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Review

Taking a lesson from the COVID-19 pandemic: Preventing the future outbreaks of viral zoonoses through a multi-faceted approach

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HIGHLIGHTS
• COVID-19 pandemic — it is high time to implement measures preventing future outbreaks.
• Viral surveillance and research on new viral strains should be a primary strategy.
• Changes to wild trade, hunting activities and meat production are needed.
• Some of the suggested measures could also bring environmental and ethical benefits.

ABSTRACT
The pandemic of the novel coronavirus disease 2019 (COVID-19) has caused a significant burden to healthcare systems, economic crisis, and public fears. It is also a lesson to be learned and a call-to-action to minimize the risk of future viral pandemics and their associated challenges. The present paper outlines selected measures (i.e., monitoring and identification of novel viral agents in animals, limitations to wildlife trade, decreasing hunting activities, changes to mink farming and meat production), the implementation of which would decrease such a risk. The role of viral surveillance systems and research exploring the virus strains associated with different animal hosts is emphasized along with the need for stricter wild trade regulations and changes to hunting activities. Finally, the paper suggests modifications to the meat production system, particularly through the introduction of cultured meat that would not only decrease the risk of exposure to novel human viral pathogens but also strengthen food security and decrease the environmental impacts of food production.

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1. Introduction

The outbreak of the novel coronavirus disease COVID-19, whose first cases were officially confirmed in late December 2019 in China and which rapidly developed into a pandemic (Cucinotta and Vanelli, 2020), has caused public fear and panic (Depoux et al., 2020; Rzymski and Nowicki, 2020), a necessity for strict sanitary measures, including imposing nationwide quarantines (Lau et al., 2020; Sidor and Rzymski, 2020), overwhelmed health systems and induced global disturbances and losses in a variety of economic sectors (McKibbin and Fernando, 2020; Nicola et al., 2020). All this has affected humanity on multiple levels: from prejudice and discrimination towards selected groups (O'Shea et al., 2020; Rzymski and Nowicki, 2020b), a need to switch to remote working and teaching (Wijesooriya et al., 2020; Zhang et al., 2020b), reorganization of healthcare systems (Magro et al., 2020; Moazzami et al., 2020; Wang et al., 2020), mental health issues (Gualano et al., 2020; Thakur et al., 2020), increase in political tensions (Gostin, 2020), a worsening of socio-economic well-being, and has exposed poverty as well as food and health disparities (Ahmed et al., 2020; Power et al., 2020; Yancy, 2020).

With nearly 54 million of confirmed cases and over 1.3 million deaths by mid-November 2020, it is beyond any doubt that a concerted effort must be made and considerable financial resources be directed to overcoming the ongoing pandemic, and this must include the development of effective and safe vaccine(s) and pharmaceuticals (Nowakowska et al., 2020; Thanh Le et al., 2020). However, outbreaks of future worldwide epidemiological events, caused by infectious agents, have to be proactively prevented, and this inter alia requires identification and efficient monitoring of different viral groups, including coronaviruses and influenza viruses, and prediction of their epidemic potential (Fan et al., 2019; Sun et al., 2020; Wartecki and Rzymski, 2020). Moreover, it is also important to limit the risk of the zoonotic events that give rise to the transmission of novel viral pathogens. This risk exists in relation to both wild animals and livestock, and the number of such events has been documented in the past (Table S1).

Zoonotic viral infections represent an important global public health issue (Reed, 2018). Due to the presence of a variety of reservoirs and vectors it is challenging to track transmission dynamics and implement control and preventive measures (Wang and Cramer, 2014). Although the interspecies transmission of viruses from their natural hosts and further human-to-human spread can be considered as relatively rare, spill-over events greatly increase the risk of the emergence of an adapted virus that is highly contagious (Plowright et al., 2017).

Here, we highlight various directions through which the transmission and spread of infectious viral agents of animal origin into the human population can be prevented or minimized. We elaborate on the role of surveillance systems and identification of novel viral pathogens in animals, changes to wild trade regulations, reduction of ferret farming, limitations to hunting activities and modifications to meat production process. The challenges to be faced during their implementation are also discussed in this paper.

2. Monitoring and identification of novel viral agents in animals

Surveillance of viral groups that are associated primarily with animal hosts is critical in understanding current and future epidemiological risks and should be proactively supported. Mounting evidence points to the zoonotic origin of SARS-CoV-2, with bats being the primary reservoir for its lineage (Andersen et al., 2020; Boni et al., 2020; Wan et al., 2020). All members of the Coronaviridae family have been associated with animal hosts. Birds and mammals, along with humans, serve as hosts for viruses belonging to the Orthocoronavirinae subfamily (Milek and Blicharz-Domańska, 2018; Wartecki and Rzymski, 2020), whereas Microcystis letovius virus 1, the only species identified so far in the Letovirinae subfamily, has been associated with the ornamented pygmy frog Microcystis fissipes Barbour (Bukhari et al., 2018). All strains pathogenic to humans belong to alphacoronavirus (HCoV-NL63 and HCoV-229E) and betacoronavirus (HCoV-O43 and HCoV-HKU1, MERS-CoV, SARS-CoV and SARS-CoV-2) genera, with all but HCoV-O43 and HCoV-HKU1 originating primarily from different bat species. One should note that based on an exhaustive review of bat coronaviruses in China, the researchers have accurately predicted in a paper published in March 2019 in Viruses that "is highly likely that future SARS- or MERS-like coronavirus outbreaks will originate from bats, and there is an increased probability that this will occur in China" (Fan et al., 2019). This considered, there is an urgent necessity to continue to screen the bat-associated coronaviruses, identify their hotspots, isolate particular strains and evaluate molecularly and experimentally their potential for cross-species transmission and assess the risks for human health. Such an effort, undertaken by the EcoHealth Alliance, has already resulted in the examination of partial genetic sequences of 781 coronaviruses associated with bats in China (Latinne et al., 2020). It is beyond any doubt that whole-genome sequencing and evaluation of pathogenic potencies to humans of these strains should be an essential part of the strategy of preventing future coronaviruses-associated outbreaks. Unfortunately and controversially, the international grant of the EcoHealth Alliance has been unexpectedly canceled by the National Institute of Health (NIH) despite its previous approval and financial support. This has caused a sharp reaction in the scientific community, including 77 Nobel Laureates urging the NIH to reconsider this decision in the light of pressuring need to prevent future spills of coronaviruses and outbreaks in humans (Science, 2020).

Importantly, it is not only Asian bats that should be covered by environmental coronavirus surveillance but also strains associated with avian hosts, including synanthropic species. A number of previous studies have already indicated that birds from different geographical areas and related to terrestrial and aquatic ecosystems serve as the reservoirs for various delta- and gammacoronaviruses (Barbosa et al., 2019; Chamings et al., 2018; Chu et al., 2011; Hughes et al., 2009; Milek and Blicharz-Domańska, 2018; Paim et al., 2019; Wartecki and Rzymski, 2020). None of these are known to be pathogenic to humans, although potential cross-species transmission must be taken into account because: i) selected strains associated with avian hosts are closely related to coronaviruses identified in mammals (Woo et al., 2009), and ii) a recent bird-swine transmission of deltacoronavirus is believed to have occurred (Lau et al., 2018), and recombination, which is a common phenomenon in coronaviruses, has frequently concerned the spike region which is involved in receptor binding (Lau et al., 2018). Furthermore, both alpha- and gammacoronaviruses related to free-living and captive marine mammals, the beluga whale Delphinapterus leucas Pallas, the harbor seal Phoca vitulina L. and the Indo-Pacific bottlenose dolphin Tursiops aduncus Ehrenberg, have been reported by a limited number of studies of wild animals (Mihindukulasuriya et al., 2008; Nollens et al.,...
2010; Woo et al., 2014). On the other hand, the comprehensive investigations of coronaviruses associated with avian hosts and marine mammals that would elucidate the mechanisms of cellular entry and pathogenesis are not available. However, betacoronaviruses, particularly those located in the Sarbecovirus and Merbecovirus subgenera, should be considered as a priority; in-depth research regarding the potential threats associated with the remaining three genera and their avian and mammalian hosts is also urgently required. It is essential to conduct studies that not only focus on the potential susceptibility of humans but also wild, domestic and livestock animals to fully understand the risks of cross-species transmissions involving intermediate hosts.

3. Limitation to wildlife trade

International trade in wild animals is currently regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2020). Countries and other entities may freely join this convention and the agreement currently has as many as 183 signatories. By joining this agreement, the participants are obliged to implement its provisions. However, illegal trade in wildlife is widespread, and it is among the most profitable of illegal activities, comparable to the trade of weapons, trafficking or distribution of narcotic drugs (Izzo, 2010; van Uhm and Wong, 2019); its annual value is over 20 billion USD (van Uhm and Wong, 2019). Its consequences, however, are undesirable and harmful and affect both local and global health as well as economic costs. This is reflected in the recent transmissions of viruses from wildlife to humans (Cucinotta and Vanelli, 2020; Reed, 2018; Smith et al., 2012a, 2012b).

The Amazon is among the regions where the wild animal trade is the most widespread. open-air markets can be found, especially near Iquitos and Manaus (South America) (D’Cruze et al., 2017; Leberatto, 2016). Many species of animals are sold there, both for meat and as pets (e.g., blue-and-yellow macaw Ara ararauna L., Amazon river dolphin Inia geofrans Blainville, least weasel Mustela nivalis L., cougar Puma concolor L., American crocodile Crocodylus acutus Cuvier, yellow-banded poison dart frog Dendrobates leucomelas Steindachner) (Sánchez-Mercado et al., 2016). These species also include the main reservoirs of viral diseases (e.g., avian influenza) that can potentially infect humans, such as the blue-winged teal Anas acuta L. (Sánchez-Mercado et al., 2016; Wartecki and Rzymski, 2020). Africa is another region with a large share of the wildlife trade. This mainly affects the large mammals characteristic of this continent, such as African elephants Loxodonta africana Blumenbach, lion Panthera leo L., gorillas gorilla Gorilla gorilla gorilla, chimpanzees Pan troglodytes and other well-known and sea animals (Bergin and NJiman, 2014; Warchol, 2004). In addition, some African countries contribute to this practice. For example, in 2019 the government of Botswana (South Africa) legalized the hunting of African elephants, which may result in increased trade in parts of these animals (Hitchcock et al., 2020). Finally, Asia, which has the most wildlife trade markets. Notorious places in this regard are above all the Golden Triangle in Southeast Asia where the following countries meet as the main source of the wildlife trade: China, Laos, Myanmar and Thailand. Among them, the Chatchachak weekend market in Bangkok (Thailand) is a place of especially intensive trade in various wild animals or/and their parts (often endangered and threatened species such as tigers Panthera tigris L., Asian bears and rhinos). This place is also a source of distribution of wild animals and their parts to almost every region of the world (van Uhm and Wong, 2019; Verissimo et al., 2012; Wyatt et al., 2020). At the same time, research into illegal wildlife trade in the region, and especially in China, is scarce (Petrossian et al., 2016; van Uhm, 2016a, 2016b; van Uhm and Wong, 2019; Wong, 2015a, 2015b). As a result of the recent episodes of animal virus transmission to humans, wet markets, popular in China (e.g., in Wuhan) that offer wild animals for consumption and for their use in traditional medicine have become the cause of intense international debate on zoonoses. However, neither MERS-CoV, SARS-CoV, nor the Influenza A viruses have led to a human disease spread and mortality on the scale of SARS-CoV-2 (Bell et al., 2004; Lau et al., 2005; WHO, 2020; Yee et al., 2009). In addition, significant mortality is sometimes recorded in animals that are legally transported in wild animals or shortly after their arrival at their destination. This phenomenon mainly affects reptiles. The most frequently mentioned reasons are bad weather conditions during transport and preferences for young specimens for sale. However, these studies are rare and do not include the illegal wildlife trade (Robinson et al., 2015). At the same time, these animals are not tested for the presence of pathogens, and the conditions of transport (especially illegal) may favor the infection of other individuals.

Despite these incidents and the identifications of numerous viruses in natural hosts potentially infectious to humans, no significant efforts have been made to limit the sale of animals that are potential reservoirs of identified viruses. On the contrary, there has been an increase in the demand for and the illegal sale of, among others, pangolins for meat in Asia and for traditional medicine in China (Latine et al., 2020; Piersen et al., 2014; Shepherd et al., 2017; Wu et al., 2004). Moreover, apart from the possible transmission of zoonotic viruses to humans, the trade of wild animals constitutes a severe threat to both the vitality of the vertebrate population (particularly mammals) and to the survival of individual species (Vié et al., 2009).

Based on estimates, there are currently approximately 18,203 species in the wildlife trade that are known to exist. Among them, a large number are endangered species. Most of the species affected by the wildlife trade are chordates (15,374 species), including 7638 species of terrestrial vertebrates (Fig. 1). Following the recent episodes of transmission of zoonotic viruses to humans, special attention should be paid to terrestrial mammals that are affected by the wildlife trade. Their estimated number of species is 1238 (Fukushima et al., 2020; Scheffers et al., 2019). However, in the context of the recent episode of avian influenza in humans, birds also appear to be a significant group of animals in this context. Although their share (in terms of the number of species) in the trade in wild animals is much greater than that of mammals (Fig. 1), they should also be surveyed for the presence of viruses that are potentially dangerous to humans.

Therefore, priority should be given to identifying all animal species traded in illegal markets around the world. And then preventively, all possible pathogens (especially viruses) should be identified (and their transmission ability to humans assessed) that are associated with these species, ranging from terrestrial mammals to other terrestrial vertebrates and aquatic animals. In addition, new research into the sanitary transport of wildlife is needed. At a later stage, actions should be taken to limit or ban the trade in wild animals that most threaten humans in terms of possible transmission of viruses. Besides protecting human health, this could also help to protect some rare and endangered animals.

4. Changes to mink farming

It is known that species from the Mustelidae family are susceptible to the infection of beta-coronaviruses. The ferrets Mustela putorius furo L. are therefore used as an animal model for studies on SARS-CoV and SARS-CoV-2 pathogenesis, routes of transmission and potential treatment options as they display clinical symptoms that closely resemble those observed in human infections (Blanco-Melo et al., 2020; Kim et al., 2020; Richard et al., 2020; Schlottau et al., 2020; Shi et al., 2020). At the same time, the American mink Neovison vison Schreber is also susceptible to selected coronaviruses such as SARS-CoV-2. This animal is farmed on a large scale in different countries for fur production. Currently, the leading mink-producer, with approx. 28% of the world market is Denmark, followed by China, the Netherlands, Russia, and the United States. The first SARS-CoV-2 mink infections were detected in the Netherlands in mid-April 2020 (Oreshkova et al., 2020).
The animals displayed the respiratory symptoms typical of COVID-19, with a fatality rate reaching as high as 10% in selected facilities and acute interstitial pneumonia found in dead animals (Enserink, 2020; Molenaar et al., 2020). The outbreaks of SARS-CoV-2 infections on mink farms were further confirmed in Denmark and Spain. According to the investigations, the infection among minks primarily occurred via transmission from a COVID-19 positive farm worker and then rapidly spread between animals. The speed of transmission was closely associated with the conditions under which the minks are farmed — high densities of caged animals that support transmission via respiratory droplets, and the level of inhalable dust in the air that was found to contain SARS-CoV-2 RNA (Oreshkova et al., 2020). All of these outbreaks led the authorities to order massive culls to prevent the infections spreading from animals to humans. As reported, by the middle of July 2020, over a million minks had been culled by gassing with carbon monoxide in the Netherlands and north-eastern Spain (Kevany, 2020).

Fig. 1. Number of all traded animal species (phyla for all traded animals, classes for terrestrial vertebrates only). Less than 8% of the species affected by the wildlife trade are terrestrial mammals, i.e., animals that present an urgent challenge in identifying viruses potentially pathogenic to humans.

One should note that SARS-CoV-2 is not the first coronavirus to be detected in farmed mink. Coronavirus-like particles were detected in fecal samples in the early 1990s and have been implicated as a causative factor of epizootic catarrhal gastroenteritis (Gorham et al., 1990). Further serological examinations in minks farmed in Denmark have evidenced the widespread presence of antibodies against the transmissible gastroenteritis virus (TGEV)-related coronavirus and indicated the circulation of this strain, the putative mink coronavirus (MCV), at least since 1981 (Have et al., 1992). Based on cross-reactivity testing, it was postulated that MCV occupies an intermediate position between TGEV and another alphacoronavirus, porcine epidemic diarrhea virus (PEDV). Both TGEV and PEDV are known to infect pigs, induce acute gastroenteritis manifested by vomiting and diarrhea, and cause high mortality in piglets (Vlasova et al., 2020). Neither of the above can be transmitted to humans and there is also no such evidence for MCV. One should, however, note that the MCV has been little studied with...
respect to its pathobiology and has not been subject to any recent surveill ance. Considering that it is known to have been circulating in some populations of farmed mink for at least 40 years, it is of high interest to understand its current prevalence among animals and to provide detailed molecular data allowing for more understanding of the potential risks of human transmission. There is also an urgent necessity to screen for the presence of any other viruses that could use mink as hosts.

The COVID-19 pandemic is the evidence that mink farming for fur represents a potential target of coronavirus spillovers and, consequently, a source of infection in humans who have contact with the animals. The ultimate solution to this is the development of an effective vaccine against SARS-CoV-2 in mink. As long as the COVID-19 pandemic continues it is highly recommended that regular surveillance of SARS-CoV-2 is conducted, not only in farmed animals but also in workers who come into contact with them to prevent bilateral infections and the need for massive culls.

Considering that some coronaviruses, such as MCV, can circulate for a long period in the mink population, it cannot be entirely ruled out that these animals may become an intermediate host for future strains pathogenic to humans. Mink fur production is experiencing a decline and the culling related to the COVID-19 pandemic will likely magnify it in the following years. Moreover, ethical and animal welfare concerns have caused fur bans to be subject to debate in an increasing number of countries, including European Union members. The Dutch parliament approved a law in 2012 prohibiting mink farming from 2024 onward, although in June 2020 it adopted a proposal to ban it already by the end of 2020 (Xia et al., 2020). In response to consumers’ ethical reasons and pressures, an increasing number of fashion brands are abandoning investments in fur (Maisely, 2018). Although worldwide resignation from mink farming is unlikely in the near future, its decline in selected areas can also be positively welcomed from the epidemiological point of view. Such decisions will have a positive ecological impact since mink production is associated with eutrophication, water consumption and high emissions of N₂O, with the climate footprint of producing 1 kg of mink exceeding five-fold the footprint of the production of 1 kg of wool (Bijleveld et al., 2011; Xia et al., 2020).

5. Changes to meat production

The growing human population and development increase the demand for meat (Whitnall and Pitts, 2019). At the same time, meat still represents a significant vehicle for food-borne diseases. Strengthening the sanitary regime during the production process has, however, positively decreased the risk of such transmission (Sofos, 2014). Nevertheless, recent surveillance studies indicate that certain meat-borne pathogens still pose a significant health issue (Todd, 2020). This is mostly related to bacterial contamination such as *Campylobacter* spp., *Escherichia coli* O157:H7, *Salmonella* spp., and *Yersinia enterocolitica* (EFSA, 2016; Todd, 2020). According to the European Food Safety Authority, the annual number of confirmed cases of food-borne zoonotic diseases exceeds 350,000 (EFSA, 2019). The other major health threat associated with meat includes *neurodegenerative* prion diseases such as variant Creutzfeldt-Jakob disease which is caused by dietary exposure to bovine spongiform encephalopathy (Bruce et al., 1997; Lasmézas et al., 2005; Will et al., 1996).

Contrary to wild meat, farmed meat is not considered to be a significant source of human viral pathogens. However, workers and veterinarians exposed routinely to livestock can pass zoonotic viruses on to the wider public which can lead to the potential risk of an epidemic (Schmidt, 2009). It is, however, estimated that approx. 75% of the novel human pathogens reported in the past few decades, disproportionately represented by viruses, have originated in animals (Jones et al., 2008; Taylor et al., 2001; Tomley and Shirley, 2009; Woolhouse and Gaunt, 2007). The risk of zoonoses is likely to increase due to the growing number of livestock animals and the expansion of human settlements in more remote areas (King et al., 2006). Particular risks in this regard are posed by the RNA viruses (Louz et al., 2005), whose genomes are replicated by RNA polymerases that lack proofreading, leading to much more frequent mutations than seen in DNA viruses (Drake, 1999; Smith and Inglis, 1987). This, therefore, increases the risk of cross-species transmission and host optimization (Kitchen et al., 2011).

The incursions of certain viruses among livestock represent a significant risk of food shortages and economic burdens. For example, outbreaks of bluetongue virus serotype 8 (BTV-8) in Europe have resulted in significant repercussions for the livestock industry due to massive mortality in sheep and cattle and restrictions on animal trade (Tago et al., 2014; Velthuis et al., 2010; Wilson and Mellor, 2009). More recently, the spread of the African swine fever (ASF) virus, a causative agent for a devastating and fatal disease in pigs, is responsible for severe production and economic losses in Europe and Asia (Gallardo et al., 2015; Pitts and Whitnall, 2019; Sánchez-Cordón et al., 2018). It has also impacted the population of wild boars, who serve as a reservoir for ASF, not only due to animal mortality but also due to implemented control measures that rely on increased hunting activities (Morelle et al., 2020). In the absence of a vaccine and challenges involved in its development (Rock, 2017), ASF outbreaks are a perfect reminder that current meat production chains can easily be destabilized by the unexpected emergence and transmission of viral disease in livestock that undermine food security.

Although there is no evidence that SARS-CoV-2 can be transmitted through food, and this fact has been explicitly emphasized by authorities such as the European Food Safety Authority (EFSA, 2020), the consumption of meat has been reported to decrease during the COVID-19 pandemic. According to the United Nation’s Food Outlook Biannual Report on Global Food Markets, per-capita meat consumption in 2020 will experience the largest decline since 2000 (FAO, 2020). This is mostly due to market disruptions caused by infection outbreaks among meat industry workers and related closures or reduced operation of meat processing plants (Middleton et al., 2020; Steinberg et al., 2020). The restaurant and school closures imposed in response to the COVID-19 pandemic are also a contributing factor (Attwood and Hajat, 2020). Assumptions frequently shared via online social media during the earlier stages of the COVID-19 pandemic, that meat production and consumption are fuelling the health risks related to infectious diseases, may also affect the dietary choices of some individuals, although the extent of this phenomenon remains unclear (Abd-Alrazaq et al., 2020). Notably, different studies have reported a general increase or lack of significant decrease in meat consumption during the nationwide lockdowns imposed in a number of countries and forcing approx. 4 billion people to stay at home (Görnicka et al., 2020; Pietrobelli et al., 2020; Ruiz-Rozo et al., 2020; Sidor and Rzymski, 2020). This highlights that the COVID-19 pandemic is unlikely to change the dietary choices regarding meat originating from livestock farming.

All in all, given the observed trends in meat demand, the forecasted steady increase and general unwillingness to switch to vegetarian diets, limitation of meat consumption cannot be considered as a realistic method to control future zoonotic spillovers. It is therefore of high importance to pursue the research and development of alternative methods to produce these products. The greatest hopes for an alternative to factory farming and its associated problems rests on cultured meat (also known as clean meat, cell-based meat, cultivated meat) (Bryant, 2020; Lee et al., 2020). Its production employs laboratory tissue engineering techniques to obtain meat for consumption without compromising nutritional profile and slaughtering animals (Zidaric et al., 2020). Such an approach meets a number of technical challenges, such as a need to use an efficient medium and scaffold on a non-animal origin, mimicking a 3D structure and texture of conventional meat products, and scaling the production on an industrial level (Kadim et al., 2015; Post et al., 2020; Stephens et al., 2018; Zhang et al., 2020a). A successful introduction of cultured meat to the market will
require reasonable costs and public acceptance (Bryant and Dillard, 2019). The consumer’s willingness to engage with cultured meat is displaying demographic variation and may differ across the cultures and populations (Arora et al., 2020; Bryant and Barnett, 2018; Zhang et al., 2020). Despite these difficulties, interest and investments in cultured meat are on the rise (Choudhury et al., 2020). Consumer acceptance is also predicted to increase in the coming years as the concept will be reaching commercialization (Bryant and Barnett, 2018). The production of cultured meat offers a number of advantages. Firstly, the production process is relatively sterile and should significantly decrease the issue of microbial contamination, which is still a challenge for the meat industry and occurs mainly at the farm level (Tesson et al., 2020), although the risks of meat spoilage during distribution would still need to be taken into account (Nychas et al., 2008). Importantly, the risk of the emergence and rapid spread of livestock pathogens (such as the ASF virus) that are a threat to food security is non-existent in the case of cultured meat. Secondly, the production of cultured meat would decrease the excessive use of antibiotics that promote the emergence and spread of antibiotic-resistant bacteria (Checucci et al., 2020; He et al., 2020). Thirdly, the production process is much more predictable and less time-consuming with several weeks needed for the conversion of nutrients and energy instead of the months or years needed in the case of meat originating from livestock (Bhat et al., 2015). Tissue engineering and cell culturing enable the regulation of nutritional content (e.g., fat of meat and its enhancement (e.g., by induction or addition of omega-3 fatty acids, carotenoids, etc.) (Stout et al., 2020). Moreover, cultured meat production requires significantly less water and less energy, and its implementation should reduce greenhouse emissions, particularly under the scenario of decarbonized energy generation (Fox, 2009; Lynch and Pierrehumbert, 2019; Tuomisto and Teixeira de Mattos, 2011). Last but not least, as it does not involve the sacrifice of animals, cultured meat is also advantageous on the ethical level (Hopkins and Dacey, 2008) while at the same time it also offers access to meat cultivated from cells primarily collected from wild and rare species eliminating the risks of zoonotic infections associated with the wild meat trade.

6. Decreasing hunting activities

Recently published studies indicate that hunting is a significant factor in decreasing biodiversity (Benítez-López et al., 2017; Johnson et al., 2020). Benítez-López et al. (2017) indicate that, as a result of hunting in the tropics, bird populations decreased by 25 to 76%, and mammal populations by 72 to 90% compared to areas where no hunting was performed. At the same time, it should be emphasized that species reduction is associated with a higher risk of transmission of zoonotic pathogens to humans (Johnson et al., 2020; Wolfe et al., 2005).

The meat trade and the trade in wild animal parts is an obvious consequence of the intense hunting of wild animals. Both of these related human activities are indicated as having potential for the spread of pathogens (especially viruses) due to the close contact between people involved in hunting and the hunted animals (Johnson et al., 2015, 2020; Karesh and Noble, 2009; Karesh et al., 2005; Wolfe et al., 2005). Many legal and illegal hunting activities, such as tracking, capturing, carrying, wounds from contact with wild animals, work related to traps, handling, transporting slaughtered animals and traditional hunting behavior, involve contact with potentially infected animals. Out of all these activities, the riskiest is the butchering of hunted animals, i.e., opening and processing the slaughtered animal, where it may come into direct contact with blood. Particular attention should be paid to mammals, especially those phylogenetically closest to humans, such as nonhuman primates (e.g., chimpanzees) (Johnson et al., 2020; Olival et al., 2017; Wolfe et al., 2005). For example, there are reports of systematic infection of hunters by simian foamy viruses in Africa, but no evidence of human-to-human transmission of these viruses (Wolfe et al., 2004). This is just one example where, inter alia through the evolution of a new strain of this virus, it can lead to its widespread appearance in the human population.

A little over 20 years ago it was considered impossible to predict the emergence of new epidemic zoonoses (Murphy, 1998). However, the progress of science and the research on new infectious diseases has led to increased acknowledgment of the process of the emergence and transmission of zoonoses. As a consequence, extensive research has been conducted on the analysis of the risk factors of their emergence and the environmental changes that drive them (Daszak et al., 2000; Fan et al., 2019; Wolfe et al., 2005). The recent virus outbreaks (avian influenza, SARS, MERS) and the current global COVID-19 pandemic had all been predicted (Fan et al., 2019). In addition, owing to studies identifying the coronaviral strains (including bat coronaviruses), carried out prior to the first documented case of human infection by SARS-CoV-2 (e.g., Latinne et al., 2020), increasingly more is known about the scale of coronavirus diversity and their primary reservoirs. Unfortunately, however, the results of these studies were not transferred into real actions related to the prevention of possible transmission of viruses to humans.

In view of the current economic and health situation in countries around the world caused by the COVID-19 pandemic, the detection of pathogens (especially viruses) in animals that are hunted is becoming a priority. It is also essential in this context to determine the potential of their transmission to humans. Apart from the financial outlay, this should not be too much of a problem as legal hunting is usually narrowly regulated at the national level and, in a global context, the species that are hunted are listed on the IUCN Red List. Another severe problem is poaching, but there are reports (e.g., Chagas et al., 2015; Lindsey et al., 2015) that indicate animal species suffering from this activity. The next reasonable step will be to limit and restrict, or more desirably, to prohibit hunting these animals, which are natural reservoirs of viruses that can potentially infect humans. However, it should be remembered that hunting wildlife is often essential for indigenous peoples to survive. Therefore, all steps should be taken to compensate these people for possible losses resulting from the introduced bans to minimize the risk of potential incidents of virus transmission to humans. Finally, an important initiative to fully recognize human infection with zoonotic viruses should be the study of indigenous people of all continents who live by hunting wild animals. According to Wolfe et al. (2007) such action will provide an invaluable database of potential carriers of zoonotic pathogens that could become the focus of new human epidemics.

7. Conclusions

The COVID-19 pandemic is a multidimensional challenge causing complex burdens and requiring a collective response. It is also a lesson to be learned and a final call to implement various measures to prevent future pandemics or at least minimize their risk in the ever-developing world. The present paper considers different strategies, the implementation of which would not only be beneficial from a healthcare point of view but in selected cases could also have positive socio-economic, ethical, and environmental outcomes.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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