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Structural Variations and Adaptations of the Mammary Gland Across Species: A Micrometric Review of Lactation and Hormonal Influences

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ABSTRACT

This review provides a comprehensive examination of micrometric studies of the mammary gland across various species, including cattle, goats, camels, pigs, sheep and buffaloes. The focus is on the structural changes that occur in the mammary gland in relation to lactation and hormonal induction. By analyzing key micrometric parameters such as alveolar size, lobular structure, epithelial height and duct dimensions, we aim to elucidate the intricate adaptations of the mammary gland during different physiological states, particularly lactation and pregnancy. The review highlights how these structural variations are influenced by hormonal fluctuations associated with reproductive cycles. During lactation, for instance, there is a notable increase in alveolar size and epithelial height, reflecting enhanced secretory activity necessary for milk production. Conversely, during pregnancy, alterations in lobular structure prepare the gland for subsequent lactation, promoting ductal development and tissue expansion. Understanding these micrometric changes is crucial for improving management practices in livestock. By correlating structural modifications with physiological states, insights can be gained into optimizing milk production and overall animal health. This review serves to consolidate existing research on mammary gland micrometry, providing a foundation for future studies aimed at enhancing our understanding of mammary gland biology across species. Ultimately, these insights will aid in developing targeted breeding and management strategies that enhance milk yield and quality in various livestock species.

Key words: Buffalo, Cattle, Goat, Mammary gland, Micrometry, Milk, Sheep.

Micrometry of the mammary gland provides critical insights into its structural adaptations across various physiological states. The mammary gland is a highly dynamic organ that undergoes substantial changes in size and structure in response to hormonal fluctuations, lactation demands and reproductive cycles (Weber *et al.,* 1977; Munford, 1964). These adaptations are essential for optimizing milk production and supporting the growth of offspring (Smith *et al.,* 2022). During lactation, for instance, the mammary gland undergoes hypertrophy and hyperplasia, leading to increased alveolar size and alterations in epithelial cell height to meet the higher demands of milk secretion (Kirkpatrick *et al.,* 2002; Gordon *et al.,* 2004). The glandular tissue is composed of specialized epithelial cells that proliferate and differentiate due to endocrine signals from lactogenic hormones, primarily prolactin and oxytocin, which facilitate both milk synthesis and ejection (Dewhurst *et al.,* 2005). Additionally, the mammary gland's blood supply adapts to accommodate increased metabolic demands during lactation, with enhanced vascularization ensuring efficient nutrient delivery and waste removal (Bishop *et al.,* 2022). Conversely, during non-lactating or dry periods, the gland's structure reverts to a less active state, characterized by reduced alveolar size and lower rates of epithelial cell proliferation (Liu *et al.,* 2017; Paramasivan *et al.,* 2012). This period is critical for restoring mammary tissue and preparing the gland for subsequent lactation cycles.

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Hormonal regulation during the dry period allows for the resolution of inflammation and the regeneration of secretory cells, thereby ensuring that the mammary gland is primed for optimal performance in the next lactation.

The mammary gland also undergoes significant changes during pregnancy, adapting in secretory tissue and overall morphology to prepare for future lactation (Patel *et al.,* 2023; Ahmed *et al.,* 2008). This preparation involves the accumulation of secretory materials and alterations in fat deposition, which support gland functionality post-calving (Sinha *et al.,* 2021). Understanding these changes is vital for effective management of breeding and feeding practices in dairy animals. This review synthesizes data from various studies to highlight micrometric variations observed across different species, including cattle, goats, camels and buffaloes (Cheng *et al.,* 2019; Lee *et al.,* 2021). Each species exhibits unique mammary gland characteristics reflecting their evolutionary adaptations to different environmental and reproductive pressures. For example, camels possess specialized mammary glands that allow for concentrated milk production, vital for survival in arid environments, while dairy cattle have been selectively bred for high milk yield (Bhatia *et al.,* 2023; Ren *et al.,* 2020).

By examining how these structural changes align with physiological states and environmental factors, we aim to provide a comprehensive understanding of the mammary gland's adaptability (Yusuf *et al.,* 2014; Zhang *et al.,* 2022). This knowledge is crucial for improving dairy management practices, enhancing lactation efficiency and advancing reproductive health strategies in agricultural and veterinary contexts (Omer *et al.,* 2023; Jackson *et al.,* 2023). In conclusion, micrometric analysis of the mammary gland serves as a valuable tool for elucidating the complex relationship between structure and function across physiological states.

This review study was conducted in the Department of Veterinary Anatomy and Histology, College of Veterinary Science andUAT, Kumarganj, Ayodhya, during May-June 2022, with the goal of systematically compiling and analyzing existing research on mammary gland micrometry across different livestock species, including cattle, buffalo, goats, sheep and pigs. The primary aim of this review was to examine and summarize the structural changes that occur in the mammary glands of these species in relation to lactation, hormonal induction and other physiological states. The following steps were undertaken to conduct this review.

Micrometric changes in different species

Cattle

In examining the micrometry of mammary glands across different cattle breeds, a range of studies highlights the influence of lactation stages, nutrition, genetics and environmental factors. Weber *et al.* (1977) documented that Holstein Friesian cattle exhibit elongated mammary lobules and varied alveolar diameters, reflecting prolonged lactation. Lepine *et al.* (1989) highlighted the impact of nutrition, noting reduced alveolar size in undernourished cows. Kirkpatrick *et al.* (2002) observed larger alveoli in high-yielding dairy cows during peak lactation. In contrast, research on Malnad Gidda cows by Naik (2015); Rao *et al.,* (2016); Sharma *et al.* (2020, 2021) and Kumar *et al.* (2024) consistently found smaller alveoli and altered structural features under nutritional and environmental stress. Smith *et al.* (2022) and Johnson *et al.* (2023) reported that genetic selection and improved diets significantly enhance alveolar size and epithelial cell height in dairy cattle. These studies collectively underscore the critical role of nutrition, genetics and environmental conditions in shaping mammary gland morphology. Through genetic selection programs focused on traits like milk yield, mammary health and overall gland development, dairy cattle breeding continues to evolve. The interaction between genetic predisposition, hormonal regulation and environmental influences is essential for optimizing mammary gland function, improving milk production and ensuring the health and welfare of dairy cattle across different breeds.

Buffaloes

Studies on buffalo mammary gland morphology reveal substantial changes due to milking regimes, hormonal treatments and dietary influences. Kumar *et al.* (2011) found that alveolar diameter increased from 90 µm in non-milking buffaloes to 140 µm in those milked twice daily. Mehta (2013) observed significant increases in both the diameter and volume of alveoli during hormonal induction, with notable changes from the 7^{th} to the 21^{st} day of treatment. Hormonal treatments, such as prolactin and oxytocin administration, are commonly used to stimulate milk production and enhance mammary gland development. Prolactin is particularly known for promoting the growth and differentiation of mammary tissues, while oxytocin stimulates milk ejection and may influence alveolar development through its effects on smooth muscle contraction. Patil *et al.* (2018) and Rao *et al.* (2022) reported that these hormonal treatments, including growth hormone (GH) and progesterone, led to even larger alveoli, reaching up to 150 µm and 165 µm, respectively. Cheng *et al.,* (2019) and Singh *et al.,* (2022) highlighted that high-protein diets resulted in increased alveolar sizes, averaging 155 µm and 150 µm, respectively. Patel *et al.* (2023) and Leishangthem *et al.* (2019) confirmed significant structural changes under hormonal treatments, with alveoli sizes reaching up to 160 µm. These findings underscore the ultimate impact of milking frequency, hormonal interventions (including prolactin, oxytocin, growth hormone and progesterone) and diet on buffalo mammary gland morphology.

Goats

Investigations into the micrometry of mammary glands in goats reveal significant changes influenced by lactation stages, breed-specific factors and management practices.

Munford (1964) noted a decrease in alveolar size with the onset of lactation, while Santos *et al.* (1999) and Bermudez *et al.* (2020) documented an increase in alveolar diameter from early to peak lactation, accompanied by variations in epithelial height. Patel *et al.* (2005) observed an increase in alveolar density during lactation, despite a slight decrease in size. Aridany Suarez-Trujillo (2012) highlighted breed-specific differences in secretory tissue and alveoli number, whereas Lee *et al.* (2021) linked higher milk yield with larger alveoli and thicker epithelial layers. Singh *et al.,* (2022) and Martinez *et al.* (2022) reported substantial variations in alveolar and lobular parameters between lactating and non-lactating stages. Perez *et al.* (2022) and Vaish *et al.* (2024) found that breeding programs significantly enhance alveolar size and epithelial thickness. These studies collectively illustrate how lactation stage, breeding and management practices shape the structure of mammary glands in goats.

Sheep

Research on sheep mammary gland morphology highlights significant changes during lactation and in response to seasonal and nutritional factors. Gordon *et al.* (2004) observed that alveolar sizes in sheep decreased from an average of 110 µm in early lactation to 90 µm in late lactation, while epithelial height peaked at 20 µm. Paramasivan *et al.* (2012) and Paramasivan and Geetha (2014) documented larger alveoli (106.05 µm) in lactating sheep compared to dry sheep (32.45 µm), with the number of alveoli per lobule decreasing during lactation, suggesting glandular enlargement and secretion accumulation. Wilson *et al.* (2016), Smith *et al.* (2020) and Fitzgerald *et al.* (2021) noted seasonal variations, with alveolar sizes increasing to up to 120 µm during lactation and decreasing during the dry period. Anderson *et al.* (2023) and Jackson *et al.* (2023) reported that nutritional supplementation led to increased alveolar sizes and epithelial cell height, with diameters reaching up to 120 µm. These findings underscore the dynamic nature of sheep mammary gland morphology in response to lactation stages, seasonal changes and nutritional inputs.

Pigs

Studies on sow mammary gland morphology reveal considerable changes throughout lactation, influenced by genetic factors and management practices. Ding *et al.* (2010) found that alveolar size increased from 120 µm in early lactation to 150 µm in late lactation, with a higher percentage of secretory epithelial cells at peak lactation. SvatoslavHluchy *et al.* (2011) reported an average alveolar size of 131.06±36.07 µm, with a glandular composition rich in secretory epithelial cells. Liu *et al.* (2017) highlighted that high milk yield breeds typically had larger alveoli (up to 140 µm), while lower-yielding breeds had smaller alveoli. Yang *et al.* (2019) and Zhang *et al.* (2022) corroborated these findings, noting increases in alveolar size from 130 µm in early lactation to 160 µm in peak lactation. Wang *et al.* (2022) and Chen *et al.* (2023) further demonstrated that genetic selection for high yield significantly enlarges alveoli, with sizes reaching up to 150 µm or more. These studies collectively underscore the impact of lactation stages and genetic selection on the structural adaptation of sow mammary glands.

CONCLUSION

Understanding the micrometric changes in the mammary gland across various species provides valuable insights into the physiological adaptations of lactation. These studies highlight the importance of hormonal regulation and its impact on mammary gland morphology. Future research should focus on further elucidating the mechanisms behind these structural changes and their implications for lactation efficiency and milk production. and to explore the molecular mechanisms underlying these adaptations and their implications for the health and productivity of dairy animals, paving the way for innovative approaches to enhance milk yield and quality.

Conflict of interest

No conflict of interest among the authors.

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