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Impact of the COVID-19 pandemic on food production and animal health

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ABSTRACT

Background: Severe acute respiratory coronavirus syndrome 2 (SARS-CoV-2) is the etiological agent of coronavirus disease 2019 (COVID-19). SARS-CoV-2 was first detected in Wuhan, China and spread to other countries and continents causing a variety of respiratory and non-respiratory symptoms which led to death in severe cases.
Scope and approach: In this review, we discuss and analyze the impact of the COVID-19 pandemic on animal production systems and food production of meat, dairy, eggs, and processed food, in addition to assessing the impact of the pandemic on animal healthcare systems, animal healthcare quality, animal welfare, food chain sustainability, and the global economy. We also provide effective recommendations to animal producers, veterinary healthcare professionals, workers in animal products industries, and governments to alleviate the effects of the pandemic on livestock farming and production systems.
Key findings and conclusions: Port restrictions, border restrictions, curfews, and social distancing limitations led to reduced quality, productivity, and competitiveness of key productive sectors. The restrictions have hit the livestock sector hard by disrupting the animal feed supply chain, reducing animal farming services, limiting animal health services including delays in diagnosis and treatment of diseases, limiting access to markets and consumers, and reducing labor-force participation. The inhumane culling of animals jeopardized animal welfare. Egg smashing, milk dumping, and other animal product disruptions negatively impacted food production, consumption, and access to food originating from animals. In summary, COVID-19 triggered lockdowns and limitations on local and international trade have taken their toll on food production, animal production, and animal health and welfare. COVID-19 reverberations could exacerbate food insecurity, hunger, and global poverty. The effects could be massive on the most vulnerable populations and the poorest nations.

1. Introduction

The coronavirus disease 2019 (COVID-19) is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). COVID-19 was declared as a global pandemic by the World Health Organization (WHO, 2020). The main cause of the disease was a previously unknown coronavirus which was first identified and reported in Wuhan, China in late December 2019 (Zhu et al., 2020; Lu et al., 2020). The possible zoonotic nature of the disease and viral spillover have made it more serious due to the transmission patterns from animals to humans and with the progression of the COVID-19 pandemic, transmisson from humans to animals and spillback events to other animal species were reproted (do Valev et al., 2021; He, 2021; El Zowalaty and Jarhult, 2020; Tazerji et al., 2020). Calssification of coronaviruses within the family *Coronaviridae* is shown in Fig. 1. The possible transmission patterns of SARS-CoV-2 from human-to-animal and animal-to-human are shown in Fig. 2.

Based on the available data at the time of this review, COVID-19 is believed to have emerged in a seafood market in Wuhan, China (Li et al., 2020; Zhu et al., 2020). Bats could be the proximal origin of SARS-CoV-2

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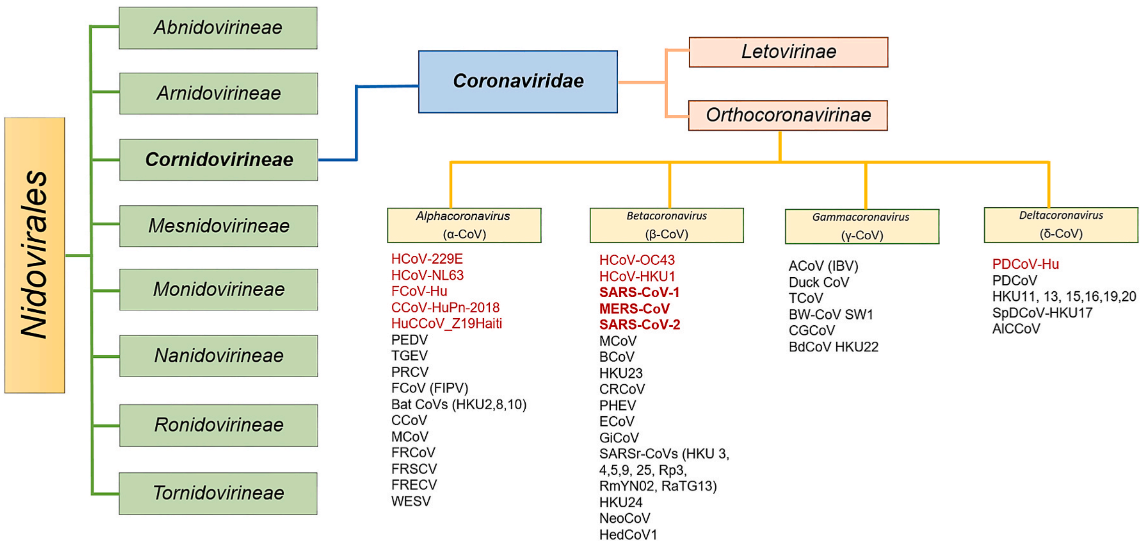

Fig. 1. The most recent classification of coronaviruses within the *Orthocoronavirinae* subfamily of the *Coronaviridae* family in the *Cornidovirineae* suborder of the *Nidovirales* order, and the respective four genera: alpha -, beta -, gamma -, and deltacoronaviruses. At present, 8 suborders have been established under the Nidovirales order. Human CoVs are in red text and highly pathogenic human CoVs are in bold red text. The figure was generated based on data from from Lefkowitz et al. (2018), Walker et al. (2020), Zhou et al. (2021), and information about viruses in accordance with the latest update in the taxonomy system of the International Committee on Taxonomy of Viruses Executive on Taxonomy of Viruses (ICTV) (https://talk.ictvonline.org/taxonomy/).

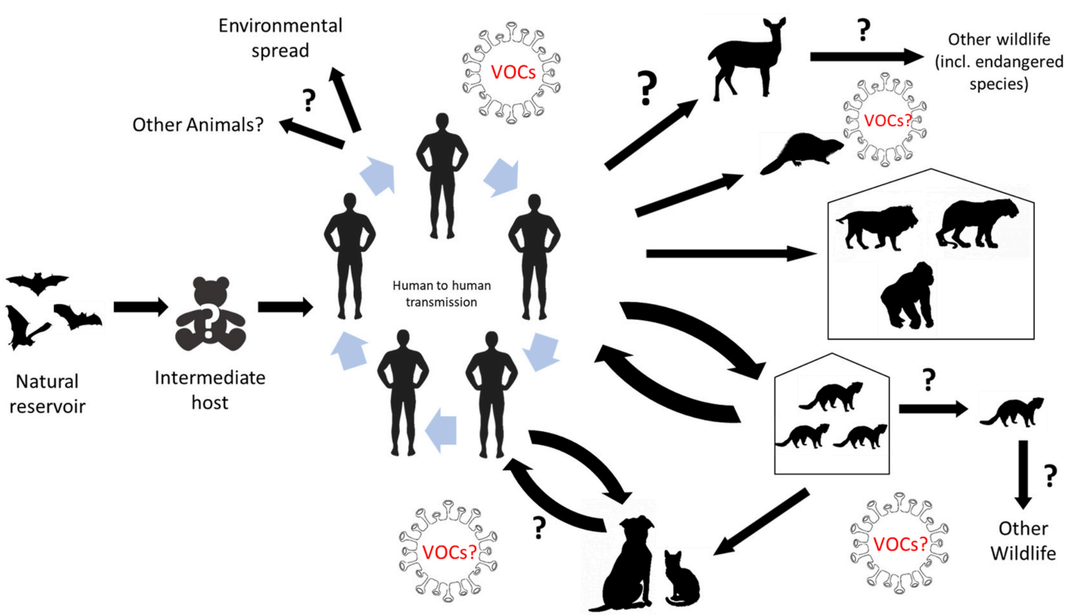

Fig. 2. SARS-CoV-2 connections with Animals and the Environment. The figure was reproduced with permission from Public Health Agency of Canada, 2021.

(Andersen, 2020) and pangolins could be a potential intermediate host because of high genome sequence similarities of isolated SARS-related viruses with the SARS-CoV-2 genome (Zhang et al., 2020). However, the origins of SARS-CoV-2 were recently reviewed elsewhere (Domingo 2021, Holmes et al., 2021), yet the host range and intermediate hosts of SARS-CoV-2 remain unknown (Liu et al., 2021; El Zowalaty and Jarhult, 2020). SARS-CoV-2 is not the first coronavirus to cross species and infect humans leading to the first pandemic in history to be caused by a coronavirus. Previously, two highly pathogenic coronaviruses, severe acute respiratory syndrome coronavirus 1 (SARS-CoV-1) and Middle East respiratory syndrome coronavirus (MERS-CoV) infected humans and caused severe diseases (Perlman, 2020).

As a result of the uncontrollable spread of COVID-19, countries imposed lockdowns, postponed or banned international travel, and limited exports and imports to control the transmission of SARS-CoV-2 (Sidor & Rzymski, 2020; World Health Organization (WHO), 2020). There were significant concerns on whether food and animal products may contribute to the transmission of SARS-CoV-2 and whether the disruption of the agricultural production chain including livestock production systems would significantly harm the global economy.

The effect of the COVID-19 pandemic on agricultural production, including crop and animal products, depends on the product, the location, and the economic status of the impacted location (Laborde et al., 2020). The current pandemic has had serious impacts on animal production, animal health and welfare, global food safety, and the global economy. Impacts include the disruption of food supply chain, shortage of labor, reduced access to markets and veterinary health services, in addition to movement restrictions and limitations on international trade. The COVID-19 pandemic has also resulted in ominous impacts on food security, leading to hunger and increased poverty in resource-limited countries (FAO, 2020a). Milk and meat industries, animal and animal-product processing industries such as slaughter-houses, and poultry sectors were negatively impacted during the course of the COVID-19 pandemic. Smashing of eggs, dumping of milk, inhumane culling of animals, and disruptions of animal feed supply chain have resulted in crisis in the global economy (Poudel et al., 2020; Weersink et al., 2020). In the current review, we highlight different routes of transmission of SARS-CoV-2 in animals and humans, possible ways COVID-19 can disrupt the animal production chain, and effects of COVID-19 pandemic on animal health and welfare, diagnosis and treatment of diseases, and the global economy. We also provide recommendations for the prevention and control of the COVID-19 pandemic and for boosting up animal production and ultimately global economy.

2. SARS-CoV-2 transmission

2.1. Transmission

Since SARS-CoV-2 is primarily a respiratory, not a foodborne, pathogen, the risk of foodborne transmission of COVID-19 is negligible (Trmčić et al., 2020). The possibility of SARS-CoV-2 being transmitted via feces is much lower than enteric viruses which are transmitted via the fecal-oral route (such as norovirus and adenovirus) which may be explained by the lower relative amounts of infectious viruses in feces (Jones et al., 2020). The presence of replication-capable SARS-Cov-2 in environmental fecal wastes and waters has not been reported (Sobsey, 2021). In addition to the droplet transmission, the National Health Commission of the People's Republic of China confirmed that aerosol transmission of SARS-CoV-2 is possible in special circumstances including long exposure to high concentration in a closed environment (Xu et al., 2020). Additionally, it was recently reported that aerosole transmission plays a role in the spread of COVID-19 (Coleman et al., 2021 and Nazaroff, 2021). Food industry premises can be considered a closed workplace setting where infected workers can transmit the virus to their co-workers through air due to the close proximity. Viral particles of SARS-CoV-2 can also end up on surfaces of food preparation areas, meat, dairy, or other animal products. In addition, SARS-CoV-2 viral particles can also be present on swab samples from isolation wards, other hospital wards, sewage treatment units, and nursing homes (Mouchtouri et al., 2020). The deposition on surfaces can lead to subsequent hand-to-mouth, hand-to-nose, or hand-to-eye transmission (Bourouiba, Dehandschoewercker, & Bush, 2014; Chao et al., 2009; Godri Pollitt et al., 2020; Tang et al., 2011; Wei & Li, 2016). Potential transmission routes of SARS-CoV-2 from animals and animal products are shown in Fig. 2. While SARS-CoV-2 does not cause foodborne illness, the virus has caused enormous disruptions to the global food supply chain. The risk of SARS-CoV-2 to food safety was detailed elsewhere (Anelich et al., 2020; Han et al., 2021).

2.2. Factors that may promote transmission in the workplace

Animal product industries usually rely on the presence of metallic surfaces and the maintenance of low humidity (dry conditions) and low temperature (Mecenas et al., 2020; Wang et al., 2020). However, these conditions can be favorable for the viability and transmissibility of SARS-CoV-2. While there was a significant reduction and exponential decay in the infectious titer, SARS-CoV-2 remained viable in aerosols for up to 3 h, on plastics for up to 72 h, and on stainless steel for up to 48 h after application (Van Doremalen et al., 2020). The viability of the virus on different environmental surfaces is shown in Table 1.

Table 1
Viability of SARS-CoV-2 on different environmental surfaces (van Doremalen et al., 2020).

Environmental conditions	Viability time	Median half-life
Aerosol	Up to 3–4 h	1.1–1.2 h
Plastic	Up to 72 h	6.8 h
Stainless steel	Up to 72 h	5.6 h
Copper	Up to 4 h	0.8 h
Cardboard	Up to 24 h	3.5 h
Glass	Up to 96 h	–

2.3. Nature of the working environment

In addition to rapid work speed and multiple long shifts, food industry workplaces tend to be very crowded with employees in close proximity to one another. Additionally, because of the loud mechanical noise, workers tend to talk louder or shout. These factors can increase the chances of the transmission of SARS-CoV-2 to the co-workers. In many industries, there is a significant number of younger employees. If the manpower in food industry (or other industries) mainly consists of youthful workforce, there can also be a high possibility of having an infected asymptomatic employee who could infect other employees.

3. Health and non-health impacts of coronaviruses on animals

3.1. Poultry

Infectious bronchitis is an avian disease caused by infectious bronchitis virus, a member of genus *Gammacoronavirus* in the family *Coronaviridae*, and is a major respiratory disease of poultry affecting lungs, kidney, and the reproductive tract and causing tremendous economic losses in the poultry industry worldwide (M Najimudeen et al., 2020). It causes multiple characteristic consequences such as kidney damage, decreased egg production, and deteriorated egg quality (M Najimudeen et al., 2020). Another significant problem of infectious bronchitis is its rapid spread. Within 48 h, the whole flock can be infected and remains as a reservoir, even after recovery. The infection usually spreads horizontally from hen to hen, but not from hen to chick. It is still possible that the infection gets transmitted via contaminated eggshells in the hatcheries (Roberts et al., 2011). Although chickens are not known to be infected with SARS-CoV-2 through the intranasal route, COVID-19 can still have economic negative impacts on the poultry industry (Hafez & Attia, 2020).

Different poultry species are susceptible to coronaviruses infections leading to the development of enteric diseases, respiratory diseases, and kidney diseases. Examples include turkey infected with Turkey coronavirus (TCoV), quail infected with Quail coronavirus (QCoV), guineafowl infected with Guineafowl coronavirus (GfCoV), and pheasant infected with Pheasant coronavirus (PhCoV) (Ito, Miyaji, & Capellaro, 1991; Panigrahy et al., 1973; Pascucci et al., 1983; Spackman & Cameron, 1983).

3.2. Swine

Porcine coronaviruses belong to four genera: *Alphacoronavirus*, *Betacoronavirus*, *Gammacoronavirus,* and *D* (Domańska-Blicharz et al., 2020). The porcine epizootic diarrhea virus (PEDV) and the transmissible gastroenteritis virus (TGEV) are alphacoronaviruses of swine which infect epithelial cells of the gastrointestinal tract. Another alphacoronavirus named the porcine respiratory coronavirus (PRCV) has no affinity to the gastrointestinal tract. A fourth alphacoronavirus is swine acute diarrhea syndrome coronavirus (SADS-CoV), which causes acute diarrhea syndrome (SADS) in piglets. A betacoronavirus is porcine haemagglutinating encephalomyelitis virus (PHEV), while a deltacoronavirus is porcine deltacoronavirus (PDCoV) (Vlasova et al., 2020). Due to similarities in protein characteristics, swine can be potential reservoir for the transmission of SARS-CoV and SARS-CoV-2 (Meekins et al., 2020; Shi et al., 2020). PDCoV is an emerging swine pathogen.

Importantly, it was recently detected from three sick Haitian children and is now recognized as a zoonotic pathogen (Lednicky, 2021).

3.3. Ruminants

Coronaviruses of ruminants include bovine coronavirus (BCoV) which infects cattle, sheep, goat, buffalo, llamas, alpacas, and can cause respiratory distress (Decaro, Campolo, et al., 2008). Examples include bubaline coronavirus (BuCoV) that infects water buffalo, alpaca coronavirus (ACoV) that infects alpaca, and dromedary camel coronavirus (DcCoV) that infects camels (Cebra et al., 2003; Decaro, Martella, et al., 2008; Sabir et al., 2016). In addition, MERS-CoV causes infections in respiratory tracts of camels. The seroprevalence of MERS-CoV in dromedaries was reported to be more than 90% in different countries in Africa, Asia, and the Middle East (Hemida et al., 2017). There is not enough evidence to suggest that cattle might have play a role in the COVID-19 pandemic. In a study on six animals, only two cattle tested positive for the virus in nasal swabs and showed specific seroconversion, indicating low susceptibility of cattle to SARS-CoV-2 infection (Ulrich et al., 2020). However, close contact of infected humans with large numbers of cattle may still lead to anthropozoonotic infections in cattle (Ulrich et al., 2020). The reason for the low susceptibility to infection is the low expression of ACE2 in the respiratory tracts of these ruminants (Zhai et al., 2020).

3.4. Fish and cold-storage foods

The SARS-CoV-2 outbreak in December, 2019 has been linked to Huanan Seafood Market in Wuhan, China (Zhu et al., 2020; Ashour et al., 2020). A second wave in June 2020 has been traced to Xinfadi Seafood Market in Beijing, China (Dai et al., 2021). Frozen seafood items contaminated with SARS-CoV-2 have been reported in China (Dai et al., 2021). Salmon-attached SARS-CoV-2 stayed in a viable status for at least 8 days at 4 °C, and 2 days at 25 °C (Dai et al., 2021). It is noteworthy that at 4 °C is the temperature of refrigerators, cold rooms, and transport carriers for storage of fish before selling in the fish or seafood market. Thus, the import and export of frozen and refrigerated fish can be a source of transmission of fish-attached SARS-CoV-2 across countries and continents. Imported frozen cod package surfaces from China showed signs of contamination by SARS-CoV-2 (Liu et al., 2020). This calls for strict inspection measures for the detection of SARS-CoV-2 in imported and exported fish during the pandemic (Dai et al., 2021). Evidence suggests that cold-storage foods may present a risk for the transmission of SARS-CoV-2 between different countries (Han et al., 2020).

3.5. Other species

Ferrets and cats have been shown to be permissive to infections with SARS-CoV-2 (Shi et al., 2020). Cats were also susceptible to airborne transmission (Mahdy et al., 2020; Shi et al., 2020). SARS-CoV-2 infection has also been reported in dogs, tigers, and lions (Mahdy et al., 2020). Other susceptible species include mice, golden hamsters, minks, and non-human primates (Mahdy et al., 2020). Clinical signs in ferrets involved fever and loss of appetite (Shi et al., 2020). Both cats and non-human primates were asymptomatic (Mahdy et al., 2020). The main features of animals experimentally infected with SARS-CoV-2 are presented in Table 2.

4. Impacts of COVID-19 on food animal production

4.1. Disruption of animal feed supply chain

The supply chain of animal feed raw materials has been negatively impacted due to animal movement restrictions resulting from the pandemic-triggered lockdowns. Regular patterns of production, supply, and consumption were severely disrupted (Guan et al., 2020). Thus, farm animals have been deprived from important feed ingredients in their diets. It has been reported that more than dairy farms have faced shortages of dry feed intake in Pakistan as a result of the pandemic (Hussain et al., 2020).

International cessations in exports and imports of animals' feeds hampered the supply of several basic raw ingredients that are important for raising and fostering livestock (Deeh et al., 2020). These raw ingredients include mixtures of carbohydrates, proteins, fats, minerals, and vitamins. As an example, Argentina-the world leader in soybean meal exports - had to reduce its exports of soybean, a critical feed ingredient, by half into feed manufacturing factories (Hashem et al., 2020; Seleiman et al., 2020). Similarly, Brazil and U.S. have also faced hurdles in their soymeal and corn exports (Hashem et al., 2020; Seleiman et al., 2020).

Local restrictions have been impacted animal feed ingredients, as evidenced by pastoralists in African dry lands who were unable to feed their animals, typically fed on natural plants (FAO, 2020c; Seleiman et al., 2020).

International and local restrictions have naturally led to increased costs of animal feed materials, which impacted animal farms in different countries. In Bangladesh, there has been a 3.7% hike in dairy feed price (Uddin et al., 2021). In India and many regions in Africa, the prices of key animal feed ingredients have increased by 15% as a result of the pandemic (Elleby et al., 2020). In the United Kingdom, the prices of soymeal, wheat, corns, molasses, and other important animal feedstuffs have increased due to COVID-19 (Department for Environment, Food & Rural Affairs, 2020).

4.2. Reduction of animal farming services and animal health services

The COVID-19 pandemic has jolted the livestock production. Pivotal livestock farming materials have been largely unavailable. These include frozen semen aliquoted in a semen straw for artificial insemination of livestock, replacement stocks (such as day-old-chicks, heifers, gilts, piglets), equipment (such as milking machines for livestock), and animal feed additives (such as vaccines, antibiotics, vitamins, minerals) (FAO, 2020b; Hashem et al., 2020; Centers for Disease Control and Prevention (CDC), 2020). Veterinary healthcare services and other animal health preventative services have been greatly reduced during the pandemic (Gortázar & de la Fuente, 2020). This caused significant delays in diagnosis and treatment of diseases. The reductions and delays resulted in halting the progress in prevention, control, and eradication of

Table 2
Main features of animals experimentally infected with SARS-CoV-2 (Hobbs & Reid, 2020).

Animal species	Clinical signs	Necropsy findings	Replication	Animal-to-animal transmission	Antibody Response
Ferret	+++	+++	+++	+++	+++
Cat	++	++	+++	+++	+++
Dog	–	–	–	–	+
Hamster	+	NA	+	++	++
Non-human primate	+	+++	++	++	++
Fruit bat	–	NA	++	++	++
Tree shrew	–	++	+	NA	NA

+++ = Highly prominent, ++ = Moderately prominent, + = Fairly prominent, - = No change, NA = Data Not Available.

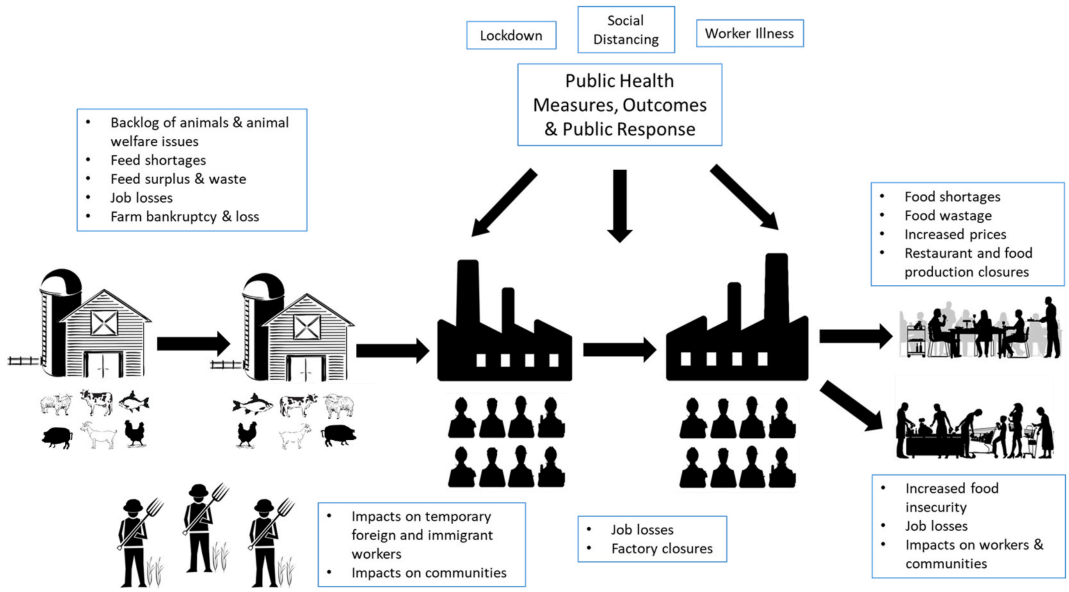

Fig. 3. Potential Impacts of the COVID-19 pandemic on Food Production. The figure was modified and reproduced with permission from Public Health Agency of Canada, 2021.

different animal and zoonotic diseases. Since zoonotic disease can also impact humans, the pandemic-triggered disruptions jeopardized human health in addition to animal health.

Furthermore, COVID-19 has negatively impacted food safety inspections, animal health extension services, and disease surveillance efforts which were important checks to prevent the spread of zoonotic diseases and other infections that impact human and animal health (FAO, 2020b; Gortázar & de la Fuente, 2020). This can create ripe conditions for future outbreaks and pandemics that can be detrimental to livestock health and human health (FAO, 2020b).

4.3. Limitations of access to markets and consumers

Amid the COVID-19 situation, markets have been disrupted throughout the world which ultimately affected animal production (Gauly et al., 2021). The closure of animal markets and restrictions on export and import operations have deprived livestock producers from precious local and global marketing opportunities (Hashem et al., 2020). In addition, intermediaries who collect animals and animal products and then process or sell them after fattening have been hit hard, which caused farmers to lose their links to major buyers (FAO, 2020b). Thus, there was a sharp decline in animal processing and slaughtering capacities which further added to the turmoil in the livestock market (Marchant-Forde & Boyle, 2020). This has impacted both animals and animal products such as milk, eggs, and meat. Some farmers had to cull their animals or dump their animal products such as milk, which caused them significant income losses. According to the FAO, these losses have been especially severe on women who were unable to obtain the necessary nutrients for their small ruminants and poultry (FAO, 2020b). Economic hardships and ongoing conflicts in different parts of the world have aggravated these losses (FAO, 2020b).

4.4. Shortage of labor

The widescale market disruption that resulted from the pandemic has impacted the agricultural workforce and caused staff shortages and layoffs in the labor force associated with animal production (Biswal et al., 2020). There is a significant proportion of migrant workers in the livestock industry and meat plants (Marchant-Forde & Boyle, 2020). Many of them had to return to their home countries due to the lockdowns, closures, and other measures that were implemented during the pandemic (Shirsath et al., 2020). During the peak of the pandemic, China closed livestock and poultry trading and slaughter markets in most of the nation, which results in labor shortage in slaughterhouses (Pan et al., 2020). Other causes for labor shortage include childcare, quarantine, and sick leave, which led to a 30% absence rate in some slaughterhouses in France and to similar issues in other countries in Africa and Asia (FAO, 2020b). Owing to these factors and to other factors, the process of bringing animals and animal products to local or global markets faced multiple hurdles.

The problem of labor shortage has had significant impacts on countries in South and Southeast Asia. In India, labor shortage has led to 23% food grain (important animal feed) production loss (Shirsath et al., 2020). Labor shortage has also led to food insecurity concerns and hunger concerns for daily wage workers in the farm and nonfarm sectors in Bangladesh (Mottaleb et al., 2020). Food insecurity has also emerged as a major pandemic-related concern in Nepal and other countries (Adhikari et al., 2021; Poudel et al., 2020).

5. Impact of COVID-19 on animal products

The worldwide demand for meat has been increasing in recent years for many factors including the rapid growth of population in many parts of the world (Sanchez-Sabate & Sabaté, 2019). However, working in slaughterhouses and meat packing plants has been considered a major risk for COVID-19 infection during the pandemic (Middleton et al., 2020). Workers in meat plants and slaughterhouses in Germany, England, Wales, and Portugal have reportedly been infected with SARS-CoV-2. (Middleton et al., 2020). The Portugal outbreak led to short-term closure of the poultry slaughterhouse and the implementation of strict hygienic measures including health screening of all employees, adding new bathing areas, and replacing old disinfectants with stronger ones (Middleton et al., 2020).

Previous reports confirmed the presence of rotaviruses and coronaviruses in raw milk and dairy products (cheese and yoghourt) (Abdou & Adham, 2013). MERS-CoV has been shown to survive for prolonged periods in milk (van Doremalen et al., 2014). The microbial composition of milk is influenced by the hygienic conditions of the animal, the animal's feed and water, air quality, environment, and equipment used for milking (Cancino-Padilla et al., 2017; Esslemont & Kossaibati, 2002). To minimize transmission of foodborne pathogens, milk and dairy products are subjected to the process of pasteurization (Oliver et al., 2005).

Table 3
Recommendations for animal producers during the COVID-19 pandemic.

	Recommendations
Farm Environment	1. Disinfect environment, equipment, and all surfaces 2. Following the all-in and all-out system for all animals 3. Separate farm animals from wild animals and limit adding new animals to the herd 4. Limit human access to the minimum required
Human Health Care	1. Vaccinations against COVID-19. 2. Frequent handwashing should be required. 3. Disinfectants should be made available for all employees. 4. Personal protective equipment use should be made mandatory. 5. Monitor workers' health and isolate employees that show COVID-19 symptoms. 6. Social distancing should be implemented according to recommendations of health experts.
Animal Health Care	1. Do not delay regular vaccinations of animals to control animal diseases. 2. Constant evaluation of prevalent diseases within the farm. 3. Avoid inhumane methods (such as inhumane culling). 4. Seek help from veterinary healthcare professionals when needed.

Although some studies suggested that SARS-CoV-2 can spread via food products as it can remain viable on inanimate surfaces for hours to days (Islam et al., 2020; Yekta, Vahid-Dastjerdi, Norouzbeigi, & Mortazavian, 2020), there is no proof that SARS-CoV-2 can spread directly through food, milk, milk products, or eggs (Duda-Chodak et al., 2020). However, it is always a good practice to understand the sources of contamination of dairy products and to try to minimize all possible routes of contamination (Kousta et al., 2010).

The COVID-19 pandemic caused global economic losses and significant negative impacts on the agri-food sector, including farming, crop production, and animal production systems (FAO, 2020d; Lopez-Ridaura et al., 2021; Tripathi et al., 2021; Gregorio et al., 2020; Lenzen et al., 2020; Siche, 2020). The potential COVID-19 impact on food production and food industry is illustrated in Fig 3. For agriculture, the pandemic impacted both supply and demand for food (FAO, 2020e). Canadian poultry and dairy sectors have been hit hard by the pandemic (Weersink et al., 2020). Farmers in the U.S. and Canada had to dump fresh milk in order to make room for new production (Weersink et al., 2020). For meat, the FAO Meat Price Index indicated that international meat prices dropped in May 2020 by 16 points (8.6%) from January 2020 (FAO, 2020f). The ovine meat registered the largest price drop (−23.5%), followed by poultry meat (−11.8%), pig meat (−9.2%), and bovine meat (−4.1%) (FAO, 2020f).

6. Conclusions and recommendations

In addition to disastrous impacts on human health, the COVID-19 pandemic has had unprecedented impacts on animal production and animal health throughout the world. Restrictions on mobility, national and international trade have disrupted the animal markets and access to consumers. This resulted in a significant crisis for animal producers and a major disruption of global economy. It also exacerbated concerns of food insecurity and hunger in different parts of the world. These changes made it crucial to develop and implement innovative strategies to mitigate, control, and overcome the global effects of COVID-19 on animal production and animal health. In addition, animal producers, animal healthcare professionals, human healthcare professionals, animal-related industries (such as meat, dairy, and poultry), governmental and non-government organizations need to coordinate and work together during the course of this pandemic and before any future pandemics that may impact global health. The following sections include some of the recommended measures regarding animals and animal production:

6.1. Recommendations for animal producers

Animal producers should take the essential preventive measure to alleviate the COVID-19-triggered crisis in animals and animal production. Regarding farm environments, recommendations include disinfection of environment, equipment, and all surfaces. In addition, the all-in and all-out system should be followed with all animals. Finally, farm animals should be kept separate from wild animals and human access should be limited. Regarding human health, all employees should be vaccinated against COVID-19. Vaccinations should also be made available to employees' families. Handwashing, disinfectants, and personal protective equipment should be used. In addition, the health status of the employees should be monitored and employees showing signs of COVID-19 should be isolated. Finally, social distancing should be implemented according to health expert recommendations. Regarding animal healthcare, regular vaccinations and health evaluations of animals should be maintained. The animals should also be treated in a humane way and veterinary healthcare professionals should be called for help when needed. The recommendations for animal farmers in their farming systems are summarized in Table 3.

6.2. Recommendations for veterinary healthcare professionals

1. Animal farms should be provided with essential services for high-quality animal health care and animal welfare.
2. Participation in all programs related to animal health or human health.
3. The safety of exported and imported raw materials of animal feed and animal products should be assured.
4. Collaborations with governmental and non-governmental organizations and human healthcare professionals to ensure availability of adequate health care systems and control of animal diseases.
5. Raise health awareness regarding the effect of COVID-19 on animals and animal products.

6.3. Recommendations for workers in animal products industries

Recommendations for handling, preparing, and transporting animal products and processed foods include:

1. Vaccinating workers and their families against COVID-19.
2. Handwashing should be done properly and regularly.
3. Raw meat should not be mixed with other food items.
4. Temperature to cook food should be high enough.
5. Storage of food should be done in refrigerators.
6. Use personal protective equipment and ensure that mouth and nose are covered.
7. Clean all surfaces and utensils with disinfectants.
8. Disinfect all surfaces that come into contact with raw food or ready-to-eat food.
9. Make disinfectants available for employees in different areas at work.
10. Isolate employees that show COVID-19 symptoms or have close contact with COVID-19 positive individuals.
11. Apply recommended social distancing between employees according to the most recent WHO and CDC guidelines.

6.4. Recommendations for governments

1. Monitor and track SARS-CoV-2 cases.
2. Ensure that animal farmers and the general public have access to accurate health information.
3. Develop risk management and risk mitigation strategies for COVID-19.
4. Establish animal disease control programs with the help of animal healthcare professionals and human healthcare professionals.

Table 4
Recommendations for veterinary healthcare professionals, workers in animal products industries, and governments during the COVID-19 pandemic.

	Recommendations
Veterinary Healthcare Professionals	1. Animal farms should be provided with essential services for high-quality animal health care and animal welfare. 2. Participation in all programs related to animal or human health activities. 3. The safety of exported and imported raw materials of animal feed and animal products should be assured. 4. Collaborations with governmental and non-governmental organizations and human healthcare professionals to ensure availability of adequate health care systems and control of animal diseases. 5. Raise health awareness regarding the effect of COVID-19 on animals and animal products
Workers in Animal Products Industries	1. Workers should receive vaccines against COVID-19. 2. Handwashing should be done properly and regularly. 3. Raw meat should not be mixed with other food items. 4. Temperature to cook food should be high enough. 5. Storage of food should be done in refrigerators. 6. Use personal protective equipment and ensure that mouth and nose are covered. 7. Clean all surfaces and utensils with disinfectants. 8. Disinfect all surfaces that come into contact with raw food or ready-to-eat food. 9. Make disinfectants available for employees in different areas at work. 10. Isolate employees that show COVID-19 symptoms or have close contact with COVID-19 positive individuals. 11. Apply recommended social distancing between employees according to the most recent WHO and CDC guidelines.
Governments	1. Monitor and track SARS-CoV-2 cases. 2. Ensure that animal farmers and the general public have access to accurate health information. 3. Develop risk management and risk mitigation strategies for COVID-19. 4. Establish animal disease control programs with the help of animal health professionals and human health professionals. 5. Facilitate the supply of animal feed and feed additives to animal producers. 6. Ease access of animals and animal products to markets and consumers. 7. Offer support to animal producers who experienced economic hardship due to the pandemic. 8. Provide alternate facilities for the storage of extra animals and animal products to help animal farmers in this pandemic and any future pandemics. 9. Collaborate with other governments and with non-governmental organizations, veterinary healthcare professionals, and other health professionals. 10. Making sure to have an adequate supply of COVID-19 vaccines.

5. Facilitate the supply of animal feed and feed additives to animal producers.
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9. Collaborate with other governments and with non-governmental organizations, veterinary health professionals, and other healthcare professionals.
10. Making sure to have an adequate supply of COVID-19 vaccines.

Table 4 includes a summary of our recommendations for veterinary healthcare professionals, workers in animal products industries, and governments.

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References

Abdou, A., & Adham, E. I. (2013). Detection of rota and corona viruses in raw milk and milk products. *Benha Veterinary Medical Journal, 24*, 79–85.
Adhikari, J., Timsina, J., Khadka, S. R., Ghale, Y., & Ojha, H. (2021). COVID-19 impacts on agriculture and food systems in Nepal: Implications for SDGs. *Agricultural Systems, 186*, 102990. https://doi.org/10.1016/j.agsy.2020.102990
Andersen, K. G., Rambaut, A., Lipkin, W. I., et al. (2020). The proximal origin of SARS-CoV-2. *Nature Medicine, 26*, 450–452. https://doi.org/10.1038/s41591-020-0820-9
Anelich, LECM, Lues, R, Farber, JM, & Parreira, VR (2020 Nov). SARS-CoV-2 and Risk to Food Safety. *Front Nutr, 27*, 580551. https://doi.org/10.3389/fnut.2020.580551
Ashour, H. M., Elkhatib, W. F., Rahman, M., & Elshabrawy, H. A. (2020). Insights into the recent 2019 novel coronavirus (SARS-CoV-2) in light of past human coronavirus outbreaks. *Pathogens, 9*(3), 186.
Biswal, J., Vijayalakshmy, K., & Rahman, H. (2020). Impact of COVID-19 and associated lockdown on livestock and poultry sectors in India. *Veterinary World, 13*, 1928–1933. https://doi.org/10.14202/vetworld.2020.1928-1933
Bourouiba, L., Dehandschoewercker, E., & Bush, J. W. (2014). Violent expiratory events: On coughing and sneezing. *Journal of Fluid Mechanics, 745*, 537–563. https://doi.org/10.1017/jfm.2014.88
Cancino-Padilla, N., Fellenberg, M. A., Franco, W., Ibáñez, R. A., & Vargas-Bello-Pérez, E. (2017). Foodborne bacteria in dairy products: Detection by molecular techniques. *International Journal of Agriculture and Natural Resources, 44*, 215–229. https://doi.org/10.7764/rcia.v44i3.1811
Cebra, C. K., Mattson, D. E., Baker, R. J., Sonn, R. J., & Dearing, P. L. (2003). Potential pathogens in feces from unweaned llamas and alpacas with diarrhea. *Journal of the American Veterinary Medical Association, 223*, 1806–1808. https://doi.org/10.2460/javma.2003.223.1806
Centers for Disease Control and Prevention (CDC). (2020). Watch for symptoms. In *Coronavirus disease 2019 (COVID 19) symptoms.* Atlanta, Georgia, USA: Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019ncov/symptoms-testing/symptoms.html.
Chao, C. Y. H., Wan, M. P., Morawska, L., Johnson, G. R., Ristovski, Z. D., Hargreaves, M., et al. (2009). Characterization of expiration air jets and droplet size distributions immediately at the mouth opening. *Journal of Aerosol Science, 40*, 122–133. https://doi.org/10.1016/j.jaerosci.2008.10.003
Coleman, K. K., Tay, D. J. W., Sen Tan, K., Ong, S. W. X., Son, T. T., Koh, M. H., … Wai, T. K. (2021 Aug). Viral Load of SARS-CoV-2 in Respiratory Aerosols Emitted by COVID-19 Patients while Breathing, Talking, and Singing. *Clinical Infectious Diseases, 6*, ciab691. https://doi.org/10.1093/cid/ciab691
Dai, M., Li, H., Yan, N., Huang, J., Zhao, L., Xu, S., et al. (2021). Long-term survival of SARS-CoV-2 on salmon as a source for international transmission. *The Journal of Infectious Diseases, 223*, 537–539. https://doi.org/10.1093/infdis/jiaa712
Decaro, N., Campolo, M., Desario, C., Cirone, F., D'abramo, M., Lorusso, E., et al. (2008a). Respiratory disease associated with bovine coronavirus infection in cattle herds in Southern Italy. *Journal of Veterinary Diagnostic Investigation, 20*, 28–32. https://doi.org/10.1177/104063870802000105
Decaro, N., Martella, V., Elia, G., Campolo, M., Mari, V., Desario, C., et al. (2008b). Biological and genetic analysis of a bovine-like coronavirus isolated from water buffalo (*Bubalus bubalis*) calves. *Virology, 370*, 213–222. https://doi.org/10.1016/j.virol.2007.08.031
Deeh, P. B. D., Kayri, V., Orhan, C., & Sahin, K. (2020). Status of novel coronavirus disease 2019 (COVID-19) and animal production. *Frontiers in Veterinary Science, 7*, 586919. https://doi.org/10.3389/fvets.2020.586919
Department for Environment, Food & Rural Affairs. (2020). *Series of straights and compound animal feed prices across Great Britain.* UK Government. https://www.gov.uk/government/statistical-data-sets/animal-feed-prices.
do Vale, B., Lopes, A. P., Fontes, M.d., et al. (2021). Bats, pangolins, minks and other animals - villains or victims of SARS-CoV-2? *Veterinary Research Communications, 45*, 1–19. https://doi.org/10.1007/s11259-021-09787-2
Domańska-Blicharz, K., Woźniakowski, G., Konopka, B., Niemczuk, K., Welz, M., Rola, J., et al. (2020). Animal coronaviruses in the light of COVID-19. *Journal of Veterinary Research, 64*, 333–345. https://doi.org/10.2478/jvetres-2020-0050

Domingo, J. L. (2021 Sep). What we know and What we need to know about the origin of SARS-CoV-2. *Environ. Res., 200*, Article 111785. https://doi.org/10.1016/j.envres.2021.111785. Epub 2021 Jul 28.

Duda-Chodak, A., Lukasiewicz, M., Zięć, G., Florkiewicz, A., & Filipiak-Florkiewicz, A. (2020). Covid-19 pandemic and food: Present knowledge, risks, consumers fears and safety. *Trends in Food Science & Technology, 105*, 145–160. https://doi.org/10.1016/j.tifs.2020.08.020

El Zowalaty, M. E., & Järhult, J. D. (2020 Feb). From SARS to COVID-19: A previously unknown SARS- related coronavirus (SARS-CoV-2) of pandemic potential infecting humans - Call for a One Health approach. *One Health, 249*, 100124. https://doi.org/10.1016/j.onehlt.2020.100124

Elleby, C., Domínguez, I. P., Adenauer, M., & Genovese, G. (2020). Impacts of the COVID-19 pandemic on the global agricultural markets. *Environmental and Resource Economics, 76*, 1067–1079. https://doi.org/10.1007/s10640-020-00473-6

Esslemont, D., & Kossaibati, M. (2002). Mastitis: How to get out of the dark ages. *The Veterinary Journal, 2*, 85–86. https://doi.org/10.1053/tvjl.2002.0742

Food and Agriculture Organization (FAO). (2020a). *Coronavirus disease 2019 (COVID-19). Addressing the impacts of COVID-19 in food crises*. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/ca8497en/ca8497en.pdf.

Food and Agriculture Organization (FAO). (2020b). *Mitigating the impacts of COVID-19 on the livestock sector*. Rome, Italy: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/ca8799en

Food and Agriculture Organization (FAO). (2020c). *COVID-19 and the impact on food security in the near East and North Africa: How to respond?* Rome, Italy: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/ca8430en

Food and Agriculture Organization (FAO). (2020d). *Guidelines to mitigate the impact of the COVID-19 pandemic on livestock production and animal health*. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/ca9177en/CA9177EN.pdf.

Food and Agriculture Organization (FAO). (2020e). *Food and Agriculture Organization. Q&A: COVID-19 pandemic - impact on food and agriculture*. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/2019-ncov/q-and-a/en/.

Food and Agriculture Organization (FAO). (2020f). Food outlook–biannual report on global food markets. In *Food Outlook* (Vol. 1). Rome, Italy: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/ca9509en

Gauly, M., Chemineau, P., Rosati, A., & Sartin, J. (2021). COVID-19 pandemic—how and why animal production suffers? *Animal Frontiers, 11*, 3–5. https://doi.org/10.1093/af/vfaa059

Godri Pollitt, K. J., Peccia, J., Ko, A. I., Kaminski, N., Dela Cruz, C. S., Nebert, D. W., et al. (2020). COVID-19 vulnerability: The potential impact of genetic susceptibility and airborne transmission. *Human Genomics, 14*, 1–7. https://doi.org/10.1186/s40246-020-00267-3

Gortázar, C., & de la Fuente, J. (2020). COVID-19 is likely to impact animal health. *Preventive Veterinary Medicine, 180*, 105030. https://doi.org/10.1016/j.prevetmed.2020.105030

Gregorio, Glenn, B., & Rico, C. Ancog. (2020). Assessing the Impact of the COVID-19 Pandemic on Agricultural Production in Southeast Asia: Toward Transformative Change in Agricultural Food Systems. *Asian Journal of Agriculture and Development, 17*(1), 1–13. https://doi.org/10.37801/ajad2020.17.1.1

Guan, D., Wang, D., Hallegatte, S., Davis, S. J., Huo, J., Li, S., et al. (2020). Global supply-chain effects of COVID-19 control measures. *Nature Human Behaviour, 3*, 1–11. https://doi.org/10.1038/s41562-020-0896-8

Hafez, H. M., & Attia, Y. A. (2020). Challenges to the poultry industry: Current perspectives and strategic future after the COVID-19 outbreak. *Frontiers in Veterinary Science, 7*, 516. https://doi.org/10.3389/fvets.2020.00516

Han, J., Zhang, X., He, S., & Jia, P. (2020). Can the coronavirus disease be transmitted from food? A review of evidence, risks, policies and knowledge gaps. *Environmental Chemistry Letters*, 1–12. https://doi.org/10.1007/s10311-020-01101-x

Han, S., Roy, P. K., Hossain, M. I., Byun, K. H., Choi, C., & Ha, S. D. (2021 Mar). COVID-19 pandemic crisis and food safety: Implications and inactivation strategies. *Trends in Food Science & Technology, 109*, 25–36. https://doi.org/10.1016/j.tifs.2021.01.004

Hashem, N. M., González-Bulnes, A., & Rodriguez-Morales, A. J. (2020). Animal welfare and livestock supply chain sustainability under the COVID-19 outbreak: An overview. *Frontiers in Veterinary Science, 7*, 582528. https://doi.org/10.3389/fvets.2020.582528

He, S., Han, J., & Lichtfouse, E. (2021). Backward transmission of COVID-19 from humans to animals may propagate reinfections and induce vaccine failure. *Environmental Chemistry Letters, 19*, 763–768. https://doi.org/10.1007/s10311-020-01140-4

Hemida, M. G., Elmoslemany, A., Al-Hizab, F., Alnaeem, A., Almathen, F., Faye, B., et al. (2017). Dromedary camels and the transmission of Middle East respiratory syndrome coronavirus (MERS-CoV). *Transboundary and Emerging Diseases, 64*, 344–353. https://doi.org/10.1111/tbed.12401

Hobbs, E. C., & Reid, T. J. (2020). Animals and SARS-CoV-2: Species susceptibility and viral transmission in experimental and natural conditions, and the potential implications for community transmission. *Transboundary and Emerging Diseases, 19*, 531–545. https://doi.org/10.1111/tbed.13885

Holmes, E. C., Goldstein, S. A., Rasmussen, A. L., Robertson, D. L., Crits-Christoph, A., Wertheim, J. O., Anthony, S. J., Barclay, W. S., Boni, M. F., Doherty, P. C., Farrar, J., Geoghegan, J. L., Jiang, X., Leibowitz, J. L., Neil, S. J. D., Skern, T., Weiss, S. R., Worobey, M., Andersen, K. G., Garry, R. F., & Rambaut, A (2021 Sep 16). The origins of SARS-CoV-2: A critical review. *Cell, 184*(19), 4848–4856. https://doi.org/10.1016/j.cell.2021.08.017

Hussain, S., Hussain, A., Ho, J., Sparagano, O. A., & Zia, U. U. R. (2020). Economic and social impacts of COVID-19 on animal welfare and dairy husbandry in Central Punjab, Pakistan. *Frontiers in Veterinary Science, 7*, 589971. https://doi.org/10.3389/fvets.2020.589971

Islam, M. S., Sobur, M. A., Akter, M., Nazir, K. N. H., Toniolo, A., & Rahman, M. T. (2020). Coronavirus Disease 2019 (COVID-19) pandemic, lessons to be learned. *Journal of Advanced Veterinary and Animal Research, 7*, 260–280. https://doi.org/10.5455/javar.2020.g418

Ito, N. M. K., Miyaji, C. I., & Capellaro, C. E. M. (1991). Studies on broiler's IBV and IB-like virus from Guinea fowl. In E. F. Kaleta, & U. Heffels-Redmann (Eds.), *Proceedings of the II international symposium on infectious bronchitis* (pp. 302–307). Giessen, Germany: Justus Leibig University.

Jones, D. L., Baluja, M. Q., Graham, D. W., Corbishley, A., McDonald, J. E., Malham, S. K., … Farkas, K. (2020 Dec). Shedding of SARS-CoV-2 in feces and urine and its potential role in person-to-person transmission and the environment-based spread of COVID-19. *The Science of the Total Environment, 20749*, 141364. https://doi.org/10.1016/j.scitotenv.2020.141364

Kousta, M., Mataragas, M., Skandamis, P., & Drosinos, E. H. (2010). Prevalence and sources of cheese contamination with pathogens at farm and processing levels. *Food Control, 21*, 805–815. https://doi.org/10.1016/j.foodcont.2009.11.015

Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science, 369*, 500–502. https://doi.org/10.1126/science.abc4765

Lednicky, J. A., Tagliamonte, M. S., White, S. K., et al. (2021). Independent infections of porcine deltacoronavirus among Haitian children. *Nature, 600*, 133–137. https://doi.org/10.1038/s41586-021-04111-z

Lefkowitz, E. J., Dempsey, D. M., Hendrickson, R. C., Orton, R. J., Siddell, S. G., & Smith, D. B. (2018). Virus taxonomy: the database of the international International Committee on Taxonomy of Viruses Executive on taxonomy of viruses (ICTV). *Nucleic Acids Res., 46*(D1), D708–D717. https://doi.org/10.1093/nar/gkx932

Lenzen, M., Li, M., Malik, A., Pomponi, F., Sun, Y. Y., Wiedmann, T., et al. (2020). Global socio-economic losses and environmental gains from the Coronavirus pandemic. *PLoS One, 15*, Article e0235654. https://doi.org/10.1371/journal.pone.0235654

Li, Q., Guan, X., Wu, P., Wang, X., Zhou, L., Tong, Y., et al. (2020). Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *New England Journal of Medicine, 382*(13), 1199–1207. https://doi.org/10.1056/NEJMoa2001316

Liu, P., Yang, M., Zhao, X., Guo, Y., Wang, L., Zhang, J., Lei, W., Han, W., Jiang, F., W, L., et al. (2020). Cold-chain transportation in the frozen food industry may have caused a recurrence of COVID-19 cases in destination: Successful isolation of SARS-CoV-2 virus from the imported frozen cod package surface. *Biosaf Health, 2*(4), 199–201.

Liu, Y., Hu, G., Wang, Y., Ren, W., Zhao, X., Ji, F., Zhu, Y., Feng, F., Gong, M., Ju, X., Zhu, Y., Cai, X., Lan, J., Guo, J., Xie, M., Dong, L., Zhu, Z., Na, J., Wu, J., Lan, X., Yuan, Z., Zhang, R., & Ding, Q. (2021). Functional and genetic analysis of viral receptor ACE2 orthologs reveals a broad potential host range of SARS-CoV2. In *Proceedings of the National Academy of Sciences Mar 2021, 118*. https://doi.org/10.1073/pnas.2025373118. e2025373118 12.

Lopez-Ridaura, S., Sanders, A., Barba-Escoto, L., Wiegel, J., Mayorga-Cortes, M., Lopez-Ramirez, M. A., Escoto-Masis, R. M., & García-Barcena, T. S. (2021 Aug 1). Immediate impact of COVID-19 pandemic on farming systems in Central America and Mexico. *Agricultural Systems, 192*, 103178. https://doi.org/10.1016/j.agsy.2021.103178.

Lu, R., Zhao, X., Li, J., Niu, P., Yang, B., Wu, H., et al. (2020). Genomic characterisation and epidemiology of 2019 novel coronavirus: Implications for virus origins and receptor binding. *The Lancet, 395*, 565–574. https://doi.org/10.1016/S0140-6736(20)30251-8

M Najimudeen, S., H Hassan, M. S., C Cork, S., & Abdul-Careem, M. F. (2020). Infectious bronchitis coronavirus infection in chickens: Multiple system disease with immune suppression. *Pathogens, 9*, 779. https://doi.org/10.3390/pathogens9100779

Mahdy, M. A., Younis, W., & Ewaida, Z. (2020). An overview of SARS-CoV-2 and animal infection. *Frontiers in Veterinary Science, 7*, 596391. https://doi.org/10.3389/fvets.2020.596391

Marchant-Forde, J. N., & Boyle, L. A. (2020). COVID-19 effects on livestock production: A one welfare issue. *Frontiers in Veterinary Science, 7*, 585787. https://doi.org/10.3389/fvets.2020.585787

Mecenas, P., Bastos, R. T. D. R. M., Vallinoto, A. C. R., & Normando, D. (2020). Effects of temperature and humidity on the spread of COVID-19: A systematic review. *PLoS One, 15*, Article e0238339. https://doi.org/10.1371/journal.pone.0238339

Meekins, D. A., Morozov, I., Trujillo, J. D., Gaudreault, N. N., Bold, D., Carossino, M., et al. (2020). Susceptibility of swine cells and domestic pigs to SARS-CoV-2. *Emerging Microbes & Infections, 9*, 2278–2288. https://doi.org/10.1080/22221751.2020.1831405

Middleton, J., Reintjes, R., & Lopes, H. (2020). Meat plants—a new front line in the covid-19 pandemic. *BMJ, 2020*, 370. https://doi.org/10.1136/bmj.m2716

Mottaleb, K. A., Mainuddin, M., & Sonobe, T. (2020). COVID-19 induced economic loss and ensuring food security for vulnerable groups: Policy implications from Bangladesh. *PLoS One, 15*, Article e0240709. https://doi.org/10.1371/journal.pone.0240709

Mouchtouri, V. A., Koureas, M., Kyritsi, M., Vontas, A., Kourentis, L., Sapounas, S., et al. (2020). Environmental contamination of SARS-CoV-2 on surfaces, air-conditioner and ventilation systems. *International Journal of Hygiene and Environmental Health, 230*, 113599. https://doi.org/10.1016/j.ijheh.2020.113599

Nazaroff, WW. (2021 Dec). Indoor aerosol science aspects of SARS-CoV-2 transmission. *Indoor Air, 6*. https://doi.org/10.1111/ina.12970

Oliver, S. P., Jayarao, B. M., & Almeida, R. A. (2005). Foodborne pathogens in milk and the dairy farm environment: Food safety and public health implications. *Foodborne Pathogens & Disease, 2*, 115–129. https://doi.org/10.1089/fpd.2005.2.115

Panigrahy, B., Naqi, S. A., & Hall, C. F. (1973). Isolation and characterization of viruses associated with transmissible enteritis (bluecomb) of turkeys. *Avian Diseases, 1*, 430–438. https://doi.org/10.2307/1589228
Pan, D., Yang, J., Zhou, G., & Kong, F. (2020). The influence of COVID-19 on agricultural economy and emergency mitigation measures in China: A text mining analysis. *PLoS One, 15*, Article e0241167. https://doi.org/10.1371/journal.pone.0241167
Pascucci, S., Misciattelli, M. E., Giovanetti, L., & Pacchioni, G. (1983). Isolamento di un coronavirus simile da quaglie giapponesi (Coturnix coturnix japonica) con syndrome respiratoria: Prima descrizione della malattia ed isolamento del virus. *La Clinica Veterinaria, 106*, 33–34.
Perlman, S. (2020). Another decade, another coronavirus. *New England Journal of Medicine, 382*, 760–762. https://doi.org/10.1056/NEJMe2001126
Poudel, P. B., Poudel, M. R., Gautam, A., Phuyal, S., Tiwari, C. K., Bashyal, N., & Bashyal, S. (2020). COVID-19 and its global impact on food and agriculture. *Journal of Biology and Today's World, 9*, 221. https://doi.org/10.35248/2322-3308.20.09.221
Public Health Agency of Canada. (2021). One Health: Holistic Approaches to Post-Pandemic Challenges Panel. In *[Conference panel presentation]. The Biosafety Level 4 Zoonotic Laboratory Network (BSL4ZNet). International Conference, Virtual Conference, 2021, October, 7.* https://inspection.canada.ca/science-and-research/science-collaborations/biosafety-level-4-zoonotic-laboratory-network/2021-bsl4znet-international-conference/eng/1620997638094/1620997884945#shr-pg0.
Roberts, J. R., Souillard, R., & Bertin, J. (2011). Avian diseases which affect egg production and quality. In Y. Nys, M. Bain, & F. Van Immerseel (Eds.), *Improving the safety and quality of eggs and egg products* (pp. 376–393). Cambridge, UK: Woodhead Publishing Limited. https://doi.org/10.1533/9780857093912.3.376.
Sabir, J. S., Lam, T. T. Y., Ahmed, M. M., Li, L., Shen, Y., Abo-Aba, S. E., et al. (2016). Co-circulation of three camel coronavirus species and recombination of MERS-CoVs in Saudi Arabia. *Science, 351*, 81–84. https://doi.org/10.1126/science.aac8608
Sanchez-Sabate, R., & Sabaté, J. (2019). Consumer attitudes towards environmental concerns of meat consumption: A systematic review. *International Journal of Environmental Research and Public Health, 16*, 1220. https://doi.org/10.3390/ijerph16071220
Seleiman, M. F., Selim, S., Alhammad, B. A., Alharbi, B. M., & Juliatti, F. C. (2020). Will novel coronavirus (Covid-19) pandemic impact agriculture, food security and animal sectors? *Bioscience Journal, 36*, 1315–1326. https://doi.org/10.14393/BJ-v36n4a2020-54560
Shirsath, P. B., Jat, M. L., McDonald, A. J., Srivastava, A. K., Craufurd, P., Rana, D. S., et al. (2020). Agricultural labor, COVID-19, and potential implications for food security and air quality in the breadbasket of India. *Agricultural Systems, 185*, 102954. https://doi.org/10.1016/j.agsy.2020.102954
Shi, J., Wen, Z., Zhong, G., Yang, H., Wang, C., Huang, B., et al. (2020). Susceptibility of ferrets, cats, dogs, and other domesticated animals to SARS–coronavirus 2. *Science, 368*, 1016–1020. https://doi.org/10.1126/science.abb7015
Siche, R. (2020). What is the impact of COVID-19 disease on agriculture? *Scientia Agropecuaria, 11*, 3–6. https://doi.org/10.17268/sci.agropecu.2020.01.00
Sidor, A., & Rzymski, P. (2020). Dietary choices and habits during COVID-19 lockdown: Experience from Poland. *Nutrients, 12*, 1657. https://doi.org/10.3390/nu12061657
Sobsey, M. D. (2021). Absence of virological and epidemiological evidence that SARS-CoV-2 poses COVID-19 risks from environmental fecal waste, wastewater and water exposures. *Journal of Water and Health, 2021182*. https://doi.org/10.2166/wh.2021.182
Spackman, D., & Cameron, I. R. (1983). Isolation of infectious bronchitis virus from pheasants. *The Veterinary Record, 113*, 354–355. https://doi.org/10.1136/vr.113.15.354
Tang, J. W., Nicolle, A. D., Pantelic, J., Jiang, M., Sekhr, C., Cheong, D. K., & Tham, K. W. (2011). Qualitative real-time schlieren and shadowgraph imaging of human exhaled airflows: An aid to aerosol infection control. *PLoS One, 6*, Article e21392. https://doi.org/10.1371/journal.pone.0021392
Tazerji, S. S., Duarte, P. M., Rahimi, P., Shahabinejad, F., Dhakal, S., Malik, Y. S., et al. (2020). Transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) to animals: An updated review. *Journal of Translational Medicine, 18*, 1–11. https://doi.org/10.1186/s12967-020-02534-2
Tripathi, H. G., Smith, H. E., Sait, S. M., Sallu, S. M., Whitfield, S., Jankielsohn, A., … Nyhodo, B. (2021). Impacts of COVID-19 on Diverse Farm Systems in Tanzania and South Africa. *Sustainability, 13*(17), 9863. https://doi.org/10.3390/su13179863
Trmčić, A., Demmings, E., Kniel, K., Wiedmann, M., & Alcaine, S. (2021 Nov). Food safety and employee health implications of COVID-19: A review. *Journal of Food Protection, 184*(11), 1973–1989. https://doi.org/10.4315/JFP-21-201
Uddin, M. M., Akter, A., Khaleduzzaman, A. B. M., Sultana, M. N., & Hemme, T. (2021). Application of the Farm Simulation Model approach on economic loss estimation due to Coronavirus (COVID-19) in Bangladesh dairy farms—strategies, options, and way forward. *Tropical Animal Health and Production, 53*, 1–12. https://doi.org/10.1007/s11250-020-02471-8
van Doremalen, N., Bushmaker, T., Karesh, W. B., & Munster, V. J. (2014). Stability of Middle East respiratory syndrome coronavirus in milk. *Emerg Infect Dis., 20*(7), 1263–1264. https://doi.org/10.3201/eid2007.140500
Ulrich, L., Wernike, K., Hoffmann, D., Mettenleiter, T. C., & Beer, M. (2020). Experimental infection of cattle with SARS-CoV-2. *Emerging Infectious Diseases, 26*, 2979. https://doi.org/10.3201/eid2612.203799
Van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B., et al. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *New England Journal of Medicine, 382*, 1564–1567. https://doi.org/10.1056/NEJMc2004973
Vlasova, A. N., Wang, Q., Jung, K., Langel, S. N., Malik, Y. S., & Saif, L. J. (2020). Porcine coronaviruses. *Emerging and Transboundary Animal Viruses, 23*, 79–110. https://doi.org/10.1007/978-981-15-0402-0_4
Walker, P. J., Siddell, S. G., Lefkowitz, E. J., Mushegian, A. R., Adriaenssens, E. M., Dempsey, D. M., Dutilh, B. E., Harrach, B., Harrison, R. L., Hendrickson, R. C., Junglen, S., Knowles, N. J., Kropinski, A. M., Krupovic, M., Kuhn, J. H., Nibert, M., Orton, R. J., Rubino, L., Sabanadzovic, S., Simmonds, P., Smith, D. B., Varsani, A., Zerbini, F. M., & Davison, A. J. (2020). Changes to virus taxonomy and the Statutes ratified by the International Committee on Taxonomy of Viruses. *Arch Virol., 165*(11), 2737–2748, 2020 Nov.
Wang, J., Tang, K., Feng, K., & Lv, W. (2020). High temperature and high humidity reduce the transmission of COVID-19. *SSRN*. https://doi.org/10.2139/ssrn.3551767
Weersink, A., von Massow, M., & McDougall, B. (2020). Economic thoughts on the potential implications of COVID-19 on the Canadian dairy and poultry sectors. *Canadian Journal of Agricultural Economics, 68*, 195–200. https://doi.org/10.1111/cjag.12240
Wei, J., & Li, Y. (2016). Airborne spread of infectious agents in the indoor environment. *American Journal of Infection Control, 44*, S102–S108. https://doi.org/10.1016/j.ajic.2016.06.003
World Health Organization (WHO). (2020). *COVID-19 and food safety: Guidance for food businesses*. Geneva, Switzerland: World Health Organization. https://www.who.int/publications-detail/covid-19-and-food-safety-guidance-for-food-businesses.
World Health Organization (WHO). (2020). *WHO Director-General's opening remarks at the media briefing on COVID-19-11 March 2020*. Geneva, Switzerland: World Health Organization. Availabe at: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19—11-march-2020.
Xu, Y., Chen, Y., & Tang, X. (2020). Guidelines for the diagnosis and treatment of coronavirus disease 2019 (COVID-19) in China. *Global Health & Medicine, 2*, 66–72. https://doi.org/10.35772/ghm.2020.01015
Yekta, R., Vahid-Dastjerdi, L., Norouzbeigi, S., & Mortazavian, A. M. (2020). Food products as potential carriers of SARS-CoV-2. *Food Control, 11*, 107754. https://doi.org/10.1016/j.foodcont.2020.107754
Zhai, S. L., Wen-Kang, W., Lv, D. H., Zhi-Hong, X., Qin-Ling, C., Ming-Fei, et al. (2020). Where did SARS-CoV-2 come from? *The Veterinary Record, 186*, 254. https://doi.org/10.1136/vr.m740
Zhang, T., Wu, Q., & Zhang, Z. (2020). Probable pangolin origin of SARS-CoV-2 associated with the COVID-19 outbreak. *Current Biology, 30*, 1346–1351. https://doi.org/10.1016/j.cub.2020.03.022
Zhou, Z., Qiu, Y., & Ge, X. (2021). The taxonomy, host range and pathogenicity of coronaviruses and other viruses in the Nidovirales order. *Anim. Dis., 1*, 5. https://doi.org/10.1186/s44149-021-00005-9
Zhu, N., Zhang, D., Wang, W., Li, X., Yang, B., Song, J., … Tan, W. (2020 Feb 20). China novel coronavirus investigating and research team. A novel coronavirus from patients with pneumonia in China, 2019. *New England Journal of Medicine, 382*(8), 727–733. https://doi.org/10.1056/NEJMoa2001017