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Blood, Milk and Meat Vitamin D in the Dromedary Camel

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ABSTRACT

In ruminants, circulating vitamin D levels may be influenced by photoperiod, nutrition, physiological stage, ambient temperature, attitude and season, whereas, in meat, vitamin D content may be impacted by vitamin D status of animal, ageing and cooking. The information on nutritional value of camel milk and meat is largely available, but, there are very few reports evaluating the vitamin D levels and their variations in blood and these products in the dromedary camel. In this context, this review proposes a gathering of current knowledge about the vitamin D in this species and discusses findings considering those obtained in other mammal animals.

KEY WORDS blood, milk, meat, oxidant stress, 25-hydroxyvitamin D.

INTRODUCTION

In mammal species, the physiological control of phospho-calcic metabolism and skeletal remodeling is normally under regulation of systemic hormones (especially calcitonin and parathormone) and vitamin D (Holick, 2007). Vitamin D has a double origin: (i) exogenous origin for vitamin D_2 or ergocalciferol in plant, and for Vitamin D_3 or cholecalciferol in animal tissues and milk), (ii) endogenous origin by skin conversion of 7-dehydrocholesterol to vitamin D_3 in the presence of sunlight. Historically, vitamin D deficiency has been associated with osteomalacia, osteopenia, osteoporosis and muscle weakness, illustrating the crucial role of vitamin D in bone mineralization and calcium (Ca) absorption. It regulates the Ca and phosphorus (P) levels in the bloodstream and promotes the healthy growth and bone turnover. These actions are mediated by the vitamin D receptor (VDR), which is principally located in the nuclei of target cells. When the calcitriol binds to the VDR, this later acts as a transcription factor by modulating the gene expression of transport proteins (such as TRPV6 and calbindin), which can enhance the intestinal Ca absorption (Holick, 2007).

Vitamin D may also play a protective role against hypertension, cardiovascular disease and some cancers and be an important modulator of the immune system by modulating the action of many genes. So, low levels of serum 25-hydroxyvitamin D (25-OH-D) seem to be associated with heart diseases, cancers, diabetes, immune deficiency, depression, neuro-degeneration and chronic pain (Holick and Chen, 2008). Vitamin D metabolism and status in camel was investigated by few authors. Yet, camels who are occupying an essential place in the rural life of the arid and semi-arid regions of Africa and Asia, are an important potential purveyor of milk and meat, in acceptable quantity and quality when other ruminants cease all production or

fail to survive (Faye, 2014). Camel meat is known by lower levels of fat and cholesterol, higher amounts of essential amino acids, polyunsaturated fatty acids (PUFAs), but also minerals and vitamins including vitamin D, in comparison to other red meats (Kadim *et al.* 2006; El Khasmi *et al.* 2013a; Raiymbek *et al.* 2015). Camel milk is known also for its richness in some vitamins as vitamin C and D (Farah *et al.* 1992; Riad *et al.* 1994).

Thus, highlighting physiological role of this hormone justifies its growing interest. The present review proposes a gathering of current knowledge about the vitamin D in the dromedary camel and discusses findings in light of those obtained in other mammalian animals.

Metabolism and role of vitamin D

The two major natural sources of vitamin D to most vertebrate animals and humans result from photochemical conversion of 7-dehydrocholesterol to vitamin D_3 by the action of ultraviolet light at wavelengths between 295 and 297 nm on the epidermal strata of the skin (Crissey *et al.* 2003), or from plants as a result of photochemical conversion of ergosterol to vitamin D_2. Once vitamin D is in the liver, it is converted to 25-OH-D (Holick, 2007). This metabolite is the major circulating form of vitamin D under normal conditions (Zerwekh, 2008). The 25-OH-D is converted to several polar metabolites. However, from all known vitamin D_2 and D_3 metabolites, only the function of 1, 25-dihydroxyvitamin D [$1\alpha,25(OH)_2D_3$] or calcitriol (produced predominantly in the kidney) has been established. 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 (Holick, 2007).

In human, circulating levels of 25-OH-D are largely linked to the consumption of oily fish, margarine and foods containing vitamin D, exposure to sunlight (Zerwekh, 2008), epidermal concentration of 7-dehydrocholesterol, melanin pigmentation, latitude, season, and exposure time of day (Olmos-Ortiz *et al.* 2015). Exposure of rats to ultraviolet light leads to a 40-fold increase in vitamin D. In contrast, similar irradiation of dogs and cats does not significantly increase dermal vitamin D concentration (How *et al.* 1994). Most herbivores can 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). Baby lamas born in autumn/winter that had lower vitamin D con-

centrations were more likely to develop rickets than those born in summer (Van Saun *et al.* 1996).

Vitamin D is transported in the plasma bound to the specific protein transcalciferin or to vitamin D-binding protein. The 25-OH-D_3 is a poor ligand for VDR, with an approximate 1% cross reactivity with these receptors compared with $1,25$-$(OH)_2D_3$ when both are in their free state (Reinhardt *et al.* 1982). In addition, only about 0.03% of serum 25-OH-D_3 is free for cell entry (Schwartz *et al.* 2014).

The actions of $1\alpha, 25(OH)_2D_3$ in multiple target tissues are mediated by the nuclear VDR, a phosphoprotein that binds the hormone with high affinity. Serum 25-OH-D level is the best marker of whole-body vitamin D status (Holick, 2007). Hypocalcemia induces the secretion of parathormone by the parathyroid gland, which reduces the excretion of Ca, inhibits phosphate reabsorption and stimulates the production of $1\alpha,25(OH)_2D_3$ in the kidneys. Then, calcitriol will increase the active phosphate transport in the intestines and stimulate Ca reabsorption in the kidney. The entry of Ca through the luminal membrane and the action of calbindin D9k which facilitates the transfer of cytoplasmic Ca across the basolateral membrane, are the major mediators of intestinal Ca absorption (Holick, 2007; Zerwekh, 2008). The $1\alpha,25(OH)_2D_3$ also stimulates osteoblast differentiation and gene expression biomarkers of bone turnover such as osteocalcin and osteoponine. When $1\alpha,25(OH)_2D_3$ is produced in large quantities, osteocytes secrete fibroblast growth factor 23 (FGF23) as inhibitor of phosphate reabsorption and calcitriol production in the kidney (Holick, 2007; Zerwekh, 2008).

Vitamin D and phosphocalcic metabolism

It is largely known that vitamin D plays a major role in bone mineralization and Ca balance and a deficit in vitamin D is associated with rickets in children, and exacerbation of osteoporosis and osteomalacia in adults. Moreover, several researches showed that vitamin D plays an important role as an agent preventing or delaying the onset of certain autoimmune (diabetes type I) and proliferative diseases (solid cancers, leukemia, psoriasis) (Holick, 2007). The measurement of circulating levels of 25-OH-D is a more reliable biomarker of vitamin D status, so, according to Horst *et al.* (1983), vitamin D deficiency in bovine species could lead to circulating rates below 5 ng/mL. In the dromedary camel, the circulating levels of vitamin D metabolites were 10 to 15 times higher than those of sheep and cattle, without any significant change in calcemia or phosphatemia (Table 1).

In ovine species and their newborns, the minimum daily intake of vitamin D required to prevent rickets are respectively 5.6 and 6.7 IU/kg birth weight (NRC, 1985).

Table 1 Circulating levels of vitamin D and its metabolites in domestic ruminants

Compounds	Species	Values	References
Vitamin D, ng/mL	Cow	4.01±0.79	Cho *et al.* (2006)
	Calf	3.34±1.43	Foote *et al.* (2004)
25-hydroxyvitamin D_3 (25-OH-D), ng/mL	Beef	35.2±7.8	Rivera *et al.* (2005)
	Cow	88±7.1	Cho *et al.* (2006)
	Calf	62.66±16.74	Foote *et al.* (2004)
	Heifer	40-50	Carnagey *et al.* (2006)
	Calf (birth)	45.7	Weiss *et al.* (2015)
	Camel	390±45	El Khasmi *et al.* (2013a)
	Lactating camel (1st day)	480±59.7	El Khasmi *et al.* (2000)
	Newborn camel (15 days)	176.4±19.6	
1,25-dihydroxy-vitamin D [1,25(OH)$_2$D], pg/mL	Sheep	50-60	Ross *et al.* (1989)
	Cow	10-100	Horst *et al.* (1983)
	Periparturient Cow	36.8±9.8	Yamagishi *et al.* (2005)
	Cow 1st postpartum day	96.6±25.9	
	Calf (birth)	149.0	Weiss *et al.* (2015)
	Non pregnant camel	835±45	Riad (1995)
	Lactating camel	301±209	El Khasmi *et al.* (2000)
	Newborn camel (7 days)	1215±248	

Cases of rickets related to vitamin D deficiency have been reported in newborn lamb (Van Saun, 2004), sheep (Bonniwell *et al.* 1988) and llamas (Van Saun *et al.* 1996). In young camel, this vitamin deficiency is the primary cause of rickets consecutive to hypophosphatemia (Kistral-Boneh *et al.* 1990). In addition, decreased bone mineral density is largely associated with a decrease in serum vitamin D and may predispose some alpacas to post traumatic fractures (Parker *et al.* 2002). According to Van Saun *et al.* (1996), the hypophosphatemia and vitamin D deficiency observed in camelids could be corrected by treatment with a supplement of vitamin D. In addition, in North Africa, the phosphorus deficiency observed in camel species is responsible for Krafft disease, which had been described for long time (Kchouk and Durand, 1958) and leads to arthritis and periarticular exostoses, then to musculoskeletal disorders followed by paralysis (Faye and Bengoumi, 2000).

Vitamin D and lactation

Higher rates of vitamin D metabolites were observed in lactating camels and their newborns compared with the empty non-lactating female for similar, unchanged, calcemia in both animal groups (Riad *et al.* 1994; El Khasmi *et al.* 2000). The higher plasma levels of 25-OH-D and 1α,25(OH)$_2$D, could probably potentiate the processes of phosphocalcic assimilation and accelerate the resorption phenomenon of the mother's bone, to meet the requirements for lactogenesis. Liesegang *et al.* (2006) reported in goat and sheep that circulating levels of 1α,25(OH)$_2$D$_3$ became very high in the first postpartum week, indicating an activation of bone remodeling which is able to compensate the Ca transfer from maternal skeleton to milk.

In addition, the high absorption coefficients measured during lactation in camel by comparison to those observed in other domestic ruminants (Faye and Bengoumi, 2000), may be explained by the high levels of 1α,25(OH)$_2$D$_3$ (El Khasmi *et al.* 2000) to survive in the desert with low resources of Ca and P.

In 4- to 6-month-old camels, the use of the stable strontium assay for functional exploration of intestinal Ca absorption has shown that intravenous injection of 1α,25(OH)$_2$D$_3$ stimulates the calcium absorption (El Khasmi *et al.* 2003).

This brings us back to associating hypercalcemia in the newborn camel, and maintenance of calcium homeostasis in lactating camel, at their high levels of 25-OH-D and 1α,25(OH)$_2$D$_3$.

Circulating levels of 1α,25(OH)$_2$D$_3$ in cattle (Naito *et al.* 1983; Rajaraman *et al.* 1997) and camel neonates (El Khasmi *et al.* 2000) increased significantly during the first postpartum days, probably as a result of increased biosynthesis of this metabolite in response to active intestinal phosphate absorption in newborn. Moreover, in newborn calves that received vitamin D (54.00 IU at a rate of 13.500 IU/week), Nonnecke *et al.* (2009) observed a positive correlation between plasma levels of Ca and those of 1α,25(OH)$_2$D$_3$.

In domestic ruminants, treatment with vitamin D, 25-OH-D or 1α,25(OH)$_2$D$_3$ at pharmacological doses, by oral or parenteral way during few days before parturition, increases simultaneously the intestinal reabsorption of Ca and the circulating levels of calcitriol, which could prevent postpartum hypocalcemia secondary to milk production (Okura *et al.* 2004; Taylor *et al.* 2008).

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In addition, hypercalcemic and hyperphosphatemic effects have been observed following intramuscular injection of 1α-OH-D in cattle (Riad *et al*. 1987) and camel (Riad *et al*. 1994), and intravenous administration of 1α,25(OH)$_2$D$_3$ in the latter species (El Khasmi *et al*. 2001a).

The degree of neonatal renal maturity to convert 25-OH-D to 1α,25(OH)$_2$D$_3$ varies among species. Thus, in lamb, tritiated 25-OH-D, administered just after birth, was metabolized to 1α,25(OH)$_2$D$_3$ only after the 18th postnatal day (Collignon *et al*. 1996). However, in the case of camel, the levels of 1α,25(OH)$_2$D$_3$ start to increase in the bloodstream as early as the 7th day of life, indicating a degree of early maturation of renal function, in the synthesis of 1α,25(OH)$_2$D$_3$. This metabolite is one of the major determinants of the regulation of phosphocalcic metabolism and bone mineralization.

To maintain milk production, the daily requirement of Ca in early lactation is about 100 g in cow (Allen and Samson, 1985). Vitamins D$_3$ and D$_2$ also can be supplemented in the ruminant diet by commercially available crystalline forms (Wolter, 1988).

During this physiological stage, domestic ruminants respond to an exogenous supply of 1α,25(OH)$_2$D$_3$ by hypercalcemia, hyperphosphatemia and increase of phosphocalcic excretion by the mammary glands (Okura *et al*. 2004; Yamagishi *et al*. 2005; Namioka *et al*. 2008). Indeed, camels in third lactation that received 1α,25(OH)$_2$D$_3$ intravenously, showed a significant increase in the concentration and excretion of Ca and P in milk (El Khasmi *et al*. 2001a). Similarly, according to Riad *et al*. (1994), in lactating camel the intramuscular injection of 1α-OH-D stimulates the secretion of both Ca and P in milk.

The effects of metabolites of vitamin D observed to maintain milk production in female, could be direct on the mammary gland, and not due to hypercalcemia and hyperphosphatemia consecutive to the treatment. In fact, in the same species, it was demonstrated that intravenous infusion of Ca gluconate (7 mg Ca/kg body weight) for 30 min, has no effect on mammary excretion of Ca and P (Riad *et al*. 1994).

On the other hand, in cattle, specific receptors to calcitriol were demonstrated in mammary glands and their number increases dramatically during lactation (Colston *et al*. 1988). The effects of vitamin D on the mammary glands in camels are like those reported in cattle (Hidiroglou *et al*. 1985) and goats (Bengoumi *et al*. 1996).

Finally, according to Smith *et al*. (1987), the status of vitamin D in the newborn lamb is positively correlated with that of its mother, and is also linked with the consumption of colostrum during the first days of lactation (Gay and Besser, 1991).

Vitamin D and reproduction

The breeding season of the Moroccan camels begins in November and ends in April, with decreasing then increasing daylight, while the non-breeding season is in summer which is strongly related to the increasing length of the photoperiod (Sghiri, 1988). In camel, activity of the leydig cells, becomes maximal during rutting season and is less active in non-breeding season with a resulting reduction in steroidogenic activity by the testes (Agarwal and Khanna, 1990).

Investigations have suggested that vitamin D and the VDR are critical for the maintenance of reproduction and fertility in mammals (Corbett *et al*. 2006; Menegaz *et al*. 2009). So, Audet *et al*. (2009) reported that vitamin D supplementation enhanced the ejaculate volume but had no effect on sperm production or quality in boars. In human species, the 1α,25(OH)$_2$D$_3$ has specific receptors which predominates on the head/nucleus and mid-piece of the spermatozoa (Corbett *et al*. 2006), and appears to be a modulator of placental steroidogenesis (Barrera *et al*. 2007) and of follicle-stimulating hormone (FSH) secretion (Zofkova *et al*. 1989). In experimental cryptorchid mouse, Hirai *et al*. (2009) noted that 1α,25(OH)$_2$D$_3$ contributes to spermatogenesis by upregulating certain specific genes in sertoli's cells and suggested that vitamin D supplementation may have implications for managing male infertility. 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 for the maintenance of normal reproduction via a genomic mechanism that can be triggered by protein kinase A (PKA) (PKA), as well as to a rapid response involving Ca^{2+}/K$^+$ channels on the plasma membrane.

In another publication, it was concluded that low concentrations of vitamin D (<50 nmol/L) were associated with decreased number and quality of spermatozoa in semen (Dabrowski *et al*. 2015).

In a previous study in camel, we reported, that circulating level of 25-OH-D was lower in winter season (rutting period) than in summer (El Khasmi *et al*. 2011; Farh *et al*. 2018), suggesting that vitamin D doesn't appear to contribute directly or indirectly to the psychological-neurological-endocrinology of camel reproduction.

The higher circulating levels of 25-OH-D observed in our dromedary camels during the non-rutting period (summer) may be explained by the increasing daylight. In fact, interaction of photoperiod (intensity, duration, wavelength) with other factors (ambient temperature, nutrition, housing, latitude) and hormonal status (thyroid and corticosterone levels) (Zia-Ur-Rahman *et al*. 2007) can influence the reproductive performance of several mammalian species (Arthur, 1992).

Melatonin has been proposed as the pineal hormone, and its timed administration replicates the effect of day length on seasonal breeding for example, in hamster (Cutty *et al.* 1981), sheep (Zaraazga *et al.* 1998) and camel (Al-Qarawi and Elmougy, 2008).

However, although photoperiodic variations have a strong influence, there is some evidence suggesting that the suprachiasmatic nucleus is an important structure regulating circadian and seasonal rhythms of most biological functions and may be sensitive to changes in ambient temperature (Pando and Sassone-Corsi, 2001). In bovine species, vitamin D status is more linked with the consumption of foods, vitamin D supplementation, degree of skin pigmentation, and sunlight exposure than diet (Holick and Chen, 2008; Zerwekh, 2008). However, in camelids (Sumar, 1996) and other ruminants (Brown, 1994), the sexual activity which is essentially androgen induced phenomenon, is largely influenced by the nutritional status.

Milk vitamin D

Camel's milk includes proteins, fatty acids, minerals and vitamins resulting in a positive impact on human health (Elagamy, 2006; Konuspayeva *et al.* 2011). Generally, milk contains about 3 times less vitamin D than circulating concentration of vitamin D and 100 times less vitamin D than the circulating concentration of 25-OH-D (Greer *et al.* 1984). In the dromedary camel, milk is rich in 25-OH-D especially during the colostral phase, which is a non-negligible source of vitamin D, for the newborn camel in an environment where phosphocalcic resources are very limited (El Khasmi *et al.* 2001b; El Khasmi *et al.* 2005) (Table 2).

In humans, it was suggested that conversion of vitamin D_3 into 25-OH-D_3 is reduced at high intakes of vitamin D_3 (Heaney *et al.* 2008). However, supplementing cows with 25-OH-D_3 in combination with a negative anionic diet for the last 13 d of gestation enhanced their serum concentrations of 25-OH-D_3 and 1,25-$(OH)_2D_3$ leading to an increase of 25-OH-D_3 content in colostrum and milk and in the serum of the neonatal calf (Weiss *et al.* 2015). So, in lactating cows, concentrations of this metabolite in colostrum and sixth milking day were correlated with their concentrations in serum (Weiss *et al.* 2015).

There are several reports reviewing the influence of diet, Ultraviolet exposure and processing on vitamin D content in bovine milk. However, despite the significance of establishing the level of this vitamin in nutritional milk products (Holick *et al.* 1992), no study was carried out in the camel.

Meat vitamin D

Meat stands for strength, health and wealth, but it's content of vitamin D was generally low, difficult to measure and had not been indicated at the beginning of food composition (Williams, 2007). A few numbers of foods (fish, meat, milk, eggs and dairy products) may naturally contain vitamin D, and the circulating levels of 25-OH-D are more influenced by vitamin D supplementation, sun exposure and diet (Holick and Chen, 2008). Among the compounds of camel meat, 25-OH-D is found at concentrations similar to those of other livestock, which could be a significant source of this vitamin for the populations in desert regions (El Khasmi *et al.* 2013a; El Khasmi *et al.* 2018; Tabite *et al.* 2018). In fact, in man, the circulating vitamin D concentrations are lower in vegetarians than in meat and fish eaters (Crowe *et al.* 2011).

According to American Institute of Medicine Committee, a serum 25-OH-D level of 20 ng/mL is required for normal bone metabolism and overall health (Yetley *et al.* 2009). The prevalence of vitamin D deficiency (serum 25-OH-D<25 nmol/L) was 36.5% in Morocco, Turkey 41.3% and 19.3% in Nederland (Van Der Meer *et al.* 2008). Without doubt, in human, vitamin D is of great importance for health and therefore, recommendations for its intake have recently been increased considerably.

In the dromedary camel, the levels of 25-OH-D_3 (ng/g) in muscle, liver and kidney were respectively 4.241 ± 1.045; 7.071 ± 1.003 and 6.154 ± 1.067 (El Khasmi *et al.* 2013b) and were close to those reported for meat of cattle (Foote *et al.* 2004; Cho *et al.* 2006) but slightly higher than those reported in other domestics species (Table 3). In the camel, although serum levels of 25-OH-D_3 were significantly higher in summer than in winter, meat, liver and kidney levels of 25-OH-D_3 showed no seasonal variation (Bargaa *et al.* 2015). According to studies conducted in New Zealand, the values (mg/100 g) of vitamin D_3 and 25-OH-D_3 were respectively 0.10 and 0.45 in beef and 0.04 and 0.93 in sheep (Cali *et al.* 1991). In an adult woman of 70 kg total vitamin D is 14,665 IU, 65% as vitamin D and 35% as 25-OH-D (Heaney *et al.* 2009). Nearly three-quarters of vitamin D is found in fats, while the 25-OH-D in the body was divided as follows: 20% in muscle, 30% in serum, 35% fat and 15% in other tissues. According to Schmid and Walther (2013), the content of vitamin D in muscle is generally much lower (up to 10 µg/g).

The camel is an important source of red meat especially in arid and semiarid areas which adversely affect the performance of other meat animals (Kadim *et al.* 2006). The camel meat is rich in PUFAs (Kadim *et al.* 2006), myoglobin and other heme compounds (Hb) that could act as pro-oxidants and thus promote the oxidation of lipids (Maqsood and Benjakul, 2011). Lipid oxidation of meat takes place just after the slaughter of the animal, generates undesirable products, and causes the degradation of fat-soluble vitamins and essential fatty acids.

Table 2 Milk levels of vitamin D_3 and 25-hydroxyvitamin D_3 (25-OH-D_3) in mammal species

Item	Stage	Values	Species	References
Vitamin D_3 (pg/mL)	1st milking colostrum	471	Cow	Weiss et al. (2015)
	6th milking day	324		
25-OH-D_3 (ng/mL)	1st milking colostrum	1.021	Cow	Weiss et al. (2015)
	6th milking day	0.458		
	1st milking colostrum	8.9±0.6	Camel	El Khasmi et al. (2001b)
	7th milking day	1.2±0.3		
	Milk	97-159	Women	Specker et al. (1985)

Table 3 25-hydroxyvitamin D_3 levels in liver, kidney and muscle of domestic animals

Tissues	Species	Values	References
Liver (ng/g)	Cow	0.27-0.53	Koshy and Van Der Slik (1977)
		4.5±2.6	Cho et al. (2006)
	Calf	2.59±0.73	Foote et al. (2004)
	Pig	0.44	Mattila et al. (1995)
	Camel	7.071±1.003	El Khasmi et al. (2013a)
Kidney (ng/g)	Cow	0.51-0.98	Koshy and Van Der Slik (1977)
		4.2±2.0	Cho et al. (2006)
	Calf	3.02±1.13	Foote et al. (2004)
	Camel	6.154±1.067	El Khasmi et al. (2013a)
Muscle (ng/g)	Cow	0.15-0.34	Koshy and Van Der Slik (1977)
		1.83±0.24	Cho et al. (2006)
	Heifer	0.6±0.1	Carnagey et al. (2006)
	Calf	1.68±0.37	Foote et al. (2004)
	Beef	0.9-0.10	Wertz et al. (2004)
		0.0-9.0	
	Pig	1.0-23.0	Health Canada (2012)
	Lamb	1.0-61.0	
	Camel	4.24±1.04	El Khasmi et al. (2013a)

Also, it interferes with the integrity and safety of foods through the formation of potentially toxic compounds such as malondialdehyde (MDA) (Kanner, 2007). The treatment of meat by cooking or cold storage improves its quality but may also lead to the oxidation of its lipids and proteins and impact its nutritional and sensory qualities (Hur et al. 2004).

In the dromedary camel, ageing time of meat influenced significantly its quality characteristics and antioxidant status from the 5th or 7th postmortem day of refrigerated storage, without any variation of proteins, fat and 25-OH-D contents (Tabite et al. 2018). In addition, in the same species, during cold storage of meat for 10 postmortem days, the levels of 25-OH-D total showed no significant variation.

Vitamin D status impacts skeletal muscle function, metabolism and hypertrophic growth and muscle fiber composition and size (Ceglia and Harris, 2013). Vitamin D might influence the postmortem muscle pH values and consequently its water holding capacity (WHC). In fact, previous studies in beef steers and pork reported that dietary vitamin D_3 supplementation increased pHu and WHC, decreased drip loss, squeezable water and cooking loss (Wilborn et al. 2004) and participated in antioxidant activity (Duffy et al. 2018).

During cold storage of raw or cooked meat, drip loss, cooking loss and MDA increased significantly, however 25-OH-D showed no significant variation during all storage times (Tabite et al. 2018). Compared to raw meat, cooked meat showed a significant increase of 25-OH-D and MDA levels on days 3, 5, 7 and 10 postmortem storage (El Khasmi et al. 2018). The 25-OH-D levels in raw and cooked meat, was positively correlated with pH and negatively correlated with redness, drip loss and MDA. Vitamin D status may impact skeletal muscle function, metabolism, hypertrophic growth, fiber composition and size (Ceglia and Harris, 2013).

In addition, previous studies in beef steers and pork reported that dietary vitamin D_3 supplementation increased ultimate pH and water holding capacity, decreased the drip loss, squeezable water and cooking loss of meat (Wilborn et al. 2004) and participated in antioxidant activity (Duffy et al. 2018).

Impact of stress

In domestic animals, several factors like handling, loading, movement, immobilization, transport, food and water privation, heat, etc may compromise the welfare of animals and increase their vulnerability to disease (Broom, 2014).

Several important indicators are used in evaluating the effects of environmental stress, such as physiological, hematological, biochemical and hormonal responses. The dromedary camel was very sensitive to stress induced by road transportation (El Khasmi *et al.* 2015; Lemrhamed *et al.* 2018) and winter season (Bargaa *et al.* 2016).

However, in the dromedary camel, plasma levels of 25-hydroxyvitamin D were not affected by road transportation (El Khasmi *et al.* 2010). Furthermore, in old and young stressed camels (transported), the mean value of plasma levels of 25-hydroxyvitamin D showed no significant differences compared to control animals (non transported) (El Khasmi *et al.* 2009). In fact, under road transportation stress, the magnitude of cortisol response was higher in old camels than in young ones, without any variation of plasma 25-hydroxyvitamin D levels with age (El Khasmi *et al.* 2009).

Concerning the impact of season on vitamin D levels in camels, although circulating levels of cortisol, thyroid hormones and testosterone were higher in winter (rutting period) than in summer (non-rutting period) (Farh *et al.* 2018). In contrary, circulating levels of 25-OH-D are higher in summer than in winter (395±25 ng/mL vs 304±22 ng/mL) (El Khasmi *et al.* 2011). The dromedary camel is largely known to be a seasonal breeder and its reproduction is characterized by a seasonal activity where the breeding season is confined to the cool winter months of the year. The rutting period might be considered as stressful situation during which, the male is very aggressive and presents some behavioral reactions like the extrusion of the soft palate, and becomes very vocal (Marai *et al.* 2009).

Impact of season
Huge seasonal variations in vitamin D status were observed in all domestic species and humans (Mc Dowell, 1989). In llamas and alpacas (Smith and Van Saun, 2001), and camels (Mohamed, 2008), the circulating levels of vitamin D are not influenced by age, but vary depending on the season. In the dromedary, the highest levels were detected during the period from February to July, while lowest levels were observed during the period from August to January (Mohamed, 2008). In the camel, the serum 25-OH-D levels (ng/mL) in summer and winter are 443 ± 96 and 276 ± 13, respectively (Shany *et al.* 1978). The seasonal variations of vitamin D in the blood were also reported in sheep (Smith *et al.* 1987) and horse (Maenpaa *et al.* 1988). These variations are much more pronounced in calves and young camels aged one year (Smith and Van Saun, 2001). On the other hand, the content of vitamin D in bovine milk had showed significant variations during the season, with lower values in winter and higher levels in summer (Kurmann and Indyke, 1994).

Variations in circulating concentrations of vitamin D in different species of camel, could be explained by the degree of coat color, as is for llamas and alpacas (Smith and Van Saun, 2001), or Arabi and Anafi camels (Mohamed, 2008). The month of birth, light intensity (Van Saun *et al.* 1996) and physiological status (lactation, neonatal development) (Riad *et al.* 1994; El Khasmi *et al.* 2000) were able to influence the status of vitamin D.

CONCLUSION

The anatomy of the camel (*Camelus dromedarius*) is characterized by long legs and long neck requiring a large amount of Ca and P. This species is living in ecosystems marked by high level of sun light which could be regarded as favorable for an important biosynthesis of one vitamin playing a pivotal role in the metabolism of these minerals. The data collected in scientific literature could suggest the possibility to use dietary vitamin D supplementation in the dromedary camel as a natural synthetic source of vitamin D in the meat of this species, especially in environment with less sun light.

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