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Review Article

Camel: A Fast Declining Animal Species but Can Strive with its Unique Climate Resilience and 'Desert to Medicine' Application

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Abstract

Camels serve as multipurpose animals providing milk by the females, used for transport or draught usually by the males, yield fiber/hair from both the sexes and finally providing meat as the animals culled from any production purposes. Modern-day camel regain its importance through its ability to produce quality meat, milk, and fiber and recognizing 'Camel Diary' as a means of opportunity for the urban farmers and 'Job-creation' for the entrepreneurs. The two most-promising climate resilient species thrive well in hot arid and semi-arid regions of the desert (e.g. *Camelus dromedaries*) and arid cold-climatic regions of the mountains (e.g. *C. bactrianus*) and continue to provide livelihood opportunity to co-habiting human population. This review is an attempt to focus on sustenance of this livestock, which has faced a rapid decline in some of the regions of the world including India due to overtaking of its principal transportation services by rapid mechanization. Nevertheless, camel's unique ability to adapt to extreme desert ecosystem with peculiar physiological (thermoregulation, water metabolism, glucose and energy metabolism, salt tolerance, forbearance against choking dust, etc.) and anatomical (fore limb and hind limb, long neck, single and double hump, third eye-lid, forestomach, etc.) differences has a significant bearing on its productive lifespan. The recognition and contribution of single-humped camel as 'Dairy Animal' has many encouraging prospects as its milk, meat and products have functional, nutraceutical and therapeutic value besides contributing to human protein nutrition. There is multiple potential role of camel milk bioactive peptides to demonstrate as antimicrobial, antiviral, immunomodulatory, anti-inflammatory, anti-oxidative and anti-hypertensive activities. Thus, the camel milk, meat and their products can be grouped under agricultural trade for international market. This era of importance would certainly draw renewed focus in developing camel as sustainable dairy animal that can fetch additional price and augment the income of the farmers.

Keywords: *Camel; Functional Food Value; Climate Resilience; Therapeutics*

Abbreviations

CFB: Compact Feed Block; CLA: Conjugated Linoleic Acid; DM: Dry Matter; FA: Fatty Acids; FAO: Food and Agriculture Organization; Hb: Haemoglobin; IgG: Immunoglobulin G: MCH: Mean Corpuscular Haemoglobin; MCHC: Mean Corpuscular Haemoglobin Concentration; MCV: Mean Corpuscular Volume; MHC: Major Histocompatibility Complex; MRT: Mean Retention Time; MUFA: Monounsaturated Fatty Acids; N: Nitrogen; NH3-N: Ammonia Nitrogen; PUFA: Polyunsaturated Fatty Acids; SFA: Saturated Fatty Acids; THI: Temperature Humidity Index; UFA: Unsaturated Fatty Acids; WBC: White Blood Cell

Introduction

The camel serve the fragile desert eco-system with its unique adaptability, functionality as 'Ship of the Desert' and food reservoir in the form of milk and meat for the co-habiting human population. The bio-physiological characteristics and unique ability of adaptation by the camel to arid and semi-arid ecology with scarce feed and water resources has earned this nickname due to indispensability as a mode of transportation and draught power in the desert ecosystem. This important attributes is now gradually getting limited due to mechanised transportation. Nonetheless, camel is continuing to play substantial role as a religious gift in marriages/rituals, in civil law and order, in defence (Border Security Forces, Para-Military Services, etc) and combats and other operational services in difficult mountain terrains [1]. This changeover subject to continuous social and economic transformation put camel population at threat of declining, if its alternate importance, e.g. climate resilience, functional attributes in milk are not immediately understood.

Camels have developed, through millennia in some of the hottest and most hostile environments in the globe and have served humans in cross-continental caravans, transporting people and goods, connecting different cultures and providing milk, meat, wool and draught since their domestication around 3000 - 6000 years ago. There are two principal camel species viz. *Camelus dromedarius* (single-humped) and *C. bactrianus* (double-humped) available in arid, semi-arid tropical and high altitude arid cold-climatic regions of the world. The world camel population stands at ~35.03 million [2], mostly in the desert ecology of Asian and African countries (viz. Arabian and Sahara deserts) like Pakistan, Arab countries, Chad, Somalia, Sudan, Niger, Kenya, Ethiopia, Mali and Mauritania. Most camel population are in developing countries and if used effectively and efficiently with a renewed focus on its productive angle, it can contribute to meeting the demand of meat and milk alongside other animals. The FAO report for meat and milk production from camel was 0.557 and 3.14 million tonnes for the year 2018 [2].

Desert ecology and camel

Desert ecology, be it hot or cold arid-climatic regions, adaptation to the environment is vital for future livestock as heat or cold stress can extremely reduce their productivity, health, and fertility [3]. Camel is considered as the most adapted domestic animal to desert conditions due to its anatomical features, thirst resistance, novel feeding behaviour and digestive physiology. Camels have comparatively less feed requirements due possibly attributed to slow metabolic rate in comparison to other ruminants. This has led to less methane production per unit body mass index [4]. Genetic studies in camel elucidate the role of several genes that contribute to its adaptive phenomenon in the desert conditions and withstand thirst and hunger for long periods [5]. Camel humps are one of the fat accumulation site (75% fat on fresh weight basis) that is used as energy store during periods of scarce feed and water and enables them to survive longer. In a well-nourished camel, the hump can form up to 20 per cent of the total body weight and this large amount of fat enables the camel to withstand prolonged periods of starvation [6]. The fat, when mobilised, produces more than its own weight in metabolic water has led to the belief that the hump can be a source of water for the water-deprived camel. Complete oxidation of the fat in the hump would release a total of just over 20 kg of water [7]. The camel thermoregulation system plays an important role in maintaining body-fluid balance and, therefore, is completely related to water availability [8]. This distinctive physiology enables camels to sustain production in the ensuing climate change scenario and altered agro-ecosystems. Further, it allows camel to provide milk, meat, wool and power and the dependent farmers can continue to consider the desert also as a producing environment. Nonetheless, the answer will always be 'Yes' to the question "Can camels serve as a model for the study of heat stress resistance in large ruminants?"

Resilient physiology

Compared to other mammalian species that may die due to circulatory failure even when the water loss is ≥ 12% of live weight [9], camels can survive and easily lose water equivalent to more than 25% of its live weight. The water balance in camel body is controlled by a number of factors including tissue osmolality and most specifically blood osmolality [10]. Unlike in all mammalian species which have concave or spherical erythrocytes, it is highly ovaloid, flat, small that facilitates their flow in a dehydrated state to cross small capillaries [11]. They are enucleated, circulate in large numbers and are very resistant to osmotic hemolysis as they swell even up to 240% of their size without bursting [12]. The kidneys possess a strong water reabsorption capacity and play a major role in the water conservation process through increasing the osmolarity and thus eliminate highly concentrated urine [5]. The intestine also reabsorbs water and the faeces is relatively dry and pelleted. They can withstand thirst and hunger for longer periods by utilizing the fat store in their humps and survive without deficit food and water [13]. Fascinatingly, camels regulate high blood glucose level (2 times the level in other ruminants) without signs of diabetes and they can consume 8 times more salt than cattle and sheep with no signs or symptoms of hypertension. The genomic analysis confirms desert adaptations and stress responses to heat and ultraviolet radiation including fat and water metabolism, aridity and defence against sand storm or dust [14]. They hypothesize kidney evolutionary adaptations to the desert environment based on transcriptomic analysis that shows this typical osmoregulation, osmoprotection and unique regulatory mechanisms for water preservation duly supported by maintenance of high concentration of blood glucose.

Camels are relatively more resistant to key infectious diseases compared to other animal species inhabiting the same agro-ecological regions. They have several distinctive immunological and molecular mechanisms against various causes of pathogenic nature as well as ailments [5]. The major histocompatibility complex (MHC) region has immune response genes that have important role in host-pathogen interactions [15].

Peculiarity in thermoregulation

The thermo-neutral zone averaging lower and upper critical temperatures are different for different species, viz. camel, 10 - 40°C, cattle 5 - 25°C, goats in temperate regions 13 - 21°C, goats in hot environment 12 - 24°C and sheep in hot environment 12 - 32°C [8]. This wide thermo-neutral zone are very close to desert ambient temperature oscillation and therefore constitute a comfortable interval for maintaining thermal homeostasis in this species allowing it to behave as a perfect endotherm homeotherm. The desert ecology is very much susceptible to climatic alterations due to variation in diurnal ambient temperature and it affects the adaptation behaviour of native animals including the camel. Assessment of blood-metabolic profile during hot and cold season revealed significant effect on rectal temperature, RBCs count, Hb concentration, MCV and MCHC while pulse, respiratory rate, packed cells volume, MCH, WBCs and differential leukocyte count were not affected [16]. A fully hydrated camel is a perfect endotherm homeotherm species displaying a relative constant body temperature with daily small fluctuations not exceeding 2°C (in the range of 36 - 39°C), even during the hot season [17]. Under prolonged water deprivation and excessive heat load, the camel switches its thermoregulation from endothermic homeothermy to become heterothermic and this unique heterothermia phenomenon is probably one of the most fascinating adaptation processes in this species that allows economy of water when camels are exposed to heat stress and dehydration. The other behavioural changes are camels become less active and lose appetite, a process underlying heterothermia which probably involves a decrease in basal metabolism. This heterothermia in camel is turned out to be cyclical, with alternating phases of poikilothermy and homeothermy, i.e. camel behaves as an ectotherm poikilotherm at night and early morning, endotherm homeotherm during the day maintaining body temperature relatively constant against rise in ambient temperature and if at all the increase in ambient temperature in the afternoon forced a few degree rise in body temperature, the camel behaves once again as an ectotherm poikilotherm and then at the end of the evening and early hours of the night, the camel stores the evening heat and maintains a constant high body temperature, a return to a homeothermy state [8]. The cycle is thus completed at night when the thermal gradient is inversed and the accumulated heat is passively dissipated. During hot summer months, the camel core temperature sometimes reaches 43°C which is irreconcilable in other livestock [18]. Camel has unique adaptive behaviour that decreases evaporative cooling mechanisms as a measure of preserving the water resource in the body during the heat stress [19].

Biodiversity and pastoralism

Agricultural production environment showed dynamic and simulated (man-environment interaction) changes that has imparted new challenges like declining quality water availability, depleting soil nutrients, climate change, farm energy accessibility, loss of biodiversity, incidence of new pests and diseases, disintegration of farms and farm-land, rural-urban migration, along with new IPR (Intellectual property rights) issues and trade regulations. In general, resisting desertification involves check in land degradation, economic water management and sustainable and integrated crop development programmes. In this endeavour camel contributes also to combat desertification due to its foraging habit and less competition with other livestock species of the desert.

Camel produce: therapeutic/functional attributes

Camel is a multipurpose animal that has multifarious usage and contribution like milk, meat, wool, transport, agricultural work, tourism, race and beauty contest. But, milk production is now becoming the primary purpose of raising camel in many countries, particularly for the dromedaries. Continually, the demand for camel milk and meat products have been augmented both locally and globally with products ranging from milk and its derivatives to nutraceuticals and therapeutics and extending to beauty products and essentials [20]. Various other natural products are also tried and prescribed as therapeutic aid to control the progression of diseases and metabolic disorders. This has attracted establishment and proliferation of a number of intensive camel dairy farms in these ecological regions of the world, which are meeting the demand of local and international markets. Thus, the national and global economy is getting enriched with a slow and steady addition of various produce and products of camel origin.

Camel milk

Camel milk is popularly referred as 'The White Gold of the Desert' [21]. Meta-analysis of the literature data on camel milk composition gave results with higher values in all the components, except ash from Asia linked probably to predominant Bactrian camel species and higher in fat content from East-Africa [22]. There is considerable compositional differences in milk from camel and other species (Table 1), the most significant being no milk-lactoglobulin as in human milk. The distinctive feature of camel milk is its minimal allergic effects due to a lower concentration β-lactoglobulin and α-casein [23-25]. Omar., *et al.* [26] evaluated camel milk by capillary electrophoresis and found that it lacks β-lactoglobulin and consists of high concentration (mg/mL) of α-lactalbumin (2.01), lactoferrin (1.74) and serum albumin (0.46). Among caseins, the concentration (mg/mL) of β-casein (12.78) was found the highest followed by α-casein (2.89) while κ-casein represented only minor amount (1.67). The presence of larger casein micelles and smaller fat globules provides camel milk a diverse colloidal structure that imparts special biological activities of protective and not-allergenic milk proteins, lysozyme, lactoferrin, lactoperoxidase and antiviral activities [27]. It is reported that the camel milk proteins have a balanced amino acids and its caloric value (Kcal/L) is 701 versus 665 in cow's milk. It is also rich in niacin, carnitine and vitamin C, minerals like Cu and Fe and high levels of IgG [28] and insulin [29]. The vitamin C content is 4 - 6 times higher than cow milk and is thus an important supplement to fight against heat stress in the desert. The disease-fighting immunoglobulin are smaller in size that allows its penetration and augment the mechanism of immunity. The ability to reduce the increased levels of bilirubin, globulin and granulocytes through consumption of camel milk has also been recognized. It has different content of casein, higher amount of vitamin B3 and lipid micelles than the bovine milk that enhances the body's defence against free radicals and displays higher antioxidant activity due to distinctive whey proteins with high content of antioxidant amino acids (Cysteine, Methionine, Tryptophan, Tyrosine and Phenylalanine). Camel milk has been reported to successfully stabilize diabetes because of the presence of insulin-like protein, which enhances the interaction with insulin receptors thereby controlling hyperglycemia in type 1 diabetes [29,30].

Constituents (g/100g)	Camel	Cattle	Buffalo	Sheep	Goat	Human
Nutrient composition (g/100g)						
Fat	4.5	4.0	7.0	6.5	3.5	4.0
Protein	3.5	3.4	5.2	5.3	3.7	1.9
Lactose	4.4	4.8	4.8	4.8	4.5	6.5
Minerals	0.79	0.7	1.0	0.9	0.8	0.2
Solids-not-fat	8.6	9.0	11.0	11.0	9.0	7.3
Total solids	12.8	13.0	18.0	17.5	12.5	12.1
Special characteristics						
Cholesterol (mg/100g)	37.0	14.0		52.0	21.0	20.0
Immunoglobulin G (mg/ml)	1.64	0.67	0.63	0.55	0.70	0.86
Saturated FA (g/100g)	2.40	2.45	3.75	3.70	2.09	1.8
Monounsaturated FA (g/100g)	1.40	1.40	2.50	2.40	1.26	1.60
Polyunsaturated FA(g/100g)	0.50	0.13	0.22	0.22	0.09	0.50

Table 1: *Composition of milk in different animal species including human [Source: 20-23,27,29].*
FA: Fatty Acids.

Camel milk is an exceptional source of balanced nutrients and has array of biological activities that modulates digestion, nutrient absorption and metabolism, growth and development and resistance to various diseases [29]. It is arguably more nutritious than cow milk due to comparatively higher fat, low in allergenic lactose, higher in minerals (potassium, iron) and vitamins (vitamin C). Camel milk is also known for its medicinal and beneficial properties and has long been used for human health. Several reports have demonstrated bio-functional and potential therapeutic properties viz. antidiabetic, wound healing, remedy against hepatitis C (HCV) infection, managing autism cure, antihypertensive and hypoallergenic effect [30,31]. Camel lactoferrin and milk casein demonstrate superior antiviral activity against HCV compared to lactoferrin from other animal species [32]. The hypoallergenic effect is attributed to the presence of immunoglobins and its protein (free of β-lactoglobulin) profile and thus serves as a good alternative for people with cow milk allergy [31,33]. Recent updates on major bio-functionalities of camel milk and its protein hydrolysates include immunomodulatory, antimicrobial, antiviral, anticytotoxic, antioxidant, antiradical, angiotensin-converting enzyme inhibitory, anticancer, anti-inflammatory, hepatoprotective and as counteractive agent reducing the harmful effects of toxins [30,31,33,34]. The principal bioactive components that modulates health-beneficial properties are protective proteins (lactoferrin, lysozyme, and immunoglobulins), minerals (Zn and Mg), vitamins (C and E), antioxidant enzymes (glutathione peroxidase and superoxide dismutase) and the bioactive peptides derived from camel milk proteins [31]. The bioactive-peptides are released during the fermentation processes (e.g. whey proteins) and hydrolysis by proteolytic enzymes (e.g. amino acids proline) that protect the body cells against oxidative damage. Some amino acid sequences are translated in the camel proteins, which might benefit human health upon release from milk during digestion process or by *in vitro* during bacterial fermentation or proteolysis with purified enzymes [35]. The camel milk has potential therapeutic effects in neurological disorders such as autism, Parkinson's, and seizures duly supported by antioxidant activity of casein and high content of vitamins C, A, and E [34]. The aetiology of many autistic cases is linked to autoimmune disease, originated principally due to alteration of an intestinal enzyme that hydrolyse milk protein casein to release peptides and amino acids of biological importance. Compared to milk from other animal species, camel milk gets easily hydrolysed and the children receiving camel milk have shown improved motor skills, joint coordination, language, cognition, improvements in behaviour and diets including skin health [36]. On similar line, camel milk is also effective in treating inflammation of the digestive system, as observed in Cohn's disease.

Camel milk is used in arid rural communities of Asia and Africa as a biomedicine to cure several other health issues like tuberculosis, asthma, gastroenteritis, oedema, neurological disorders, etc. The antipathogenic properties of camel milk have also been investigated to substitute for drugs and hence to overcome drug resistance. Whole camel milk showed significant dose-dependent *in vitro* anthelmintic activity against *Haemonchus contortus* as ascertained by worm motility and egg hatching inhibition compared to cow, ewe and goat milk due to higher contents of protective protein (lactoferrin) and vitamin C [37]. The camel milk whey proteins are more heat stable in comparison to that from cattle and buffaloes, but heat treatment tends to cause loss of vitamin C, IgG, lactoferrin and lactoperoxidase and therefore, a balance between standardized temperature for the pasteurization of camel milk and preservation of these positive health-assistive properties needs to be ascertained. It needs to be emphasized that the therapeutic properties of whole milk should remain intact in its delivery form and less weightage should be given to manufacturing low-yield products (chocolates, cheese, paneer etc).

Camel meat

Camel meat is usually a by-product of traditional systems of production, obtained mainly from old males and females that have superannuated and become less effective in serving transportation, providing milk, or to be used as breeding females. They are considered as a good source of meat particularly in arid regions where the performance of other meat animals gets adversely affected due to climate-change. World camel meat production is around 557432 tonnes, besides 33309 tonnes from other camelids and additional 80280 tonnes from edible offals [2].

An average camel carcass weight around 250 kg and thus can supplement substantially to total meat production for human consumption. Certain parts of the carcass such as the hump and liver considered a delicacy that is favoured in Middle Eastern markets. The hump is mainly composed of fat, and invariably accounts for 8.6% of the carcass weight and have thus significant effect on dressing yield of the carcass as percent of pre-slaughter weight and empty live weight. The hump is usually used for cooking and it contributes to 64.2 to 84.8% fat on fresh weight basis and is very rich in saturated fatty acids (SFA; 63.0%) [38]. A mature camel grows to reach live weights of about 650 kg at 7 - 8 years of age and produce carcass with dressing yield of 55 to 70%. Yousif and Babiker [39] reported average slaughter weight 456 kg with mean empty body weight 404.8 kg of mature, fattened desert camels yielding 55.8 and 63.6 dressed out percentage, respectively. There is 57% muscle, 26% bone and 17% fat in an average camel carcass with fore halves (cranial to rib 13) always heavier than the hind halves. There is 78% water, 19% protein, 3% fat, and 1.2% ash (Table 2) in camel lean meat with very few intramuscular fat and offers a competitively healthy food for the humans [40]. Although the difference in carcass characteristics between camel meat and beef are not large, the low level of intramuscular and subcutaneous fat has separated out camel meat, a high-priced product, in the desert environment. Compared to beef, camel meat has higher amino acids and mineral contents. The non-carcass components, viz. head, feet and hides accounts for 2.4, 3.4 and 7.3% of live weight and the share of edible non-carcass components are high that serve as valuable protein source for the people in the arid desert [41]. Camel meat, specifically from young animals, contains low fat with low cholesterol, good source of amino acids and minerals compared to beef or lamb [40] and may thus be considered healthier. It is recommended to slaughter between 1 to 3 years of age as camels are not fully-grown (60 - 70% of full live weight at ≤ 3 years of age) and meat would be relatively tender. The monounsaturated fatty acids (MUFA) in camel meat constitute 1/3rd of the total fatty acids (FA), majority of which is oleic (C18:1) followed by palmitoleic (C16:1) acids [42]. Ten different polyunsaturated FA (PUFA) are reported in camel meat, e.g. linoleic acid (C18:2) accounts for 2/3rd, followed by arachidonic acid (C20:4). The PUFA: SFA ratio was 0.36 as compared to beef 0.22, mutton (sheep) 0.26 and goat meat 0.36 [43]. The camel meat has wider linoleic to linolenic acid metabolites ratio (10.9) than cattle (2.0), sheep (2.4) and goat (2.8). The biceps femoris muscle from seven male camel of 1 to 3 years of age is relatively rich in PUFA (18.6%) and its fat content (1.2 - 1.8%) is lower than beef (4.0 - 8.0%) [42]. An important meat quality characteristic termed as 'expressed juice' has influence on nutritional value, appearance and palatability and it is reported with higher values in meat from camels slaughtered at 1 - 3 years than those at 6 - 8 years of age, possibly due to differences in fat content and binding ability of meat.

Constituents (g/100 g)	Camel for beef	Beef cattle	Buffalo	Sheep	Goat
Dressing%	51.4 - 56.6	52.5 - 54.4	50.8 - 53.3	49.3 - 52.9	49.0 - 52.4
Moisture%	73.2 - 77.7	70.8 - 75.2	71.4 - 75.1	68.9 - 72.7	69.4 - 75.2
Chemical composition (%DM basis)					
Protein%	18.2 - 22.1	19.8 - 22.6	19.5 - 23.1	19.6 - 21.8	18.9 - 22.8
Fat%	1.88 - 11.8	4.62 - 11.0	2.23 - 3.98	3.90 - 14.9	1.58 - 8.42
Ash%	0.85 - 1.00	0.92 - 1.18	0.67 - 1.09	1.05 - 1.20	0.87 - 1.00
Collagen%	0.53 - 0.57	0.35 - 0.67	0.20 - 0.50	0.24 - 0.35	0.36 - 0.45
Myoglobin%	0.37 - 0.61	0.22 - 0.59	0.27 - 0.32	0.20 - 0.38	0.21 - 0.65
Cholesterol (mg/100g)	50.0 - 59.2	48.7 - 73.6	46.0 - 61.0	50.0 - 170.0	41.0 - 71.2
Fatty acid composition (%)					
SFA	49.6 - 51.8	35.3 - 49.1	44.2 - 54.7	44.2 - 52.7	51.2 - 58.0
UFA	48.2 - 50.4	47.6 - 59.0	42.8 - 55.8	47.3 - 55.8	42.0 - 48.8
MUFA	29.9	35.0 - 46.4	31.4 - 40.3	37.3 - 49.8	38.7 - 43.9
PUFA	18.6	3.8 - 14.3	11.4 - 16.0	10.05 - 15.80	3.36 - 8.43
PUFA:SFA ratio	0.36	0.18 - 0.30	0.20 - 0.36	0.19 - 0.39	0.15 - 0.41
ω6:ω3 ratio	2.08 - 4.41	1.44 - 10.38	2.47 - 6.37	1.28 - 5.65	2.03 - 6.08

Table 2: *Composition of meat (% DM basis) from different animal species (Source: 38-42,45].*
FA: Fatty Acids; SFA: Saturated FA; UFA: Unsaturated FA, MUFA: Monounsaturated FA; PUFA: Polyunsaturated FA.

Camel meat is rich in essential FA (ω3, ω6), many essential amino acids, minerals, vitamins and bioactive compounds (carnosine, anserine, glutathione, etc.) [38]. In many countries, camel meat is generally considered a functional food for cures of many ailments and enhancing performance. It is believed to have therapeutic effects for nearly thirteen different diseases like hypertension, hyperacidity, pneumonia and respiratory diseases and also as aphrodisiac by the people of Somali and India [44]. Processed camel meat products e.g. burgers, patties, sausages and shawarma also add to functional food similar to that from other ruminants.

Rumen ecology contributing to functional food value

Unlike ruminants, camels are categorized as pseudo-ruminants because the foregut has three distinguishable compartments, a large compartment 1 (C1) that is separated by strong transversal muscular ridge into a cranial and a caudal portion, a comparatively small compartment 2 (C2), conjoined with C1 and a long, tube like form compartment 3 (C3), originates from C2 and functionally similar to abomasum [46]. The C2 and C3 resemble that of rumen and reticulum of ruminants and a functional omasum is absent that connects at one end to reticulum and other to abomasum in ruminants. The camel digestive system has adapted to harsh environmental ecology that are not favourable to other herbivore species by having a large foregut, leading to a much longer mean retention time (MRT) for the ingested feed substrates. They can utilize low-quality lignocellulolytic feeds, which are not preferred by other livestock species. Although the regulation of forestomach motility is similar, the basic pattern of motility is entirely different and certain separation of feed particles from fluid seems to occur throughout the motility cycle, thereby achieving a longer MRT of fibrous feed particles [47] compared to actual ruminant species, e.g. cattle, buffaloes, sheep, goats, etc. Camel also could maintain a pH closer to neutral that supports improved degradation of fibrous and lignocellulosic feedstuffs [48]. Greater stability of the physico-chemical conditions (pH, NH_3-N) of the fermenting environment in the C1 compartment after the meal, as well as a higher rate of emptying of the liquid phase, are favourable elements for the development and activity of microorganisms [49]. It is also hypothesized for existence of different absorptive mechanism due to difference in lining of tubular glands in the ventral parts of the compartments 1 and 2 and the total surface compartments of the forestomach [50]. With these anatomical and functional dissimilarities, understanding the complexity of camel rumen microbial ecology vis-a-vis other herbivores or ruminant species will enlighten the superiority of functional food (milk or meat) value in this climate-resilient species as discussed earlier. In the rumen, degradation of plant biomass is governed by microbial fermentations, and thus an increased efficiency of digestion by the camel could be attributed to rumen microbial composition and ecology. Camel rumen has very close taxonomic and functional resemblance with that of cattle as both the animal species are herbivores with similar fermentative digestion process. There is dominant *Bacteroides* species (*Bacteroidetes* 55.5%) followed by *Firmicutes* 22.7% and *Proteobacteria* 9.2% [51]. Rabee., *et al*. [52] is also of similar opinion that the camel rumen microbial composition is comparable to other ruminants with differences in proportional dominance of bacterial (*Firmicutes* and *Bacteroidetes*) and archaeal (*Candidatus Methanomethylophilus*) community. The abundant bacterial genera are *Prevotella, Fibrobacteres, Ruminococcus* and *Butyrivibrio*. Thus, the rumen microbial community governs significantly in influencing the camel milk quality traits with special reference to fat yield and composition. The rumen microbiome of camel is structurally similar but compositionally different in comparison to other ruminants [53]. The microbiome analysis has documented significant abundance of cellulolytic bacteria as evidenced from variation in establishment of members of *Fibrobacter, Clostridium, Ruminococcus* and *Treponema* in the solid fraction, and that of *Prevotella, Verrucomicrobia, Cyanobacteria*, and *Succinivibrio* in the liquid fraction of rumen digesta. The author have also made a culture collection of different ruminal microbes having one or multiple functional properties e.g. fiber degrading, lipid-metabolizing, tannin degrading, phytochemical-resistant, CLA-producing, etc. and it is envisaged that the peculiarity and superior health-advantage in camel milk and meat can be modulated for human-health attributes.

Camel for milk/meat and sustainability

The dromedary camel has regained interest as a production animal in recent years, mostly for dairy because of renewed interest and societal preferences for camel milk with added health benefit. This has led to the development of intensive camel dairy farming and camel milk processing, mirroring the dairy cattle industry. Five percent of total world milk production is contributed by camels in sub-Saharan Africa, and Somalia is rated as the highest camel milk producer followed by Kenya and Mali [2]. Although, camel contributes marginally to total world milk supply, its essentiality for human health in arid and semi-arid areas are numerous, viz. i) meeting the need of co-habiting human population and addressing the food safety of communities culturally attached to camel products, ii) reassuring the economic-livelihood of resident population through maintenance of agricultural and transportation activity in inaccessible desert areas. A large pool of literature view that if camels are reared under same environment as cattle, buffalo or other camelids, there is no doubt it will produce milk of high quality. Most of the camel populations are under traditional farming systems and currently, a few focal urban camel dairies are coming up to exploit the therapeutic potential of camel milk and milk products. Therefore, it is important to incorporate all these aspects in the camel rearing systems for addressing desertification and also for a sustainable development of the desert.

Pasture sustainability

Primarily, camel is a browser, but it has also adapted to grazing due to changing ecology and thrives well on a range of fodder plants, including shrubs, thorny and saltbushes, and even aromatic species normally not liked by other ruminant livestock species. The distinct feature of their adaptability to survive on these halophytes (i.e. vegetation tolerant to high salinity) and to digest forages of poor digestibility, such as shrubs and trees [19,20] make them the most resilient animal species to thrive in the desert ecology. Camelids excrete less

N in the urine and effectively recycle urea through the lining of pre-stomachs [49] and this N-saving allows them to maintain a minimum production of microbial proteins in N-deficit dry and matured pasture during the summer. Despite this distinct potential and enhanced role in food security of the people in the harsh-environment of the globe, camel productivity is somewhat less focused in comparison to other domesticated ruminants. Every likely, camel contributes to animal protein requirement reasonably at a lower cost in the arid zones based on feeds and fodder that are generally not utilized by other livestock. Camel grows more or less in a similar pattern as that observed in other livestock. The average daily gain (ADG; g/d) of Bikaneri camels increased from 400 g during 0 - 1 year to 720 g during 7 - 8 years and then declined to 300 g at the later stages (10 - 11 years of age) [54]. Since, pre and post-weaning growth rates have significant effects on final weights of camels, nursing ability of mothers based on milk yield and sustained lactation have major impact on early weight gain in suckling calves and later the post-weaning growth rate depends mainly on husbandry practices, availability of pasture/vegetation and browse in the area. Poor reproductive efficiency in camels is generally attributed to their delayed puberty, seasonality, and long inter-calving interval. Most of the breeds weigh 450 - 550 kg at maturity and the Indian camels can reach 600 kg and are thus considered heavier camel breeds of the world.

Pasture-based management

In fact, this perceived low productivity is primarily due to poor management and infringement of traditional nomadic pasture systems because of geopolitical reasons and therefore, many of the perceived reasons for poor productivity can be alleviated with proper management and application of technologies based on research addressing socio-economic implications. Mixed crop-livestock systems helps feed many people in the world, and it helps farmers obtain an income in different agro-ecologies [55]. The poor as well as the wealthy farmers can thus take risks to cope with input shortage, i.e. 'low external input systems' (practiced by the poor), or to best utilize excess nutrients, 'high external input systems' (adapted by the rich) that enhance sustainability. So, economization in the major input cost from feeds and feeding throws challenges to nutritionists and agronomists to look for suitable and available forage biomass that can be harvested and stored in times of plenty, cultivated suitable forage species for maximum biomass production, increasing carrying capacity of shrinking land resources by adopting silvi-pastoral system and pushing forage processing technique for minimizing wastage, enhancing transportation and forage/ feed banking to feed during shortage/unavailability, scarcity and natural calamities. Exploration of promising and alternate feed resources like *Moringa oleifera*, cactus (*Opuntia* spp), monsoon herbages (*Amaranthus* sps., *Commelina diffusa, Indigofera cordifolia, Crotalaria medicaginea, Boerhavia diffusa, Tribulus terrestris*, etc.), *Blepharis sindica*, Acacia pods, Juliflora pods, spices straws, etc. have not only widen the forage base but also narrowed down the gap between supply and demand [56]. Camels usually accustomed to a variety of vegetation that apparently delivers adequate nutrition, viz. *Haloxylon aphyllum*, *H. persieum*, *Salsola gemmaseens*, *S. orientabs*, *Astragalus spp*, *Aristida karelinii* and *A. pennate* during autumn and winter, plant biomass with short life cycles (ephemerals) during spring and saltbush, sour-plants and thorny-shrubs during summer [57].

Every pasture land depending on the soil fertility and agro-climatic conditions has a carrying capacity and animal grazing need to be based on carrying capacity of land and it should include fodder trees/shrubs which can provide foliage during summer in a complementary way with grasses and it has been postulated that the biomass yield nearly doubled in a three-tier silvi-pastoral system that can suffice fodder requirement of double the livestock population [58]. In most of the camel-rearing areas, production of feeds and fodder from the agricultural food-crop systems, establishment of multi-utility trees and shrubs and even cactus are some of the prospective approach for round-the-year feed supplies [56] and it also contributes to enhancing soil fertility that has far reaching implications for natural resource management. A sustainable integrated livestock-tree-crop production systems seems inevitable if major issues across the systems viz. inter-alia nutrient flows, waste disposal, putting into practice the ever-promising rotational grazing system, surplus storage and feed banking for round the year feeding are properly addressed. It needs to intervene for a farming systems perspective to reorient research programmes that includes inter-disciplinary and people's participatory approach (PPA) or community-based participation, especially in the development of village forestry, reclamation of community pasture land and scientific land-use system for upgradation of degraded and unused land. Such an approach will be associated with substantial profits and benefits due to integration of cumulative and assertive efforts directed at forage biomass production and ensuing productivity sustenance of livestock as well as camel in the dry areas.

Strategic and supplementary feeding

Raising livestock on grazing/browsing or pasture-based extensive system, semi-extensive and intensive systems are in general practice around the globe that is principally dependent on available resources, agricultural practices and climate-change scenario. Accordingly, the quality of animal products differs from one production system to other that has effect on both extrinsic (e.g. weight gain, age at slaughter and carcass weight, dressing yield, etc.) and intrinsic (e.g. composition and conformation, carcass fat content and colour, meat composition, colour, tenderness, flavour, etc.) aspects of carcass and meat quality [59]. Bhakat., *et al*. [60] recommended practice of grazing during cool hours of the day for better growth performance in camel calves due to comparatively lower temperature humidity index (THI). Since camel are raised mostly on pasture and browses, it may have positive effects on meat tenderness, shelf-life, colour and flavour besides enriching its functional food value with ω3 FA, especially eicosapentaenoic and docosahexaenoic acid [61]. Moreover, similar to synthesis of conjugated linoleic acid (CLA) in ruminants, role of camel rumen in production of CLA by a similar microbial population cannot be ignored.

The natural pastures are generally unavailable in the dry summer season and characterized by mature, more lignified fibrous and relatively biomass having very low nutritive values leading to limited intake, digestibility and utilization. In this period, the performance of ruminant animals is seriously impaired resulting in heavy productivity losses in the current as well as in subsequent years. It is therefore realized that maintenance during periods of scarcity is sustenance of future productivity. Inadequate or deficit nutrition lead to weight loss and poor body condition and the realimentation cost for recuperating the animal to its original physiological state asks for additional nutritional input, which is often uneconomical. A total mixed ration can be prepared for stall-feeding of lactating camel and the growing calves during periods of feed scarcity and summer months, when the grazing area lacks any feed resources and this can be made in to pellets or compact feed block (CFB) for easy delivery, transportation and storage. Complete feed blocks can be prepared and fed to lactating camel for sustaining lactation and milk yield [62] and this can be made economical by incorporation locally available feed and forage resources.

Breeding and reproduction: A real challenge

Growth and development in camel population is hindered by its low reproductive efficiency characterized by advanced age at first parturition, long gestation and lactation period, seasonal breeding, and high rates of pregnancy and neonatal losses. The male camel matures at an age of 4 - 5 years while female at the age of 3 - 4 years and the gestation period is 390 days. Improving the performance of managers and the ideal use of herders are important factors in maintaining high reproductive efficiency in camel herds besides other strategic approaches like reduction of age at first mating, the interval after calving, control reproductive disorders and calf management to reduce mortality could improve the reproductive performance and quality of camel herds [63,64]. In line with the successful genetic improvement programmes in developing countries for sheep and goats, camel dairies can also put on similar line of cooperative community based breeding programs starting with a nuclear flock formed by the farmers group and expanding to include more groups in future. International Camel Consortium for Genetic Improvement and Conservation (ICC-GIC) need to focus on developing breed societies through which the promising breed improvement programmes can be implemented for faster genetic gain for ultimate reach of the farmers' community. For faster propagation, there is urgent and concurrent need of assisted reproductive technologies (induced ovulation, semen collection and handling, semen freezing and artificial insemination, etc). A promising protocol for planned breeding called FWsynch (Follicular-wave synchronization), a hormonal (GnRH and PGF2α) induced technique to synchronize the follicular wave, has recently been developed with satisfactory results [65].

Seasonality of reproduction in camels has long been recognized, and accordingly, the breeding season in India goes from late September to March analogous to the monsoon season and early summer, in Saharan and sub-Saharan regions it is somewhat longer and runs from October until May and in the Middle East, it goes from late October until late April [8]. Critically, overlooking the seasonality factors, these breeding period corresponds to availability of feed resources, and camels probably use these environmental factors to predict the suitable climate for breeding so that birth occurs during a good grazing period to maximize the survival of offspring. Environment has a significant role in alteration of length of gestation, scheduling of parturition and birth weight of calves. Heat stress has a significant effect on feed intake by the female dromedaries that reduce their feed intake leading to reduced ovarian follicular dynamics, and sometimes complete interruption of ovarian activity [66]. Camel oocytes were sensitive to acute heat shock showing delayed maturation, reduced ooplasmic diameter and increased chromosomal abnormalities, while cumulus cells tolerated acute and chronic heat shock because of an increase in heat shock proteins expression [67].

Although the gestation period in camel is 390 days (range: 344 - 429 days), a wide variation does exist that ranges from 73 to 89 days [68]. The season of calving has also an effect on average gestation period, approximately longer by 18 days in dromedary camel conceiving in November compared to those in May. It has also been observed that calves born in autumn and winter are heavier and have better survival rate than calves in spring and early summer. The seasonality of reproduction is associated with climatic conditions (i.e. photoperiod) independent of nutritional factors. But, the nutritional status that regulates body condition score has a significant influence often reflecting an endogenous circannual rhythm in foetal development and this peculiar phenomena could be a useful *in vivo* model to study the effect of the climate-change and environmental variability on foetal-maternal communication, development of foetus and scheduling of parturition.

Conclusion

In the era of modern transport and communication system, the age-old dependency on camel is now getting out-dated. This has ultimately opened up other less-important attributes of camel and now, there is an increasing demand for camel milk and meat and their products. Concurrently, the climate change and ensuing desertification in the affected countries brings back dromedaries (*C. dromedarius*) and Bactrian camels (*C. bactrianus*) with renewed importance, and is now the focus of animal scientists on climate-resilience research and other progressive camel farmers or enthusiastic entrepreneurs as a means of profit making livestock husbandry. The countries having larger camel population are in various stages of development relating to agriculture and setting up infrastructure. Therefore, major challenges in creation of intensive or peri-urban camel dairy or beef industries demands huge financial investment besides support and coordination between all the stakeholders.

The interactions between genetics and environment, climate-change and physiological adaptation, regulation of extrinsic and intrinsic factors on milk and meat production and modulation on their quality attributes are some of the important areas of research in both Dromedary and Bactrian camels. The study on camel's unique thermal regulation mechanism and the homeorhetic regulation of mammary cell function has far-reaching significances. The international scientific community has to turn its attention to a good performance control of dairy production in camels. Besides genetic improvement and physiological and reproductive management, the principal input cost of rearing, i.e. feeding and nutrition, cannot be overlooked. The promising approaches could be i) expanding the forage resource base by exploring feeding value of available alternate plant biomass and including them in pasture land development or reclamation of unused land, ii) adopting mixed cropping in silvi-pasture system, and iii) harvesting, processing and feed banking of the excess forage biomass to feed during scarcity. Multipronged strategies are needed to explore the complexities concerning adaptive capabilities of camel as a multipurpose animals of the desert, in the face of untoward climatic-challenges and its ability to thrive well on scarce resources of the desert, but considered exceptional for food security and benefiting to human health services vide its produce and products of therapeutic importance. Tactical intervention in production and application of marketing strategies for higher return from produce and products open up avenues for future investment and maximizing profit from livestock enterprises. Camels can thus very-well contribute to augment human food security, specifically the need of animal protein, and also promise job opportunity and socio-economic upliftment thereby broadening its usage as an animal that produce therapeutic milk and meat for its changed and most significant ' Desert to Medicine' application.

Conflict of Interest

The author has no financial or other conflict of interest in publishing this article.

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