University of Thi-Qar Journal of agricultural research

Thi-Qar Journal of agricultural research

ISSN Onlin:2708 -9347, ISSN Print: 2708 -9339 Volume 15, Issue 1 (2026)

https://iasj.rdd.edu.iq/journals/journal/issue/20226 *https://doi.org/10.54174/utjagr.v13ii 39.*

Comparative Histological and Histochemical Study of Sweat Glands in the Eyelid and Abdominal Regions of Female One-Humped Camels (Camelus dromedarius)

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I. ABSTRACT

The skin of the dromedary camel (Camelus dromedarius) is an extensively adapted structure for desert living and contains one of the most specialised integumentary systems. Thermoregulation of dromedary camels is thoroughly investigated; however, there is little information about the histologic and histochemical characteristics of sweat glands located in the anatomical divisions of the body, primarily in the female dromedary. Therefore, this study provides a comparative histological and histochemical description of sweat glands located in the eyelid and abdominal skin of the female dromedary camel. Skin samples were obtained at a local abattoir in the Almuthana Governorate, Iraq, from 6 apparently healthy adult females. Polyester wax (paraffin) was used as an embedding medium, and paraffin-embedded samples were sectioned into 5.0 µm thick sections for staining with haematoxylin and eosin (H&E), Masson's trichrome (MT), and periodic acid-Schiff (PAS) reagents. Morphometric measurements included the number of sweat glands in a microscopic field. In the two sampled regions, both contained a two-layered, coiled, apocrine tubular sweat gland, lying within a dense, irregular collagenous connective tissue capsule and lined by simple cuboidal epithelium. The glands are closer together in relation to space occupied by glands when comparing the two sets of glands. The presence of positive glycoproteins as secretory substances of the sweat glands in both the eyelid and abdominal regions was confirmed by PAS staining. Additionally, Masson's trichrome staining revealed abundant collagen in the dermis of both body regions. These results provide baseline data to support future studies comparing regional differences in sweat gland morphology in the female dromedary camel.

Keywords : Camelus dromedarius; apocrine sweat glands; eyelid skin.

II. INTRODUCTION

The one-humped camel (Camelus dromedarius) is one of the most physiologically successful large mammals to be found on earth. This species of camel has adapted well to the extreme xeric (very dry) conditions of the Arabian Peninsula, the Saharan Belt of North Africa, and semi-arid areas of Asia [1,2]. The integumentary system plays an important role in this adaptation through its thermoregulatory, protective, and secretory functions within an extremely hot, brightly lit environment that lacks an adequate water supply [3]. Consequently, knowledge of the histological and histochemical properties of camel skin will provide insight into how living organisms utilise physiological strategies to survive in deserts [4].

Mammals have skin consisting of several layers (the epidermis, dermis, and hypodermis), along with structures that protrude from the skin surface, such as hair follicles, sebaceous glands, and sweat glands [5,6]. The sweat glands of

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mammals can be categorised into eccrine (merocrine) and apocrine types based on their method of secretion. Eccrine glands secrete a hypotonic solution that aids in dissipating body heat through evaporative cooling. In contrast, the fluid from the apocrine glands contains a more complex mixture of functions, including thermoregulation, olfactory communication, and maintenance of the skin's surface film [6,7]. The predominant type of sweat gland in the dromedary camel is the apocrine type, in contrast to humans and equids, where the eccrine type is predominant [6,8].

The dromedary camel has several integrated mechanisms for thermoregulation. Although the camel's hump provides a concentrated source of energy in the form of adipose tissue, it also does not provide a reservoir of water [1,3]. Evaporative sweating is an important mechanism during high thermal stress in camels, and the skin surface is the primary site of evaporative moisture loss [3,4]. The spatial arrangement and architectural composition of eccrine-type sweat glands are different relative to different areas of the body in the dromedary, which implies that these body areas have different functions, which may also be tied to the heat load of that area and the secretory requirements of that area [9,10].

The eyelid is a skin structure in many mammals that has a unique morphology, is typically thin and highly flexible, has specialised glands adjacent to the eye, and has a high density of sensory receptors [11]. In the dromedary, the skin is further modified to protect the eye from particulate materials being blown by the wind and from excessive solar radiation; this is evident in that the cilia are much longer and the tissue along the margin of the eyelid is thicker than in areas of skin with more typical morphology [9,10]. The eyelids contain apocrine glands that secrete products onto the ocular surface microenvironment and are important to the function of the eye. Therefore, a histological description of the eyelid skin in the dromedary has both anatomical and ophthalmological importance [11].

The abdominal region of the camel has a larger surface area available for evaporative heat loss and cooling the animal; therefore, this region of the body is exposed more than other regions of the body when the animal is in a sternal recumbent position lying down on a hot substrate, when compared to other body regions [10]. Although the eyelid and abdomen regions of the dromedary camel have both been documented to have significant morphological representations of sweat glands, a systematic histological and histochemical assessment comparing the two regions of the body for sweat gland morphology has not been published in the form of a regional/functional comparison for female dromedary camels [5].

III. MATERIALS AND METHODS

2.1 Animals and Ethical Considerations

Six healthy adult females, one-humped camels (Camelus dromedarius), slaughtered in Alsamawa abattoir in Almuthana governorate, were used in this study. Camels were chosen because they exhibited no evidence of dermatological disease (macroscopically) or systemic disease. Animal age was determined by examining teeth and verifying with the animal's owner, and was from 4-8 years. All samples were obtained postmortem, and no experimental interventions were made on the live animals.

2.2 Tissue Sampling

Bilateral symmetric sites were used to obtain full-thickness samples (about 1 × 1 cm) of skin: the upper eyelid and the ventral abdominal regions at midline. Samples were obtained using sterile disposable scalpels and excised within 10 minutes of animal slaughter; the specimens were then placed directly into 10% neutral buffered formalin (NBF) and fixed in NBF for 48 – 72 hours at room temperature.

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2.3 Histological Processing

Standard paraffin embedding methods were used to process specimens placed on a fixed specimen base. Specimens were dehydrated using ethanol at 70%, 80%, 90%, 95%, and 100% before being cleared in two xylene changes and impregnated with paraffin wax with a melting point of 56-58 °C. Tissue sections were cut from paraffin wax using a rotary microtome to a thickness of 5 um, placed on poly-L-lysine-coated glass slides, and allowed to dry overnight at 37 degrees Celsius [12].

2.4 Staining Protocols

Consecutive slices of each specimen were subjected to three standardised histochemical procedures. Haematoxylin and Eosin (H&E) staining was used to assess overall histological structure, epithelial organisation, and glandular morphology, following the protocol described by Bancroft and Gamble [12]. Masson's Trichrome (MT) staining for differentiating collagen fibres (blue) from muscle and cytoplasm (red) to determine the composition of dermal connective tissue [14]. Periodic Acid-Schiff (PAS) staining was performed for the detection of neutral polysaccharides and/or glycoproteins: sections were sequenced through the process of 0.5% periodic acid oxidation for 10 minutes, rinsing in distilled water, treating with Schiff's regent for 15 minutes, followed by counter-staining with Mayer's haematoxylin [13,14].

2.5 Microscopy and Image Acquisition

Using an Olympus BX53 compound light microscope (Olympus Corporation, Japan) equipped with a calibrated DP72 digital camera, all stained areas were viewed under the microscope, and photomicrographs were taken at 40×, 100×, and 400× using the cellSens Standard imaging system, with counts and measurements made using a calibrated scale bar. All morphometric data were derived from measurements made with the imaging system and a calibrated scale bar.

2.6 Morphometric Measurements

Assessment of H&E-stained sections included the measured number of sweat gland tubular profiles in standard magnification field (0.5 mm^2 area at 100× magnification—5/section). For each sample, three separate and distinct sections were analysed (totalling 15 sections), and the number of analysed fields was five per section (75 fields).

2.7 Statistical Analysis

The data were analysed using IBM SPSS Statistics version 26 [16]. Presentation of results included mean ± standard error (Mean ± SE). Significant pairwise differences within body regions were determined by applying the Least Significant Difference (LSD) test. A P-value of $P \leq 0.05$ was considered statistically significant, whereas $P > 0.05$ was denoted as NS.

3. RESULTS

3.1 General Histological Architecture

Sections of eyelids (Fig. 1) and abdominal skin (Fig. 4) stained with H and E showed that both areas had a keratinised stratified squamous epithelium above an underlying dense, irregular connective tissue (the dermis). Both the eyelid and abdominal skin contained well-developed, coiled, tubular apocrine sweat glands in the dermis, with abundant collagenous stroma. The glands had a single layer of cuboidal eosinophilic secretory epithelial cells with round nuclei located at the base of the cells. Hair follicles were associated with the eyelid (Fig. 3) and abdominal dermis (Fig. 5). Masson's trichrome-stained sections of the eyelid and abdominal dermis confirmed that the major component of the dermis

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surrounding the glands in both locations was collagen (Figs. 2 and 5). The PAS-stained gland epithelial and luminal contents of the apocrine glands in both eyelid and abdominal regions were moderately to strongly positive, and the size of the lumen of the apocrine glands in the abdomen was more variable (Fig. 6).

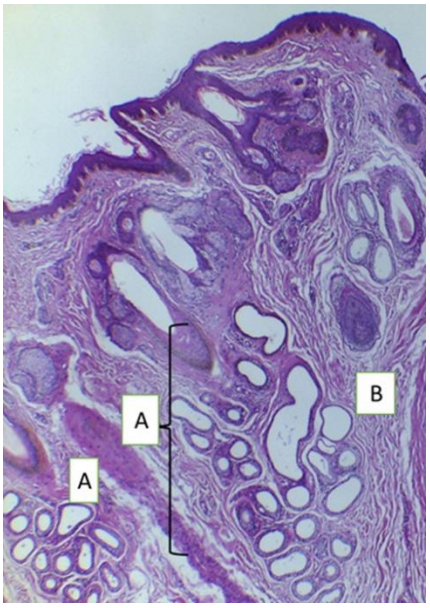

Fig. 1. Histological section of eyelid skin of female one-humped camel (Camelus dromedarius) showing numerous coiled tubular apocrine sweat glands in the dermis (A). Dense irregular connective tissue of the dermis surrounds the glandular structures (B). H&E stain, 100×.

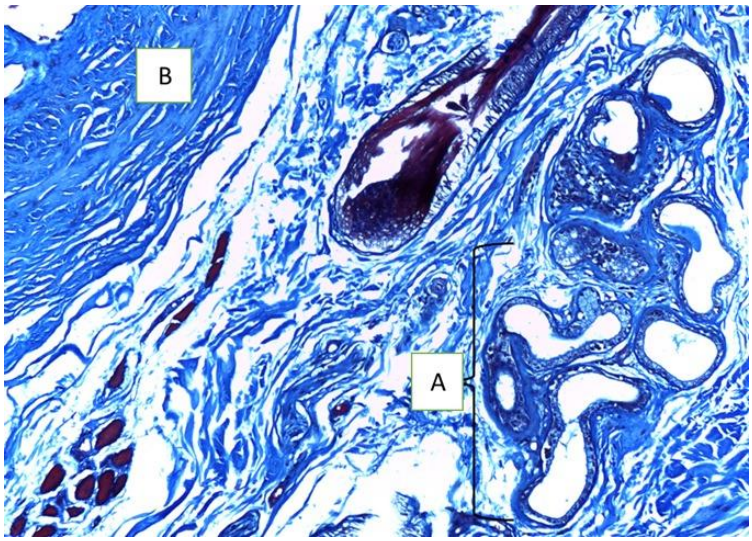

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Fig. 2. Histological section of eyelid skin of female one-humped camel (Camelus dromedarius) showing coiled tubular apocrine sweat glands in the dermis with wide lumina, embedded within dense collagenous connective tissue (A). Abundant collagen fibres of the dermis stained blue (B): Masson's Trichrome stain, 100×.

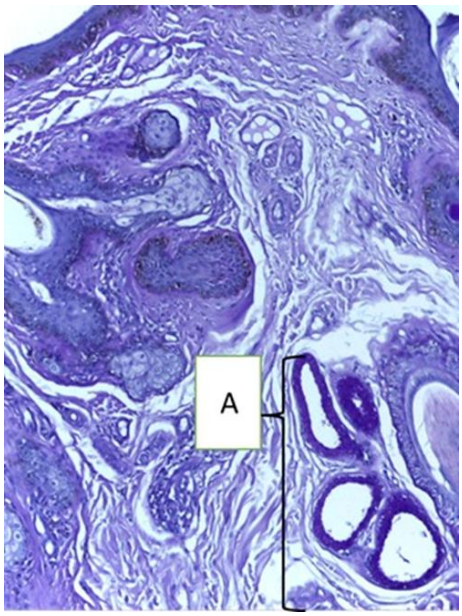

Fig. 3. Histological section of eyelid skin of female one-humped camel (Camelus dromedarius) showing well-developed hair follicles associated with coiled tubular apocrine sweat glands in the dermis, characterised by relatively large lumina and lined by simple cuboidal epithelium, embedded within dense, irregular connective tissue. PAS stain, 100×.

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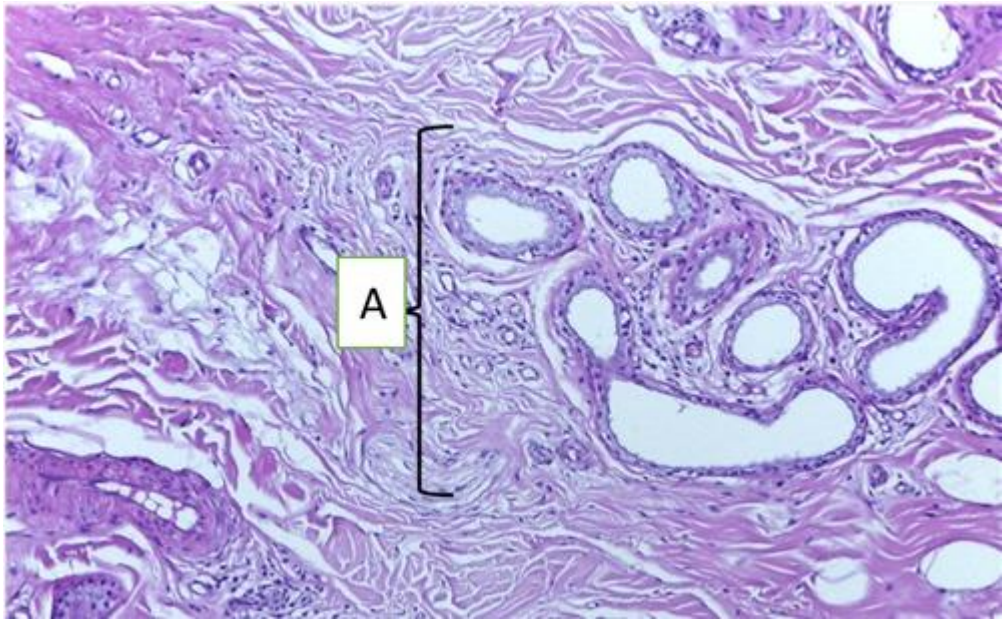

Fig. 4. Histological section of abdominal skin of female one-humped camel (Camelus dromedarius) showing coiled tubular apocrine sweat glands in the dermis, embedded within dense, irregular connective tissue rich in collagen fibres. H&E stain, 100×.

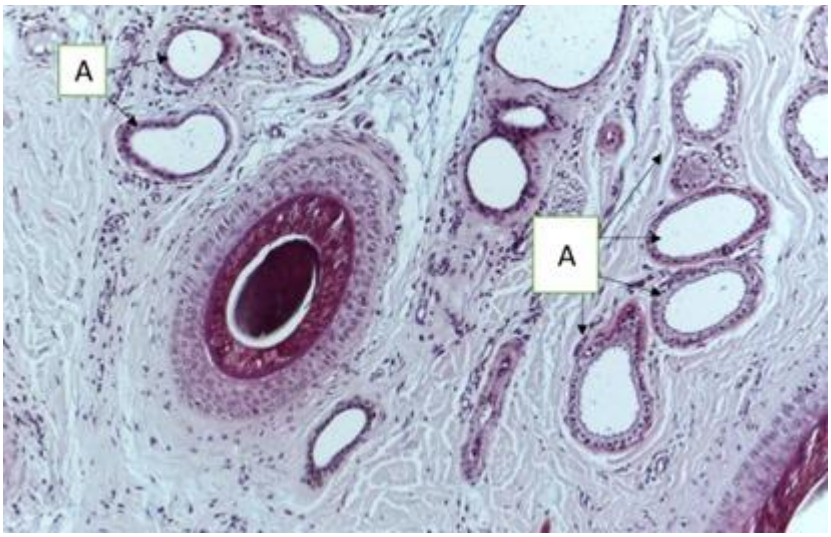

Fig. 5. Histological section of abdominal skin of female one-humped camel (Camelus dromedarius) showing a well-developed hair follicle associated with coiled tubular apocrine sweat glands in the dermis, characterised by wide lumina and lined by simple cuboidal epithelium, surrounded by dense, irregular connective tissue: Masson's Trichrome stain, 100×.

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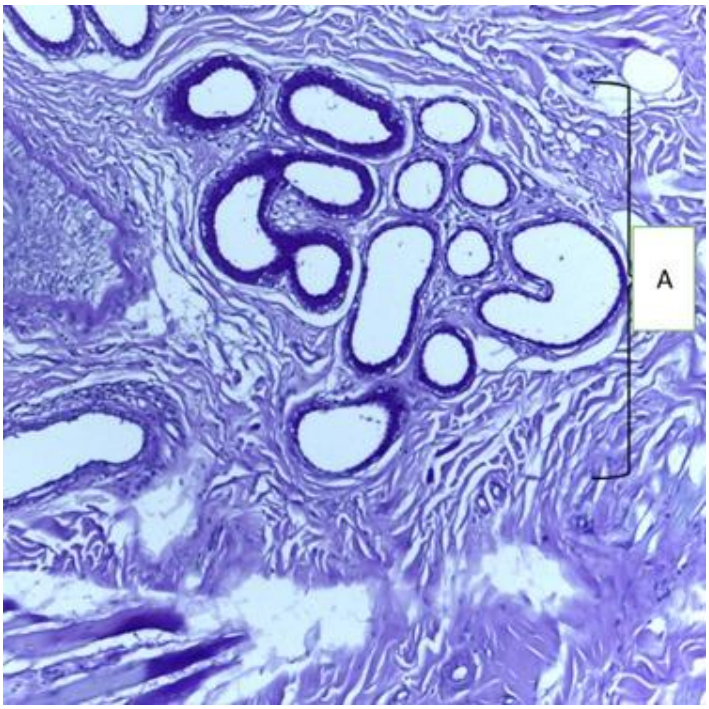

Fig. 6. Histological section of abdominal skin of female one-humped camel (Camelus dromedarius) showing coiled tubular apocrine sweat glands in the dermis with markedly wide and irregular lumina, lined by simple cuboidal epithelium, embedded within dense collagenous connective tissue. PAS stain, 100×.

3.3 Sweat Gland Morphometry – Female Camels

The female camel's sweat glands are found in different locations across the body. (Table 1) shows the diameter and number of sweat glands in the eyelid and abdomen of female camels. The average diameter of adult camel sweat glands was (18.8 ± 1.13 µm) in the eyelid, with 24.0 ± 1.62 per field; 19.8 ± 1.07 µm in the abdomen, with 20.0 ± 0.96 per field. There were significant differences in sweat gland size (LSD = 1.750, $P < 0.05$) and number (LSD = 5.094, $P < 0.05$) among these two body parts the eyelid had the smallest diameter, and the abdomen had the fewest sweat glands.

Table 1. Morphometric parameters of sweat glands in female one-humped camels (Camelus dromedarius).

Parameter	Eyelid Mean ± SE	Abdomen Mean ± SE	LSD
Gland diameter (µm)	18.8 ± 1.13 c	19.8 ± 1.07 bc	1.750 *
Glands per field	24.0 ± 1.62 b	20.0 ± 0.96 b	5.094 *

Different letters within the same row indicate statistically significant differences (LSD test). * $P \leq 0.05$.

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4. DISCUSSION

This research examines, histologically and histochemically, the sweat glands found in the eyelids and abdominal skin of the female one-humped camel. The findings presented here contribute quantitative morphometric data to an area of research with limited region-specific integration of integumentary studies of this species. The presence of coiled tubular apocrine sweat glands as the predominant type of sweat gland in both anatomical regions supports the classification of dromedary sweat glands as primarily apocrine, which agrees with previous descriptive studies on the histology of camelid skin [6,17]. In contrast, however, the predominance of eccrine glands for thermoregulatory sweating in both primates and equids is well established [7,8].

The presence of a simple cuboidal epithelial lining of the glandular tubules in both anatomical regions constitutes a canonical histological hallmark of apocrine secretory units. It is similar to other studies of the dermis of cattle, goats, and sheep. This type of epithelial morphology is consistent with the moderate protein-synthesising demands characteristic of apocrine-type cells, and with the description provided for dromedaries by Taha and Abdel-Raouf [17]. H&E sections consistently demonstrated the presence of myoepithelial cells in the periphery of the tubular glandular structures, which is in agreement with published ultrastructural descriptions of the architecture of camelid apocrine glands [20].

A major morphometric finding in this study is that the gland diameter in the eyelid (18.8 ± 1.13 µm) is significantly smaller than in the abdomen (19.8 ± 1.07 µm). Both values are less than those observed for the neck. The diameter of sweat glands is generally considered a correlate of the secretory capacity of the gland, as wider tubular profiles permit a greater quantity of luminal secretory volume per unit [21]. The diameter of eyelid secretory glands is smaller than that of glands in other regions of the body. However, the density of secretory glands found in the eyelid (24.0 ± 1.62 secretion glands per viewable unit) is greater than that found in the abdomen (20.0 ± 0.96 secretion glands per viewable unit), suggesting that the eyelid depends on many small-diameter secretory glands to produce needed skin secretions. In terms of their contribution to the tear film lipid layer and ocular surface microenvironment, the small diameter, dense, secretory glands in the eyelid are functionally similar to modified apocrine secretory glands in large mammals [11,18].

On the other hand, the distribution of larger, low-density, secretory glands in the abdomen corresponds to the greater evaporative output per gland required by the greater thermic exposure of the entire ventral (abdomen) body surface, as measured [1,3,22]. The presence of abundant collagen fibres provides the blue colouration of the dermal layer of the eyelid and abdomen, as confirmed by Masson's Trichrome staining (Fig. 1). Dense, irregular connective tissue is also a well-characterised characteristic of the dermis of dromedaries [17,23]. It is thought to provide the dermis with the structural framework necessary for anchoring the sweat gland's tubular apparatus, resistance to mechanical deformation, and preservation of integumentary integrity in harsh desert conditions [24,18].

PAS-positive staining of glandular secretory epithelium and lumen of sweat glands was evident in both eyelid and abdominal skin. PAS-positive material within apocrine secretory cells usually indicates neutral glycoproteins, glycolipids and mucopolysaccharides [13,14]. Acinar-secreted glycoproteins are suggested to confer the viscoelastic properties of the surface film and facilitate semiochemical-type communication [19]. Compared to abdominal glands, which exhibit greater PAS-positive luminal content likely due to larger lumen diameter and higher secretion volume [13,14], this, in turn, relates to the thickness of the skin layers. For example, in female camels, there was no significant difference in epidermal thickness of the body series (LSD = 4.077). Male ungulates have been shown to exhibit androgenic effects on keratinocyte proliferation; the aforementioned variation suggests a potential relationship to androgen lethargy [25].

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The limitations of this work should be acknowledged. The small number of five animals limits the extent to which these findings can be generalised; therefore, at least ten additional animals would strengthen our understanding. Future studies would benefit by incorporating additional histochemical staining such as Alcian blue for acidic mucopolysaccharides, as well as immunohistochemical analysis to identify specific endocrine proteins and androgen receptors.

IV. CONCLUSION

Sweat glands in the abdominal skin and eyelid of the female one-humped camel (Camelus dromedarius) are coiled tubular apocrine structures comprised of simple cuboidal epithelial cells, which are located in the dermis of dense collagenous tissue. The presence of glycoprotein-containing secretory products was confirmed by utilising a PAS stain, and the presence of collagen fibres in the dermis was confirmed through Masson's Trichrome staining. Although the eyelid glands are significantly smaller than the abdominal glands, they are more densely packed, as evidenced by 18.8 ± 1.13 µm in the eyelid (24.0 ± 1.62 glands per field) and 19.8 ± 1.07 µm in the abdomen (20.0 ± 0.96 glands per field). These findings indicate that the two locations have evolved distinct morphologies in response to differential thermoregulatory and secretory demands. Thus, the present study provides the basis for future studies of the dromedary integument from physiological, comparative and applied perspectives.

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