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Vitamins of camel milk: a comprehensive review

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Abstract

Several authors base their arguments to promote the health benefits of camel milk on components such as vitamins. However, except for vitamin C, the number of references is limited and, overall, reported concentrations in the literature are highly variable because of the use of different analytical methods, materials and study contexts. The present review gives up-to date information regarding the values of fat- and water-soluble vitamins (A, D, E, K, B1, B2, B3, B5, B6, B7, B9, B11, B12 and C) reported in milk of large camelids from different parts of the world.

Keywords: camel, colostrum, fat-soluble vitamins, milk, water-soluble vitamins

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Introduction

Vitamins are organic nutrients required in small amounts in the diet for animals. Those nutrients, essential for health, could be dramatic for both animals and humans in the case of deficiency. Thirteen vitamins are described (fourteen if we include vitamin B11). They are classified according to their biological and chemical characteristics at the origin of their biochemical functions (co-factor of many enzymes, regulators of mineral metabolism, antioxidant properties). Two groups are described, based on their solubility in fat or water, leading to the distinction between fat-soluble and water-soluble vitamins. On modern farms, vitamins are included in feed or mineral blocks, while in most of the camel farming systems only vitamins present in the natural diet are available for the animals. In any case, the unique source of vitamins for young camels is milk. The vitamin composition of camel milk is regarded by many authors as partly the origin of some of its health benefits for consumers (Al-Haj and Al-Kanhal, 2010; Claeys et al., 2014; Mullaicharam, 2014; Kumar et al., 2015; Yadav et al., 2015; Jilo and Tegegne, 2016; Kaskous, 2016, Alavi et al., 2017; Singh et al., 2017; Abrhaley and Leta, 2018, Bulca, 2018). Yet, except for vitamin C, references regarding the quantities of other vitamins in camel milk are not very common. The present review aims to provide up-to-date information on the vitamin composition of camel milk.

Fat-soluble vitamins (A, D, E, K)

Because fat-soluble vitamins are concentrated in the fatty part of the milk, their content level obviously depends on the fat content in the product. Unfortunately, this information (fat content of the analyzed milk) is often lacking in the published references. Unless the milk is fortified by vitamin additives, skimmed milk is devoid of fat-soluble vitamins.

Vitamin A (retinol)

Vitamin A (or retinol) is involved in the protection of the tegument and in the vision. In consequence, hypovitaminose A could affect the skin provoking hyperkeratosis and the vision provoking a specific crepuscular blindness. Vitamin A plays also an important role in the protection of mucosa, which would explain its specific role in reproductive performances (Clagett-Dame and Knutson, 2011), but in our knowledge, no data regarding this role are available for camels. Night blindness in camels, linked to deficiency in vitamin A, was described in Djibouti (Faye and Mulato, 1991) and Sudan (Agab, Abbas, and Le Horgne, 1992; Agab et al., 1993). In Sudanese camels, among the cases of disease reported in summer, 18% were night blindness. Annual prevalence was assessed at 7.5% (Agab and Abbas, 1999). In Eritrea, this prevalence among camels was 2.1% (Gebrehiwet, 1999). According to these authors, night blindness increased during the hot season, then disappeared almost completely later in the year, probably because green fodder as a source of β-carotene (pro-vitamin A) was highly available in autumn.

Regarding the role of vitamin A in the protection of teguments, a recent study achieved in Morocco reported a significant lower serum retinol concentration in camels affected by mange compared to healthy camels (35.3 ± 10.8 vs 44.4 ± 5.9 µg/100 ml respectively). A more important difference was observed in adults (males and females) over 8 years (Lyaktini et al., 2013). Besides, vitamin A supplementation is suggested by some authors to boost mange treatment (Fassi-Fehri, 1987; Palanivelrajan et al., 2015).

To our knowledge, one of the first references to vitamin A determination in dromedary camel milk was that of Ahmed et al. (1984) in Egypt who reported a mean value of 390 µg/l, which was quite similar to that published recently by Ibrahim and Khalifa (2015): 380±3 µg/l. Later, in 11 pooled milk samples from Saudi Arabia, Sawaya et al. (1984) published lower values of 150±1.9 µg/l. In their monthly study of camel milk throughout the year, Haddadin et al. (2008) reported a mean value of 267±80 µg/l. However, the most cited reference is that of Farah et al. (1992) who reported a mean value of 100 µg/l with a range of 50 to 140 µg/l from 20 dairy camels. Such values in camel milk appeared low when compared to that of cow milk, where a range of 100-1000 µg/l is generally admitted (Oste et al., 1997). In samples collected in camels and cows living in a similar environment, Wernery (2003) reported 100-150 µg/l in camel milk compared to 170-380 µg/l in cow milk. With a range of 100-380 µg/l for Bactrian camel milk, a similar observation was reported by Wang et al. (2011). Claeys et al. (2014), comparing different dairy species, also revealed on average a lower vitamin A concentration (µg/l) in camel milk (50-970) compared to sheep (410-500), goat (500-680), cow (170-500) or buffalo milk (690). A similar hierarchy was reported in a recent review (Singh et al., 2017), with lower values in camel milk (201±100 µg/l) than in cow milk (609±256 µg/l). Only one reference has reported a higher concentration of vitamin A in camel milk (18.6±1.97) compared to cow milk (7.26±0.65 mg/l) (Sboui et al., 2016). Despite a lower fat content, the retinol concentration in human milk (107-647 µg/l) appeared comparable to that of camel milk (Butte et al., 1981).

Camel colostrum contains significantly more retinol than milk: 307±132 *vs* 201±100 µg/l respectively, according to Stahl et al. (2006). These values, relatively higher than those in other references, were however lower than in cow milk samples analyzed as a reference (609±256 µg/l). There is no comparative study between dromedary and Bactrian camels, but in the rare references on the quantity of vitamin A in Bactrian milk, values appeared considerably higher: 757 µg/l on average, for example, in Khan and Apanna (1967) or even 970 µg/l with no significant change throughout lactation in Zhang et al. (2005). Such differences can be explained by the higher fat content in Bactrian milk compared to that of the dromedary (Faye et al., 2008).

The pro-vitamin A (β-carotene) concentration in camel milk is lower than in cow milk. As a consequence, the color of camel milk is white while cow milk is creamy in color. The concentration of β-carotene in camel colostrum was relatively high (3.2 µg/l), while in milk the quantity was below the detection limit (<3.2 µg/l). In comparison, cow milk contained 996 µg/l on average (Stahl et al., 2006).

Globally, the high variability of vitamin A in milk is linked to feeding. In dairy cows, for example, β-carotene concentration is lower in milk collected in high-input in-door dairy farms where concentrates constitute a huge part of the diet; this is the reverse of low-input farms based on pasture (Buttler et al., 2008). To our knowledge, there was no similar study on the effect of the feeding system on vitamin A in camel milk. However, in their survey, Faye and Mulato (1991) observed cases of night blindness, mainly in periurban farming systems (where the diet was richer in cereals as concentrates), while no cases were reported in pastoral systems. A seasonal variation in vitamin A concentration has been observed (Haddadin et al., 2008), with lower values at summer time and higher in winter. Considering the camel reproductive cycle, with calving mainly in winter and lactation peaking in summer, the seasonal changes in vitamin A are correlated to the seasonal variations of fat concentration in the milk (Musaad et al., 2013), as for other fat-soluble vitamins (Figure 1).

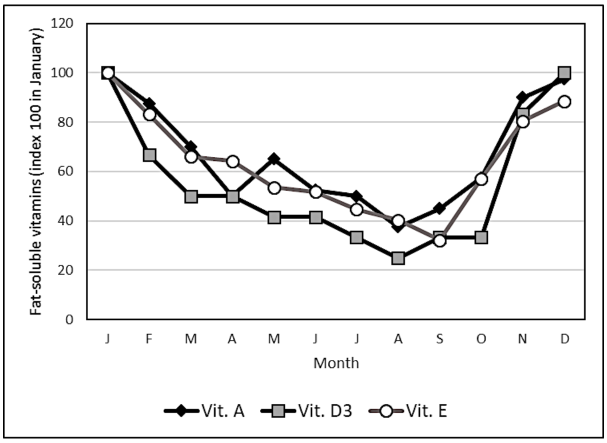

Figure 1. Seasonal changes in fat-soluble vitamins in camel milk (After Haddadin et al., 2008)

Vitamin D (cholecalciferol)

Vitamin D is a secosteroid contributing to the intestinal metabolism of main minerals (calcium, magnesium, phosphorus) and trace-elements (iron, zinc). Hydroxycholecalciferol (vitamin D3) and ergocalciferol (vitamin D2) are the most important forms. The herbivorous diet is generally poor in vitamin D, so biosynthesis of vitamin D in the skin and liver from the cholesterol is the main source for animals. This synthesis is dependent on sun exposure. However, an enzymatic activation occurring in the liver and kidney is necessary for making the vitamin active. In the liver, vitamins D3 and D2 are converted to calcifediol (25-hydroxycholecalciferol abbreviated 25-OH-D3) and 25-hydroxyergocalciferol respectively. After 2 hydroxylations achieved in the liver, calcifediol is the more active form for stimulating intestinal absorption of calcium. This metabolite regulates calcium and phosphorus concentrations in the blood, thus contributing to bone remodeling in all mammals (Holtrop et al., 1981), including the camel (El-Khasmi and Faye, 2011). Because of this role in mineral metabolism, vitamin D deficiency leads to bone disorders notably during growth, provoking osteomalacia and rickets. Such disorders have been described in Bactrian camels (Liu, 2005) as well as in dromedaries (Kristal-Boneh et al., 1999).

Camel plasma vitamin D concentration is 10 times higher than in cattle blood (El-Khasmi and Faye, 2011). Such higher plasma concentration contributes to the regulation of calcium and phosphorus excretion in milk (Riad et al., 1994; Riad, 1995). A seasonal variation of plasma vitamin D3 was reported (Mohamed, 2008).

As in plasma, vitamin D concentration in camel milk seems higher than in cow milk (Gnan and Sheriha, 1986); indeed, the mean value in camel milk (approximately 1 ng/ml) is higher than values reported in cow milk (Kunz et al., 1984): 50.4±4.1 pg/ml for vitamin D, 490±50 pg/ml for 25(OH)D3 and 9.7±1.0 pg/ml for 1,25(OH)2D3 which is comparable to human milk (Hollis et al., 1986). In a comparative study, Sboui et al. (2016) reported 8 times more vitamin D in fresh camel milk (15.6 ± 2.01 ng/ml) than in cow milk (1.78 ± 0.99 ng/ml).

According to El-Khasmi et al. (2001), the 25-hydroxyvitamin D is higher in colostrum just after parturition (8.9±0.6 ng/ml) but decreases to 1.2±0.3 ng/ml after a week. Such milk values seem comparable to ewe milk which was 1.7±0.22 ng/ml, 20 days after IV injection of 50 mg vitamin D_3 (Hidiroglou and Knipfel, 1984). However, in their study on fresh and freeze-dried camel milk, Ibrahim and Khalifa (2015) found 6 ng/ml. Haddadin et al. (2008) observed a seasonal variation with an average of 3.0 ± 0.2 ng/ml, comparable to that of vitamin A (Figure 1).

Vitamin E (tocopherol)

Vitamin E (named tocopherol), a fat-soluble vitamin, includes 4 different molecules (the most bioactive being α-tocopherol) and 4 tocotrienols. It has been recognized for a long time as a natural biological antioxidant and the first line of defence against peroxidation which severely damages cells and tissues. Vitamin E is also acting in synergy with the selenium (Se) as a component of the reproductive performance of farm animals and to prevent white muscle disease (WMD) due to a severe Se deficiency.

WMD has been described in young camels, especially in the Gulf countries (Al-Qarawi et al., 2001; El-Khouly et al., 2001; Seboussi, et al., 2004). However, normal vitamin E concentrations in camel serum and milk and their variability have only been explored during the last 10 years (Seboussi et al., 2008; Seboussi et al., 2009; Faye and Seboussi, 2010). Vitamin E deficiency was also incriminated in sudden deaths occuring in large camelids showing myocardial degeneration and necrosis (Finlayson, 1971).

Some authors stated that there is no vitamin E in camel milk (Ronald de Almeida, 2011), information confirmed again in a recent book published in 2017 (Alavi et al., 2017). In fact, vitamin E concentration (determined by HPLC) in camel milk is comparable to that of cow milk: 56 and 60 µg/100ml respectively (Farah et al., 1992), but in the seasonal study of Haddadin et al. (2008) mean vitamin E concentration in camel milk was 1.78 ± 0.58 µg/100ml only. Stahl et al. (2006) reported higher values in colostrum (136.9±98.4) compared to milk (32.7±12.8 µg/100ml). However, this concentration was significantly lower than in cow milk, which was used as a control (171±114 µg/100ml). Comparable values were found in the comparative study of Sboui et al. (2016): 27.6 ±2.07 in camel milk *vs* 33.5 ±2.17 µg/100ml in cow milk. Higher concentrations with a significant breed effect (from 211 to 426 µg/100ml) were reported in ewe milk (Michlova et al., 2014).

Considerably higher concentrations (despite the use of the same analytical method) were reported by Wang et al. (2011). Indeed, these authors found less vitamin E in camel milk (12.8 mg/100ml) than in cow milk (16.1 mg/100ml), but it corresponded to 200 times the previous references. Ibrahim and Khalifa (2015) also reported higher values with a concentration of 2.6 mg/100ml in whole fresh milk and 2.34 mg/100ml in freeze-dried camel milk. Those values, however, are comparable to those in human milk (12.2 mg/100ml), although other references gave lower values, for example, from 0.46 to 0.80 mg/100ml in Carribean countries (Boersma et al., 1991). As for other fat-soluble vitamins, α-tocopherol content varies according to seasonal fat concentration in milk, i.e., the reverse to the lactation curve (Figure 1).

Vitamin K (Phylloquinone)

Vitamin K is mainly implicated in the synthesis of prothrombin, playing in consequence a pivotal role in blood coagulation. Three vitamin Ks are described: (i) fat-soluble vitamin K1 or phylloquinone synthetized by plants, (ii) fat-soluble vitamin K2 or menaquinone, synthetized by ruminal and intestinal microflora, and (iii) water-soluble vitamin K3 or menadione, a precursor of vitamin K2.

The requirements for ruminants are covered by both dietary intake and microbial biosynthesis in the rumen and gut. Usually, ruminal microflora synthesize a sufficient quantity of vitamin K, explaining why ruminants do not need a dietary source for vitamin K, except in the case of rodenticides' intoxication (main component being coumarin).

Impaired coagulation linked to vitamin K deficiency is rarely observed in livestock, except in the case of an abundant presence of an antagonist such as dicoumarol as its occurs in plants like *Melilotus sp*. (clover). To our knowledge, vitamin K deficiency has never been reported in camels.

For camel plasma, only one reference is available (Homeida et al., 2010) with plasma vitamin K1 of 41.5±10.5 ng/100ml in adult camels and 18.4±2.4 ng/100ml in less than 1 year old camels. These authors suggested that the low value in young camels could be linked to the low milk concentration in vitamin K, but no data were cited for camel milk. According to the same authors, plasma vitamin K in camels is higher than in other species. However, in their comparative study, Sboui et al. (2016) found a lower concentration in camel milk (20.84±1.23) than in cow milk (64.9±3.12) but without mentioning units. In their publication on vitamin K in the milk of different species, Indyk and Woollard (1997) reported values of 0.54 µg/100ml for vitamin K1 and 0.40 µg/100ml for K2 in cow milk, 1.18 and 0.79 µg/100ml respectively in goat milk, and 1.34 and 1.35 µg/100ml respectively in ewe milk.

Water-soluble vitamins (B complex, C)

Water-soluble vitamins present in milk are thiamin (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3), pantothenic acid (vitamin B5), vitamin B6 (pyridoxine), vitamin B9 (folate), vitamin B12 (cyanocobalamin) and vitamin C (L-ascorbic acid). It is generally considered that cow milk contains a convenient amount of thiamin, riboflavin and cyanocobalamin. In contrast, the amounts of niacin, pantothenic acid, pyridoxine, L-ascorbic acid, and folate are small in cow milk which is not regarded as an important source for these vitamins in the diet for consumers. What about camel milk?

Vitamin B1 (thiamine)

The role of vitamin B1 deficiency in a human neurological disease named "beri-beri" has been known for a long time. In ruminants, thiamine deficiency is responsible for polioencephalomalacia (PEM), also called cerebro-cortical necrosis (CCN) which provokes severe nervous disorders, sometimes leading to death. PEM has been reported in camels. Affected animals exhibit a staggering gate and muscle tremors. In some cases, the animals become blind and stay sternally recumbent (Abbas et al., 2008). PEM is linked to overconsumption of simple carbohydrates, and under-consumption of fiber. So, the disease is affecting racing camels, their diet being generally deficient in fiber and containing rapidly fermentable energy provoking acidosis (Wernery and Kinne, 2001).

The first reference regarding thiamine concentration in camel milk was that of Sawaya et al. (1984) who reported a mean value of 33 µg/100ml, which is slightly lower on average than in cow milk, which is 47 µg/100ml according to Lalic et al. (2014). For Alhadrami (2003), camel milk thiamine concentration is in the range 28-90 µg/100ml. For El-Agami (2009), the range is narrower: 33-60 µg/100ml. This range is comparable to that observed in cow milk, i.e., 20-80 µg/100ml (Öste et al., 1997). On average, camel milk sampled in Bangladesh contained 38.8 µg/100ml (Nahar et al., 2016). Camel milk contained a higher concentration of thiamine than human milk: 50 *vs* 13 µg/100ml respectively (Shamsia, 2009). In whole fresh camel milk, Ibrahim and Khalifa

(2015) reported a mean value of 44.3±4.0 µg/100ml without significant changes in freeze-dried or skimmed camel milk (47-51.3 µg/100ml). Throughout the year, thiamin concentrations varied slightly between 44 µg/100ml in winter and 50 µg/100ml in spring (Figure 2), but without a clear seasonal pattern (Haddadin et al., 2008). In Bactrian camels, Zhang et al. (2005) observed a higher thiamin concentration in colostrum (51 µg/100ml) than in milk (12 µg/100 ml). Without mentioning the unit, Sboui et al. (2016) reported slightly lower vitamin B1 in camel milk (1.54±0.34) than in cow milk (1.84±0.87).

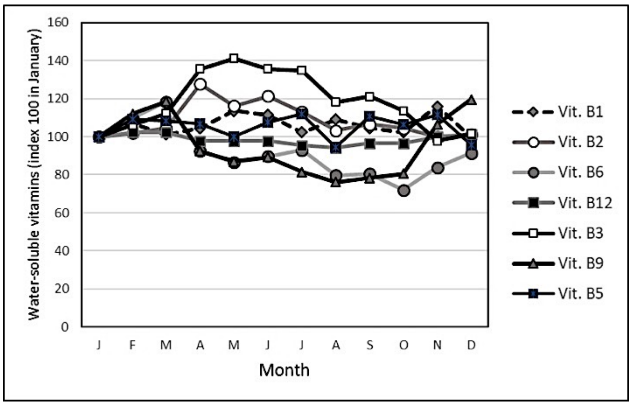

Figure 2. Seasonal changes of group B vitamins in camel milk (After Haddadin et al., 2008)

Vitamin B2 (Riboflavin)

Riboflavin (formerly called vitamin G) is participating as coenzymes (flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD) in a wide variety of flavoprotein enzyme reactions, involved in many biological processes, especially in the energetic metabolism. Vitamin B2 participates in the metabolism of carbohydrates, lipids and proteins. In animals, vitamin B2 deficiency is resulting in growth failure and ataxia (Patterson and Bates, 1989) and other symptoms such as hair loss, corneal opacity, kidney degeneration, and inflammation of the intestinal tract. The issue can be fatal.

In camels, such symptoms in relation to riboflavin deficiency were never reported, and globally, related references are very scarce in relation to this species. To our knowledge, no reference on the level of riboflavin in camel plasma is available.

In dromedary milk, some references on riboflavin concentration are available: 41.6 ±1.6 µg/100ml (Sawaya et al., 1984), 57 µg/100ml with a range of 43-78 µg/100ml (Farah et al., 1992), 56 ± 11 µg/100ml (Mehaia, 1994), 70 µg/100ml (Shamsia, 2009). Lower values were reported in camels living in Bangladesh: 6.4 µg/100ml on average (Nahar et al., 2016). In contrast, higher concentrations were observed by Ibrahim and Khalifa (2015): 155.3±22 µg/100ml in whole fresh camel milk and 159.3±11 µg/100ml in skimmed milk. On average, Haddadin et al. (2008) reported 168±14 µg/100ml with a range of 155-188 µg/100ml, the maximum being observed in spring and the minimum in winter (Figure 2). In Bactrian camels, high concentrations also were reported: 124 µg/100ml (Zhang et al., 2005) without significant change throughout lactation. Riboflavin concentration in camel milk is comparable to that in cow milk: 156 µg/100ml on average according to Farah et al. (1992) or 184 µg/100ml according to Mehaia (1994). The range in cow milk is 80-250 µg/100ml (Oste et al., 1997). In the comparative study of Sboui et al. (2016), a lower concentration was observed in camel milk (7.85±3.45) compared to cow milk (11.34±1.0), but the units were not mentioned. Riboflavin content is thermostable: after heat treatment (100 °C for 30 min.), the concentration remained at 52 µg/100 ml (Mehaia, 1994).

Vitamin B3 (Niacin)

Niacin, also named nicotinic acid or vitamin PP, plays a pivotal role in the metabolism of all nutrients (fat, carbohydrate and protein) and DNA synthesis as a precursor of nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP). Niacin deficiency provokes pellagra, a severe skin disease. To our knowledge, although some cases of niacin deficiency were reported in young ruminants a long time ago, no case was described in camels (Hopper and Johson, 1955).

The sources of vitamin B3 in ruminant animals are: (i) the diet, (ii) the conversion of tryptophan to niacin, and (iii) the ruminal synthesis. The bioavailability of niacin in feedstuffs, where it is widely present, is higher than in cereal grains and their by-products. Consequently, niacin deficiency is more often observed in monogastric animals than in ruminants (Luce et al., 1966). There are no available data on plasma niacin concentration in camels.

There is a big difference between the niacin values reported for camel milk content and other milks. Sawaya et al. (1984) reported 461±24 µg/100ml, i.e., a higher value than in cow (107 µg/100ml), goat (277 µg/100ml) or buffalo (91 µg/100ml) milk but similar to ewe milk (417 µg/100ml) according to the USDA Nutrients Database. Higher concentrations were also reported in camel milk (391.2±3.38 µg/100ml) than in cow milk (165.6±4.34 µg/100ml) by Sboui et al. (2016). Vitamin PP concentration in camel milk was also higher than in human milk: 520 vs 210 µg/100ml (Shamsia, 2009). In whole fresh camel milk, Ibrahim and Khalifa (2015) reported a concentration of 361 ± 19 µg/100ml with no significant difference with skimmed or freeze-dried milk. The mean value reported throughout one full year by Haddadin et al. (2008) was lower than the previous references (78±10.2 µg/100ml), but the seasonal variation was more important than for other group B vitamins (Figure 2), with a maximum in May (93.2) and a minimum in November (64.5 µg/100ml). The mean value recorded by Nahar et al. (2016) was considerably lower than in the previous references: 11.6 µg/100ml only.

Vitamin B5 (Panthotenic acid)

Panthotenic acid is involved in the coenzyme-A (CoA) synthesis which plays a pivotal role in animal metabolism of nutrients (proteins, carbohydrates and fats) as acetyl-CoA. It also play an essential role in the biosynthesis of fatty acids, cholesterol and acetylcholine. Vitamin B5 deficiency provokes similar symptoms as for other vitamin B deficiency (fatigue, apathy, impaired energy production). In vitamin B5 deficiency affecting non-ruminating animals, signs such as nervousness, gastrointestinal and immune system disorders, loss of appetite, reduced growth rate and skin lesions were observed (Smith and Song, 1996). Because the synthesis of pantothenic acid by ruminal microorganisms is 20 to 30 times more than in forages, vitamin B5 deficiency in ruminating animals was never described, and there is no effect from pantothenic supplementation on the growth performance of cattle. No available references on plasma pantothenic acid were reported in camels contrary to cattle (Song et al., 1990).

In camel milk, Sawaya et al. (1984) reported vitamin B5 concentration at 88±22 µg/100ml, which was lower than cow (362 µg/100ml on average), goat (310 µg/100ml), sheep (407 µg/100ml) and buffalo milk (192 µg/100ml). Similar values were reported by Ibrahim and Khalifa (2015), both in fresh camel milk (81.3±8 µg/100ml) and skimmed milk (86±3 µg/100ml). However, according to Haddadin et al. (2008), the mean monthly values over a full year were considerably higher (368±21.3 µg/100ml) with no clear monthly variations (range 350-391 µg/100 ml, Figure 2).

Vitamin B6 (Pyridoxin)

The active form of vitamin B6 contributes to several biochemical reactions like decarboxylation and transamination. It is involved in amino-acid metabolism including the synthesis of histamine, hemoglobin and neurotransmitters like serotonin, dopamine, epinephrine, norepinephrine and Gamma-aminobutyric acid. It intervenes also as a coenzyme in methionine and selenium metabolism. It is involved in the metabolism of glucose and lipids and implicated in increasing or decreasing the expression of certain genes.

Vitamin B6 deficiency was regularly reported in farm animals. Symptoms such as delayed growth, dermatitis, convulsions, anemia and alopecia are described. Because of active ruminal synthesis of vitamin B6, deficiency is mainly affecting non-ruminating animals. However, calves with non- functioning rumen can be affected when a milk substitute is used for feeding (Johnson et al., 1950).

To our knowledge, as for the former B vitamins, vitamin B6 deficiency was never described in camels. No reference is available for the plasma vitamin B6 in camels.

The concentration of vitamin B6 in camel milk is around 50µg/100ml: 52.3±11.5 for Sawaya et al. (1984), 54 µg/100ml on average for Zhang et al. (2005), and 55±8.1 µg/100ml on average for Haddadin et al. (2008). These values are comparable to those reported in other species: 36 (cow milk), 46 (goat milk), 60 (sheep milk) and 23 µg/100ml (buffalo milk). Vitamin B6 concentration in camel milk is relatively constant throughout lactation (Zhang et al., 2005), with a range between 43.3 in October and 71.2 µg/100 ml in March (Figure 2, Haddadin et al., 2008).

Vitamin B7 (Biotin)

Due to its involvement in cell growth and more widely in fat and amino-acid metabolism, Vitamin B7 is used in humans, as a supplement for strengthening hairs and nails. Biotin deficiency in herbivorous animals could be observed in the case of digestive disorders, notably in ruminants receiving a cereal grains-based diet. In such cases, the symptoms of deficiency are not specific: lethargy, dermatitis, anemia, poor growth. In dairy cows, biotin deficiency related to lameness was observed. In addition, it has been stated that vitamin B7 supplementation can protect against hoof disorders (Bhadauria et al., 2013). A biotin supplementation could improve dairy performance (Chen et al., 2011).

To our knowledge, no data regarding biotin concentration in camel milk are available. In cow milk, the concentrations are in the range of 2-4 µg/100ml. Buffalo milk contains higher concentrations, 11-13 µg/100 ml (Claeys et al., 2014).

Vitamin B9 (Folic acid)

Vitamin B9 is involved in the production and maintenance of cells, DNA and RNA synthesis. Therefore, folic acid is important during active cell division (growth of the young and gestation). Folic acid deficiency could provoke anemia (by decreasing the number of erythrocytes), diarrhea, poor growth and fetal neural tube defects during pregnancy. High interaction between vitamins B9 and B12 occurs, an indirect lack of folates being caused by a vitamin B12 deficit. No case of vitamin B9 deficiency was reported in camels and few references are available in the literature, but probably folic acid supplementation could have a beneficial impact on dairy production, as for cattle (Girard et al., 2005).

The mean concentration of folic acid in racing camel plasma appeared lower than in dairy cows without folate supplementation (Snow et al., 1992; Ragaller et al., 2009). In camel milk, the values reported by Sawaya et al. (1984) were on average 10 times lower than in cow milk: 0.41±0.06 µg/100ml *vs* 3.8 to 4.3 µg/100ml (Ragaller et al., 2009). A similar difference was recorded by Sboui et al. (2016): 0.69±0.43 in camel milk *vs* 15.52±3.32 µg/100ml in cow milk. However, Ibrahim and Khalifa (2015) reported higher concentrations in whole (8.2±0.1 µg/100ml) and skimmed camel milk (8.6±3 µg/100ml). Such values are close to that reported by Haddadin et al. (2008), i.e., 8.7±1.5 µg/100ml, with a variation throughout the year between 7 µg/100ml in August and 11 µg/100ml in December (Figure 2).

Vitamin B11 (L-Carnitin)

Called L-carnitin because of its high content in meat, vitamin B11 (or BT) is involved in the catabolism of lipids. It is not officially a vitamin for humans, but it should play an essential role in the catabolism of fatty acids, especially their penetration to mitochondria. It is involved in the production of muscular energy, notably during an extended effort. In camel milk, one reference only is available (Alhomida, 1996), where the concentration of total L-Carnitine was 410 ± 35 nmol/ml, i.e., less than goat (600±70) or sheep milk (612±55 nmol/ml), but more than cow milk (235 to 290 nmol/ml, according to the breed).

Vitamin B12 (Cyanocobalamin)

Because vitamin B12 is involved in the normal functioning of the nervous system, including the brain, cyancobalamin deficiency provokes important nervous damage. Cobalt is a mineral trace element being part of the cyancobalamin molecule; therefore, in ruminants, vitamin B12 is synthetized by the rumen flora, and the lack of cobalt can lead to vitamin B12 deficiency.

In ruminants, cyancobalamin is also involved in gluconeogenesis. Thus, cobalt or vitamin B12 deficiency affects the energetic metabolism, provokes a loss of appetite and growth depression (Friesecke, 1980) leading to severe emaciation. Cobalt supply helps affected animals to recover rapidly.

Although cobalt deficiency is commonly observed in grazing livestock reared in tropical countries (McDowell, 2003), no vitamin B12 deficiency with clinical symptoms was reported in camels (Faye and Bengoumi, 2018). Few data are available on vitamin B12 values in camel blood or milk (Mohamed, 2006).

In camel milk, according to Sawaya et al. (1984), cyanocobalamin concentration is 0.15µg/100ml, which is low compared to cow milk (0.44 µg/100ml) or sheep milk (0.71 µg/100ml). For other authors, the concentration in cow milk could reach higher values, up to 1.05 µg/100ml (Matte et al., 2012). The concentration in colostrum is 10 times higher (Marca et al., 1996). However, Ibrahim and Khalifa (2015) reported higher values: 3.2 µg/100ml in whole fresh camel milk and 3.6 µg/100ml in freeze-dried camel milk, while Haddadin et al. (2008) found a monthly mean over one year at 0.85±0.02 µg/100ml, with no significant monthly changes (Figure 2).

Vitamin C (L-Ascorbic acid)

Vitamin C is the more abundant vitamin in camel milk. However, it is highly unstable – especially with temperature changes – for both low or high temperatures. Published data are mainly based on frozen biological samples, except some references from Kazakhstan (Konuspayeva et al., 2010a; Konuspayeva et al., 2010b; Konuspayeva et al., 2011). Thus, most of the data are probably underestimated.

According to Zhao et al. (2015), one cup of Bactrian milk (250g) is sufficient to cover 100% of the daily human requirements for vitamin C, although Singh et al. (2017) considered that the same quantity of dromedary milk would provide 10.5% only of the recommended daily intake, and Medhammar et al. (2012) stated that 2 cups (500 ml) is necessary for covering 100% of the recommended nutrient intake for children 1-3 years. The richness of camel milk in ascorbic acid is well known since the publication of Sawaya et al. (1984) who reported a value of 23.7±2.65 mg/l. Such concentration was confirmed later by Farah et al. (1992): 37.4 mg/l with a range of 26-61; and by Saini et al. (2007): 32.3±9 mg/l. On average, the quantity of vitamin C would be 3 to 5 times higher than in cow (Stahl et al., 2006) or human milk (Wang et al., 2011). For El-Agami (2009), the between-species difference is not so important: the content of vitamin C in camel milk was on average 52 mg/l while other species had 27 (cow), 22 (buffalo), 29 (sheep), 16 (goat), 35 (human), 49 (donkey) and 61 mg/l (mare milk). Comparing camel and human milk, Shamsia (2009) reported 46 mg/l and 35 mg/l respectively. In their comparative study, Claeys et al. (2014) reported that the range of values in camel milk (24-184 mg/l) was higher than in other dairy species (Figure 3). In fresh camel milk, Sboui et al. (2016) also found vitamin C concentrations reaching 169.7±5.1 mg/l, i.e., 6.7 times higher than the fresh cow milk (25.6±2.4 mg/l) used as a control. Similar levels were published by Ahmed et al. (2017): 184±21.1 and 53±14.3 mg/l in camel and cow milk respectively.

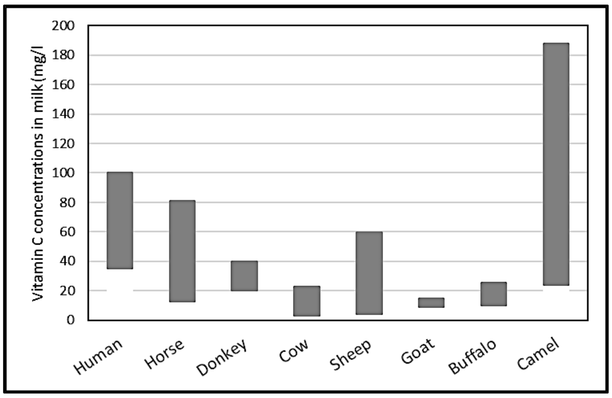

Figure 3. Range of vitamin C values in different milk (After Claeys et al., 2014)

Physiological factors affecting milk content of vitamin C

Globally, vitamin C concentration is lower in colostrum than in milk. In Chinese Bactrian camels, colostrum concentration was 10 mg/l, then the value increases significantly after one week to reach 29.6 mg/l after 3 months of lactation (Zhang et al., 2005). In the Kazakh Bactrian camel, vitamin C concentration was stable between 19 and 32 mg/l for the first week of lactation, then increased up to 113 mg/l after one week (Konuspayeva et al., 2010b). In dromedary camels, Stahl et al. (2006) also found a lower concentration in colostrum: 35.6 ± 10.6 *vs* 52.5 ± 15.8 mg/1 in milk. Mohamed et al. (2005) reported a slightly significant increase throughout lactation in camels from Sudan. Haddadin et al. (2008) found a slight monthly change, between 30.2 and 35.5 mg/l, but without a clear seasonal pattern. In the Indian camel, no significant difference was found in early lactation (52.6 ± 4.7 mg/m) compared to late lactation (48.4 ± 2 mg/l) (Mal et al., 2007). In the Kazakh Bactrian camel, higher values of vitamin C were observed: from 48 to 256 mg/l (mean 184), with a tendency to increase throughout lactation with a maximum at week 31, i.e., in the summer season (Konuspayeva et al., 2010a). Summer milk contained more vitamin C (227 ± 110 mg/l) than autumn (180±62 mg/l) or winter (157±58 mg/l) milk. The lowest vitamin C concentration was recorded in spring at 75±59 mg/l (Konuspayeva et al., 2011).

The authors attributed these high values to the types or breeds (mainly Bactrian camel) and the analysis conditions, the analyzed milk samples being fresh, contrary to most other references where frozen milk was analyzed. Indeed, storage through freezing decreased the vitamin C content in camel milk (Wang et al., 2011) as well as human milk (Bank et al., 1985). In freeze-drying whole camel milk, vitamin C concentration decreased by 16%: 29.7±2.4 mg/l *vs* 35.5±3.5 mg/l in fresh whole milk (Ibrahim and Khalifa, 2015).

Unlike most authors, Mohamed et al. (2005) reported no significant different concentrations between colostrum and milk (around 44 mg/l) in all Sudanese camel breeds. However, significant breed effect was reported with different levels of L-ascorbic acid, with concentrations being slightly higher in Arabi camel (54.8 and 47.8 mg/l for colostrum and milk respectively) than in Anafi camel (44.5 and 40.9 mg/l) and Bishari camel (42.3 and 39.1 mg/l).

In Kazakhstan, where Bactrian, dromedary and hybrids are cohabiting, sometimes in the same farms, in addition to high individual variability (15 to 435 mg/l) a significant regional effect (from 80±61 to 175±118 mg/l in four different regions of the country) was reported (Konuspayeva et al., 2011). Moreover, Bactrian milk appeared richer in vitamin C (169±110 mg/l) than in dromedary (146±93 mg/l) or hybrid (133±129 mg/l) camels.

In addition, a slight effect of parity was observed, with higher values being reported in multiparous camels compared to primiparous: 46.3±4.7 vs 44.9±1.0 mg/l. Finally, for the same authors, the milk vitamin C concentration was shown to be affected by mastitis: a significant decrease appeared in milk of affected camels (26.8±4.4) compared to healthy ones (47.4±5.2 mg/l).

Effect of heat treatment

Vitamin C content is also very sensitive to heat treatment. The loss percentage is 27% at 63 °C for 30 min and 15% at 73 °C for 15 s (Mehaia, 1994). Those proportions were higher than in cow milk, which was 18% and 10% respectively. At 100 °C for 30 min, the vitamin C content was only 8.3 mg/l with a 67% loss (fresh camel milk contained 24.9 mg/l), while in the same conditions cow milk passed from 14.3 to 7.5 mg/l, i.e., a 48% loss (Mehaia, 1994). After direct or indirect boiling (using a water-bath), Mohammed and El-Zubeir (2016) reported a decrease in vitamin C in milk from 23.70±2.06 to 9.11±0.30 and 16.83 ± 0.59 mg/l respectively. In contrast, no significant decrease of vitamin C after different mild heat treatments (63°C/30 min; 72°C/15 s; 78°C/15 s) was reported by Hessein et al. (2013): values passed from 50.5±11.35 in fresh camel milk to 48.5±11.8, 47.1±11.4 and 45.4±11.1 mg/l respectively. Indeed, pasteurization does not affect the vitamin C concentration in milk, passing from 40.9 to 38.4 mg/l, i.e., 6.1% reduction only (Wernery et al., 2005).

Conclusion

Finally, if camel milk is rich in vitamin C and to a lesser extent in niacin (vitamin B3) and vitamin D, the concentrations of other vitamins are not exceptional or even low. The tonic and anti-oxidant effects of vitamin C probably play a role in the beneficial reputation of camel milk, but it is not sufficient to attribute to this product all the medicinal virtues that consumers expect. Moreover, the analytical methodology used for the determination of those vitamins in the milk may differ from one author to another. Probably, the observed variability could be attributed partly to these differences in the analytical methods used. Finally, the common claim that camel milk is “rich in vitamins” is based on a limited number of references, except for vitamin C. Moreover, few studies were focused on factors of variation (lactation stage, parity, season, region, breed…). The determination of vitamins in a few milk samples without an accurate description of the context brings limited information. The ambition of the present review was also to encourage the scientific community to undertake additional studies for filling the gaps regarding the vitamin composition of camel milk.

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