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Adaptive Responses of Dromedary Camel Body Coat to Seasonal Climatic Variations in the Northwest Coast of Egypt

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ABSTRACT

The dromedary camel's body coat is a crucial adaptive feature, enabling survival in diverse and challenging environments. This study investigated the seasonal and spatial variations in the body coat characteristics of adult female dromedary camels (*Camelus dromedarius*) in response to the semi-arid climatic conditions of Egypt's northwestern coastal desert. Conducted at the Maryout Research Station from June 2023 to May 2024, the study continuously monitored meteorological data, including ambient temperature and relative humidity, to calculate the Temperature-Humidity Index (THI). Twelve non-pregnant, non-lactating female camels (12-14 years old, avg. 345 ± 8.12 kg) were housed in partially shaded barns with a controlled diet and daily grazing access. Approximately 50 g hair samples were collected from eight body regions to measure coat depth, fiber diameter, fiber type ratio, fiber length, crimp frequency, and medullation index.

Results revealed significant seasonal and spatial variations in coat parameters. Coat depth was approximately 40% greater in winter, providing essential insulation, while the thinner summer coat aided heat dissipation and solar protection. The neck region consistently exhibited the greatest coat depth and fiber diameter, suggesting a functional need for enhanced protection in this exposed area. Spatial differences were also evident in fiber length and crimp frequency, with longer fibers in summer (e.g., neck and hump) potentially offering increased UV protection. These findings underscore the complex interplay between seasonal climatic changes and anatomical factors in shaping the dromedary camel's hair coat, reflecting profound evolutionary adaptations. Future research should further explore these adaptations to optimize camel husbandry and management in varying climates.

Keywords: Body position, Desert, Hair, Season.

INTRODUCTION

The body coat of the dromedary camel exemplifies a remarkable adaptation, serving as a dynamic shield that enables the animal to thrive in various global regions and fluctuating environmental conditions (Abdoun et al., 2013). This adaptability is essential for optimizing thermoregulation and overall survival in dromedary camels. Various factors, including species (in comparative studies), breed, age, and sex, significantly influence the coat's characteristics in dromedary camels (Alibayev et al., 2020; Zabek et al., 2022). Furthermore, coat color (Bianchini et al., 2006; Castanheira et al., 2010; Abdoun et al., 2013), geographical location (Iniguez et al., 2014), and body condition (Brown Brandl, 2009) also play critical roles in dromedary camels, while genetic differences (Gayan and Olson, 2003; Ansari-Renani et al., 2010; Helal, 2015) and specific body regions further contribute to its diversity (Taha et al., 2006; Pastrana et al., 2024).

Beyond adaptation, dromedary camel fiber presents significant potential as a textile resource, valued for its strength, luster, smoothness, and warmth (Helal et al., 2007; Sharma and Pant, 2013; Burger et al., 2019). The inherent qualities of camel fiber attract consumers, highlighting its untapped promise both as a standalone material and in blends with other fibers (Maisnam, 2019; Fesseha and Desta, 2020; Sharma and Pant, 2013).

Structurally, the camel's coat consists of two distinct fibrous layers: an outer layer of longer, thicker fibers and an inner layer of shorter, finer fibers (Guirgis et al., 1992; Taha et al., 2006; Ansari-Rinani, 2008). These layers adjust seasonally, working together to provide optimal protection against climatic variations (Abdou *et al*., 2006; Taha *et al*., 2006; Ansari-Renani, 2008; Taha, 2010). For instance, during winter, the inner coat can constitute 83.97% of total fibers for enhanced insulation, while the outer layer reduces to 16.03%. In summer, the outer layer expands to 37.50%, aiding in heat dissipation (Taha, 2010). These seasonal shifts are influenced by various factors, including skin follicle activity and environmental conditions (El-Sayed and Abou El-Ezz, 1999; Abdou et al., 2006; Ansari-Renani, 2008).

The physical location on the camel's body also affects coat characteristics, with the fleece on the sides being most abundant and the hump containing the coarsest fibers (Taha et al., 2006). This intricate dual-layer structure and its seasonal adjustments are vital adaptations that enable dromedary camels to thrive in harsh desert environments, enhancing their thermoregulation and providing essential protection from extreme temperatures (Alibayev et al., 2020).

This study aimed to examine the impact of seasonal climatic fluctuations in the semi-arid desert environment of Egypt's northwestern coast on the body coat characteristics of single-humped camels (*Camelus dromedarius*).

MATERIALS AND METHODS

This study was carried out at the Maryout Research Station "situated at a latitude of 30.99°N and a longitude of 29.78°E, with an altitude of 32 meters above sea level. It is located 35 km southwest of Alexandria city and represents the semi-arid desert conditions of the northwest coastal belt of Egypt.", affiliated with the Desert Research Center (DRC), Ministry of Agriculture and Land Reclamation, Egypt. The experiment lasted for four successive seasons, starting in the summer of 2023 (June) and ending in the spring of 2024 (May).

Meteorological Data

Throughout the experiment, daily meteorological data, including average ambient temperature (Tav, °C) and relative humidity (RH, %), were continuously recorded using a HOBO Pro Series data logger (Onset, USA). We then calculated the Temperature-Humidity Index (THI) using the equation established by Habeeb *et al*. (2018):

$$THI(°C) = Tav - 0.55 \times (1 - (0.01 \times RH) \times (Tav - 14.5))$$

Following Tulu et al. (2022), THI values were categorized to assess heat stress levels: less than 27.8 indicated no heat stress, while values between 27.8 and 28.9 suggested moderate heat stress. A THI ranging from 28.9 to 30.0 signified severe heat stress and 30.0 or higher represented very severe heat stress.

Experimental Animals and Management

This study utilized 12 adult female dromedary camels (*Camelus dromedarius*), none of which were pregnant or lactating. The camels ranged from 12 to 14 years of age and had an average body weight of 345±8.12 kg.

The animals were housed in partially shaded barns and received a consistent daily diet. This diet included 2.5 kg/head of a concentrate feed mixture, which was composed of 65% yellow corn, 20% wheat bran, 10% soybean meal, and 5% cottonseed meal. In addition to the concentrate, each camel received 2.5 kg of alfalfa hay and 1 kg of rice straw daily.

Throughout the experimental period, the camels were also allowed to graze freely for 5 hours each day on a natural range. This range featured local vegetation, including *Atriplex sp*. shrubs, *Kochia indica*, and *Acacia sp*. shrubs. Fresh water was provided twice daily to all animals for the duration of the study.

Hair Sampling

Hair samples (approximately 50 g) collected from eight distinct body regions of each camel. These sampling sites included the neck, nape, withers, hump, hip, shoulder, mid-side, and breech, as visually depicted in Fig. 1. Sampling was conducted by using a surgical scissors sterilized with 70% ethanol between each sampling process. A 10 x 10 cm stencil was used to standardize the area, and hair was clipped to 1 mm above skin level at marked sites (tattooed for longitudinal tracking). The same sites were anatomically identified each season using non-invasive markers. Immediately after collection, samples were sealed in labeled foil pouches containing desiccant to prevent moisture absorption.

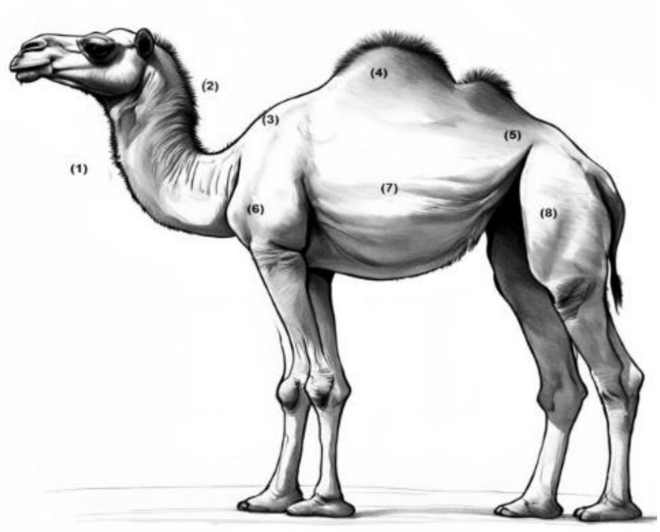

Fig. (1). Hair sampling positions: (1) Neck, (2) Nape, (3) Withers, (4) Hump, (5)Hip, (6) Shoulder, (7) Mid-side and (8) Breech.

Coat Characteristics Assessment

The following parameters were measured to characterize the dromedary camel's coat:

Coat Depth

In conjunction with hair sampling, coat depth was measured at each of the eight previously mentioned body locations. A millimeter ruler was applied vertically from the skin surface to the fur surface, with measurements recorded in centimeters for all experimental animals.

Fiber Diameter

Fiber diameter was determined using an Image Analyzer (Blue edition, Zen, 2012) with a 10/0 lens. Short sections of a small fiber tuft were mounted in liquid paraffin oil on a microscopic slide and covered. The mean fiber diameter and its standard deviation were calculated from 300 fibers for each experimental animal.

Fiber Type Ratio

The fiber type ratio was assessed for each camel by manually counting fibers, following the methodology by Guirgis (1967). A small staple of fibers was placed on black velvet and separated into four distinct types; Fine (non-medullated), Coarse (medullated), Heterotype (mixed fiber with medullated and non-medullated parts) and Kemp (fibers with more than 85% of their cross-sectional area as medulla).

A total of approximately 300 fibers were analyzed per sample. The benzene test (Ryder and Stephenson, 1968) was used to differentiate between coarse and fine fibers; medullated fibers were visible when immersed in benzene, whereas fine fibers were not. The percentage of each fiber type was then calculated.

Fiber Length

After classification, fiber length was measured from 20 randomly selected fibers of each type per sample, using a ruler to the nearest 0.5 cm (Taha, 2010). Just enough tension was applied to straighten the fiber without stretching, and the length was recorded as the distance from the base to the tip.

Crimp Frequency

Crimp frequency was assessed by randomly selecting 10 fine and 10 coarse fibers. Each fiber was placed on black velvet without longitudinal tension. A single crimp was defined as the distance between the bottoms of two consecutive crimps. The number of crimps per centimeter was measured at the middle part of the fiber using a ruler. The average crimp frequency per centimeter was then calculated for each fiber type in each sample.

Medullation Index

The medullation index (MI) was calculated using the method adapted by Guirgis (1973) for whole fleece fiber types. This involved multiplying the percentage of each fiber type by its corresponding class number, summing these products, and then dividing by 10.

Statistical Analysis

Data were analyzed with the SAS (2012) program using a general linear model (GLM) procedure for analysis of variance. Means were significantly separated using Duncan's multiple range tests. The fixed effect model used was $Y_{ijk} = \mu + S_i + P_j + SP_{ij} + e_{ijk}$, where Y_{ijk} is the observation k of i^{th} season, j^{th} animal position, i^{th} j^{th} season × animal position interaction, μ is an overall mean, Si is the fixed effect of season (summer and winter), Pj is the fixed effect of animal position (Neck, Nape, Withers, Hump, Hip, Shoulder, Mid side and Breech), SP_{ij} is the interaction effect between season and animal position, and e_{ijk} is the random error assumed to be normally distributed with mean=0 and variance=σ^2e.

RESULTS AND DISCUSSIONS

Meteorological Data

Seasonal changes in meteorological data during the experimental period are presented in Figure 2. Average ambient temperature (Tav) was highest during summer, moderate in autumn and spring, and lowest in winter. Relative humidity (RH%), however, peaked in autumn, was moderate in winter, lowest in spring, and increased in summer, though remaining below autumn levels.

To evaluate the camels' exposure to heat stress across the four successive seasons, the Temperature-Humidity Index (THI) was calculated. THI was highest in summer at 27.27, moderate in autumn (24.6) and spring (23.1), and lowest in winter (18.30) (Fig. 2). According to Tulu et al. (2022), a THI below 27.8 indicates no heat stress, 27.8–28.9 moderate heat stress, 28.9–30.0 severe heat stress, and ≥ 30.0 very severe heat stress. Based on these thresholds, the THI values recorded throughout this study indicate that the camels were not exposed to severe heat stress during any of the seasons.

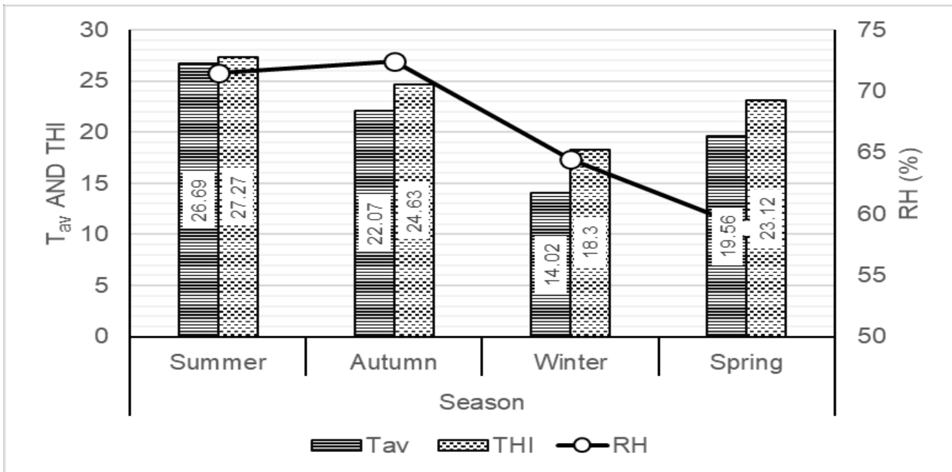

Fig (2). Average ambient temperature (Tav, °C), relative humidity (RH, %) and temperature-humidity index (THI).

Coat Characteristics:

Data in Table 1 presents the hair coat parameters of she-camels. The coat depth was significantly ($p<0.05$) thicker in winter compared to summer, with a difference of approximately 40% from the summer depth. This indicates a seasonal adaptation for insulation in winter and protection from intense solar radiation in summer, as supported by Gebreyohanes and Assen (2017). These findings are consistent with the work of Guirgis *et al*. (1992) and Taha (2010), who also observed a significant seasonal impact on dromedary coat depth across various regions in Egypt. The thicker winter coat likely traps a layer of insulating air, which reduces heat loss (El-Hassanein, 1989). Coincidently, THI analysis revealed higher heat stress in summer (27.27) compared to winter (18.30), aligning with a 40% reduction in coat depth during summer. This suggests a dynamic adaptive mechanism: camels minimize thermal insulation under moderate heat stress (THI <27.8) by reducing coat density, while increasing it in winter to conserve body temperature.

Additionally, significant ($p<0.05$) spatial variations in coat depth were noted. The neck region displayed the thickest coat, while the hip had the thinnest, with intermediate values in other areas.

This aligns with Guirgis et al. (1992), who reported increased summer shedding in dorsal regions of dromedary camels. Nelson *et al*. (2015) also found denser hair in the neck, shoulders, and hump of the dromedary camels. These spatial differences likely reflect the variation in the degree of protection required depending on the region on the camel's body, with more exposed areas like the neck requiring greater protection. Although the interaction between season and sampling position was significant ($p<0.05$), winter coat depth was greater across all sites (Fig. (3)), highlighting a consistent seasonal pattern in the heterogeneous distribution of hair coat. The neck and hump consistently exhibited the greatest depth, while the mid-side and breech showed the least, potentially reflecting varying thermoregulatory demands of different body regions. The hump and neck are the camel's body parts most exposed to environmental conditions. Positioned at the top of the body, the hump has a distinctive semi-pyramidal shape, while the long, cylindrical neck extends forward. Both features result in a larger surface area being subjected to weather elements. As a result, these areas require effective insulation that shielding them from intense daytime sunlight and frigid nighttime winds to regulate heat retention and loss in the harsh continental desert climate. In contrast, the mid-side and breech are lateral body regions, allowing heat balance to distribute evenly across both sides. For instance, when one side faces the sun and gains heat, the opposite side remains shaded and loses heat.

Regarding fiber diameter in she-camels, it was significantly ($p<0.05$) larger in summer than in winter. Taha (2010) also reported thicker summer fibers in dromedary camel, suggesting a thermoregulatory function, with positive correlations between fiber diameter, ambient temperature, and solar radiation. The finer winter fibers may result from reduced skin follicle activity and dormancy (Ansari-Renani, 2008), although Guirgis et al. (1992) noted an opposite trend. Fiber diameter also varied spatially, with the coarsest fibers found at the nape and neck (38.43 and 38.40, respectively) and the finest at the hip and mid-side (29.00 and 29.50, respectively). This is consistent with findings by Guirgis et al. (1992), as well as studies on Bactrian camels (Sahani et al., 2003) and dromedaries (Taha et al., 2006). Helal (2015) attributed these variations to multiple factors, including body location, while Pastrana et al. (2024) noted an increasing fiber base diameter from the mid-region to the back in adult dromedaries. Variations across different studies (Bhakat et al., 2015; Sahani et al., 2003; Harizi *et al*., 2007) may reflect breed-specific morphotypes influenced by environmental factors and functionality (Frank et al., 2006; Pastrana et al., 2024). The interaction between season and sampling position on fiber diameter was significant ($p<0.05$), with summer diameters being larger across all sites (Fig. (3)).

The significant ($p<0.05$) effects of season and body position were also observed on fiber length and crimp frequency. Coarse and fine fibers were significantly longer in summer than in winter, consistent with Guirgis et al. (1992). Spatially, the longest coarse fibers were found on the neck and nape, while the shortest were on the breech, mid-side, and wither. Fine fibers were longest on the hump and shoulder, and shortest on the breech and withers, consistent with Sahli *et al*. (2015) and Bhakat and Sahani (2001). These spatial variations likely arise from differences in follicle activity and physiological factors (Abdou *et al*., 2006; Ansari-Renani et al., 2010). The interaction between season and sampling position on fiber length was significant ($p<0.05$) (Fig. (4)), with longer summer fibers, particularly in exposed areas like the neck and hump for coarse fibers, potentially providing UV protection (Akbar et al., 2024).

Crimp frequency was significantly ($p<0.05$) higher in summer than in winter for both coarse and fine fibers. This seasonal impact on crimp frequency may be attributed to the different activity rates of skin follicles between different seasons. This expectation is supported by what was indicated by Ansari-Renani (2008), who found that the activity of camel skin follicles was less in winter than in summer. Hynd et al. (2009) discovered that wool fiber crimp forms due to uneven cell growth in curved hair follicles, where pressure changes during hardening cause the fiber to bend. How tight these curls are depending on when hardening happens. Delayed keratinization keeps fibers flexible longer and reducing crimp incidence. Therefore, the lower crimp frequency found in the current study may be attributed to lower cell proliferation and/or less keratinization rate in winter than in summer.

Table (1). Seasonal and Spatial Coat Characteristics of Dromedary Female Camels (Mean ± Standard Error)

Item	Coat depth (cm)	Fiber diameter (µm)	Fiber Length (cm)		Crimp Frequency (crimp/cm)		Fiber type				
			Coarse fibers	Fine Fibers	Coarse fibers	Fine fibers	Kemp	Medullated	Heterotype	Fine	Medulla Index
Effect of season	*	*	*	*	*	*	**	*	*	ns	ns
Summer	1.99^{b}	32.81^{a}	5.65^{a}	6.91^{a}	0.28^{a}	0.52^{a}	2.61^{a}	51.27^{b}	0.00^{b}	46.23	15.26
Winter	2.78^{a}	32.02^{b}	3.05^{b}	3.40^{b}	0.10^{b}	0.28^{b}	0.40^{b}	53.53^{a}	0.60^{a}	46.91	15.20
Effect of position	*	*	*	*	*	*	ns	*	ns	ns	*
Neck	3.32^{a}	38.43^{a}	8.35^{a}	5.38^{b}	0.20^{ab}	0.33^{de}	1.47	59.96^{a}	0.41	38.43	15.12^{abc}
Nape	2.21^{bc}	38.40^{a}	7.66^{a}	5.53^{cb}	0.21^{ab}	0.26^{e}	1.70	55.85^{ab}	0.11	42.38	14.42^{c}
Withers	2.24^{bc}	29.95^{cd}	2.41^{d}	4.06^{e}	0.10^{c}	0.28^{e}	1.08	40.30^{c}	0.51	58.26	14.69^{c}
Hump	2.13^{bc}	34.51^{b}	5.82^{b}	6.99^{a}	0.26^{a}	0.50^{ab}	1.67	45.88^{bc}	0.19	52.27	14.43^{c}
Hip	2.01^{c}	29.00^{d}	3.23^{c}	5.18^{b}	0.10^{c}	0.57^{a}	1.30	50.12^{abc}	0.48	53.25	14.96^{bc}
Shoulder	2.25^{bc}	30.00^{cd}	3.28^{c}	6.41^{a}	0.17^{b}	0.44^{bc}	1.81	51.30^{abc}	0.21	47.19	15.69^{abc}
Mid side	2.53^{b}	29.50^{d}	2.26^{d}	4.17^{cd}	0.11^{c}	0.42^{c}	1.70	50.83^{abc}	0.11	42.38	16.10^{ab}
Breech	2.41^{bc}	29.57^{cd}	1.81^{d}	3.56^{e}	0.09^{c}	0.40^{d}	1.33	57.45^{a}	0.41	38.43	16.45^{a}
Interaction Effect	*	*	*	*	*	*	*	*	*	ns	*
Overall means	*2.39*	*32.42*	*4.35*	*5.16*	*0.19*	*0.40*	*1.51*	*51.46*	*0.30*	*46.57*	*15.23*
SEM	*0.07*	*0.16*	*0.12*	*0.09*	*0.01*	*0.01*	*0.22*	*1.82*	*0.03*	*2.10*	*0.20*

*Sig.: Significance, ns: Non-significance, *P<0.05, **P<0.01, SEM standard error of means.*
Means in the same row and trait having different superscripts are significantly different (P<0.05).

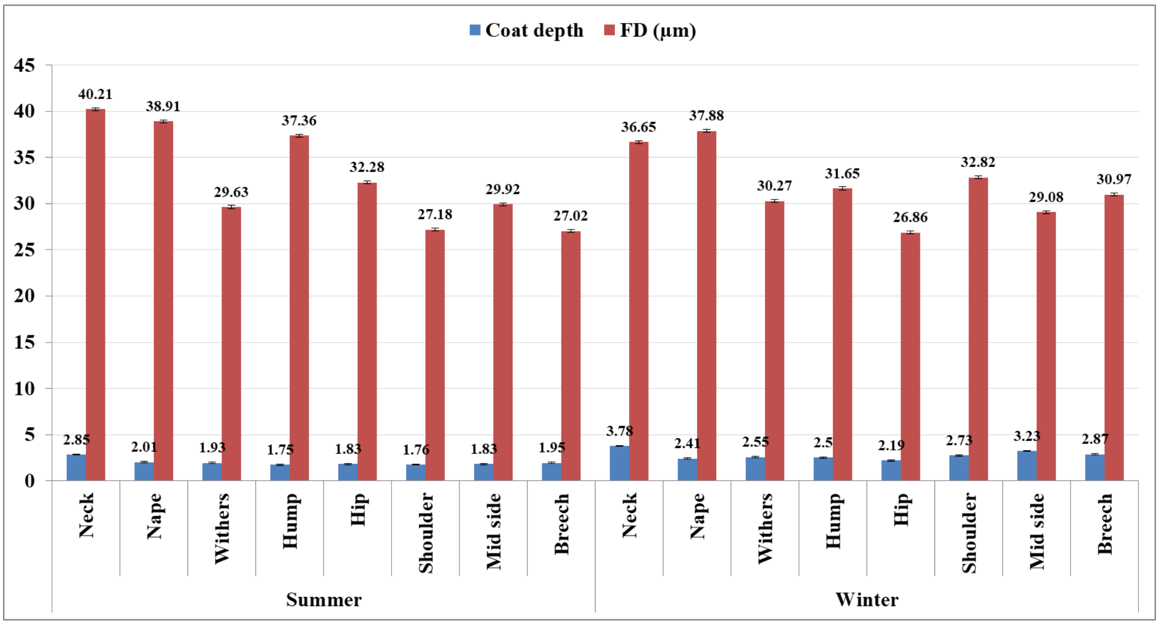

Fig. (3). The interaction effect between season and body position on coat depth and fiber diameter of studied camels.

Spatially, the crimp frequency for coarse fibers was highest at the hump position, while it was lowest at the breech position, corresponding to the fine fibers at the hip and nape positions, respectively. Notably, crimp frequency increased with fiber length (Akbar et al., 2024). The interaction between season and sampling position significantly ($p<0.05$) affected crimp frequency (Fig. (5)).

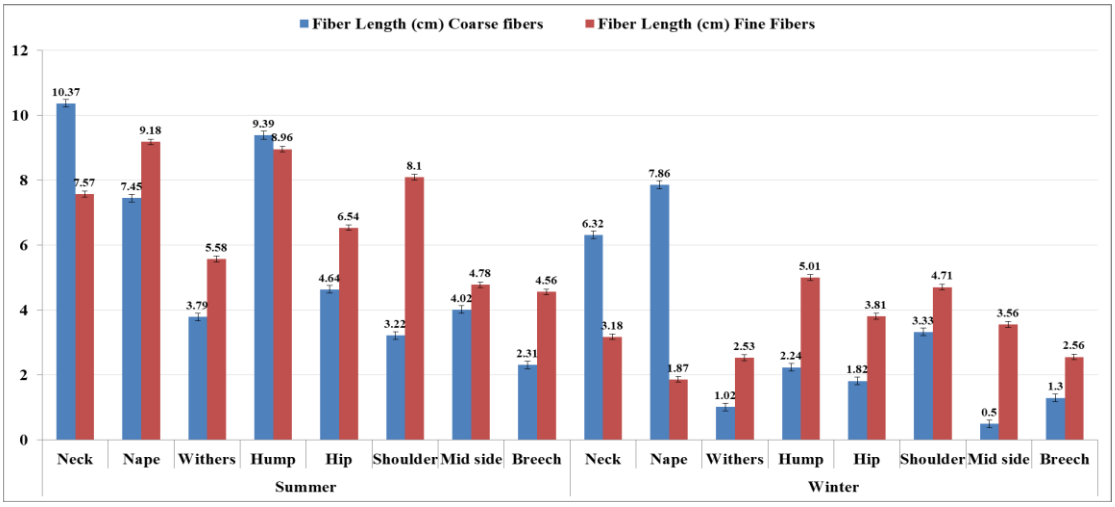

Fig (4). The interaction effect between season and body position on the length of coarse and fine fibers of studied camels.

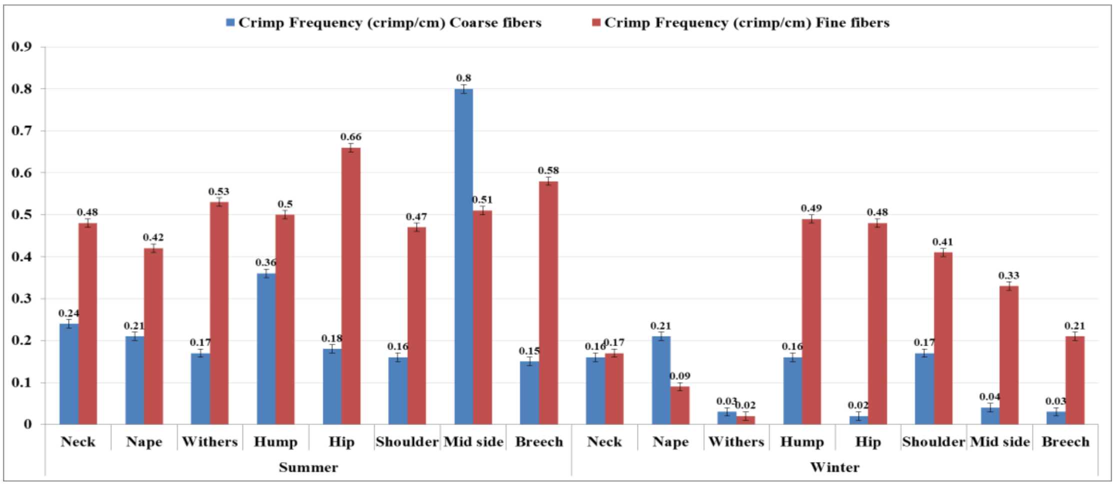

Fig. (5). The interaction effect between season and body position on crimp frequency of coarse and fine fibers of studied camels.

Season significantly ($p<0.01$) affected the percentages of kemp fibers (higher in summer) and had significant ($p<0.05$) effects on medullated and heterotype fibers (lower in summer), suggesting an adaptive response for UV protection by kemp fibers (Helal et al., 2015) and insulation by medullated fibers (Ku´znicka & Grondkowska, 2014). The fine fiber percentage and medulla index were not significantly affected by season.

Body position significantly ($p<0.05$) influenced medullated fibers, which were highest in the neck, breech, and nape positions and lowest in the withers position. The medulla index was significantly ($p<0.05$) higher in lateral regions (breech, mid-side, and shoulder) and increased from anterior to posterior. The interaction between season and body position showed inconsistent trends for fiber type percentages (Fig. (6)), while the medulla index remained consistent across seasons for each position. These variations in fiber types and medulla index across body regions likely represent functional adaptations to specific environmental demands and physical stresses (Alibayev et al., 2020).

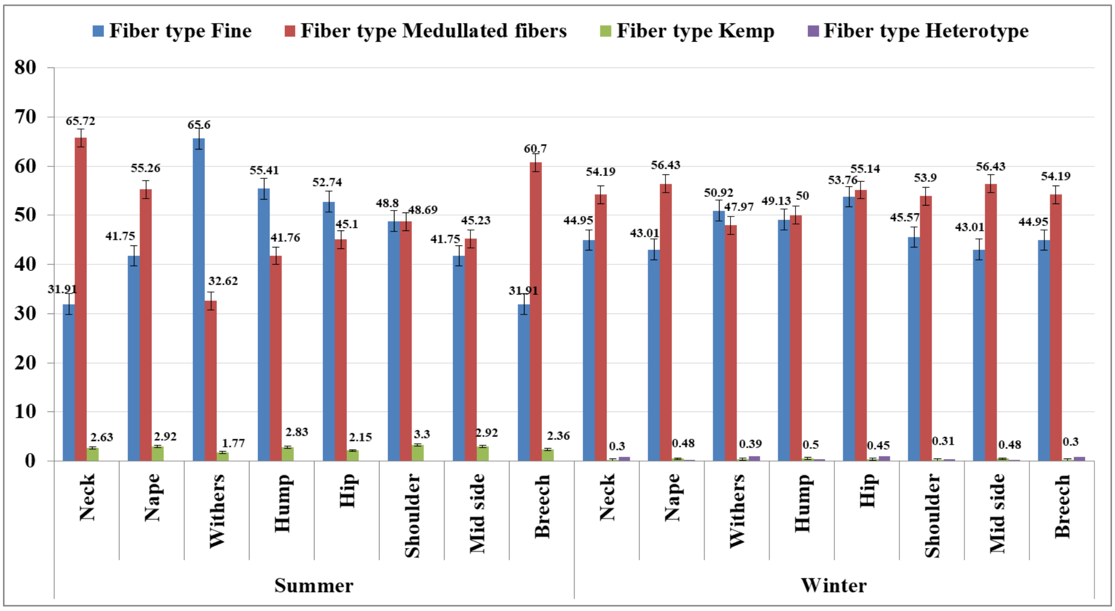

Figure 6. The interaction effect between season and body position on fiber types of studied camels.

CONCLUSION

This study reveals significant seasonal and spatial variations in she-camel coat depth and fiber diameter, reflecting adaptive responses to environmental conditions. The winter coat is ~40% thicker than in summer, providing insulation against cold, while the thinner summer coat reduces heat retention and protects against solar exposure. Notably, the neck region consistently had the greatest coat depth and fiber diameter, suggesting a thermoregulatory role in this highly exposed area.

Spatial variations in fiber characteristics further emphasize the camel's adaptability, with significant differences in fiber length and crimp frequency observed across body positions. The longer fibers in summer, particularly in areas like the neck and hump, may offer additional UV protection.

Overall, these results underscore the complex interplay between seasonal changes and anatomical factors in shaping the hair coat characteristics of she-camels, reflecting their evolutionary adaptations to diverse environmental challenges. Future research could further investigate these adaptations and their implications for camel husbandry and management in varying climates.

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الملخص العربي

الاستجابات التكيفية لغطاء جسم الجمل العربي للتغيرات المناخية الموسمية في الساحل الشمالي الغربي لمصر

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يُعد غطاء جسم الجمل العربي سمة تكيفية أساسية، تُمكّنه من البقاء في بيئات متنوعة وصعبة. تم في هذا البحث دراسة الاختلافات الموسمية والمكانية في خصائص غطاء جسم إناث الجمل العربي البالغة *(Camelus dromedarius)* استجابةً للظروف المناخية شبه القاحلة في الساحل الشمالي الغربي لمصر. أُجريت الدراسة في محطة بحوث مريوط من يونيو 2023 إلى مايو 2024، وتم مراقبة البيانات الجوية باستمرار، بما في ذلك درجة الحرارة المحيطة والرطوبة النسبية، لحساب مؤشر درجة الحرارة والرطوبة (THI). تم إيواء اثنتي عشرة جملًا غير حامل وغير مرضعة (12-14 عامًا، بمتوسط وزن 345 ± 8.12 كجم) في حظائر مظللة جزئيًا مع نظام غذائي مُتحكم فيه وإمكانية الوصول إلى الرعي اليومي. تم جمع عينات شعر تزن حوالي 50 جرامًا من ثماني مناطق من الجسم لقياس طول الوبر، وقطر الألياف، ونسبة نوع الألياف، وطول الألياف، وتواتر التجعد، ومؤشر التبلور. كشفت النتائج عن اختلافات موسمية ومكانية كبيرة في معايير الوبر. كان طول الوبر أكبر بنسبة 40٪ تقريبًا في الشتاء، مما يوفر عزلًا أساسيًا، بينما ساعدت الالياف الرقيقة في الصيف على تبديد الحرارة والحماية من الشمس. أظهرت منطقة الرقبة باستمرار أكبر طول للوبر وقطر للألياف، مما يشير إلى وجود حاجة وظيفية لتعزيز الحماية في هذه المنطقة المكشوفة. كانت الاختلافات المكانية واضحة أيضًا في طول الألياف وتواتر التجعد، حيث من المحتمل أن توفر الألياف الأطول في الصيف (مثل الرقبة والسنام) حماية أكبر من الأشعة فوق البنفسجية. تُبرز هذه النتائج التفاعل المُعقّد بين التغيرات المناخية الموسمية والعوامل التشريحية في تشكيل فراء الجمل العربي، مما يعكس تكيفات تطورية عميقة. ينبغي أن تُواصل الأبحاث المستقبلية استكشاف هذه التكيفات لتحسين تربية الإبل وإدارتها في مناخات مُختلفة.

الكلمات الدالة: موضع الجسم، الصحراء، الوبر، الموسم.