, middle and lower teat diameters were considered as the best fitting group in the current study. In the case of Murrah buffaloes, teat liner 2 (30 cm length, bore size 20 mm) was used and had an upper, middle, and lower inner diameter (mm) of 26.65, 20.27, and 15.66, respectively. In Murrah buffaloes, the teat size that falls in the range of 21.11 to 31.64 mm, 18.27 to 25.53 mm and 17.48 to 18.54 mm, respectively for upper, middle and lower teat diameters were considered as the best fitting group in the current study. Those teat sizes that do not fall under the stipulated range for each breed were considered as normal fitting groups and observations were made accordingly. The healthy, subclinical mastitis and clinical mastitis were evaluated using the California Mastitis Test (CMT) and infrared thermography (IRT) via infrared thermal camera (Darvi DTL007 camera, TAK Technologies Pvt. Ltd., Noida, Uttar Pradesh, India) during the study period (Gayathri et al. 2023; 2024). The wet and dry bulb thermometer reading in the milking parlor was recorded during the study period.

Statistical analysis

In this study, data analysis was conducted using IBM SPSS Statistics version 26.0 (IBM Corporation, Armonk, New York, USA). Univariate linear models were used to analyze the data obtained from Sahiwal cows and Murrah buffaloes. For post hoc analysis, the Duncan Multiple Range Test (DMRT) with a significance level of $p< 0.05$ was utilized to compare the means of multiple groups and determine which pairs are significantly different from each other. Receiver Operating Characteristic (ROC) curves were used to assess thermograms' overall diagnostic performance in mastitis diagnosis. The effectiveness of thermograms in detecting mastitis was evaluated based on sensitivity and specificity. Additionally, the Area Under the Curve (AUC) was calculated to gauge the accuracy of the diagnostic tests. The ideal cut-off point was estimated using "Youden's J statistic," where J= Sensitivity + Specificity – 1 (Youden, 1950).

Results and Discussion

The average dry bulb and wet bulb thermometer readings were 26.25 °C and 24.00 °C, respectively, while the average relative humidity was 82.9 %. The calculated average THI was 76.78.

Sahiwal cows

Among the total teats measured in Sahiwal cows, the average teat diameter at upper, middle, and lower ends (mm) were 35.64 ± 0.81 (18.62 to 59.07), 29.15 ± 0.72 (15.06 to 51.88), and 21.24 ± 0.52 (11.52 to 39.54). The average teat length was 6.33 ± 0.14 cm (3.10 to 10.10). The average distance from the ground level (milking parlor) to the lower tip of the teat was 40.40 ± 0.56 cm, 87.50 % of which falls under 1SD, 95.31 % in 2SD. The average inner diameter covered by the teat cup liner (1) (bore size 24mm) over the upper end of the teat was 33.80 ± 0.81 mm (Figure 1, 2). The mean values of teat sizes to teat cup liner size in both the groups showed a significant difference (p<0.05) in UTD (upper teat diameter), MTD (middle teat diameter), LTD (lower teat diameter) of Sahiwal cows. The mean values of teat length of both the groups were comparable whereas teat tip distance from the ground showed a significant difference (p<0.05) between the groups (Table 1).

The results of Table 2 revealed a total of 80 and 48, 62 and 66, and 32 and 96 teats fall under group 1 and group 2, for UTD, MTD, and LTD, respectively. Among group 2 for Sahiwal cows, 53.75 and 22.50, 62.90 and 17.74, and 59.38 and 9.38 per cent of the teats were affected by SCM (sub-clinical mastitis) and CM (clinical mastitis), for UTD, MTD, and LTD, respectively. In group 1, 43.75 and 18.75, 37.87 and 24.24, and 46.87 and 25.00 per cent of teats were affected by SCM and CM, for UTD, MTD, and LTD, respectively. Compared to healthy teats, the UTD corresponding to the SCM and CM-affected teats showed a significant difference (p<0.05) among both the groups of Sahiwal cows. The MTD and LTD corresponding to the mastitis-affected teats compared to healthy teats were comparable within group 1 and showed a significant difference (p<0.05) within group 2 of Sahiwal cows.

The ROC analysis revealed a higher sensitivity, specificity, and accuracy for USST and TSST parameters for Sahiwal cows. The cut-off temperature with sensitivity, specificity, and accuracy (95% confidence interval) in the case of USST for SCM was ≥ 35.35 ºC, 0.98, 0.93, and 0.98 (0.97-0.99) and for CM, was ≥ 36.35 ºC, 0.98, 0.96, 0.99 (0.99-1.00) and that of TSST for SCM was ≥3 4.45 ºC, 0.97, 0.98, 0.99 (0.98-1) and for CM was ≥ 35.75 ºC, 0.97, 0.98, 0.99 (0.99-1), respectively. The statistical analysis of the thermograms revealed that the mean udder and teat surface temperature of SCM and CM-affected quarters compared to healthy quarters of Sahiwal cows showed a significant difference (p < 0.01) between the groups. In addition, the mean values of USST and TSST of SCM and CM-affected quarters compared to healthy quarters showed an increase of 1.00, 2.13 ºC, and 1.17, 2.42 ºC, respectively (Figure 3).

Murrah Buffaloes

The average teat diameter at the upper, middle, and lower ends (mm) was 30.19 ± 0.66 (21.11 to 31.64), 27.48 ± 0.55 (18.27 to 25.53), and 20.51 ± 0.31 (12.14 to 21.59). The average teat length was 7.36

Table 1 Mean ± S. E. of morphometric teat parameters of groups 1 and 2 - Sahiwal

Teat Parameter	Group 1	Group 2
UTD (mm)	29.42^{a} ± 0.41	39.37^{b} ± 1.06
MTD (mm)	23.63^{a} ± 0.31	35.02^{b} ± 0.27
LTD (mm)	19.61^{a} ± 1.02	26.81^{b} ± 1.74
TL (cm)	5.75 ± 0.26	6.19 ± 0.19
TTDG (cm)	42.12^{b} ± 0.73	39.37^{a} ± 0.83

Means bearing different superscripts differ significantly (^{a,b}p<0.05)
UTD- Upper teat diameter, MTD -Middle teat diameter, LTD- Lower teat diameter, TTDG- Teat tip distance from the ground, TL- Teat length.

Table 2 Mean ± S. E. values of UTD, MTD, LTD to the udder health status of groups 1 and 2 Sahiwal cow teat quarters

Health status	Upper teat diameter (UTD)	
	Group 1 (mm) (n)	Group 2 (mm) (n)
Healthy	28.50^{ax} ± 0.64 (18)	31.50^{ax} ± 1.81(19)
SCM	30.58^{bx} ± 0.51 (21)	42.88^{by} ± 0.98 (43)
CM	28.55^{ax} ± 0.95 (9)	42.73^{by} ± 1.91 (18)
	Middle teat diameter (MTD)	
	Group 1 (mm) (n)	Group 2 (mm) (n)
Healthy	22.81^{x} ± 0.61 (25)	27.97^{ay} ± 2.55 (12)
SCM	24.06^{x} ± 0.34 (25)	36.47^{by} ± 1.18 (39)
CM	24.27^{x} ± 0.57 (16)	35.78^{by} ± 2.51 (11)
	Lower teat diameter (LTD)	
	Group 1 (mm) (n)	Group 2 (mm) (n)
Healthy	19.20^{x} ± 0.48 (27)	15.04^{ay} ± 1.32 (10)
SCM	20.22^{x} ± 0.40 (45)	29.92^{by} ± 1.61 (19)
CM	19.47^{x} ± 0.49 (24)	34.68^{by} ± 3.32 (3)

Means bearing different superscripts differ significantly (^{a,b,c} p < 0.05) between rows; (^{x,y} p < 0.05) between columns). The parenthesis in each row indicates the number of observations. SCM- Subclinical mastitis, CM- clinical mastitis

Fig. 1 Mean ± S. E. values of thermograms in Sahiwal cows

Means bearing different superscripts differ significantly (p<0.01) (A, B, C- USST; P, Q, R-TSST) USST- Udder skin surface temperature, TSST- teat skin surface temperature

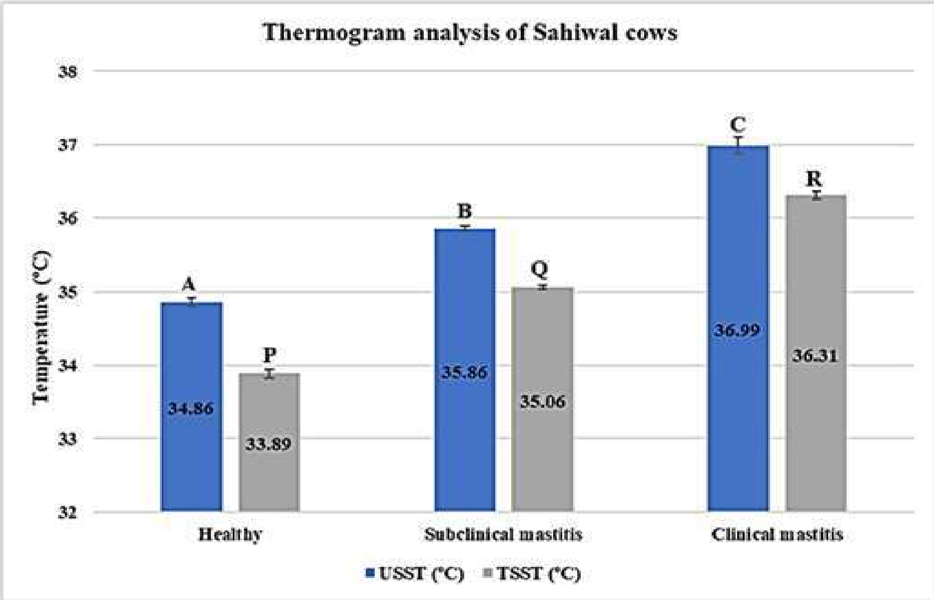
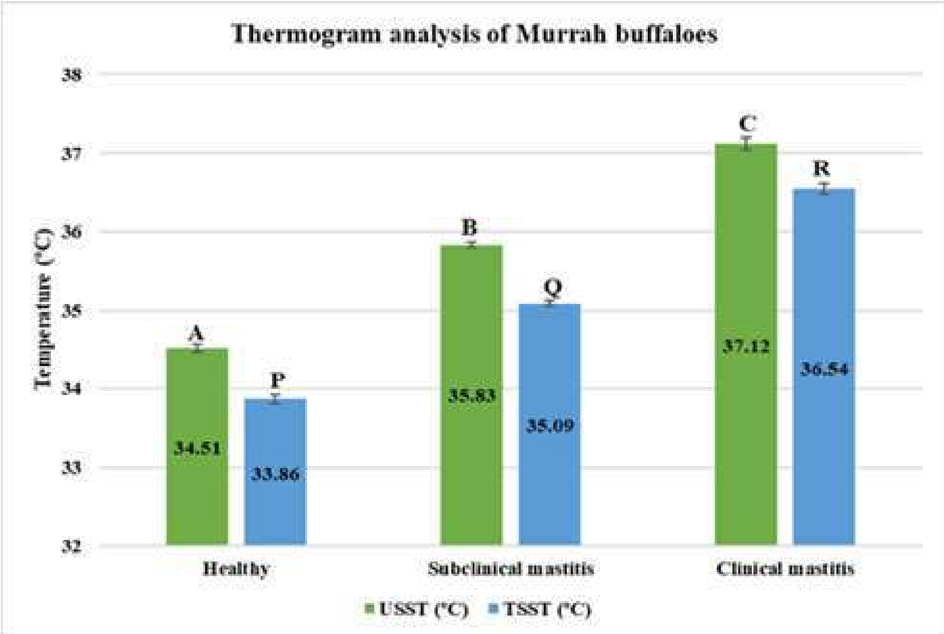


Fig. 2 Mean ± S. E. values of thermograms in Murrah Buffaloes

Means bearing different superscripts differ significantly (p<0.01) (A, B, C- USST; P, Q, R-TSST) USST- Udder skin surface temperature, TSST- teat skin surface temperature



± 0.17 cm (4.01 to 14.02). The mean values of desirable and undesirable teat lengths obtained were 7.18 ± 0.24 cm and 7.58 ± 0.3 cm, respectively. The average distance from the ground level (milking parlor) to the lower tip of the teat was 44.84 ± 0.57 cm, 87.20 % of which falls under 1SD, 96.8 % in 2SD. The average inner diameter covered by the teat cup liner (2) over the upper end of the teat was 30.34 ± 0.61 mm (Figure 4, 5). The mean values of teat size of both the groups to teat cup liner size showed significant differences (p<0.05) in the upper, middle and lower teat diameters of Murrah buffaloes. The mean values of teat length were comparable in both groups. The mean values of teat tip distance from the ground were similar between group 1 (44.24 ± 0.78 cm) and group 2 (45.59 ± 0.83 cm) Murrah buffaloes (Table 3).

Results of Table 4 revealed that 55 and 70, 78 and 47, and 58 and 67 teats fall under group 2 and group 1, for UTD, MTD, and LTD, respectively. A total of 27.27 and 3.63, 17.94 and 2.56, and 18.96 and 3.44 per cent of the teats were affected in group 2 by SCM and CM-affected quarters UTD, MTD, and LTD, respectively, in Murrah buffaloes. In group 1, all the teats were healthy for UTD and MTD, but for LTD, 5.97 per cent of the teats were affected with SCM. Compared to healthy teats, the upper, middle and lower teat diameters corresponding to the SCM, CM-affected teats showed a significant difference ($p< 0.05$) among group 2 of Murrah buffaloes.

The ROC analysis revealed a higher sensitivity, specificity, and accuracy for USST and TSST parameters for Murrah buffaloes. The cut-off temperature with sensitivity, specificity, and accuracy (95% confidence interval) in the case of USST for SCM was ≥ 35.35 ºC, 0.99, 0.96 and 0.99 (0.99-1) and for CM was ≥ 36.45 ºC, 0.98, 0.98, 0.99 (0.99-1) and that of TSST for SCM was ≥ 34.45ºC, 0.99, 0.96, 0.99 90.99-1) and for CM was ≥ 35.75 ºC, 0.98, 0.98, 0.99 (0.99-1), respectively. The mean udder and teat skin surface temperature of subclinical and clinical mastitis-affected quarters compared to healthy quarters of Murrah Buffaloes showed a significant diffidence ($p<0.05$) between the groups . Compared to healthy quarters, the mean USST and TSST of SCM and CM-affected quarters showed an increase of 1.32, 2.61 ºC, and 1.24, 2.69 ºC, respectively.

The microclimatic evaluation revealed that the Sahiwal cows and Murrah buffaloes were under mild heat stress conditions in the milking parlour (Dash et al. 2016). All the observations about teat morphometry and teat liner of the milking machine were taken in a similar environment of the milking parlour for the respective animals. Research findings have indicated that meteorological factors like humidity and ambient temperature can influence the performance of IRT (Almeida et al. 2022). Consequently, USST and TSST might also be impacted when thermal imaging is conducted in an unregulated environmental setting (Polat et al. 2010). However, in our current investigation, thermal imaging was conducted at morning milking hours within a milking parlour environment with mild heat stress conditions.

Sahiwal cows

The average teat diameter in Sahiwal cows at upper, middle, and lower ends (mm) were 35.64 ± 0.81, 29.15 ± 0.72, and 21.24 ± 0.52. Bello et al. (2023) reported that the average MTD (cm) of the fore teat and rear teat among 2nd, 3rd, and 4th parity of white Fulani cows were 2.11 and 2.01 cm, 2.11 and 1.91 cm, 2.09 and 1.90 cm, respectively. The results obtained regarding MTD were not in line with the observations of Bello et al. 2023. This difference in average MTD may be due to the breed difference. The average teat length observed in the current study was 6.33 ± 0.14 cm, but

Table 3 Mean ± S. E. of morphometric teat parameters of groups 1 and 2 in Murrah buffaloes

Teat Parameter	Group 1	Group 2
UTD (mm)	$26.91^{a} \pm 0.33$	$34.59^{b} \pm 1.19$
MTD (mm)	$22.41^{a} \pm 0.27$	$30.69^{b} \pm 0.62$
LTD (mm)	$17.71^{a} \pm 0.24$	$23.21^{b} \pm 0.28$
TL (cm)	7.18 ± 0.24	7.58 ± 0.23
TTDG (cm)	44.24 ± 0.78	45.59 ± 0.83

Means bearing different superscripts differ significantly ($^{a,b}p<0.05$) between the groups. UTD-Upper teat diameter, MTD -Middle teat diameter, LTD- Lower teat diameter, TTDG- Teat tip distance from the ground, TL- Teat length

Table 4 Mean ± S. E. values of UTD, MTD, LTD to the udder health status of groups 1 and 2 Murrah buffalo teat quarters

Health status	Upper teat diameter (UTD)	
	Group 1 (mm) (n)	Group 2 (mm) (n)
Healthy	$26.76^{x} \pm 0.34$ (70)	$32.76^{ay} \pm 1.18$ (38)
SCM	--	$37.39^{ab} \pm 2.79$(15)
CM	--	$46.97^{b} \pm 8.31$ (2)
	Middle teat diameter (MTD)	
	Group 1 (mm) (n)	Group 2 (mm) (n)
Healthy	$22.39^{x} \pm 0.28$ (47)	$29.74^{ay} \pm 0.58$ (62)
SCM	-- (0)	$32.91^{ab} \pm 2.33$ (14)
CM	-- (0)	$39.23^{b} \pm 3.95$ (2)
	Lower teat diameter (LTD)	
	Group 1 (mm) (n)	Group 2 (mm) (n)
Healthy	$18.06^{x} \pm 0.26$ (63)	$23.13^{y} \pm 0.26$ (45)
SCM	$17.2^{x} \pm 1.65$ (4)	$24.06^{y} \pm 1.17$ (11)
CM	--	25.63 ± 0.26 (2)

Means bearing different superscripts differ significantly ($^{a,b,c}p < 0.05$) between rows; ($^{x,y}p < 0.05$) between columns). The parenthesis in each row indicates the number of observations. SCM- Subclinical mastitis, CM- clinical mastitis

Oshin et al. (2022) reported the average teat length of Sahiwal cows in their experiment was 7.82 ± 0.19 cm. This may be due to the individual animal difference in the teat length. Similar to the observations of the present study, Sinha et al. (2022) reported the average teat length of fore and rear teat among the healthy and mastitis-affected groups as 6.75 and 7.26 cm; 5.21 and 8.93 cm among the Sahiwal cows. Also, the authors reported the average teat diameter of healthy and mastitis-affected groups as 2.58 and 2.69 cm, respectively. The average shortest distance from the fore teat end to the floor for healthy and mastitic groups was 42.38 and 41.83 cm, respectively, and that of the rear teat was 43.51 and 41.98 cm, respectively, in Sahiwal cows. These findings were in line with the present study's observations.

In the current study, the variability in UTD relating to teat morphometry in group 2 is due to the different teat shapes among the Sahiwal cows. The teat diameter influences the incidence of SCM and CM (Gleeson et al. 2004). Danish et al. (2018) reported several teat shapes in Sahiwal cows such as cylindrical, funnel, bottle, and pear-type with the highest frequency of teat shapes being funnel-shaped. Authors also reported that the shorter-sized teats are more prone to mastitis than the lengthier ones because the short teat canal enables the quicker movement of the microbes than the larger ones. Saleh et al. (2023) reported the average MTD of Friesian cows as 2.74 cm which was lower than the average MTD of Sahiwal cows in the present study. The variation in the teat diameters in the present study in comparison to other reports may be due to the variations in experimental animals in terms of breed status, milk flow rate and teat wall thickness. Sunder et al. (2022) evaluated teat measurement parameters such as overall teat diameter (OTD), diameter at the level of Furstenberg (FTD), teat canal length (TCL), teat wall thickness (TWT), and cistern diameter (CD). Results in their study revealed that OTD in mastitis-affected quarters was significantly more than in healthy quarters. A significant correlation ($p<0.01$) of OTD was manifested with FTD and TWT. The most probable causes of teat end trauma during the milking process are poorly fitting cup liners, excessive temporary vacuum losses, lack of vacuum reserve, hasty removal of the milking unit without closing the vacuum, and disproportionate milking vacuum. Thus, an increased teat-end callosity paves the way for a surface to which bacteria can easily adhere. The present study did not focus on the teat wall thickness and its associated effect on udder health status. However, these findings are also applicable to the present study as the intramammary infection (IMI) status was higher among group 2 rather than group 1.

In group 1, 43.75 and 18.75 per cent of udder were affected by SCM and CM, respectively, in the present study. However, these values were less than the group 2 teats of Sahiwal cows. This could be due to the variation in the teat end shape, steak canal, and teat orifice along with the smooth muscle sphincter and length of the central ligament. The Sahiwal breed, widely acknowledged as an indigenous dairy cattle breed in tropical and subtropical regions, exhibits a remarkable genetic capacity for sustained milk production throughout its productive lifespan. This breed can thrive in significant temperature variations and demonstrates resistance to parasites (Ilatsia et al. 2012). Despite the inherent lower susceptibility of indigenous cows to mastitis, their intensive selection for increased milk yield has rendered them more vulnerable to mastitis. In addition, machine milking blips induce changes in the teat dimensions and cause changes in the teat tissues, such as hyperkeratosis and congestion, which could be another reason for IMI.

In accordance with a research investigation carried out by Polat et al. in 2010, the sensitivity and specificity values of USST were reported as 95.6 % and 93.6 %, respectively, yielding an accuracy rate of 98.5 %. These outcomes were achieved by implementing a threshold of >34.7 ºC in combination with SCC exceeding 400 x 10^3. Similarly, Gayathri et al. (2023) reported sensitivity, specificity and accuracy values of pre-milking TSST as 0.96, 0.95 and 0.99 at a cut-off value of ≥36.5 ºC for CM, respectively and that of SCM was 0.95, 0.92 and 0.98 at a cut-off value of ≥35.8 ºC, respectively. These findings were in line with the results of the current study, thereby further substantiating the potential efficacy of thermographic parameters in the identification of udder health status in Sahiwal cows. The degree of increment in CM cases of USST in the present study was in line with the observation reported by Metzner et al. (2014) in dairy cows (2.06°C) by *E. coli* infusion in the udder. Reports have also revealed an increment in USST during SCM to the tune of 0.8°C in KF cows by Sathiyabarathi et al. (2018), which were concurrent to the present study.

Murrah Buffaloes

The average teat diameter at the upper, middle, and lower ends (mm) were 30.19 ± 0.66, 27.48 ± 0.55, and 20.51 ± 0.31. The average teat length of Murrah buffaloes for the present study was 7.36 ± 0.17 cm, but Poudel et al. (2022) reported 8.46 ± 0.17 cm among the Murrah buffaloes of Chitwan district, Nepal. Also, the authors reported the mean teat diameter of Murrah buffaloes as 3.59 ± 0.17 cm, which was higher than the present study. Similarly, Chandrasekar et al. (2016) reported the average teat length of Nili-Ravi buffaloes for left fore quarter, left rear quarter, right fore quarter, and right rear quarter as 3.89 ± 0.11, 4.03 ± 0.17, 3.93 ± 0.17, 4.13 ± 0.30.19 cm, respectively, which was lower than the present study. In line with the present study, Prasad et al. (2010) reported that the average teat diameter for Murrah buffaloes was 2.76cm. The authors reported a significant variation in the mean teat diameters of bowl, globular, goaty, and pendulous shapes with respect to the udder of Murrah buffaloes as 2.76, 2.75, 2.60 and 2.93 cm, respectively. The average teat length of the bowl-shaped teat concerning the udder was 7.33 cm, which was in line with the current study rather than with globular (7.80 cm), goaty (8.98 cm), pendulous (2.84 cm) teats of Murrah buffaloes.

In the current study, all the teats were healthy in group 1 of UTD and MTD but LTD showed SCM (5.97 %), indicating that liner size is optimum in Murrah buffaloes. In group 2, irrespective of the region of the teat diameter, the IMI status was higher compared to group 1. The variation in the diameter of these teats could be due to the difference in teat shape and thickness, leading to the risk of IMI. The various shapes found in Murrah buffaloes are cylindrical, funnel, bottle, conical and pear-type teat shapes, with the cylindrical shape being the most frequently observed (Danish et al. 2018). In addition, the variation in liner size of the milking machine could impede the proper function of the vacuum, disrupting blood and lymph circulation. It can result in unnatural strain on the teat tissue, causing pain and triggering immune reactions in lactating animals. These artificial physiological and pathological changes in the circulatory system can harm the teat ends, reduce the effectiveness of the udder's defence mechanisms (Gleeson et al. 2004), and potentially lead to mastitis. These changes in teat condition can be categorized into short-term, medium-term, and long-term. Short-term changes caused by circulatory disorders include teats becoming discoloured and swollen and exhibiting openings in the teat canal, as reported by Vermaak et al. (2022). These short-term changes can be reversed from one milking session to another or within a few hours. Recent findings from Holst et al. (2021) demonstrated that round liners outperformed triangular ones regarding higher milk flow and shorter milking time. It indicates that round liners are better for the health and condition of the teats. In the present study, round liners were used in the milking machines for dairy animals. Also, the best-fitting group of Murrah buffaloes with respect to teat liners were free of mastitis in the current investigation. So, an effective teat cup liner seals both ends of the shell completely airtight and provides a mouthpiece and shaft that are appropriately sized to accommodate a range of teat shapes and sizes, minimizing liner slippage, cluster dropping, and potential damage that could lead to mastitis (Kaskous and Pfaffl, 2023). An efficient teat cup liner makes milking as quick and thorough as possible, reducing congested teats, discomfort, and potential injury (Bobic et al. 2018). It is easy to clean and maintain its integrity over time without significant changes. Therefore, the design of teat cup liners must be tailored to the specific characteristics of each breed.

In line with the current study, Gayathri et al. (2024) observed the sensitivity, specificity and accuracy of pre-milking USST for SCM as 0.95, 0.92 and 0.98, respectively, at a cut-off value of ≥35.4°C and for CM, it was 0.95, 0.91 and 0.94, respectively, at a cut-off value of ≥36.4°C in Murrah buffaloes. The authors also reported the sensitivity, specificity and accuracy of pre-milking TSST for SCM were 0.93, 0.92 and 0.97, respectively, at a cut-off value of ≥35.1°C and for CM, it was 0.88, 0.87 and 0.95, respectively, at a cut-off value of ≥36.2°C in Murrah buffaloes. In addition, the increment in temperature observed in thermogram analysis of the current study in Murrah buffaloes was in line with the observations reported by Zaninelli et al. (2018) in Holstein Friesian cows to the tune of 1.89 °C for CM cases and that for SCM cases, the results were following the reports of Bolanos et al. (2021) in Holstein cows to the tune of 0.4-1.1°C.

The present study indicates that the best-fitting group have less IMI compared to the normal group of Sahiwal cows and Murrah buffaloes, reflecting the highest milking efficiency. Thus, the current study assesses the teat size fitting to the teat liners of milking machines for indigenous dairy breeds of Sahiwal cows and Murrah buffaloes maintained in an organized dairy farm.

Conclusion

The milk production and productivity enhancement in the dairy sector is technology-driven. The milking machine is a game-changer device applied in the dairy sector to boost profitability. The present study indicates the variability in the teat size, regarding the upper, middle and lower teat diameters of the Sahiwal cows and Murrah buffaloes. The intramammary health status of the best-fitting group in terms of teat size compared to the teat cup liner of the milking machine was better than the normal groups. Thus, addressing variations in teat size and optimizing teat cup liner fitting with milking machines, offers promising prospects for enhancing milking efficiency and promoting better animal welfare standards in Sahiwal cows and Murrah buffaloes.

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Conflict of Interest

The authors have no conflict of interest.

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