Hormonal profile in rutting and non-rutting periods in dromedary camel (*Camelus dromedarius*)

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Abstract

The dromedary camel is a seasonally breeding animal. The breeding season (also called "rutting period" or "rut") of this species coincides with the winter months and is characterized by significant changes in circulating hormonal levels. During the rutting period (winter season), the circulating levels of testosterone, cortisol and thyroid hormones are significantly higher than in the summer (non rutting season), however levels of vitamin D are very low in the winter, compared with those analyzed in non-rutting period (summer season). These changes may modulate the reproduction function and the thermoregulatory adaptation. Concentrations of circulating hormones during the rutting period vary greatly in the literature which could be explained by environmental and experimental conditions. In the camel, understanding the seasonal fluctuations of the hormonal profile of the camels, can contribute to a fundamental knowledge of the reproduction physiology of this species, and will be of great importance to veterinarians in confirming their clinical diagnosis and enhancing the capacities of camel production and reproduction. The mechanisms of TH, glucocorticoids and vitamin D in the modulation of reproductive function and fertility in the dromedary remain to be studied.

Keywords: Testosterone, Thyroid hormones, Cortisol, Vitamin D, Season, Camel, Morocco.

Profil hormonal en périodes de rut et de non-rut chez le dromadaire (*Camelus dromedarius*)

Résumé

Le dromadaire est un animal à reproduction saisonnière. La saison de reproduction (également appelée «période de rut» ou «ornière») de cette espèce coïncide avec les mois d'hiver et se caractérise par des changements importants des taux circulants de plusieurs hormones. Pendant la période de rut (saison hivernale), les taux circulants de testostérone, de cortisol et d'hormones thyroïdiennes sont significativement plus élevés qu'en été, alors que les taux de vitamine D sont très faibles en hiver, par comparaison à ceux analysés durant la saison estivale. Ces changements hormonaux pourraient moduler la fonction de reproduction et l'adaptation de la thermorégulation de l'animal. La variation dans la littérature des valeurs des concentrations de la plupart de ces hormones circulantes pendant la période de rut, pourrait s'expliquer par les conditions environnementales et expérimentales dans lesquelles les études ont été réalisées. Chez le dromadaire, l'étude des fluctuations saisonnières du profil hormonal pourrait contribuer à la connaissance fondamentale de la physiologie de la reproduction de cette espèce, et sera d'une grande utilité pour les vétérinaires pour orienter leur diagnostic clinique et améliorer les potentialités de production et de reproduction de cette espèce. Les mécanismes des hormones thyroïdiennes, des glucocorticoïdes et de la vitamine D dans la modulation de la fonction de reproduction et de la fertilité chez le dromadaire restent à étudier.

Mots-clés: Testostérone, Hormones thyroïdiennes, Cortisol, Vitamine D, Saison, Dromadaire, Maroc

INTRODUCTION

The dromedary camel (*Camelus dromedarius*) is able to survive under harsh environmental conditions and plays a vital role in the subsistence economy of pastoral peoples in arid and semi-arid regions by providing efficient services in agriculture as well as valuable products such as milk, meat and hair (Faye, 2014). In several mammalian species the reproductive performance is influenced by multiple interactions between photoperiod, ambient temperature, nutrition, housing, latitude and hormones (Wilson, 1984; Zia-Ur-Rahman *et al*., 2007).

Camels are known as seasonal breeders but sexual behaviour is very variable due to the wide geographical distribution of this species. Generally its breeding season is related to the period of low humidity, low temperature and increased rainfall (Skidmore, 2005). Globally, the camel breeding season runs from September to June in the different parts of the Northern World, and from June to September in the Southern parts of the World (Marai *et al*., 2009). The reproductive efficiency of camel under natural conditions is generally regarded to be low. This is probably due to the relatively short breeding season, a longer prepubertal period, a long gestation period of 13 months, a prolonged (8-10 months) period of lactation-related anestrus leading to a long intercalving interval, and the lack of use of assisted reproductive techniques such as embryo transfer and artificial insemination (Skidmore, 2005). So, the scientific community is increasingly interested in intensifying camel productions, diversifying their

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use and, valuing this species to enrich the economy and ecology of desert regions in the face of climate change.

Testosterone (T), glucocorticoids, thyroid hormones (TH) and vitamin D have long been known to be important in animal nutrition as they may play an important role in some metabolic activity, bone formation and reproductive function, and may be considered as indicators of the metabolic and nutritional animal status (Todini, 2007; Roth, 2008). In addition, cortisol (COR) and TH have been used as indicators of stress in horses (Fazio *et al*., 2015), alpacas (Anderson *et al*., 1999), goat (Kadim *et al*., 2006) and dromedary camel (Nazifi *et al*., 2009; Baraka, 2012; El Khasmi *et al*., 2015). In this context, baseline data on the hormonal profile and its variations at different physiological stages (perinatal, postnatal, gestation, lactation) and different environmental conditions (season) in dromedary camels will be of a great benefit for breeders, veterinarians and clinicians.

Previous researchs on indices of various hormonal profiles in camels during the breeding season are incomplete and/or show wide fluctuations. Therefore, in this review, we discuss the circulating levels of some hormones (T, TH, COR and vitamin D) during the rutting (winter) and non-rutting periods. A comparison of these levels with those observed in other animals are included.

TESTOSTERONE

The importance of the hypothalamic–pituitary–testicular axis (HPTA) in the regulation of male fertility is well known. Spermatogenesis in mammals is regulated by a number of peptide and steroid hormones, mainly follicle-stimulating hormone (FSH), luteinizing hormone (LH) and testosterone (T). The production of FSH and LH is stimulated by gonadotropin releasing hormone (GnRH) made by the hypothalamus. T is a steroid hormone, secreted primarily in males by the Leydig interstitial cells in the testicles under the control of the pituitary gland. This hormone is necessary for the spermatogenesis and development of the genitals, and therefore for fertility. It is also able to modulate the development and maintenance of libido, the secretory activity of male accessory glands, and the development of increased muscle mass and other secondary sexual characteristics comprising the male phenotype (Meachem *et al*., 2001). In addition, T influences the synthesis of a number of caput and cauda epididymal proteins. Some of these proteins are important for improvement of spermatozoa maturation, storage and their acquisition of fertilizing ability (De Pauw *et al*., 2003).

Seasonal variation in reproduction is common in mammals as an adaptation to annual changes to their environment, and has been described by serum and faecal T as well as testis volume and sperm output in the breeding season in bucks (Todini, 2007), sheep (Notter, 2002), and camel (Maha *et al*., 2016).

The dromedary camel (*Camelus dromedarius*) is regarded as seasonal breeder and its breeding season is confined to the coolest winter months of the year (Wilson, 1984; Skidmore, 2005). The impression gained is that decreasing day length is the stimulus to seasonality, but it is obvious that in dromedary camels near the equator factors such as rainfall, nutrition and management (Wilson, 1984) may override the effect of photoperiod (Merkt *et al.,* 1990) and allow breeding to occur throughout the year (Arthur *et al.,* 1982). The breeding season of camels varies geographically, since the environmental factors affect temporally the pattern of reproduction in this species (Gambe and Okela, 1977). Daylight ratio and temperature are able to influence the annual sexual cycles (Hafez *et al*., 1987). However, Abdel-Rahim *et al*., (1994) suggested that dromedary camels can reproduce during any season of the year providing there is an abundant food supply and good management.

The dromedary is known for its late sexual maturity and generally reaches puberty at the age of 3-4 years (Musa *et al*., 1993). Under normal conditions, the male dromedary becomes pubescent at the age of about 3 years, but its reproductive activity becomes complete only around the age of 6-7 years (Arthur *et al*., 1985). During the breeding season, males exhibit morphological, behavioral and endocrinological peculiarities, but the short breeding season, low libido and high aggressiveness are still some of the major causes of economic loss, poor reproductive performance and injuries in the camel breeding and industry.

The onset of the breeding season in camels is mostly associated with the display of certain behavioral characteristics. These include the increased activity of the poll gland, loss in body weight, exteriorization of the soft palate (dulla) and frequent urine spraying (El-Hassanein *et al*., 2004). In addition, the male shows other sexual behaviors such as sniffing, flehmen, whistling, tail flapping, salivary production, nervousness and poll gland secretion when in the presence on females (Padalino *et al*., 2015).

Peak T concentrations in breeding (winter) and non-breeding (summer) seasons vary according to the literature (Table 1). The rise in T concentration is negatively correlated with the environmental temperature and rainfall which is in accordance with previous reports for camels (Deen, 2008). Libido in males subsides in March or April, and cessation of libido and capability to copulate appears to be associated with decline in T concentration (Deen *et al*., 2005). In addition, elevation of the ambient temperature during summer (non- rutting season) seemed to play the main role in affecting the camel reproductive activities through disturbance of testis function (Maha *et al*., 2016).

Table 1: Circulating levels of testosterone (ng/mL) in rutting (winter) and no-rutting periods (summer) in male camels

Winter	Summer	References
7.56±0.20	2.32±0.15	Maha *et al*., 2016
13.49±1.37	1.58±0.30	Pasha *et al*., 2015
1.63±0.37	3.43±0.37	Al-Saiady *et al*., 2015
42.13±2.78	3.42±0.43	Deen *et al*., 2005
8.23 ± 2.11	2.13 ± 1.08	El Khasmi *et al*., 2011
7.95±1.85	2.89±0.26	El-Bahrawy and El Hassanein, 2011
2.74±0.48	1.11±0.25	El-Harairy and Attia, 2010

In camels, T concentrations and spermatogenesis are higher in the colder months of the breeding season, ie in the winter (rutting period) (El-Harairy and Attia, 2010; El-Kon *et al*., 2011). Generally T levels are consistently higher in testicular tissue than in circulating blood, and all of these concentrations increase significantly at puberty and during the breeding season (El-Harairy and Attia, 2010). According to several studies in camels the levels of T in testis, epididyme and seminal plasma, are significantly higher than those measured in the blood during the breeding season, and the sexual activity of this species is marked by an increase in the number and size of Sertoli cells and Leydig cells (El-Harairy and Attia, 2010; Maha *et al*., 2016). In addition, during the dromedary breeding season, the testis increases greatly in weight and size due to the extensive development of interstitial tissues (Pasha *et al*., 2013), and circulating testosterone concentrations are positively correlated with mating duration and volume of ejaculated sperm (Deen, 2008).

The morphological characteristics and staining pattern types of testicular cells in dromedary camels are similar to alpaca testicular cell morphologies as described by Stelletta *et al*., (2011). The cytological profile in camel testicles during the rutting season showed a significant increase in number of spermatozoa, spermatids, Sertoli cells, spermatocytes and spermatogonia in comparison with the non-rutting period (Stelletta *et al*., 2011).

In seasonal animals, photoperiod would be the most important factor allowing animals to regulate the time of reproduction and calving (Malpaux *et al*., 2002). The pineal gland and melatonin are therefore part of the neuroendocrine pathway controlling the reproductive system and inducing changes in gonadotropin secretion (Sweeney and O'Callaghan, 1995). According to El Allali *et al.,* (2005) the seasonality in camels is controlled by fluctuation in the melatonin hormone which is produced by the pineal gland during the night. Short or decreasing days stimulate the secretion of LH, which induces testicular growth and the release of T. In contrast, long or increasing days depress the secretion of LH, testicular growth, and the release of T (Pelletier *et al*., 1998).

THYROID HORMONES

Thyrotropin-releasing hormone (TRH) secreted from the hypothalamus binds to its receptors on the pituitary to control release of thyroid-stimulating hormone (TSH) which is then secreted by the anterior pituitary. This later binds to the TSH receptor on thyroid epithelial cells to signal the thyroid gland to secrete thyroid hormones (TH). This is named as the hypothalamus-pituitary- thyroid axis (HPThA). TH have a profound effect on the stimulation of energy metabolism, maturation of the skeleton through their effect on maturation of growth cartilage, stimulation of transcription of nuclear genes, as well as protein synthesis and respiration in mitochondria (Norris, 1997). Their role in metabolic pathways and antioxidant enzyme activities are well known in camels (Zia-ur-Rahman *et al.* 2007; Lektib *et al*., 2016).

In camels, circulating levels of TH increase at the age of puberty (Elrayh *et al*., 2009) but are lower in non pregnant females (Bengoumi *et al*., 1999) and higher during gestation as well as in the fetus and newborn (El Khasmi *et al*., 1999). Increased plasma levels of TH are needed for increased energy requirements during pregnancy (Nathanielsz *et al*., 1973) and are necessary for milk production after delivery (Tomov *et al*., 1984). In addition, thyroid status in camels is dependent on the presence of selenium (Nazifi *et al*., 2009), body metabolism, water availability (Yagil *et al*., 1978) and season (Nazifi *et al*., 1999; Abdel-Magied *et al*., 2000).

Seasonal changes in the circulating concentrations of TH had been stated in several domestic animals (Abdel-Samee, 1996; Nazifi *et al*., 1999; Ashutosh *et al*., 2001). Higher concentrations of TH are observed in the winter and the rainy season compared with those observed in the summer (Table 2), and are known to influence the productive performance and heat production in sheep (Nazki *et al*., 1986) and camel (Abdel-Magied *et al*., 2000; Tajik *et al*., 2013). Generally, as the circulating levels of TH are higher during the winter season they may be regarded as indicators of cold stress and adaptations to the environment in several species such as cattle (Grandon, 1997), sheep (Ashutosh *et al*., 2001), goat (Todini, 2007), alpacas (Anderson *et al*., 1999) and camel (Bargaâ *et al*., 2016a).

Furthermore, the histological aspect of the dromedary thyroid also varies with the season. Thus, histological studies of the thyroid gland of this species during the season have shown that follicular cells of this gland are hypoactive in summer compared to winter (Abdel-Magied *et al*., 2000). In addition, during the warm season, there is a slowing of the general metabolism, and therefore of the activity of the thyroid in camels (Bengoumi and Faye, 2002) and sheep (Kamal *et al*., 1989). In cattle, the response to TRH stimulation in terms of TH is reduced in bovines exposed to high temperatures (32°C) compared to those exposed to lower temperatures (4°C). Thus, the exposure to heat stress leads to a decrease in plasma T3 and T4 level from 4.55 and 21.27 to 3.21 and 16.70 pmol/L respectively in goats (Sivakumar *et al*., 2005).

Ultimately, in domestic animals, circulating TH concentrations increased with decreasing ambient temperatures. According to several studies, acute cold stress or some degree of cold acclimation resulted in an increase of TH secretion rates, as in camel (Yagil *et al*. 1978), llama (E1-Nouty *et al*., 1978), Holstein calves (Baccari *et al*., 1983), sheep (Ashutosh *et al*., 2001) and goat (Abdel-Samee, 1996). Also, Khanna *et al*., (1996) reported that T4 levels in the summer fell gradually in dehydrated dromedary camels and increased after rehydration, whereas in the winter T4 levels increased in dehydrated camels.

In contrast to the above reports, Ashutosh *et al*., (2001) reported that in Indian native sheep the concentration of serum T3 was maximal in the summer, followed by the rainy season. Also, according to Zia-ur-Rahman *et al*., (2007) circulating levels of T3 and T4 (ng/mL) in dromedary camels, decrease during rutting period coinciding with the winter season. This decrease may be due to the fact that the animal spends most of its time during this period of sexual activity in search of camels (Zia-ur-Rahman *et al*., 2007). Nazifi *et al.,* (1999) have reported that dromedary thyroid metabolism is higher in summer compared to winter (Nazifi *et al*., 1999). In addition, plasma T4 increases with seasonal changes in daily food intake and body weight gain of red deer and reindeer during summer (Barboza *et al*., 2004).

Seasonal reproduction is generated by an endogenous circannual rhythm of reproductive neuroendocrine activity and is synchronised by the photoperiod (Rosa and Bryant, 2003). Parkinson and Follett (1994) showed that hypothyroidism abolished the seasonal (photorefractory) inhibition of reproductive ability and regression of testis in Welsh Mountain rams and suggested that thyroid gland may be involved in seasonal transition of reproductive activity in the ram. In this species, thyroidectomy, reduced sperm density and motility and increased percentage of abnormal spermatozoa (Brookes *et al*., 1965).

In camels, higher T3 levels are observed in the epididymal plasma during the rutting season compared with those observed in the non-rutting season (2.16±0.08 ng/mL vs 1.98±0.07 ng/mL) (Maha *et al*., 2016). According to Beyzai and Adibmoradi (2010), the number of the follicular epithelial cells of thyroid in ostriches were significantly increased in winter. These reports and several others (Huszenicza *et al*., 2000; Krassas *et al*., 2010; Dutta *et al*., 2013; Lal *et al*., 2016; Maha *et al*., 2016) suggest that TH may play an important role in the mammalian reproduction function. Furthermore, recently, it was stated that hyperprolactinemia and hypothyroidism may play a key role in etiopathogenesis of infertility in woman (Lal *et al*., 2016).

The thyroid gland has also been suggested to have a significant effect on the male reproductive tract, spermatogenesis, male fertility (Singh *et al*., 2011) and stimulation, differentiation and maturation of Sertoli cells (Buzzard *et al*., 2003).

Specifically, TH receptors are located on the Sertoli cells in the seminiferous tubules suggesting that TH may affect the growth and development of the male testes (Cooke, 1991). The effects of differing concentrations of TH on the reproductive system have been studied extensively in human subjects and animal models and have shown that changes from the normal thyroid function resulted in decreased sexual activity and fertility (Krassas *et al*., 2010). In Khuzestan buffaloes, Mayahi *et al*. (2014) have studied the seasonal variation of semen quality (semen volume and spermatozoa parameters) and have stated a significantly higher concentration and motility of spermatozoa in winter, with a positive correlation between spermatozoa concentration and T3 value in blood serum. Data from other animal species (such as deer, sheep, cattle, birds, and mink) also suggest that T3 is a component of the neuroendocrine system that regulates seasonal cycles of reproductive activity (Dutta *et al*., 2013).

Additionally, in immature male mice aged less than 4 weeks, the administration of slightly supra-physiological T4 doses resulted in a tendency toward early maturation and shortening of the development period. Conversely, larger TH doses resulted in decreased testes weights and seminal vesicles, both in mice and rabbits (Krassas *et al*., 2010). There is some evidence that indicates that the factors that have an inhibitory effect on thyroid function might reduce reproductive efficiency (Huszenicza *et al*., 2000). In fact, rats made transiently hypothyroid by propylthiouracil administration showed a decrease in testicular size, retardation in Sertoli cell differentiation, and a prolongation of Sertoli cell proliferation time (Bunick *et al*., 1994). They also showed an arrest of sexual maturity, decreased testosterone concentration as well as an absence of libido and ejaculate (Weiss and Burns, 1988).

CORTISOL

In mammals, cortisol (COR) is one of the hormones secreted by the adrenal gland in response to stress and is the principle hormone in the hypothalamic-pituitary-adrenocorticol axis (HPAA) which affects both neurotransmission and neuroendocrine control (Engelking, 2000). Adrenocorticotrophic hormone (ACTH) release can be triggered under conditions of chemical, physical, and emotional stress, such as extreme external cold or heat (Engelking, 2000) and leads to an increase in COR secretion. Many studies have showed that blood COR is the most reliable indicator for assessing stress in goats (Aoyama *et al*., 2005), horses (Fazio *et al*., 2015) and dromedary camels (El Khasmi *et al*., 2015). It was also reported that circulating COR levels varies depending on the season in most of these species (Alila-Johansson *et al*., 2003; Baraka, 2012).

In dromedary camels, COR levels determined in serum, hair and feces (Bargaâ *et al*., 2016b) in the winter and rainy seasons (rutting season) were significantly higher than those measured in summer (non-rutting season). The same seasonal changes in cortisolemia were reported in cows (Titto *et al*., 2013), goats (Alila-Johansson *et al*., 2003) and sheep (Nazki and Rattan, 1991). In contrast, a higher cortisolemia (ng/ml) in summer rather than winter had been observed by Baraka (2012), and Elias and Weil (1989). The same comparison had been reported in the same species for corticosteroneemia by Zia-ur-Rahman *et al*., (2007). These authors have suggested that this adrenocortical hyperactivity observed in summer is probably caused by external heat stress and body dehydration following intense sweat losses as a major thermolytic pathway.

The adrenal activity of dromedaries is stimulated by ACTH. In fact, it was shown in this animal that an intravenous injection of ACTH (0.5 mg) increased the level of cortisol in the blood and that of the metabolites of the glucocorticoids in the faeces (Sid-Ahmed *et al*., 2013). Twenty-four hours after the injection, the COR level rose from 0.6-10.8 to 10.9-42.2 ng/ml in the blood, and from 286.7 to 2559.7 ng/g in the faeces. Positive correlations between circulating and fecal levels of COR have been reported in camels (Bargaâ *et al*., 2016b), cattle (Tallo-Parra et al., 2015) and cats and dogs (Accorsi *et al*., 2008). In addition, in horses, salivary COR concentrations increased significantly during the breeding season, and were correlated with increased circulating levels of T (Aurich *et al*., 2015).

In camels, the rutting period might be considred as a stressfull situation with high levels of circulating COR (Table 3). In fact, during this period, the male can get very agressive and present some behavioural characteristics such as the extrusion of the soft palate as well as becoming very vocal (Marai *et al*., 2009). In this species, high serum malondialdehyde levels, low serum catalase activity (Lektib *et al*., 2016) and high hemolysis (Bargaâ et *al*., 2016a) were reported in winter suggesting a stress oxidant of the rutting season. In addition, Alonso-Alvarez *et al*., (2007) reported that an experimental elevation of testosterone levels in adult male zebra finches (*Taeniopygia guttata*) had been able to increase oxidative damage and inhibit antioxidant activity during a free radical attack.

Thermal stress includes both heat stress, during the extreme summer season as well as cold stress, during the extreme winter season, both of which lead to the secretion of glucocorticoids. In camels, COR and testosterone are both critical endocrine variables that affect stress responses and sexual activity in winter. Environmental stress can cause low sperm quality which is closely related to low fertility and production of livestock (Alejandro *et al*., 2014). Elevated circulating glucocorticoid levels in response to cold stress have also been clearly documented in farm animals (Dantzer and Mormede, 1983).

T levels in Awassi rams exposed to electrical stimulation stress during the breeding season appeared to decline over time (Alomar *et al*., 2016). A cause-effect relationship between adrenal hormones and T levels following electro-ejaculation has been suggested for certain species such as cattle (Welsh and Johnson, 1981) and cats (Carter *et al*., 1984). On the other hand, during stressful events in mice, the blood level of T may be reduced due to the deterioration of blood flow in the testicles (Kamiya *et al.*, 2003). The assumption of a regulatory role of cortisol on spermatogenesis is further supported by experiments where apoptosis within the germinal epithelium was induced by exogenous application of dexamethasone in rats (Yazawa *et al*., 2002).

VITAMIN D

Vitamin D is either obtained from diet or synthesised in the skin from 7-dehydrocholesterol. In the liver, vitamin D undergoes hydroxylation into 25-hydroxyvitamin D (25-OH-D), the major circulating form of the vitamin. Another hydroxylation at 1- α-carbon takes place in the renal tubules to form 1,25- dihydroxyvitamin D or calcitriol [1,25$(OH)_2$-D], the biologically active form. Calcitriol maintains the plasma calcium and phosphorus levels by increasing the expression of the epithelial calcium channel-TRPV6 and the intracellular calcium transporter- Calbindin 9 K (Lips, 2006). Vitamin D is synthesized in the skin of many herbivores and omnivores, including humans, rats, pigs, horses, poultry, sheep and cattle. Circulating 25-OH-D is considered as a biomarker of vitamin D status and it is closely linked with the consumption of foods and exposure to sunlight (Zerwekh, 2008).

In camels, the circulating levels of 25-OH-D are higher during the non-rutting period (summer) than those observed during the rutting period (winter) (395±25 ng/mL vs 304±22 ng/mL, El Khasmi *et al*., 2011). However, in the same species, tissue (muscle, liver and kidney) concentrations of 25-OH-D showed no seasonal variation (Bargaâ *et al*., 2015). The higher circulating levels of 25-OH-D observed in our camels in summer may be explained by the increased daylight during this season. According to Hymoller *et al.,* (2009), the vitamin D status in cattle is determined by season rather than supplementation.

Species vary in their ability to form vitamin D in their skin. This cutaneous biosynthesis is a function of 7-dehydrocholesterol concentration in the epidermis, melanin pigmentation, and the solar zenith angle which depends on latitude, season, and time of day (Olmos-Ortiz *et al*., 2015). Exposure of rats to ultraviolet light leads to a 40-

Table 2: Circulating levels of thyroid hormones in rutting (winter) and non-rutting periods (summer) in male camels

Winter	Summer	References
T4 : 15.44 ± 0.35 µg/dL T3 : 3.25 ± 0.10 ng/mL	T4 : 13.46 ± 0.24 µg/dL T3 : 2.33 ± 0.10 ng/mL	Maha *et al*., 2016
T4 : 105.53 ± 7.72 nM T3 : 2.00 ± 0.05 nM	T4 : 177.60 ± 21.87 nM T3 : 2.65 ± 0.10 nM	Nazifi *et al*., 1999
T4 : 20.41 ± 0.25 pM T3 : 17.24 ± 0.25 pM	T4 : 12.64 ± 0.09 pM T3 : 14.52 ± 0.25	Rejeb *et al*., 2011
T4 : 219.40 ± 0.99 nM T3 : 4.17 ± 0.24 nM	T4 : 115.70 ± 7.20 nM T3 : 2.80 ± 0.21 nM	Tajik *et al*., 2013
T4 : 271.9 ± 65.35 nM T3 : 4.06 ± 0.45 nM	T4 : 155.68 ± 33.1 nM T3 : 1.55 ± 0.31 nM	Bargaâ *et al*., 2016a

T3 : triiodothyronine, T4 : tetraiodothyronine or thyroxine, FT3 : free T3 and FT4 : free T4.

Table 3: Circulating levels of cortisol in rutting (winter) and non-rutting periods (summer) in mammalian species

Species	Winter	Summer	References
Rams	0.63–2.27 nmol/L	11.30 nmol/L	Alomar *et al*., 2016
Cattle	2.35 ± 0.11 ng/mL	12.37 ± 0.19 ng/mL	Chandra *et al*., 2012
Camel	8.0 ± 1.3 ng/mL	45.0 ± 11.9 ng/mL	Elias and Weil, 1989
Camel	28.5 ± 4.8 ng/mL	38.6 ± 5.3 ng/mL	Baraka, 2012
Camel	135.43 ± 17.17 ng/mL	93.92 ± 18.19 ng/mL	Bargaâ *et al*., 2016b
Camel	78.50 ± 13.12 nmol/L	106.51 ± 14.63 nmol/L	Baraka, 2012

fold increase in vitamin D. In contrast, similar irradiation of dogs and cats does not significantly increase dermal vitamin D concentration (How and Hazewinkel, 1994). Most herbivores are able to produce vitamin D in response to ultraviolet irradiation of the skin, as indicated by the higher concentrations of serum vitamin D in shorn sheep compared with unshorn sheep (Hidiroglou *et al*., 1985). Furthermore, when transferred to lower altitudes or higher latitudes where solar radiation is much lower, serum vitamin D concentrations in llamas and alpacas decline to low levels, especially during winter (Van Saun *et al*., 1996). Crias (lama) born in autumn/winter that had lower vitamin D concentrations were more likely to develop rickets than those born in summer (Van Saun *et al*., 1996).

Circulating levels of 25-OH-D in camels are much higher than those of bovine species, however, the amounts of 25-OH-D in camel meat may be considered similar to those measured in bovine meat (El Khasmi et al., 2011; Bargaâ *et al*., 2015). These high circulating levels may modulate the reproduction activity in camels. In mammalian species, several investigations have suggested that vitamin D supplementation may have implications for managing reproductive performance and male infertility, as well as contributing to spermatogenesis by upregulating certain specific genes in the Sertoli's cells (Hirai *et al*., 2009; Menegaz *et al*., 2009). Furthermore, in Vitamin D-deficient male rats with incomplete spermatogenesis and degenerative testicular changes, Menegaz *et al*. (2009) suggested that calcitriol may play a critical role in the maintenance of normal reproduction via a genomic mechanism that can be triggered by protein kinase A, as well as a rapid response mechanism involving Ca^{2+}/K^{+} channels in the plasma membrane. In another publication, it was concluded that both low (<50 nmol/L) and high (>125 nmol/L) concentrations of vitamin D are associated with decreased number and quality of spermatozoa in semen (Dabrowski *et al*., 2015).

CONCLUSION

High circulating levels of TH and COR associated with peak T concentrations in rutting camels, suggest that during the breeding season (winter) these hormones play an important role in the reproduction of the animal, and may be considered as indicators of cold and rut stress. The mechanisms of TH, glucocorticoids and vitamin D in the modulation of reproductive function and fertility in dromedary remains to be studied. As the winter season coincides with active spermatogenesis and steroidogenesis, low ambient temperatures and aggressive sexual behavior, we recommend that camels be supplied with trace minerals and vitamins D, E and C during the winter season.

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