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CAN UNCONVENTIONAL MEAT OR BUSHMEAT ACT AS A SOURCE FOR SARS-COV-2

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ABSTRACT

Coronavirus disease 2019 (COVID-19), first reported in people exposed to a local seafood wholesale market in Wuhan, China has already affected more than 76 million people around the globe resulting in the death of nearly 1.7 million people as of December 21, 2020. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) can potentially infect other animal species owing to the superior host adaptability. Sporadic cases of natural SARS-CoV-2 infections have been reported in dogs, cats, lion, puma, and tiger while experimental inoculation in several other susceptible animal species resulted in infection. Although, bats are considered the reservoir host for SARS-CoV-2, pangolins, a wild mammal of order *Pholidota*, is suspected to be the missing link that contributed to transmitting the virus to human beings due to its wide consumption in the Chinese culinary practice. Unconventional meat is consumed in a large quantity all around the world since it acts as a 'low cost' or 'costless' nutritional source in underdeveloped countries. However, in certain communities, geographies, and niches of the globe, meat from wild and other free-ranging mammals, rodents, and reptiles are used as delicacies. The overexploitation of these 'unconventional meat animals' for various reasons threatened biodiversity and contributed to the emergence of novel diseases having significant public health implications. With the swift emergence of SARS-CoV-2, humans have recognized the important role played by wildlife and their ecosystem in the emergence of novel infections. The interface between human and wild animals is

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considered the hotspot that facilitate cross-species jumping and disease spillover. Establishing an efficient surveillance system at a potential human-animal interface can limit the spread of novel zoonotic diseases such as COVID-19.

1 Introduction

Coronavirus disease 2019 (COVID-19) has already affected more than 76 million people around the globe resulting in the death of nearly 1.7 million people (https://covid19.who.int/) as of December 21, 2020. The novel zoonotic coronavirus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was first revealed in people exposed to a local seafood wholesale market in Wuhan, China. Although the outbreak was initially limited to China, subsequent events involving the efficient human-to-human spread resulted in rapid spread across the globe (Dhama et al., 2020a; Al-Rohaimi & Al Otaibi, 2020; Sharun et al., 2020a). Furthermore, air travel accelerated the SARS-CoV-2 spread across international borders in a short period (Sharun et al., 2020a).

SARS-CoV-2 is the third zoonotic coronavirus that is reported to infect human beings following its predecessors MERS-CoV (Middle East respiratory syndrome coronavirus) and, SARS-CoV (severe acute respiratory syndrome coronavirus) (Dhama et al., 2020a). Although the newly emerged coronavirus from Wuhan, China was initially named 2019 novel coronavirus (2019-nCoV), it was later renamed as "SARS-CoV-2" owing to the high similarity with SARS-CoV (Sharun et al., 2020b). Scientists around the world have already made great progress to develop SARS-CoV-2-specific therapeutics, immunotherapeutics, and vaccine candidates with several of these candidates exhibiting safety and efficacy in randomized clinical trials (Alijotas-Reig et al., 2020; Begum et al., 2020; Dhama et al., 2020b; Frediansyah et al., 2020; Sharun et al., 2020c; Sharun et al., 2020d; Sharun et al., 2020e). Considering the need for developing rapid therapeutics against COVID-19, researchers are attempting to repurpose already developed drugs with established safety profiles that are being used to treat other disease conditions (Frediansyah et al., 2020; Haritha et al., 2020; Sharun et al., 2020f; Sharun et al., 2020g; Singh et al., 2020).

In contrast to the previous zoonotic coronaviruses, SARS-CoV-2 is endowed with the ability to infect other animal species owing to the superior host adaptability (Hassani & Khan, 2020; Hobbs & Reid, 2020; Jo et al., 2020; Leroy et al., 2020; Salajegheh Tazerji et al., 2020; Sharun et al., 2020h). Sporadic cases of natural SARS-CoV-2 infections have been reported in dogs, cats, lion, puma, and tiger (Rodriguez-Morales et al., 2020; Sharun et al., 2020h; Tiwari et al., 2020). Similarly, large-scale outbreaks are also reported among the mink population reared in the farms of several countries (Sharun et al., 2020i). Furthermore, studies based on experimental inoculation have also identified several other susceptible animal species (Faslu Rahman et al., 2020; Muñoz-Fontela et al., 2020; Sharun et al., 2020h; Tiwari et al., 2020). However, the ability of such species to get infected under the natural condition as well as to transmit the disease to the same

species and/or to other species including human beings are currently unknown (Delahay et al., 2020; Dhama et al., 2020c).

This is not the first time our existence is challenged by the emergence of a pandemic as a result of the invalid and primitive food habits followed by different societies around the globe. Considering the impact created by this pandemic, we have to modify and refine our food habits and food culture especially in terms of the consumption of unconventional meats derived from wildlife. In this review, we have analyzed the role played by the consumption of unconventional meat in the emergence of novel zoonotic diseases with special reference to the current COVID-19 pandemic and future implications.

2 Meat consumption pattern and unconventional meat sources

Animal tissues became a part of human food year's back, probably 2-2.6 million years ago (Ferraro et al., 2013). According to studies, meat consumption helped humans to reduce the weaning age of child thus an increased reproduction rate and increased brain mass and intelligence (Psouni et al., 2012). After all, humans started rearing animals for food and the meat industry became a huge arena in modern agriculture. According to the Food and Agriculture Organization of the United Nations (FAO), the total meat production of the world is 333 million, with an average per capita consumption of 34.1 kg per annum. It consists of 40% white meat and 60% red meat (OECD & FAO, 2020).

Unconventional meat is consumed in a large quantity all around the world. Conventional meat sources like beef, pork, mutton, chevon, and chicken are popular among meat consumers. But, in certain communities, geographies, and niches of the globe, meat from wild and other free-ranging mammals, rodents, and reptiles are used as delicacies. Unconventional meat sources are acting as a 'low cost' or 'costless' nutritional sources in underdeveloped countries. In addition, an increasing trend in the commercialization of wild or farmed 'unconventional meat sources' is growing worldwide day by day. Unfortunately, the overexploitation of these 'unconventional meat animals' commercially for various reasons put a threatening effect on biodiversity and subsequent health effects to human beings (Sangenistsapp et al., 2016).

3 Bushmeat euphoria and the driving forces of consumption

Pangolins are a delicacy in China (Figure 1), Pheasants in the UK. Elk is the favourite of Americans, Ostrich meat is popular among South Africans, Marmot is a delicacy of Mongolians, and so on. Bats are considered to be a food source in several resource limited countries (Figure 2). Bushmeat euphoria started along the hunter-gatherer started to hunt a wild animal for food. Later on, the growth of civilization and



Figure 1: Pangolins are considered a delicacy in China ("Pangolin" by adamtusk is licensed under CC BY 2.0).



Figure 2: Bats are considered to be a food source in several resource limited countries ("Barbecued Bat" by John Pavelka is licensed under CC BY 2.0).

subsequent animal farming for food purposes reduced the hunting of wild animals and bushmeat euphoria. But, still, a portion of the global population is interested in the consumption of bushmeat for fulfilling various needs like nutritional purpose, medicinal beliefs, tourism, and recreational purposes, etc. A variety of animal-derived food items are helping the sustainment of many Asians, Africans, and American communities. It is closely related to their culture and gastronomic quenching. Besides this bushmeat is a 'valuable' commodity in the black market. After narcotics, the bushmeat trade shares second place in black market trades (Toledo et al., 2012).

Global wildlife trade for human consumption purpose values about 400 billion US dollars (FAO, 2020). In China alone there are more than 20,000 wildlife farms with a turnover of 18 billion per year (Mukpo, 2020). There are several other 'wildlife farms' across different countries where the bushmeat consumption and export is intensive. These markets and 'wildlife farms' act as the source of bushmeat for human consumption internationally. Hunting of wild animals is still practiced for bushmeat harvesting in different parts of the globe like African countries (McNamara et al., 2020). Wildlife hunting, handling, processing, and consumption are highly risky activities as chances of getting pathogens from wild animals are more.

Researchers and the scientific community have identified the occurrences of monkeypox, Ebola, and a large number of other highly infectious diseases due to bushmeat. One of the most fatal diseases, an acquired immunodeficiency syndrome (AIDS) is presumably originated from a virus, which was contracted via hunting, cooking, or consuming the meat of wild animals (Jones, 2020). Immensely high and life-threatening risks due to bushmeat hunting have been widely described because of the wildlife sales in the wet markets. This grave risk might be necessary in the case of limited availability of food and wild animal meat. Nonetheless, bushmeat demand also persists in unnecessary conditions, for instance, in the USA and Europe, which are the prevalent places for large quantity imports of illegitimate bushmeat and meat (Chaber et al., 2010; Smith et al., 2012). Studies have documented that upper-income families in Africa also prefer to buy bushmeat even though its significant health risks and the accessibility to alternate food choices (Ordaz-Németh et al., 2017). According to FAO, a total of 842 million people suffer from chronic hunger are not able to fetch their bread and butter to conduct an active life (FAO, 2013). So, people from food deficient places prefer any kind of consumable which can provide nutritional requirements. Protein,

being a major macronutrient for growth and development, derived from animal sources is consumed widely from a variety of sources. In many parts of the African continent wild animals haunted and collected for food contributes to the protein requirement of native people as well as this 'bushmeat' fetches a higher price than livestock meat (Ntiamoa-Baidu, 1997). People involved in the procurement (haunting!), marketing will get a substantial profit from the selling of meat (Lindsey et al., 2013).

In tropical and subtropical areas, the consumption of bushmeat is majorly associated with poverty and food insecurity. Whereas in people belonging to economically higher strata, consumption of bushmeat is considered as 'prestigious'. Modern food tourism is also related to the consumption of a variety of bushmeat and its byproducts. Culinary tourists and food neophilia tourists are enthusiastic about the local dishes available at each destination they are visiting. Cuisines with wild animal meat are also used as a destination pulling factor to enhance tourist's experience (Symons, 1999). The major species that are threatened by hunting for human consumption in each mammalian order are given in Figure 3.

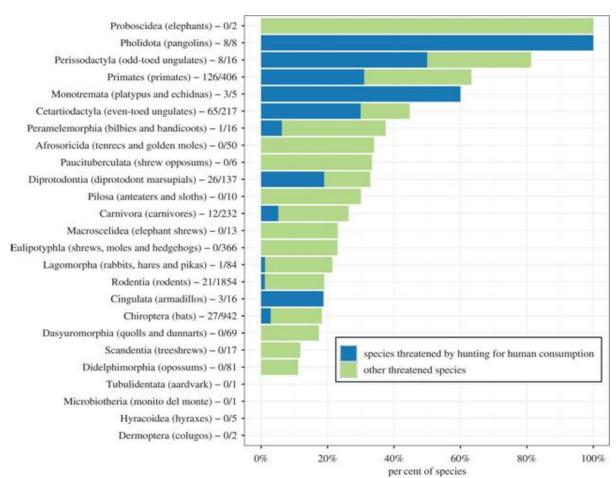


Figure 3: The major species that are threatened by hunting for human consumption in each mammalian order. Reproduced from Ripple et al. (2016) under Creative Commons Attribution License (CC BY 4.0).

The belief of the therapeutic effects of wild animal products is as old as human civilization (Li et al., 2020). Various wild animal meat and organs are used for preparing ethnic medicines in numerous conventional medicines. Traditional Chinese Medicine is a huge consumer of animal products that elicits the impact on the environment as well as potential health hazards (Liu et al., 2016). Because of the wide acceptability among common people, the demand for wild fauna for traditional medicine preparation is increasing and it impacts our biodiversity as well as equilibrium badly (Still, 2003).

4 Disease transmission through wild meat

'Zoonosis' is the hot word world discussed amidst the current pandemic situation. Wildlife and zoonosis are closely inter-related terms as most of the emerging infectious diseases (EID) are zoonotic. Over 335 EID outbreaks were reported in-between 1940 and 2004 (Jones et al., 2008). New diseases are emerging at a rate of 50+ per decade, and out of the emerging diseases more than half of the diseases are animal-related (Jones et al., 2008). Specifically, 72% of animal-related diseases are of wild animal origin, and the rest, 28% is the domestic animal origin (Jones et al., 2008).

The history of AIDS can be taken as an example of the spread of disease from wild animal hunting, trading, and butchering as the spread of the virus occurred from non-human primates to humans by above-mentioned practices. It is proven that the spread and transmission of AIDS have occurred among people who are involved in bushmeat hunting, handling, trading, and butchering (Ncube et al., 2016). Chagas disease caused by the Trypanosoma cruzi is reported to be transmitted by consuming poorly cooked or T. cruzi infected raw wild animal meat (Coura, 2015; Dias, 2006). In Latin American countries like Brazil, Colombia the prevalence of the disease is higher due to the consumption of game meat (da Silva & Garavello, 2009; Gurgel et al., 2009). Trichinellosis is another disease caused by Trichinella spiralis worm through consuming inadequately frozen/ improperly cooked or cured wild meat especially wild pork and venison (deer meat) worldwide (Garcı'a et al. 2005; Meng et al. 2009).

Humans recognized the importance of wildlife and their ecosystem in the emergence of novel infections and maladies from previously occurred outbreaks. After the Ebola virus outbreak in Africa in 2013-16, wild animal trade and consumption were banned by law. But, the hunting and consumption of wild fauna continued, and the ban of these activities was not effective at the root level (Bonwitt et al., 2018).

SARS-CoV-2 emergence has implicated various food products as potential carriers of this novel virus, made meat consumption a topic of debate while posing animal-source foods and food systems as unsafe. This has put thrives on bush meat trades, meat

processing plants as a risk factor and new front line during COVID-19 pandemic, and posing consumers fears and food safety drives (Attwood & Hajat, 2020; Duda-Chodak et al., 2020; Gan et al., 2020; Goli, 2020; Günther et al., 2020; Han et al., 2020; Jacob et al., 2020; Thippareddi et al., 2020; McNamara et al., 2020; Meseko et al., 2020; Middleton et al., 2020; Waltenburg et al., 2020; Yekta et al., 2020). Further investigations would through more light to reach a conclusive consensus, and to adopt appropriate prevention and control strategies from food industry perspective, adequate approaches to safeguard food production technology and produce safer foods.

5 Linking wild animals and COVID-19

A large number of epidemiological and virological debates recommend that COVID-19 is a zoonotic disease (Córdoba-Aguilar et al., 2020; Fung et al., 2020; Haider et al., 2020; Irian, 2020; Mazinani & Rude, 2020; Tiwari et al., 2020). Reduction of the interphase between human and wild animals made the exposure of previously unknown pathogens to humans and cause the spread of several deadly diseases including COVID-19. Pangolin (*Manis pentadactyla*), a wild mammal of order *Pholidota*, is supposed to be the 'missing link' of the SARS-CoV-2 virus spread among humans due to its wide consumption in Chinese culinary and pharmacopeia (de Sadeleer & Godfroid, 2020). In case of COVID-19, intermediate host has played an important role in the transmission of SARS-CoV-2 to human beings. Although several animal species are considered to be the intermediate host, the real culprit is yet to be identified (Zhao et al., 2020).

The suspected origin of the disease, COVID-19, Wuhan 'wet market' was a hub of various live wild animals, which are kept, slaughtered, processed, and consumed. The close packing of animals in cages under inevitable poor hygienic environments results in a massive amount of animal excretions. The produced animal excreta are likely to harbor a great number of zoonotic microorganisms with potential menace to human health. The transmission risk of these hazardous microbes can be further increased via the highly risk customers (Jones, 2020). A wide range of pathogens are in close contact with human beings and spillover the dangerous organism believed to happen in the Wuhan market, which spread all over the world. A belief of live or freshly killed meat has more nutritional and vital value than previously killed or frozen meat is the basic reason behind the existence of 'wet' markets (Zhu & Zhu, 2020). Extensive evidence revealed that selling wildlife carry extremely high, and serious health risks. The COVID-19 pandemic emphasized to finish the sales of wildlife at wet marketplaces (Daly, 2020).

Many current metagenomic sequencing-based studies have demonstrated that pangolins may harbor β -CoVs ancestral to SARS-CoV-2 (Van Damme et al., 2020). Figure 4 illustrates the

phylogenetic analyses of whole genome sequences depicting the evolutionary relationship of SARS-CoV-2 with Pangolin-CoV and other coronaviruses isolated from different hosts. The genomes of pangolin CoV share 85-92% homology of a nucleotide sequence with SARS-CoV-2. In a previous report, detected viral contigs from lung specimens of diseased pangolins was found similar to SARS-CoV-2 (Liu et al., 2019). Therefore, the pangolin is considered one of the possible intermediate animal hosts of SARS-CoV-2 (Van Damme et al., 2020). Nevertheless, the scientific literature lacks evidence supporting the direct pangolin source of SARS-CoV-2 because of the sequence discrepancy between pangolin-associated beta-CoVs and SARS-CoV-2. Moreover, the SARS-CoV-2 evolutionary pathway in pangolins, bats, and other

mammals needs to be determined (Ye et al., 2020).

Following the outbreak of SARS-CoV-2 that originated in the wet markets of China, the role played by trade and consumption of wild meat in the emergence of novel pathogens has been widely discussed (Halabowski & Rzymski, 2020; Jalava, 2020; McNamara et al., 2020 Mizumoto et al., 2020). As a result, the immediate response was the temporary closure of China's "wet markets" that significantly affected the wildlife trade in general (McNamara et al., 2020). On the other hand, the uncontrolled growth of human populations further contributed to the shrinking of natural habitats thereby reducing the gap between wildlife and humans. The increase in human activity at the interface disrupts

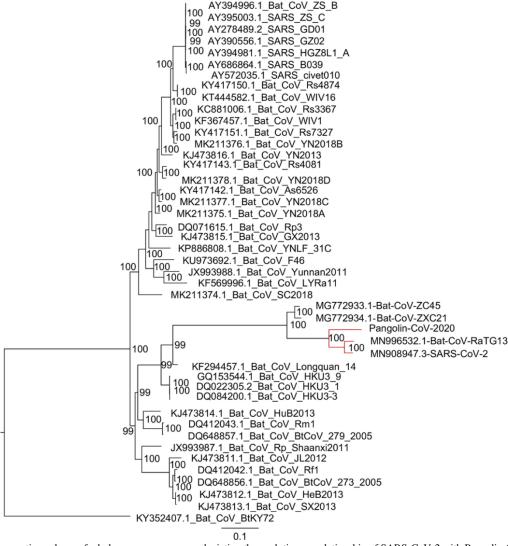


Figure 4: Phylogenetic analyses of whole genome sequences depicting the evolutionary relationship of SARS-CoV-2 with Pangolin-CoV and other coronaviruses isolated from different hosts. Reproduced from Liu et al. (2020) under Creative Commons Attribution License (CC BY 4.0).



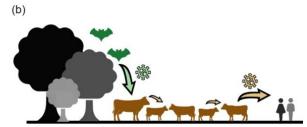


Figure 5: The pathway indicating the transmission of zoonotic virus from the wildlife to human beings. (a) Transmission through direct consumption of wildlife; (b) Transmission mediated via domestic animals (intensive husbandry). Reproduced from Jacob et al. (2020) under Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0/).

the ecology of wild animals thereby affecting the balance. Such interactions will increase the likelihood of emergence and transmission of novel viruses (Figure 5) (Jacob et al., 2020; McAloose et al., 2020). However, a direct ban on the wild animal trade and consumption will have an impact on the individuals who rely on it for their livelihoods (McNamara et al., 2020). Rather than going for complete ban, there is a need to regulate the trade of wild animals and their products. Therefore, governments have to develop and establish efficient legislation that can regulate the trade of wild animals at the same time protects the habitats (Borzée et al., 2020).

The two main drivers that provides optimal conditions and facilitates infectious agents to jump the species barrier from wild animals to humans are the human encroachment into forest ecosystem (agricultural expansion) and the commodification of wild animals and their products (Platto et al., 2020; Volpato et al., 2020). Human activities such as illegal bush-trafficking and deforestation has played a major role in the emergence of SARS-CoV-2 (Contini et al., 2020). Coronaviruses are characterized by frequent reassortments and recombination especially in wet animal markets where several species of animals are interacting (Perveen et al., 2020). The available evidence reports the occurrence of sporadic cases of SARS-CoV-2 infection in several domestic and wild animals under captivity that are having close contact with infected humans (Kumar et al., 2020). SARS-CoV-2 possesses the potential to get transmitted to the wildlife, especially in case of non-human mammals owing to the superior host adaptability. Therefore, interactions between human and wild animal species (some of which are classified as threatened) could facilitate this process (Gryseels et al., 2020).

Conclusion

Meat and animal products are some of the unavoidable commodities of human feeding habit from antiquity. A major chunk of the protein and other nutrients requirements of the population is satisfied by these products. But, situations like pandemic outbreak happened now making some of the meat and

animal product consumers rethink from non-vegetarianism. The overexploitation of these 'unconventional meat animals' for various reasons threatened biodiversity and contributed to the emergence of novel diseases having significant public health implications. The interface between human and wild animals is considered to be the hotspot that facilitate cross-species jumping and disease spillover. Establishing an efficient surveillance system at a potential human-animal interface can limit the spread of novel zoonotic diseases such as COVID-19.

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