Perspective

The impact of COVID-19 on Old World Camelids and their potential role to combat a human pandemic

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Implications

- COVID-19 pandemic is affecting the camel sector, which is contributing to food security in arid countries.
- COVID-19 pandemic has an ambiguous impact by limiting camel development but boosting the demand for camel milk.
- Camel immunology is unique and supports the combat against coronaviruses.

Key words: camel market, coronavirus, immunology, large camelids, pandemic

Emerging Infectious Diseases and Human Pandemics

Working in the animal production sector, we are all aware of the importance and consequences of various infectious diseases affecting livestock. In the last 30 years, there were a number of major zoonotic or nonzoonotic animal disease outbreaks, such as bovine spongiform encephalitis, food and mouth disease, and African swine fever, just to mention a few, with enormous direct and indirect effects on animal production and on international trade causing huge economical losses (Knight-Jones and Rushton, 2013; Patterson et al., 2020). However, these infectious diseases mainly affected specific regions of the world, only a portion of the food supply chain and stakeholders involved in that activity. But, these outbreaks did not have an overall, profound effect on society. Up to the beginning of 2020, we could not imagine the immense impact of a human pandemic that we are experiencing today with the COVID-19 caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The most severe human pandemic at the edge of our living memory was the so-called Spanish flu outbreak in 1918–1919. Unfortunately, the information on the economic impact of this influenza pandemic, including its effect on the agricultural sector is absolutely limited (Garrett, 2007). Notwithstanding, the scientific community has recognized the potential impact of emerging infectious diseases on human health a long time ago and provided recommendations to mitigate its economic and social effects (i.e., among crop and livestock farmworkers; Steege et al., 2009). Already, in 1998, Burke, the famous American epidemiologist, listed the criteria that might implicate certain viral families as possible candidates to cause new pandemics. He mentioned the Coronaviridae as the most dangerous viral family because of their ability to mutate and reassort (Burke, 1998). His view proved to be right as new diseases, such as the SARS in 2003 and the Middle East respiratory syndrome (MERS) in 2012 emerged and were wake-up calls. Then, in 2020, the COVID-19 shocked the world. The severity of the impact of this human pandemic on different livestock sectors depends on a number of factors, including the stage of development, level of intensification, and globalization of that particular sector of animal production. In this review, we summarize the main effects of this pandemic on camel breeding, focusing mainly on dromedaries that are new players in the international animal production arena.

The Role of Camelids in Food Security in Arid and Semiarid Regions

Camel breeding has been a common activity in arid countries in Africa (North Africa and Sahelian countries) and in Asia (Middle East, South, and Central Asia up to China) throughout history. Despite the marginal importance at the

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world level, the social and economic role of these species in arid lands is widely commented and is strongly increasing due to the recent enthusiasm for camel products (Faye, 2018). Highly adapted to the desert ecosystem (Figure 1), camels are multipurpose animals used for production (milk, meat, wool, and manure; Figure 2), leisure (racing and beauty; Figure 3), transportation, and agricultural work. No other domestic species provides such a variety of uses for the human population, especially in harsh environmental conditions. However, the potential role of camels as an important food source in arid regions has not been taken into account seriously until recently. Albeit, the camel population shows a constant 2% yearly increase in the last 50 years reaching approximately 35 million heads in 2018 (Faye, 2020). This population increase is partly due to desertification and, therefore, the geographical expansion of these species and to the renewed interest in camel products, mainly camel milk. In parallel with population growth, the production of camel milk and meat have also been growing at a rate of over 3%–5% yearly, reaching an estimated 3.14 million tons of milk and 557,000 tons of meat in 2018 (http://www.fao.org/faostat/en/#data/QL). However, most of the animals are kept in nomadic, semi-intensive, and peri-urban systems and their products, especially milk, are mainly consumed locally without further processing (Faye et al., 2014; Nagy et al., 2017). Only a small portion of production enters the food supply chain and is integrated into national or international markets. However, camel farming and production are going through intensification over the last 15–20 years (Figure 2). As a consequence, an ever-increasing quantity of raw camel milk is processed commercially and more and more new camel milk-based dairy foods are developed and enter the globalized world economy (Nagy, 2016). Despite this favorable trend, the camel industry today—in general—remains only locally or regionally important. Therefore, global events and forces, such as the present pandemic do not exert a strong direct influence on it. Nevertheless, indirect effects are still important and are summarized below.

Effect of the Pandemic on the Camel Breeding and Production Sector

The impact of the COVID-19 pandemic is similar to that observed in other livestock sectors. The camel sector was impacted by five main ways: 1) through infection and disease of the owners or staff in camel farms leading to disorders in the manpower management, 2) through the difficulties in the local and international distribution network of camel products due to the restriction of movements, especially during the time of confinement, 3) through changes in the consumers' behavior toward the unexpected health crisis, 4) through the cancelation of touristic or sport event linked to camel breeding (Figure 3), and 5) through national and international travel restriction of professionals, service personals, scientists etc.

1) It is difficult to have statistics regarding the infection rate among camel farms' staff but, at least in the Middle East, where MERS outbreak was observed among the staff working with camel (shepherds, staff in slaughterhouses and camel market, and camel milk plant), the host–pathogen interaction, host immune responses, and pathogen immune evasion strategies could be better understood and may help for setting up anti-COVID-19 vaccine (Prompetchara et al., 2020).

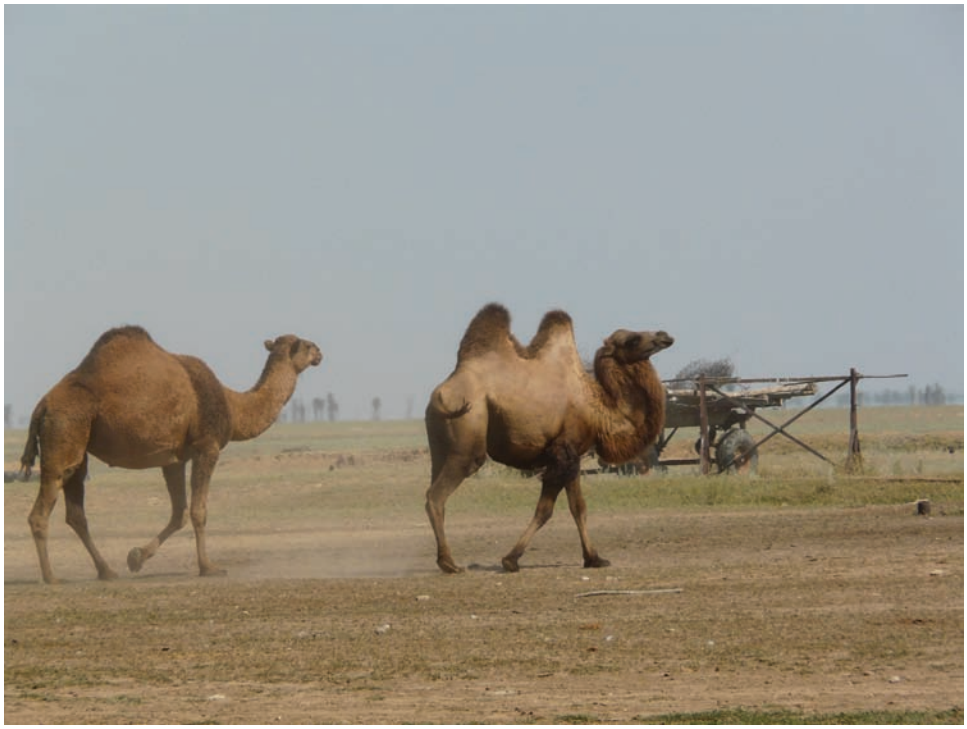

Figure 1. The two main large camelids: *Camelus dromedarius* and *Camelus bactrianus* (photo: B.F.).

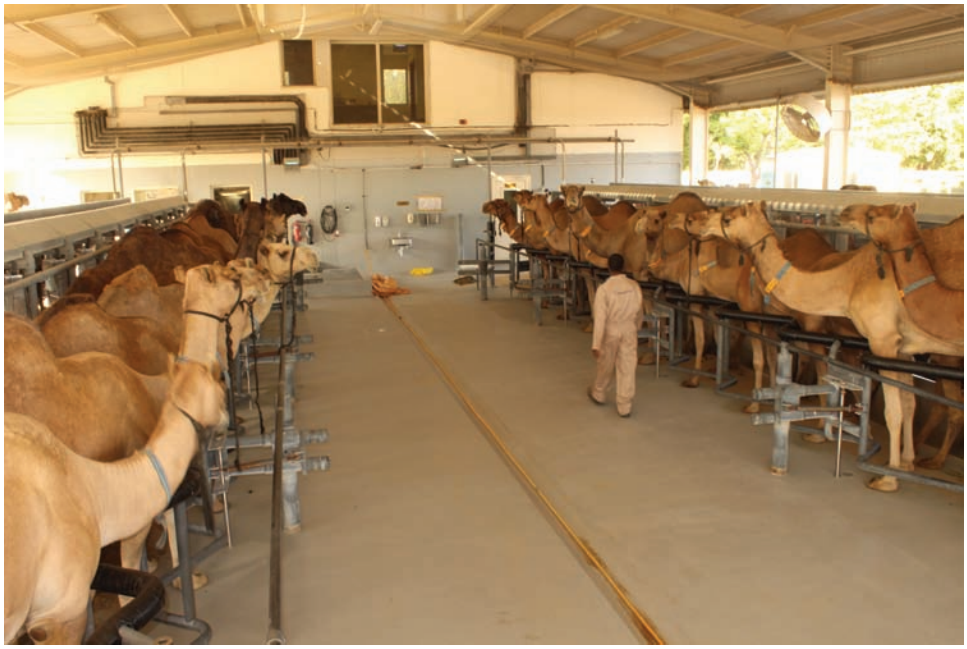

Figure 2. Dromedaries in milking parlor in intensified camel farming (photo: P.N.)

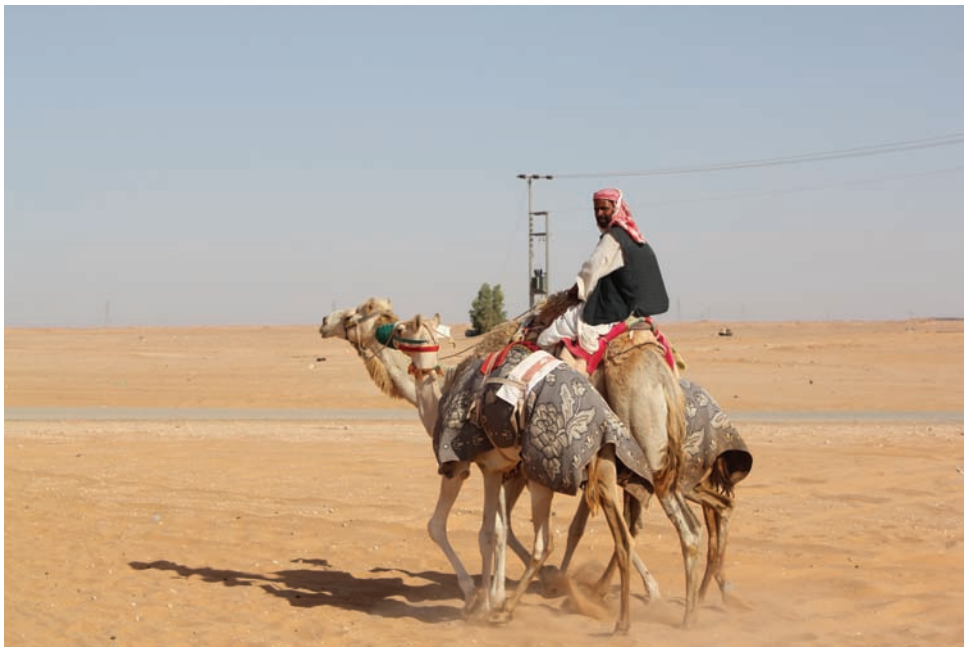

Figure 3. Camel used for racing in Saudi Arabia (photo: B.F.).

The hypothesis of cross-immunity between MERS-CoV and SARS-CoV-2 seems to be justified (Yaqinuddin, 2020).

2) The international camel meat market is mainly organized from Sahelian countries (from Mauritania to Somalia) to North Africa (Libya and Egypt being the most important import countries) and to Arab Peninsula. The export is based on live animals, by trucks, boat, or even by foot (Faye, 2013). Therefore, the closures of borders may limit the transboundary movement, directly impacting the regional markets. The export/import statistics for 2020 are not yet available but, based on the former crisis due to MERS-CoV occurring in Saudi Arabia that resulted in a 30% decrease in the importing camel flow from the Horn of Africa (Faye, 2019), a similar figure could be expected with COVID-19 crisis. Within countries, the restriction of movement, notably during the confinement, has caused difficulties regarding the collection of camel milk and its transportation to processing plants or the transporta-

tion of camels to slaughterhouses in the countries where the camel meat sector is well developed. Dairy plants experienced shortages with their supply chain of packaging materials.

3) The health crisis has impacted the consumers' habits. However, a different pattern could be observed for camel meat and camel milk. During the confinement, consumers have increased the purchase of nonshortly perishable food (paste, flour, and canned goods). However, perishable items, such as fresh meat, were less consumed. In contrast, camel milk consumption was boosted in some countries. Based on scientific information regarding the potential use of llama immunoglobins for developing therapeutic antibodies (Dong et al., 2020) and because of the similarity between lama and camel IgG, the myth that camel milk consumption could boost COVID-19 immunity became a commercial argument. Therefore, the price of camel milk soared in parallel with high demand, for example, in Kazakhstan (Figure 4; Konuspayeva, personal communication). Despite transport restrictions, the demand increased also on international markets. For example, the demand from China for camel milk produced in Kazakhstan increased by 20% (http://www.chinadaily.com.cn/a/ 202007/06/ WS5f0288dda310834817257656_3.html).
4) The restriction on international tourism has impacted directly the camel breeders involved in camel trekking or any other events including camels (fantasia, festival, and camel ride). Most of the Sahara festival expected during spring 2020 was canceled as the festival of Saharan cultures at Amdjarass in Chad. In Gulf countries, where camel racing is very popular, such events were canceled, then organized with a limited number of spectators (https://www.thenational.ae/ uae/ coronavirus-camel-races-resume-but-the-majlis-stays-shut-1.1071394).

Effect of the Pandemic on International Cooperation and on Various Development Projects

International travel restrictions seriously impacted ongoing and future international technical and scientific cooperation. Most of the camel countries belong to the group of developing states and some are among the poorest in the world, especially Sahelian countries, which represent 78% of the world camel population (Faye, 2020). The development of the camel sector in those countries is depending on financial support from different projects supported by international organizations, such as FAO (e.g., in Chad or in Mauritania) or on EU (projects such as CARAVAN, CAMELMILK, and CAMELSHIELD) or some NGOs. In most of the cases, the COVID-19 pandemic has postponed expected activities (training, experiments, capacity building, and support for inputs) and sometimes delayed financial supports.

Role of Camels in Coronavirus Infections and Their Unique Immunology That Support the Combat Against COVID-19

The MERS-CoV is a beta coronavirus like SARS-CoV-1 and SARS-CoV-2 causing similar symptoms in humans (fever and respiratory problems). The infection in

Figure 4. Increasing demand in camel milk for its suspected immune-protective effect against COVID-19.

dromedaries takes a mild course from asymptomatic to mild nasal discharge (Hemida et al., 2014, 2017; Nowotny and Kolodziejek, 2014). First described in the Middle East in 2012, MERS has appeared in more than 25 countries on four continents (except Australia) since. However, MERS-CoV-specific antibodies have been found in camel blood samples as early as 1992, showing a long-term prevalence of this virus in camels from the Middle East and North Africa (Gossner et al., 2016). Recently, also the transfection from dromedary to Bactrian camel has been proven (Lau et al., 2020). The transmission from camel to humans takes multiple ways, airborne (droplet) infection (Dawson et al., 2019; Dudas et al., 2018), camel urine, and food borne through the consumption of unpasteurized milk and raw meat (Gossner et al., 2016). Although humans act as transient and terminal host, the human-to-human transmission rate is low (Dudas et al., 2018). As the consumption of camel milk and meat is on the rise and camel products gain access to wider markets, the impact of camel-associated zoonotic diseases on public health and economy will also grow with increasing urbanization. Recent releases of whole-camel genomes include detailed information on immune response regions (Lado et al., 2020, Fitak et al. 2020, Ming et al. 2020), while ongoing studies aim to understand patterns of immunogenetic diversity in dromedaries in response to MERS-CoV infection (Burger, unpublished data). The knowledge gained with all these studies during and after the SARS and MERS outbreaks has been essential for fighting COVID-19 as the scientific community has been better prepared to deal with the new pandemic. This is clearly shown in the time COVID-19 vaccines are prepared. Normally, it takes 10 years to develop an effective vaccine, while this process might be completed in less than 2 years for COVID-19 (Thanh Le et al., 2020).

Camelids are not only characterized by their remarkable adaptation to harsh climate and production potential but also by their extraordinary immunology and now play an important role in fighting infectious diseases. This is because camelids are the only mammals that can produce homodimeric immunoglobulins consisting of heavy chains only without a light chain in addition to conventional antibodies. The antigen-binding fragment is reduced to a single variable domain of the heavy chain and, thus, reduces the size of the antibody (Arbabi-Ghahroudi, 2017; Ciccarese et al., 2019; Muyldermans et al., 2009), which can be used for biotechnology and clinical applications as so-called "nanobodies." These nanobodies, due to their small size, have an enormous potential for diagnostic use and therapeutics. New research by several groups (Dong et al., 2020; Hanke et al., 2020; Wrap et al., 2020) has shown that the peripheral blood mononuclear cells of camelids can be used to produce specific nanobodies that effectively neutralizes beta coronaviruses. These nanobodies are excellent candidates for antiviral therapy.

About the Authors

Peter Nagy: is a veterinarian, graduated from the University of Veterinary Medicine in Budapest, Hungary in 1990. He worked in his alma mater until 1999 as assistant professor on large animal reproduction, theriogenology and endocrinology. He obtained his PhD degree in 1998 on Equine reproduction. Peter has been working with dromedary camels over 20 years. In 2000–2002, he developed an embryo transfer and artificial insemination program for dromedary camels in the Sultanate of Oman. Since 2003, he has been in Dubai, UAE to develop and manage the world first large-scale camel milking farm (EICMP, Camelicious). Peter is a founding diplomat of the European College of Animal Reproduction (ECAR), an honorary professor at the Széchenyi István University in Hungary and chairman of the Camelid Working Group of EAAP. He is one of the founders and co-organizer of the ICAR Satellite Meetings on Camelid Reproduction. **Corresponding author**: peter@camelicious.ae

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Pamela Burger: graduated in 2004 as veterinarian at the Vetmeduni Vienna, Austria, with a focus on neurodegenerative disorders in cheetahs and snow leopards. As a postdoc she started investigating the genetic origin and process of domestication in Old World camels, with the question to identify the species status of the critically-endangered wild two-humped camels in Mongolia and China. In 2015 she founded the International-Camel-Consortium-for-Genomic Improvement-and-Conservation (ICC-GIC) together with colleagues from Italy, Saudi Arabia, France and Kuwait. Pamela Burger is head of the Population Genetics and Conservation group at the Research Institute of Wildlife Ecology, Vetmeduni Vienna. Her current projects investigate the immune genome of camels in response to economically relevant and zoonotic diseases. The latest publications (2020) in Nature Communications Biology and BMC Genomics investigate genomic selection signals during domestication in Old World camels and global migration patterns in dromedaries, as well as nucleotide diversity in immune response genes.

Judit Juhasz: is a veterinarian, received her degree in 1988 from the University of Veterinary Medicine in Budapest, Hungary. She worked as a reproductive specialist at the Experimental Station of the University where she developed the equine artificial insemination program. She received her PhD degree in 2002 on Equine andrology. Judit has been working with dromedary camels over 20 years. In 2000–2002, she worked in the Sultanate of Oman to develop an embryo transfer and artificial insemination program for racing camels. Since 2003, she has been in Dubai, UAE to develop, then to manage the world first large-scale camel milking farm (EICMP, Camelicious) where she is Chief Veterinary Officer since 2006. Judit has special interest in sustainable animal welfare and large-scale farm management. She is also one of the founders and co-organizer of the ICAR Satellite Meetings on Camelid Reproduction.

Bernard Faye: veterinarian, specialized in tropical veterinary medicine, PhD Paris University and HDR Montpellier University. Stay in Africa (Ethiopia, Niger) for research and development activities (1975–1983) before joining National Institute of Agricultural Research (INRA) as director of ecopathology laboratory. Joining CIRAD (Centre for International Cooperation in Agricultural Research for Development) as Head of Animal Productions Program (1996). Starting interest for camels in Ethiopia in 1975, studying mineral metabolism. Gradually, through his multiple research programs in cooperation and his international network of camel scientists (North, Western and Horn of Africa, Middle-East, India, Central Asia, Latin America), he founded the International Society for Research and Development on Camelids (ISOCARD). In 2010-2015, working in Saudi Arabia as FAO consultant in a camel research center. At present, emeritus researcher at CIRAD. Author of 400 scientific publications, 320 communications, 45 books and chapters, 210 technical reports and 12 scientific editions. Website: http://camelides.cirad.fr and http://www.isocard.net.

Conclusion

There is no specific impact of COVID-19 on the camel sector compared to what we experience in other livestock sectors or, more generally, the agricultural sector. However, the specificity of the immune system in camelids, and the reputation of camel milk with its true or expected health effects on consumers contribute to the development of camel products through increasing demand. This trend might help to compensate for the losses due to the pandemic.

Conflict of interest statement. None declared.

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