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Camelids for Sustainability: A Socio-Economic Perspective

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BP and AK did the conceptualization and study design. Authors AK, BP and PS Investigated the study. Authors AK and BP did data visualization. Authors AK, BP and PS wrote original draft of the manuscript. Authors BP and AK wrote, reviewed and edited the manuscript. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The Camelidae family includes the Old-World camelids, represented by the Dromedary (one-humped) camel (*Camelus dromedarius*) and Bactrian (two-humped) camel (*Camelus bactrianus*), as well as the New-World camelids, also known as South American camelids (SACs), which consist of Llama (*Lama glama*), Alpaca (*Lama pacos*), Guanaco (*Lama guanicoe*), and Vicuña (*Vicugna vicugna*). Known for their resilience, camelids exhibit specialised anatomical, physiological, and behavioral adaptations that enable them to thrive across a spectrum of challenging environments—from arid deserts to the elevated Andean highlands. Apart from being an intertwined part of cultural heritage, camelids emerge as vital economic contributors for local communities, providing invaluable resources such as fibre, milk, and meat, thereby playing a central role in the economic well-being of these regions. Amidst the escalating effects of climate change, with conventional agriculture and livestock production becoming virtually impossible, these miracle species are emerging as the centrepiece of global interests. This paper

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aims to promote awareness of the crucial roles played by camelids by investigating their inherent connection with the traditions and heritage of indigenous communities while also examining their contribution for ensuring sustainable economic growth and food security.

Keywords: Camelids; camel; llama; alpaca; vicuña; guanaco; sustainability; SDGs.

1. INTRODUCTION

Modern camels are classified within the order Artiodactyla, specifically in the suborder Tylopoda, and further categorised into the family Camelidae, which comprises the tribes Camelini (Old World camels) and Lamini (New World camels) [1]. The evolutionary origins of dromedary and Bactrian camels can be traced back to the middle Eocene period, approximately 40 to 45 million years ago. During this time, the predecessors of Camelus and New World or South American camels (NWCs or SACs) appeared on the North American continent. Following their divergence into the tribes of Lamini and Camelini, the latter migrated to the eastern hemisphere via the Bering land bridge, subsequently known as the Old World camelids [2]. Fig. 1 shows the lineage of camelids.

There are two species in the Genus Camelus: the Bactrian camel (*Camelus bactrianus*), found in both wild and domesticated forms, and the dromedary camel (*Camelus dromedarius*), or Arabian camel, which is now completely domesticated. They are also known as “Old World Camelids” or large camelids [2]. Camels live in herds with a dominant male, females, and offspring. They have humps, which store fat for energy, with dromedaries having one and Bactrians having two. Camels have adaptations for the desert, like long eyelashes and the ability to close their nostrils to keep out sand, as well as thick lips to eat prickly shrubs [3]. The domestication of Arabian and Bactrian camels took place simultaneously around the III millennium BC, specifically in the respective habitats of the dromedary along the coastal regions of the Arabian Peninsula and the Bactrian in SW-Central Asia [4].

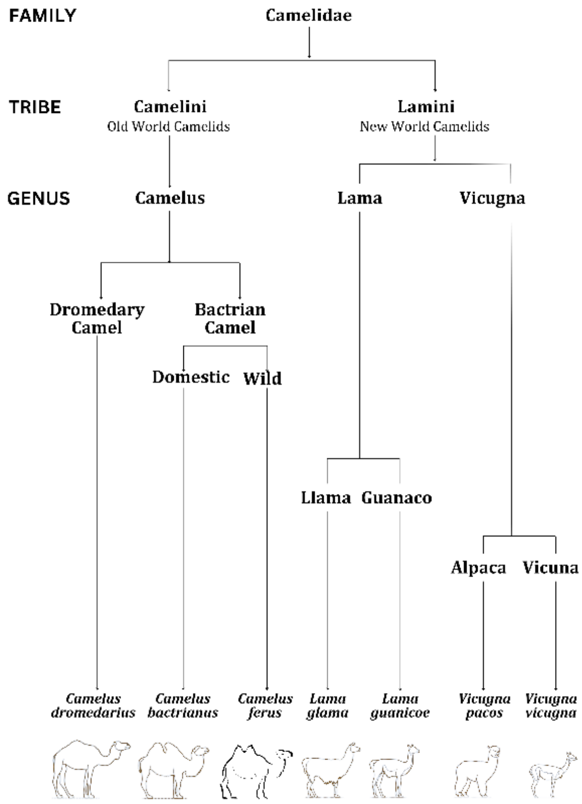

Fig. 1. Phylogeny of family Camelidae

The dromedary represents 94% of the overall camel population, with the Bactrian camel comprising a mere 6%. In 1961, the global camel population was 12.9 million, but by 2018, it had increased to 35.5 million, signifying a notable growth [5]. At present, the Wild Camel Protection Foundation (WCPF) approximates the wild Bactrian camel population to be alarmingly low, with only approximately 950 individuals remaining. Consequently, these camels have been categorised as “critically endangered” on the IUCN Red List. The dromedary surpasses the other two camel species in height, making it the tallest among them. In contrast to the camelids of the genus Lama, the dromedary possesses a hump and exhibits a longer tail, smaller ears, squarer feet, and greater shoulder height, while also having four teats as opposed to the two found in the Lama species [6]. The *Kharai* camels, alternatively referred to as swimming camels, hold significant significance as a breed of dromedaries in Gujarat, India. They exhibit the remarkable ability to traverse vast distances in the sea in order to reach their designated grazing areas. Their nomenclature originates from the Hindi term *"khara"* signifying salinity. This distinctive and scarce breed is exclusively located along the Gujarat coastline, relying heavily on mangroves or saline plant species for sustenance [7,8]. Regrettably, these camels are presently classified as endangered species, facing an imminent threat to their very existence.

Bactrian camels are predominantly distributed in Central Asian countries such as Mongolia, China, Kazakhstan, north-eastern Afghanistan, Russia, Crimea, and Uzbekistan, with smaller populations also found in northern Pakistan, Iran, Turkey, and India [9], whereas more than 80% of the world's total dromedary population is found in Africa. The wild Bactrian camel is small in size, possesses a streamlined physique with slim legs, narrow feet, a laterally compressed body [10], and smaller, lower, more conical humps, often reaching about half the size of its domestic counterpart [11]. This species also displays a distinctive foot shape and a flatter skull, as indicated by its Mongolian name, "*havtagai*", meaning "flat-head" [12]. It tolerates saltier water than any other mammal, including its domestic counterpart [12].

New World Camelids, or South American Camelids (SAC), consist of four species. The four existing species can be divided into two broad groups on the basis of their origin. The first group, *Salqa*, has a natural origin and encompasses Guanacos (*Lama guanicoe*) and Vicuñas *(Vicugna vicugna*). The second group*, Uywa,* comprises Llamas (*Lama glama*) and Alpacas (*Vicugna pacos*), which originated through the collaborative influence of nature and the ancient inhabitants of the Andes around 5000 years ago [13].

The socio-economic conditions of desert and highland ecology are profoundly influenced by both camels and SACs. They have become intricately woven into every aspect of the local folks, encompassing ritual, religion, food, language, music, and beyond. Amidst the unforgiving environment, camelids stand witness to every challenge confronted by the local population. The indispensable contributions of fibre, milk, and meat from camelids have emerged as pivotal economic pillars in the desert and highlands, surpassing other resources that often succumb to environmental adversities. In the face of shrinking cultivable land due to climate change, the integration of camelids into the farming system becomes inevitable, paving the way towards sustainability. Declaring 2024 the “International Year of Camelids” (IYC 2024), the United Nations emphasises the pivotal role played by camelids in advancing sustainable socio-economic development in desert and highland regions. Aligned with the United Nations' vision to attain Sustainable Development Goals (SDGs), the objective of the paper is to disseminate awareness about the multifaceted role of camelids in ensuring comprehensive welfare ranging from poverty alleviation to food and nutritional security. This review examines the socio-cultural impact of camelids alongside their economic contribution to the lives of local, indigenous communities in desert and highland ecosystems.

2. SOCIO-CULTURAL SIGNIFICANCES OF CAMELIDS

Camels have played a crucial role in shaping the traditions, economies, and daily lives of different communities around the globe. From the *Raikas* of India to the *Pashtun* tribes of Pakistan, camels have been a reliable companion for these people in the treacherous desert battleground where survival is a constant challenge. The *Raika* people, a pastoral community in India, have relied on camels for their livelihood and survival since time immemorial. They treat their camels with the utmost care, considering them not merely as livestock but as members of their extended family [14]. This signifies the depth of the bond between *Raikas* and their camels. India is the habitat of the Dromedary Camels discovered in Gujarat, Haryana, and predominantly in Rajasthan. Within this region, the *Raikas* have long followed specific customs concerning the utilization of these camels. These customs include refraining from killing or consuming their meat, selling their milk, wool, or any female camels. The only exception is the annual livestock fairs held in cities like Pushkar, Nagaur, and Tilwara, where the sale of male camels is allowed [15]. Such practices are proudly highlighted by proverbs such as “To sell milk is like selling one's own son” and "Marry me into a village with many she-camels” among the community [15]. The level of understanding and communication the *Raika* have developed with their camels is truly remarkable. They've mastered the art of camel husbandry, knowing each camel's personality, needs, and health requirements, and can even interpret the smallest sign or behaviour of a camel. They also possess the ability to discern which plants the camel has consumed simply by observing the colour and flavour of the milk.

The *Afar* people, an ethnic group primarily residing in the Horn of Africa, also have a fascinating relationship with camels. The *Afar* camel pastoralists unanimously support the notion that they would rather lose a son than lose a camel, as the death of a son can be overcome, while the death of a camel leads to stagnation, the loss of movement, and the collapse of their household [16]. They engage in agriculture, specifically growing maize, which they favor as a meal when served with camel milk. In their society, not owning any camels indicates poverty; having 1-2 camels signifies extreme vulnerability; 10 camels are the minimum level for survival; 70 camels or more denotes wealth; and having over 100 camels is considered significant wealth [16]. In the *Afar* way of life, camel-herding has been highly regarded, and those who engage in this occupation hold the highest social status. Camels symbolise great honour in their community and are only slaughtered at significant events such as weddings or funerals, unlike other domestic animals [17]. The *Gāli Sāré* poems, which are sung by the *afar* people as a camel praise song, address various social and environmental concerns by consistently acknowledging the significant psychological, social, cultural, and religious impact that camels have on the *Afar* nomads [18]. The *Gāli Sāré* oral poems use the female camel as a symbol for a mother [19], representing Mother Nature or the generous provider of all necessities for the *Afar* people, a comparison shared by the nearby Somali community [20]. There is a saying among *Afar* people, *“Qeb radeleh-kuukan gira-kee-yoh xaleleh-waasan-idqiso-num biyaktah,”* in which camel-breeding is compared with warfare to suggest the difficulty involved, but it also highlights the notion that perseverance leads to eventual success [17].

Gabra, Rendille, and *Ariaals* are the major camel keepers in Northern Kenya. The *Rendille* people, an ethnic group from northern Kenya, have a deep and unique relationship with camels. They usually start their day by consuming a blend of milk and blood *(banjo)* before heading out for herding. They have intricate knowledge of camel herding techniques, including the ability to guide and manage large camel herds efficiently. For example, mother camels are purposely not provided with water for a month after giving birth, as *Rendille* people adopt this method to help their animals adapt to challenging environments where obtaining water can be extremely arduous [21]. Regular salt is essential for all livestock, as its absence can lead to decreased resistance to lameness and trypanosomiasis, as well as a decline in activity. Therefore, the *Rendille* intentionally guide their livestock, particularly camels, to waterholes with brackish water and salt licks while also providing them with salt-shrubs such as *Dasysphaera prostrata* and *Salsola denciroicles africana* for feeding, even supplying salt to camels during their journey to waterholes [21]. They believe that *Capparis tomentosa* is a toxic plant that makes camels dizzy, unable to walk, and eventually kills them, discouraging grazing in the mountains. They have acquired a deep understanding of camel care by inheriting and sharing this knowledge from generation to generation. The *Rendile*'s respect and reverence for camels can be seen in their traditions and rituals. They celebrate and honour the camel through events such as camel races, beauty contests, and even camel weddings. Five times a year, the *Rendille* perform social ceremonies in their settlements to promote the fertility of their livestock, referring to the group of camels used for subsistence as “*gaalimoolo”* and the group for reproduction as “*gaaliforr”* [21]. Rituals such as “*soorriyo”* and “*alma’do”*, a fertility ceremony for married women and livestock, particularly camels, are an important part of their culture. Thus, camels serve as an essential part of the *Rendile*'s nomadic lifestyle. Instead of selling their camels, they often choose to transfer them through a rental system [22], which allows them to gain socio-economic benefits while sharing resources.

The *Gabra*, along with the neighbouring *Rendille*, are camel herding people who rely solely on their livestock for sustenance, refraining from farming or hunting, and occasionally using ostrich eggs mixed with water as a medicinal supplement for their camels [23]. The *Rendille* prefers fresh and sour camel milk, while the *Gabra* have a weaker preference for camel milk and meat compared to other livestock [22,23]. Among them, milk mixed with blood is called *galgach*. The camel ownership system in the *Gabra* community is similar to that in *Rendille*. Individuals have primary rights and marks over camels, but they are also considered communal property. Camels bear both a private mark and a lineage or phratry brand, depending on the community [21]. The *Ariaals*, on the other hand, are also a fascinating community living in northern Kenya, known for their unique blend of camel and cattle herding. They are considered a harmonious combination of the *Rendille*, who are camel herders, and the *Samburu*, who are cattle herders. This distinctive mix makes their economic activities quite diverse and interesting [24]. They follow the *Rendille* traditions of *soorriyo* (sacrificial ritual), *alma'do* (fertility ceremony), and *Samburu* '*ilmugit'* rituals for the wellbeing of their camels [24]. The Berbers use camel hair cloth for tents and sacks [25]. In fact, studies speculate that the use of camels and Roman limes for trade may have led to the development of a common language that evolved into modern Berber dialects [26].

The noble Bedouin of North Arabia remain independent camel breeding societies, and their status, power, and prestige depend upon their great camel herds and means of maintaining them at full strength. Camels serve as a means of exchange between the Bedouin and settled societies, facilitating the acquisition of grain supplies, hardware, and textiles for the clothing and tent cloth needs of the Bedouin [27]. Within Bedouin society, camels are distributed through kinship mechanisms, involving various practices such as bridal gifts, blood vengeance compensation, *zakat* contributions (mandatory charitable contributions paid by adult Muslims), recompense to herdsmen, incidental gifts, inheritance, sharing during misfortune, and customs of hospitality and generosity. However, between tribes of equal status, thievery and raid are the sole methods of distribution [27]. In Bedouin Arabic, camel raiding, known as "*ghazw*," aims to capture highly valued milking camels or fine riding mounts, with baggage camels considered of secondary value [27]. According to Robinson's research in 1936, the *Mehri* tribe successfully developed a unique breed of dromedaries that were widely recognized for their impressive combination of size and speed [28]. The *Mehri* cavalry unit brought *Mehri* camels to North Africa during the conquests, where they are now widespread and known as Coastal Camels. Among these breeds, the Eid camel stood out for its speed and high milk production, becoming a symbol of swiftness. However, as several tribes transitioned to horsemanship, the camel was no longer favoured and eventually abandoned. Mongolian herders are said to partake in the *coaxing* ceremony, [Fig. 3(b)] wherein they utilise a formal ritual to encourage a female camel to embrace either a recently born calf or an orphan by closely tethering the mother to the calf and initiating a melodic chant accompanied by gestures [29]. The tune is gradually adjusted in response to the mother's initial aggression until she eventually accepts the calf [29].

Apart from these, there are many other tribes and communities in different parts of the world that have a deep socio-cultural relationship with camels, such as the *Pashtun* tribes of Afghanistan and Pakistan, the Mongolian nomads of Mongolia, the Kazakh people of Kazakhstan, the *Rashaida* tribe of Sudan, Eritrea, and Saudi Arabia, the *Tuareg* people of the Sahara Desert, the *Masai* tribe of East Africa, and countless others. Each of them has their own cultural ways and beliefs associated with this sacred animal. However, there is not much literature available on them, and some of them have not even been studied properly with special reference to camel ecology. It is almost impossible to understand these communities without first understanding their companies, the camel, the beast which makes life possible in the harsh arid and semi-arid regions by drinking non-potable water and reciprocating with milk, meat, and fibre for sustenance. Life cannot exist without man and camels' alliance in the unforgiving deserts.

Similarly, SACs too share a strong connection with the lives of indigenous communities. Throughout the earliest human settlement of the Americas, spanning over 11,000 years, Andean communities have utilized SACs. Pre-Hispanic indigenous communities heavily relied on SACs as their primary source of resources. The *Selk'nam* fostered religious ties with animals and prohibited guanaco hunting in designated sacred areas to ensure unrestricted breeding [30]. Once every four years, the *Inca* Empire conducted the "*chaku*" ceremony across the Andes, a ritual of significant ceremonial importance. The *chaku* involved herding thousands of vicuñas into stone corrals for shearing, with local people surrounding vast areas and guiding the animals towards extensive corrals [31]. SACs hold a royal connection as the *Inca* Empire bestowed significant economic and symbolic value upon them, particularly for their fine fibre. The exclusive task of spinning and weaving vicuña textiles and garments was entrusted to a select group of women known as "virgins of the sun." Worn by the Inca elite, these garments served as symbols of power and prestige [32]. Today, the Vicuña continues to serve as the emblematic species of Peru, representing wealth and prosperity. Integral to Peru's coat of arms, the Vicuña is honoured with its dedicated holiday, National Vicuña Day, celebrated on November 15th.

In the future, the socio-cultural significance of camelids among various communities and tribes around the world is expected to continue to play a significant role. Camelids will remain integral to the traditions, livelihoods, and identities of these communities, symbolizing resilience, adaptability, and a deep connection to their ancestral heritage. Additionally, as global awareness of sustainable practices grows, camelids may also gain recognition for their eco-friendly attributes, such as their ability to thrive in arid environments and provide sustainable transportation and milk production, which will lead to increased efforts to preserve and protect their populations, fostering cultural diversity and sustainable development in these communities.

3. SUSTAINABLE ECONOMIC CONTRIBUTION

3.1 Old World Camelids

3.1.1 Milk

Contrary to their bovine counterparts, these lactating xerocoles, domesticated for at least 3000 years, are a prerequisite to the food and economic security of the world. Camel milk is the linchpin for millions of people in pastoral and agro-pastoral areas of north and east Africa, Central Asia, and the Indian subcontinent. A glimpse into history reveals that before the conception and spread of Islam, many Arabs were herdsmen who lived off the milk from their camels [33]. Later, Prophet Muhammad described it as a miracle of the almighty and a disease remitter, following which nomadic desert tribes initiated its consumption.

The pastoral area of Ethiopia is the main camel belt in Africa. It is known as a camel culture, a monoculture that is expressed as an adaptation to arid ecology through dependence on the camel based on uniform husbandry methods and mobility [34]. Milking camels in the Horn of Africa goes beyond a simple laborious activity; it has integrated itself as a fundamental aspect of the local culture and heritage [35]. Only boys, unmarried women or ritually clean men are allowed to milk the animals [35]. The nomads of the *Ahaggar* in the Sahara depend on camel milk to give them a balanced diet [36]. They have a saying, “Water is the soul; milk is life”, and hungry people say, “I've lost the taste of milk.”

Among the two species of camels, i.e., the Dromedary (camels of the plains) and the Bactrian (camels of the mountains), the former has milking capabilities higher than the latter, which produce 5 litres of milk per day. *Camelus dromedarius,* with a lactating length of 8-18 months and daily milk production of 2.5-15 kg, has surpassed the hybrid species too. The hybrid ‘Kazakh’ gave more milk than the hybrid ‘Turmein.’ [37,38]. Camels hailing from Pakistan and Afghanistan are recognized for their capacity to produce significant milk yields, reaching up to 30 liters per day. In Kenya, the *Sakuye* camel produces an average of 4 kg of milk daily, with a maximum of 12 kg, which is far more than what the local cows beget. The geographical distribution of camels (dromedaries) in India, is in the states of Gujarat, Haryana, Maharashtra, Madhya Pradesh, Punjab, Rajasthan, and Uttar Pradesh. Lactation yields range from 2000 kg [39] to 2700–3600 kg under good feeding conditions [40].

With their adeptness to survive in parched, waterless conditions for about 3 weeks and produce milk while feeding on substandard, dodgy fodder, camels hold the most sustainable realm in the dairy industry worldwide. Unlike a dairy cow, which is parted from her calf when it is born and then gives milk for six to nine months, a camel can share her milk with the farmer and her calf for 12–18 months. Reports indicate that it is now common to see camel milk marketing and consumption in big cities and towns in Africa where camels are not found [41]. In addition, owing to its purported medical value, interest in camel milk has grown in recent years among consumers in Europe and North America [42-44]. Kenya is currently the leading camel milk producer globally, with an annual production volume of 1.165 MMT, followed by Somalia (0.958 MMT) and Mali (0.271 MMT) [45].

3.1.1.1 Composition

Although there is a considerable variation in camel milk composition as per existing literature due to differences in methods of analysis, milking intervals, season, feed, etc; studies state that the white opaque liquid obtained from the Dromedary camel has a fat content of 1.2-6.4%, [46] and that obtained from the Bactrian camel has 4.3-5.3 %. Konuspayeva *et al.* (2009) reported an overall gross composition (g/100 mL) of 3.35 ± 0.62, 4.46 ± 1.03, 12.47 ± 1.53, and 0.79 ± 0.09, protein, lactose, total solids, and ash contents, respectively, for dromedary and Bactrian camels based on a meta-analysis of literature data [47]. Camel milk further has low levels of sugar and cholesterol, while higher levels of vitamins (A, B, C, D, E) and minerals like potassium, magnesium, zinc, iron, and calcium are present. It differs from bovine milk as it lacks β-lactoglobulin (β-Lg), has a small amount of κ-casein (κ-CN), and has a larger amount of β-casein (β-CN) in its casein micelles [48]. Also, due to the lack of A1 beta-casein, it is convivial for patients suffering from lactose intolerance. It has A2 beta-caseins and immunoglobulins, which help in maintaining the immune system of the body [49]. The main whey proteins present in camel milk include lactoferrin, immunoglobulins, lactophorin, peptidoglycan recognition proteins, lactoperoxidase, serum albumin, lysozyme, and α-lactalbumin [50,51]. Talking about taste, American camel milk is said to have a sweet, slightly salty, and creamy taste, while camel milk from the Middle East has a nuttier and smokier flavour [52]. Therefore, with higher concentrations of mono and polyunsaturated fatty acids, non-allergic properties, anti-diabetic properties, and ease of digestibility, camel milk can be considered an elite and superior substitute to cow's milk in succeeding decades.

3.1.1.2 Therapeutic uses

Milk from this most impregnable livestock has several health benefits too. The *Raikas* and *Rabaris*, tribal communities in Rajasthan and Gujarat, have depended on camel milk for centuries, using it not just as a dietary staple but also as a crucial medicinal beverage. The members of these communities have said that even during drought, they survive solely on camel milk, which helps keep them fit and healthy [49]. Camel milk has been shown to lower blood sugar and improve insulin sensitivity in people with both type 1 and type 2 diabetes [52]. Camel milk may benefit neurodegenerative diseases like Parkinson's and Alzheimer's, but only a few animal studies have investigated this potential [52]. It further aids in keeping the heart and skin healthy and boosts the immune system.

3.1.1.3 Dairy products from camel milk

As per reports, with a decline in the nomadic population over time, the camel stood at a decent number. Thus, instead of exploiting just the bovine animals for milk, utilizing camel milk aided sustainability by maintaining equilibrium between the two. However, marketing of camel milk outside camel-inhibiting areas remained trivial and meagre due to the nonexistence of processing amenities. Due to increasing demands and advancements in the food processing industry, especially the dairy sector, camel milk broached from a mere household to a global market level. But camel milk products are yet to beat the diversified bovine ones. A few major consumables manufactured out of camel milk are discussed below:

Camel milk butter: The white-coloured, waxy-appearing camel milk butter is obtained using a large quantity of camel milk. Butter from camel milk *(Shmen)* is produced by pastoralists in the Algerian Sahara by using a traditional churning method [53]. Similarly, Bedouins in the Sinai Peninsula [54] and pastoralists in northern Kenya [55] traditionally make butter from camel milk. The difficulty of processing camel milk into butter is attributed to the little tendency of camel milk to cream up due to a deficiency of the protein agglutinin that promotes the clustering of fat globules [56,57] and the small size of the fat globules [57]. Nowadays, commercial butter made from camel milk is available in the Middle East (e.g., from Camelicious in Dubai) [58]. Camel milk butter, renowned for its versatility in cooking, medicinal applications, and use as a hair pomade, along with the highly sought-after clarified version (ghee), stands as a product with widespread consumer appeal [59]. Techniques for obtaining premium quality butter by appropriate churning and at suitable temperatures are being researched.

Camel milk cheese: Production of cheese from camel milk is difficult due to the poor coagulability of the milk [60]. Commercial rennet is therefore put into use. The transgenic camel chymosin (Chy-Max M1000) recently developed significantly improves curd formation in camel milk [61]. Moreover, ultrafiltration and concentration of camel milk (two- or four-fold) were reported to improve the gelation of camel milk by Rennet [62]. As a result, various camel cheese varieties have been developed and are now available on the market [63,64]. The possibilities of making various types of cheeses from camel milk, including soft white cheese (Domiati-type) [65], soft unripened cheese [66], soft brined cheese [67], semi-hard cheese [68], soft cheese, fresh cheese, blue cheese, ricotta cheese, pressed cheese [69], cottage cheese, dried curd cheese *(Aarts)*, and soft French-type cheese (*Camembert)* [70], have also been reported. There have been reports indicating the feasibility of producing cheese from camel milk through the blending of camel milk with the milk of other mammals. However, a standardized protocol for making ripened camel milk cheese has not yet been developed [71]. This product is expected to become economical and easy to process in the forthcoming time.

Camel milk powder: Currently, spray drying technology has been used to produce camel milk powder in countries such as Saudi Arabia, the UAE, India, and Pakistan [70,72]. Inlet temperature, direction of feed and level of total solids, water activity, and the yield of camels are a few of the factors affecting the power quality and quantity. Higher whey proteins and ash contents were observed in camel milk powders as compared to bovine milk powder [73], along with exhibiting higher bulk densities.

Fermented camel milk products: Popular fermented camel milk products include *Susac, Laben, Gariss, Shubat, Chal,* etc. A dried fermented camel milk called *Oggtt* is produced in Saudi Arabia [57,70]. The production process involves allowing camel milk to ferment at room temperature for two days, followed by churning the fermented milk. The resulting buttermilk is then boiled with continuous stirring until it reaches a thick consistency. Another dried camel milk product produced in Kazakhstan and Uzbekistan is called *Kurt* [70,74,75]. With an extended shelf life, a salty flavour profile, and a solid texture, it stands out for its distinctive characteristics. *Chaka,* or *Suzma*, a kind of strained yogurt, is traditionally used to make *Qurt*/*Kurt* [74]. It used to be the main protein source for people residing in the arid desert parts of Uzbekistan [74].

Camel milk as a probiotic and prebiotic food: Pro and prebiotic refer to the intestinal microflora and the resistant starches, respectively, which improve gut health. Non-bovine milk has the potential to form the base of such innovative dairy products due to its structure of proteins, lipids, and sensory properties. Yakult is a prominent example of bovine dairy-based probiotics. Substantial research on camel milk would lead to the manufacture of more such beneficial beverages.

3.1.1.4 Future

Addressing the elements forming the core drawbacks of camel milk would include its stability, shelf life, and processing impediments. There is a requirement for extensive research in these domains to sustainably exploit camel milk. Consumption of unpasteurized camel milk may lead to food poisoning, but ultra-heat treatment (UHT) results in protein denaturation and colour changes. Therefore, non-thermal novel technologies like High Pressure Processing (HPP), Pulsed Electric Field may be tested to pasteurize camel milk. These methods would prevent spoilage and deterioration as well. Due to the absence of rennet, larger casein micelles, and high salt concentrations, camel milk is difficult to coagulate and curdle. This hurdle may be subdued using genetic engineering techniques. Also, there is a need for further study to assess the effects of various additives like phosphates and hydrocolloid stabilizers such as carrageenan to improve heat stability and reduce sedimentation in camel milk [58].

3.1.2 Fibre

The luxurious, versatile fur-like material produced by dehairing camels, comprising guard hair and undercoat, is referred to as camel fibre. Like fibres obtained from other artiodactyls, camel fibre has an enthralling history owing to its significant usage in traditional and industrial practices. With its roots lying in Asia and North America, camel hair was primarily produced in Mongolia. It was also perfectly collected in the mountainous regions of Tibet, Nepal, Iran, Afghanistan, China, and Russia. Bactrian camels produce premium-quality wool when compared to their dromedary counterparts. Camels possess protective outer coats made of coarse fibers, which can grow up to 15 inches (40 cm) in length. The finer, shorter fibers of the insulating undercoat, ranging from 1.5 to 5 inches (4 to 13 cm), are commonly referred to as camel hair or camel hair wool. Collection of camel fibre may be done by shearing, combing, or simply by hand gathering the naturally shed fibre. After collection, the coarse and fine hairs are separated and then washed to remove any dirt or debris before being spun into yarn suitable for weaving or knitting.

Camel hair is, generally, camel-colored (a medium reddish brown), but anything from creamy white to almost black can be found within the camel population [76]. It can be stained using vibrant dyes. The strength is comparable to that of wool with a similar diameter but falls short of the strength exhibited by *mohair*. Camel hair is soft, durable, slightly crimpy and elastic. It further evinces thermostatic and insulating properties, for which it is employed to knit overcoats, blankets, carpets, shawls, etc. The wearing of camel hair clothing is mentioned in the Bible (Matthew 3:4), and it was traditionally used for tents, carpets, and cloaks by the Berbers and in other areas where camels were kept [77]. Pure camel hair is recorded as being used for western garments from the 17th century onwards, and from the 19th century on a mixture of wool and camel hair was used [78]. The first fashion brand to popularize camel hair in clothing was Jaeger, a British manufacturer that specialized in the use of fine woolen fabrics for coats and suits [79]. It became popular in the United States in the 1920s and 1930s, having been introduced through the sport of polo, where a casual camel hair coat was worn by players in between matches [80].

Some renowned camel yarn and fabric manufacturing companies are American Woollen Company (USA), DanRoy dva Shinto LOC (USA), Fukaki Woollen Textile Co. (Japan), South Trading (Hong Kong), Todd & Duncan (UK), Cariaggi Lanificio S.P.A. (Italy), etc [81]. In India, the ICAR-National Research Centre on Camel, along with other institutes, is working to organize the camel wool market. Khamir, a pilot-stage innovation project by craftsmen in Kachchh, Gujarat, is working to develop and market products made of locally sourced camel wool [82]. Considering the comfort and grandeur that garments knitted out of camel fibres render, their diversified usage in the following eon can be predicted.

3.1.3 Meat

Meat from this beast of the Bedouin has been native to arid regions of the Middle East and North-East Africa. Because of its unique physiological characteristics, including a great tolerance to high temperatures, solar radiation, water scarcity, rough topography, and poor vegetation, the Dromedary camel is a good source of meat, especially in areas where the climate adversely affects the performance of other meat animals [83]. Desired parts of camel meat consist of the loin, ribs, and brisket. Meat quality is a function of the camel's breed, its age, and the muscle consumed. Other discriminating meat variables are myofibrillar protein index, meat colour components (L* and a*, b*), and cooking loss [84].

The colour of camel meat is characterized as ranging from raspberry red to dark brown, while the fat content in camel meat is distinctly white [83]. It is similar in taste and texture to beef [83]. According to the Food and Agriculture Organisation (FAO), old males and unproductive females are used as a source of meat. Camels reach live weights of about 650 kg at 7–8 years of age and produce carcasses with weights ranging from 125 to 400 kg that contain about 57% muscle, 26% bone, and 17% fat, with the fore halves (cranial to rib 13) significantly heavier than the hind halves. Camel lean meat contains about 78% water, 19% protein, 3% fat, and 1.2% [83]. Enriched with potassium, followed by phosphorus, sodium, and calcium, camel meat is also a storehouse of vitamins like thiamine, riboflavin, pyridoxine, and alpha-tocopherol. Raiymbeka *et al.* (2015) reported that the mean value of the essential amino acid index of Dromedary meat and Bactrian meat was 216.9 and 191.6, respectively, which was high compared to other red meats, and both meats were rich in methionine and leucine [85].

Globalisation has not only led to the territorial expansion of camelid farming but also to a much more integrated camel product market. It has further contributed to an increased percentage of slaughter. However, slaughtering rates among countries fluctuate based on religious beliefs and sentiments. Various camel meat-based ethnic products consumed across the world include *Guedid, Khliaa ezir, Fregate, Tarfa-Gara, Cachir, Maynama* (Algeria, Morocco), *Tidkit, Khlii, Mkila, Tehal/tehane* (Morocco), *Madfoon* (United Arab Emirates, Saudi Arabia), *Soudjouk, Suçuk, Nakanek, Pastirma,* and *Merdouma* (Egypt) [86]. Some other delicacies made out of camel meat include hamburgers, sausages, patties, etc.

The pharmaceutical benefits of camel meat are as widespread as those of camel milk. Camel meat is used to treat seasonal fever, sciatica, and shoulder pain. Camel meat soup was used to cure corneal opacity and to strengthen eyesight [87]. It is also used to ease haemorrhoidal pains, and the hump fat is used to remove tapeworm [88]. Camel meat is known for its high percentage of iron, one of the important components of blood haemoglobin which helps to reduce the risk of anaemia. It contains carnosine (181.7 mg/100 g), a dipeptide known for its antioxidant properties, and is converted to another bioactive compound called anserine [89].

To increase consumer acceptance of camel meat by improving palatability, shelf life, and quality, food industries tend to practise ageing, smart packaging, and pre-treatment (with antioxidants or by *curing* using nitrates and nitrites to reduce microbial load, discoloration, and shear value). The aging is an intricate process that enhances several quality attributes, influenced by physicochemical parameters, the rate of acidification, alterations in osmotic pressure, and the activity of proteolytic and glycolytic enzymes [89]. Further storage at a temperature of about 4°C reduces spoilage by pathogenic microbes like salmonella. Camel meat storage has been experimented with using different packaging approaches like vacuum packaging, active packaging, Modified Atmospheric Packaging (MAP), etc. There are reports of active packaging films utilizing nano montmorillonite-chitosan and nano montmorillonite-carboxymethyl cellulose loaded with varying concentrations of *Ziziphora clinopodioides* essential oil, which have been shown to improve the overall quality of minced meat samples. The active-packaged samples were reported to have reduced thiobarbituric acid reactive substance (TBARS) and peroxide values as well as received higher scores by sensory panellists for odour, colour, and overall acceptability [90]. Synergistic use of various biopreservation techniques, such as refrigeration, modified atmospheric packaging, along with the use of *nisin* improved the shelf life without any adverse effects on the sensory attributes of camel meat [91].

Food security and nutrition stand as pivotal concerns on the global agenda, intricately tied to the Sustainable Development Goals (SDGs), which include the ambitious objective of eradicating all forms of malnutrition worldwide by the year 2030 [92]. With an edge over beef or lamb due to its low intramuscular fat (1.1 to 10.0%), low cholesterol content, and high iron content, camel meat can be considered a potent alternative to red meat consumption worldwide [89]. Their responsibility of "The Heroes of Deserts and Highlands" is heightened as they play a crucial role in sustaining rural activities and household economies in some of the most remote areas of our planet. The path forward for camelid breeders involves not just the inevitable intensification of farming but also a simultaneous commitment to preserving camelid diversity, enhancing resource management to deliver high-value products demanded by urban populations, and safeguarding the future of these animals. [93].

3.1.4 Other

Folks around the globe are acquainted with camels trouncing food scarcity over the years. But there persist other multifarious ways in which camels benefit us. Notable areas entail regenerative agriculture, ecotourism, cosmetic production, leather yield, fertilizer production, drug production, etc. Camels increase biodiversity on farms, while also protecting the land. Using the rotational grazing technique, camels have been found to increase grass density [94]. Further, a genetic improvement program that might boost productivity and profitability might be advantageous. Small holders may benefit from this by receiving a fair and secure income and good working conditions, which could contribute significantly to social equity and local economies [95].

The 5000-year-old document *'Damar Tantra'* is the oldest known medical treatise to first mention the therapeutic use of human urine [96]. In particular, drinking camel urine alone or mixed with milk is a widely renowned practice within the scope of folk medicine [97]. This practice is attributed to the absence of ammonia, low urea, and other beneficial chemical properties of camel urine. Research on camel urine has shown that it has antifungal and antibacterial activity and is able to protect the liver from CCL4-induced damage [98,99]. Gastroprotective and ulcer-healing effects of camel urine have also been reported [100]. Camel urine has potential activity as an antiplatelet and anticancer agent as well [101].

Camel milk has been proven to display cosmetic effects due to the presence of *α*-hydroxyl acids, known for plumping the skin and smoothing fine lines. In a different study, *α*-hydroxyl acids from camel milk were found to eliminate wrinkles as well as age spots [102]. Extensive research on the cosmeceutical properties of camels may therefore bring revolutionary improvements to the beauty and skincare industries. Beautiful in its architecture and dry and odourless, camels' manure/dung is used as a fueling agent in many developing countries, especially among the pastoralists' communities. In north-eastern Balochistan and southern Afghanistan, it is used as a fertilizer for pomegranate and wine trees. In Australia, some camel pet keepers use camel manure for gardening, and they obtain very good results [103,104]. Being a slow-release fertilizer, its effect is retained for a decent number of years. Reports have found that camel dung has almost the same value as that of other ruminants' dung [105]. Other uses of camel dung include the generation of biogas, power, and bio-paper.

An India-based social enterprise called 'Camel Charishma' claims to have pioneered the production of paper from the dung of *Kumbhalgarh* camels. They employ local women in factories to manufacture the most bio-diverse paper on earth, that has its own rugged character. As no trees are cut to produce the pulp, it is a sustainable approach to paper making. According to existing literary sources on camel leather, it is an expensive, durable, and rare leather obtained from camel skin. It is used mostly for manufacturing premium fashion products like bags and wallets, as it renders them a unique look. The role of camel leather in the making of musical instruments like tables, *dhol*, etc by folk musicians can also be traced. In India, hides are obtained from adult camels that are allowed to linger on till they die. Leather making is a complex phenomenon when compared with fur making as the former involves additional operations like the liming process for dehairing, the bating process, dyeing, and resin/lacquer finishing. Camel leather is used as a base material for decorative objects like lamp shades, containers, etc [106]. The concepts of 'net-zero carbon emissions' and 'animal-based tourism' are found to complement each other. Camels are exotic elements that can be found within adventure travel companies promoting ecotourism activities. Such recreations contribute to sustainable livelihoods for local communities and educational empowerment towards nature and its conservation [96]. Ecotourism with camels would also significantly contribute to reducing greenhouse gases that lead to air pollution, along with declining the carbon footprint [107]. Camel racing [Fig. 3(c)], an ancient tradition observed by the Bedouin community to commemorate notable events, has evolved into a lucrative industry worth millions of dollars. Its popularity has soared, particularly in Arab nations of the Middle East like Oman, and it is also practiced in other locations like India, Kenya, Australia, and more.

3.2 New World Camelids/ South American Camelids

3.2.1 Fibre

Fibre production from SACs constitutes the mainstay of the local economy in Andes. The timeless regal value of precious SAC fibre spans from the ancient Inca period to the contemporary era. Fibres from all four species of SACs are considered luxury fibres with impressive market value [108]. Fig. 2 represents the variation in fibre fineness between all the camelids.

What sets alpacas apart from other camelids is their specialized breeding for the sole purpose of fibre production. Two varieties of alpacas exist: *Suri* and *Huacaya*, each exhibiting distinct fibre qualities. *Suri* alpacas, known for their scarcity, showcase fine, long, silky fibres, in contrast to the more common, shorter, and coarser fibres of *Huacaya* alpacas. The average length of alpaca fibres falls between 125 and over 200 mm [108]. The 22.5 μm baby alpaca hair stands as the finest among alpaca fibres, surpassing even the excellence of *Suri* alpaca, and is used in developing women's scarves and stoles. Out of the extensive range of over 52 potential natural colors, industry-wise, white and grey hold the highest value [109]. The inherent medullated nature of alpaca fibres contributes to the widely recognized soft, warm, lightweight, and luxurious qualities of alpaca fabrics, outperforming un-medullated wool. The Alpaca fibre market is anticipated to attain a value of $5.32 billion by the end of 2033, according to the most recent analysis, marking an impressive increase from its 2023 market size of USD 3.65 billion [110].

Fig. 2. Comparison of fibre fineness between different camelids species

Llamas, the largest among SACs, play a significant role as fibre producers, though not as prolifically as alpacas. '*Kara'* and *'Chaku'* are the two types of llamas, with the latter distinguished by its fine and soft fibre, predominantly utilized in various industries. Llama fibre quality is characterized by an average staple length of 190 mm and a mean fine fibre diameter of 22.9 µm [111]. The properties of fibre are comparable to those of alpaca, except that Llama fibre is double-coated [108]. The fleece exhibits a predominant brown color and does not possess the same allure as that found in alpaca.

Vicuña fibre is an element of immense interest for its mammoth economic value. It is recognized as the world's finest and most expensive natural fibre. In the era of the Inca Empire, the exclusive privilege to wear vicuña garments was reserved solely for the royal family [112]. The Incas practiced sustainable use of vicuñas through periodic roundups known as "*chakus*" or "*chakku*" every 3–5 years, [Fig. 3(d)] during which some animals were sheared and then released back into the wild [113]. But the aftermath of the Spanish conquest and uncontrolled hunting led to the virtual extinction of the Vicuña population. By 1965, the world population of Vicuñas had shrunk to around 6,000 individuals. As a much-needed response, the governments of Bolivia, Peru, Chile, Argentina, and later Ecuador signed the Convention for the Conservation and Management of the Vicuña in 1969, commonly referred to as the Vicuña Convention [114]. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) initially categorized vicuñas under 'threatened with extinction', later modifying the designation in 1987, thereby enabling the harvesting of fleeces for fabric production. Andean countries successfully devised management plans for vicuñas, ensuring the authorized method by CITES involves shearing live animals in a "*neo-chaku*" system that combines pre-Hispanic capture techniques with contemporary animal welfare protocols [114]. A coordinated effort from all fronts led to a dramatic surge in the Vicuña population, marking it as one of the most successful endeavours to revitalize a species. After a hiatus of two decades, Vicuña fibre made a comeback in the market during the mid-1990s.

Vicuña scarves are renowned for their exceptional lightness, allowing them to be effortlessly pulled through a ring. The individual fibres exhibit a diameter ranging from approximately 6 to 35 µm and a length spanning 12 to 65 mm [108]. The most coveted fibre originates from the lower chest, just behind the front leg. In the commercial context, vicuña fibre should fall between 13 and 15 mm in length. In addition to its exceptional quality, the massive price of vicuña is linked to its scarcity, given that an adult vicuña produces only about 200-250 grams of fine hair every two years [113]. Referred to as the 'Fibre of the Gods,' Vicuña fibre carries an enormous price tag, with Vicuña fabric reaching a cost of US$4000 per meter and a full-length pure Vicuña overcoat demanding as much as US$12,000 [108].

Guanaco, too, is subject to CITES regulations, meaning that the shearing and processing of its fibre must comply with the guidelines set by CITES. Guanaco exhibits a dual coat structure, with a coarse outer layer serving as protection and a much finer undercoat. It holds the status of being the second-finest natural fibre globally. Young guanacos' fleece can attain significant fineness (13.3 µm) [108]. Despite being recognized as one of the finest fibres worldwide, Guanaco often takes a back seat to the more common Alpaca wool and the highly esteemed Vicuña wool.

3.2.2 Milk

The harsh climate of the South American highlands makes it impossible to go with conventional dairy. Therefore, harnessing the potential of South American camelids (SAC) for milk production emerges as a promising alternative. Due to a scarcity of research in this domain, there is a lack of clear understanding regarding the nutritional profile of milk obtained from South American camelids. Being domestic species, Llama and alpaca milk hold real good promise. Among various camelids, alpaca milk stands out with a higher protein content (4.53%) [115]. The milk yields in SAC may be a lot lower than those of dairy cows, yet given the adversities, the production remains consistent. Per individual, llamas exhibit an average daily milk yield of around 62 mL [116]. Milk, characterized by a low β-lactoglobulin content, is gaining attention. β-lactoglobulin is considered responsible for cow's milk protein allergy (CMPA) in children, an immune-mediated hypersensitivity reaction [117]. Llama milk, devoid of measurable levels of β-lactoglobulin, holds promise as a potential alternative to cow milk for children [118]. In milk from SAC species, the levels of rumenic acid, also known as conjugated linoleic acid (CLA), fall between 1.05% and 1.64% [109]. CLA has emerged as a promising agent with anticarcinogenic potential [119].

Fig. 3. (3a) The official logo of "International Year of Camelids" (IYC 2024) [124]; (3b) The Mongol herders' "Coaxing Ritual" for encouraging female camels' acceptance of newborn calves or orphans [125]; (3c) Camel race as an emerging sporting interest [126]; (3d) The traditional *Chaku* ceremony to collect Vicuña fibre [127]

3.2.3 Meat

In the high-altitude Andean regions, where cattle and goats struggle to adapt, llama and alpaca meat serves as a crucial protein source for the local population [120]. Ancestrally rooted, Andean *charqui* stands out as a well-known traditional salted dried meat product, derived from the meat of alpacas, llamas, or alpaca-llama hybrids in Peru, Bolivia, Argentina, and Chile [121]. The primary role of these animals should be viewed as contributing to fibre production, with meat production reserved for those individuals discarded from this population.

Primarily owing to its larger carcass, llama is preferred over alpaca in the production of high-quality meat [122]. Llama meat exhibits favourable nutritional attributes, including a notable protein content of 22.42%, low fat at 3.51%, and minimal cholesterol content at 58.16 mg/100g, positioning it as a viable alternative in the challenging Andean conditions [123].

4. CAMELIDS AND CLIMATE-CHANGE

Camelids are robust animals, demonstrating the ability to withstand extreme climatic conditions effectively. They have undergone unique anatomical, physiological, and behavioural adaptations, making them perfectly equipped for survival in diverse harsh environments, spanning from the arid Sahara to the freezing highlands of the Andes. An analysis of camel genomes reveals their remarkable anatomical adaptations, which allow them to thrive in harsh climates, including features such as double eyelashes, a nictitating eye membrane, closable nostrils, a thick coat of hair inside the ear, thick lips for consuming prickly shrubs, a hump for storing fat, a small oval RBC, modified kidneys to minimize water loss, and an extended large intestine for optimum absorption [128].

In the near future, climate change is anticipated to diminish agricultural areas, imposing limitations on extensive crop and animal production. Studies propose that the cultivation of drought-resistant camels could offer a practical alternative for vast regions in Africa, expected to turn increasingly arid by 2050, making conventional food production nearly impossible [129]. In absolute terms, camelids produce significantly lower amounts of CH_4 than ruminants of comparable body size [130]. One study indicates that increasing camel populations by approximately 10%, along with goat populations, and decreasing dairy cattle populations by around 24% could lead to a 5.7% rise in milk production, reduced water and feed resource demand, and, most importantly, lower dairy emissions by approximately 7.9%, enhancing dairy production resilience against climate change in north sub-Saharan Africa [131].

SACs, adapted to the Andean highlands, showcase climate-specific morphological traits like padded feet and mobile lips. Their physiological adaptations include retaining particles in the pseudo-rumen for enhanced digestibility of low-protein, high-fibre forage, along with efficient metabolic water use [132]. Recent research suggests that the presence of llamas in areas uncovered by receding glaciers can accelerate the formation of stable soils and ecosystems, offering a potential mitigation strategy for some of the adverse impacts of climate change [133]. In this study, researchers divided plots into two groups – one with llamas and the other as control plots without llamas. Over the course of three years, they tracked soil quality and plant species prevalence. The llama-inhabited plots exhibited significant rises in soil organic carbon and nitrogen levels, along with a substantial 57% increase in plant cover [133].

5. CONCLUSION

This review affirms that Camelids, owing to their multidimensional contributions and ability to combat climate change, will emerge as the key to sustainability in the coming years. It is crucial to understand that the current general public awareness and research endeavors in this field are still inadequate to fulfil the intended purpose. The rise in awareness is anticipated to attract more investments, which is essential for addressing the research gap and promoting capacity development in the camelids sector. Achieving sustainability from camelids for a secure future necessitates a collaborative approach involving all system participants, ranging from local communities and the general public to government and research entities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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