



Influence of COVID-19 on the poultry production and environment

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Abstract

Although chickens are not susceptible to SARS-CoV-2, several coronavirus disease outbreaks have been described concerning poultry processing facilities in different countries. The COVID-19 pandemic and the developed strain caused 2nd, 3rd, and recent Indian strain waves of epidemics that have led to unexpected consequences, such as forced reductions in demands for some industries, transportation systems, employment, and businesses due to public confinement. Besides, poultry processing plants' conditions exacerbate the risks due to the proximity on the line, cold, and humidity. Most workers do not have access to paid sick time or adequate health care, and because of the low wages, they have limited reserves to enable them to leave steady employment. In addition, workers in meat and poultry slaughterhouses may be infected through respiratory droplets in the air and/or from touching dirty surfaces or objects such as workstations, break room tables, or tools. Egg prices have increased dramatically during the lockdown as consumers have started to change their behaviors and habits. The COVID pandemic might also substantially impact the international poultry trade over the next several months. This review will focus on the effect of COVID-19 on poultry production, environmental sustainability, and earth systems from different process points of view.

Keywords Coronavirus · Economic losses · Global environment · Poultry production · Food security and safety

Introduction

Coronavirus infections have been associated with many diseases, such as the Middle East respiratory syndrome (MERS) (WHO 2019) and severe acute respiratory syndrome (SARS)

(Law et al. 2020) in humans. Recently, a new coronavirus (SARS-CoV-2 or COVID-19) has been isolated; it is responsible for the recent COVID-19 pandemic, and new strains developed that spread in European Union (EU), causing the 2nd lockdown (Alagawany et al. 2021; Saghir et al. 2021).

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COVID-19 infection causes a systemic disease that is spread via airborne/droplets/aerosol. COVID-19 has indirectly affected humans, animal production, the environment, earth systems, social and economic conditions worldwide (Sharun et al. 2021). There have been rumors about the potential involvement of eggs and chicken meat in the spread of COVID-19, which resulted in a dramatic drop in demand for poultry goods beginning in February 2020, just before the declaration of the lockdown and culminating in the deterioration of poultry economics due to working capital erosion. From local farmers to large integrators, all aspects of poultry processing were severely impacted, much worse than the Avian influenza outbreak of 2006 (Das and Samanta 2021).

There is great attention on the adverse impact of the environment inside poultry house and increase the harmful dust and gaseous and the incidences of asthma, allergy diseases and repository and pulmonary disorders diseased among poultry workers and keepers. In addition, a high prevalence of nasal (51.1%) and asthmatic (42.5%) symptoms were observed in poultry keepers mainly, which may increase the susceptibility of works to Covid-19 (Viegas et al. 2013; Arcangeli et al. 2020; Clarke et al. 2021). Recent evidence indicates high incidences of COVID-19 among patients with chronic diseases and respiratory diseases (Hafez and Attia 2020). The contents of nitrogen (N) and phosphorus (P) in poultry litter and its negative impact on soil surface and groundwater because of continuous poultry litter application raises the risk of *depletion* of surface and the quality of the groundwater supplies (Bolan et al. 2010). The use of poultry litter has been shown to raise the edge-of-field losses of N and P in surface and subsurface runoff. Nitrate-N losses in groundwater will accumulate to amounts that surpass reasonable human intake limits (10 mg/L) (Colt 2006). Therefore, it is logical to expect the direct and indirect relationship between the economic and environmental influence of COVID-19 with concern to the poultry production sector through a health issue. This review shed light on the impact of COVID-19 on poultry production and the environment.

COVID-19

The family *Coronaviridae* contains two subfamilies: *Torovirinae* and *Coronavirinae*. *Coronavirinae* comprises four genera: *Alphacoronavirus* and *Betacoronavirus* mainly infect mammals, *Gammacoronavirus* infects avian species, and *Deltacoronavirus* infects mammalian and avian species (Phan et al. 2018; Attia et al. 2021). *Torovirinae* is divided into two genera: *Torovirus*, which originates from mammals, and *Bafinivirus*, isolated from fish (Tokarz et al. 2015) (Fig. 1). The different serotypes and varieties of COVID-19 are summarized in Table 1.

The *Betacoronavirus* genus contains COVID-19, SARS-CoV, and MERS-CoV (Shereen et al. 2020). COVID-19 is an enveloped virus that is highly infectious, even though it is easily destroyed by soap and common disinfectants. COVID-19 infection causes a systemic disease in which fever, dry cough, and fatigue have been most commonly reported; in some cases, diarrhea and vomiting can also be observed. Although chickens are not susceptible to SARS-CoV-2 (Schlottau et al. 2020), several coronavirus disease outbreaks have been described concerning poultry processing facilities in different countries as Brazil, Canada, and Spain (Durand-Moreau et al. 2020). Studies have linked livestock plants to a high potential for a community spread in the surrounding areas (Middleton et al. 2020; Taylor et al. 2020). Work routines in livestock processing make plants susceptible to local outbreaks of respiratory viruses. The long work shifts near coworkers, difficulty maintaining proper face-covering due to physical demands, and shared transportation among workers (Taylor et al. 2020). Besides, the virus thrives in lower temperatures and very high or very low relative humidity, and metallic surfaces retain live viruses for longer than other environments (Middleton et al. 2020).

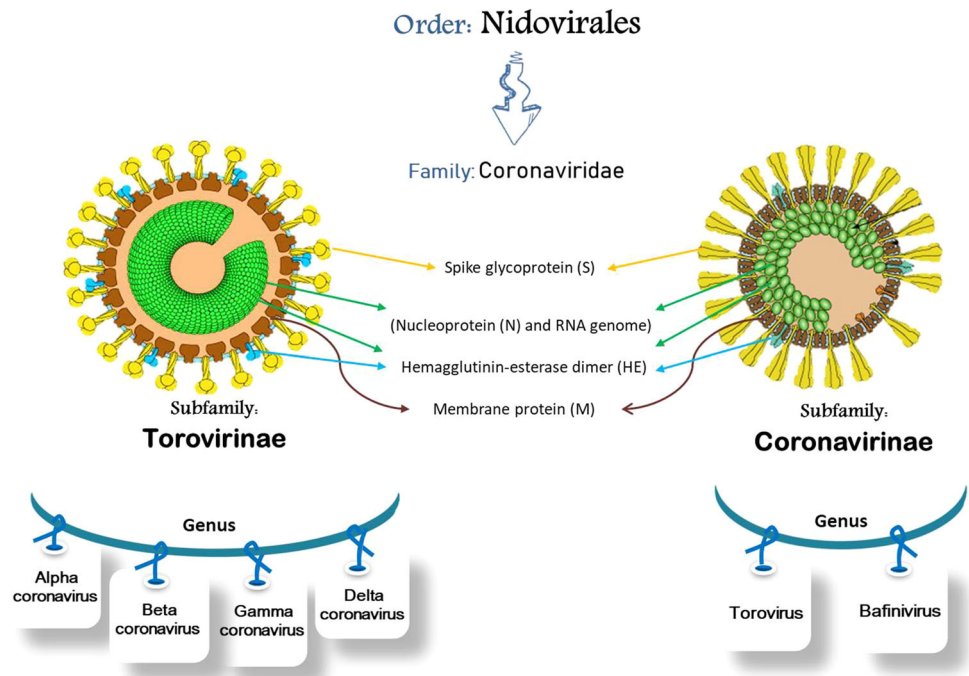
The virus is thought to spread principally via respiratory droplets from an infected person to a healthy one through close contact. Strategies to prevent the spread and the strengthening of COVID-19 include increasing public awareness about transmission and decreasing trade activities. The possibility of the viruses spread among people is related to the biological properties of each virus. Still, it is also affected by external factors such as temperature, humidity, population density, and thus lack of hospital beds (Islam et al. 2020). In addition, the symptoms of the infection have multiple facets.

The public services and facilities must provide decontaminating reagents for cleaning hands daily. In addition, physical contact with wet and contaminated objects should be considered in dealing with the virus, avoiding contact with confirmed or suspected patients, and using face protective devices (Rothan and Byrareddy 2020; Islam et al. 2020).

Another way to contrast the SARS-CoV-2 spread is to know the virus's mechanisms and develop appropriate therapeutic strategies. Essential acquired knowledge is that the virus comes in the human cells through its high binding affinity with angiotensin-converting enzyme 2 (ACE2) (Benseñor and Lotufo 2020; Chen et al. 2020). So, Chen et al. (2020) proposed that specific antibodies and small molecules can prevent the binding between ACE2 and the receptors (RBD) of the virus, and this way could represent a potential strategy against COVID-19 disease prevention and control.

To control a further outbreak, strategies should be developed and applied around the world. A myriad of lessons has been learned from the COVID-19 pandemic, which pays great attention to the relationship among humans, wild animals, and

Fig. 1 Types of COVID-19 virus



livestock. Where there is a high human population density, the government in each country must be ready with specific

pandemic plans to avoid the suffering of the health systems (Benseñor and Lotufo 2020). Other lessons will be learned

Table 1

Type	Serotype	Varieties	Disease	References	
Human	Alphacoronavirus	HCoV-229E	Upper respiratory tract infections, especially the common cold and acute otitis media.	Ding et al. 2021	
	Betacoronaviruses	HKU1	upper or lower respiratory tract infection	Ding et al. 2021	
		NL63 (HCoV-OC43)	New Haven coronavirus causes severe acute respiratory syndrome	Krzysztof Pyrc et al. 2007	
		HCoV-EMC or MERS-CoV	MERS	Jasper et al. 2015	
		SARS-CoV-1	SARS	Tratner 2003	
	SARS-CoV-2 or 2019-nCoV	COVID-19	Lai et al. 2020		
Animal	Cattle	Betacoronavirus	Bovine coronavirus (BCV)	Sever enteritis in calve	Fulton et al. 2011
		Alphacoronavirus	Feline coronavirus (FCoV)	Sever feline infectious peritonitis and mild enteritis in cat	Sykes 2014
	Dogs	Alphacoronavirus	Canine coronavirus (CCoV)	Respiratory diseases and enteritis	Buonavoglia et al. 2006
		Mink coronavirus	Ferret enteric coronavirus	Epizootic catarrhal enteritis	Provacia, et al. (2011).
	Ferret systemic coronavirus		Syndrome similar to feline infectious peritonitis		
	Pigs	Deltacoronavirus	Porcine coronavirus HKU15	Gastroenteritis	Wang et al. (2014).
			Porcine epidemic diarrhea virus (PEDV)		
	Rabbits	Betacoronavirus	Rabbit enteric corona virus (RECV)	Acute gastrointestinal disease and diarrhea in young European rabbits	Kerr and Donnelly 2013
	Rats	Alphacoronavirus	Lucheng Rn rat coronavirus	Severe respiratory symptoms specially in young rats	Lucheng Rn rat coronavirus 2021; La Regina et al. 1992

because it will take time to develop an effective and successful vaccine and/or specific antiviral therapy for COVID-19 (Islam et al. 2020; Rahman et al. 2020). Therefore, it is essential to determine whether a neutralizing antibody and/or SARS-CoV-2-specific T cell response is sufficient to prevent clinical disease transmission, determine the magnitude of the reactions required to provide protection and the longevity of these protective responses (Sariol and Perlman 2020).

In 2019, the weakness of health systems worldwide came into focus due to insufficient hospital beds, lack of adequate diagnostic kits, inadequately trained physicians, and high numbers of deaths, including health professionals, physicians, nurses, and health care workers. Therefore, it is fundamental to pay more attention to the development of medical education, health care programs, fighting poverty, and addressing hunger rather than developing instruments of war, namely bombs, missiles, and nuclear weapons. Furthermore, with limited knowledge about the COVID-19 pandemic and our increasingly interlinked and multifaceted world, what is ultimately and necessarily required are robustness, flexibility, and pliability to deal with unforeseen future situations and dialogs (Luo 2020).

In general, the average worldwide lethality of SARS-CoV-2 is approximately 2.21% (total deaths divided by the total confirmed cases), which is quite a bit lower than SARS (9.6%), and far below MERS-CoV (34%) and Ebola (65.7%). The overall numbers of infections worldwide, specifically in several leading coronavirus countries and authors' countries (Brazil, Germany, Italy, Saudi Arabia; Egypt) are reported in Table 2. The cases are continuing to growth with the release of the 2nd and 3rd waves of the disease and the new Indian strains. USA, India, Brazil, Russia, and France are the leading countries in the incidences and death in Covid-19 cases. The USA is the dominant country in confirmed cases and death, followed by India and Brazil, which showed a high incidence of confirmed cases. From the death cases per million-population point of view, the countries can be ranked

as Italy>USA>Brazil> France>Russia>Germany>Saudi Arabia> India> Egypt. In Saudi Arabia, prevention and control programs for COVID-19 have so far achieved considerable success. As of February 28, 2021, the confirmed number of cases infected with COVID-19, as reported by (19 and 20) in Saudi Arabia, was 362,601 (1.04% of the total population), and recovered patients was 356,387, which represents 98.3 of the confirmed cases. Thus, there have been 6,214 deaths or 179 cases per million of the population (WHO 2020a). In Egypt, India, and Saudi Arabia, the cases are much lower than the global cases, showing 104, 108, and 179 cases per million people, respectively, compared to the average global cases with 230 per million people. Details about total cases and deaths due to COVID-19 around the globe are shown in Table 3.

These discrepancies may be due to several factors, such as early lockdown, decreased trade activities that block transmission pathways, and increasing public awareness of disease control and prevention, which was initiated with early confirmed cases in March 2020. In addition to the use of active and random surveys, other programs, such as working from home, may be implemented as a part of the control and prevention programs when necessary.

In Italy, the situation has been quite different, with 2,067,487 confirmed cases and 73,029 death cases. Several hypotheses have been considered to explain the high mortality rate, as a relatively older average age of the Italian people, more intensive social contacts among children and older people, and underestimating the total number of COVID-19 cases in Italy (Worldmeters 2020). According to Onder et al. (2020) and WHO (2020a), from December 31, 2019 to February 28, 2021 there have been 25,933,806 confirmed COVID-19 cases in Europe. The five countries reporting the most cases are Russia (3,131,550), the United Kingdom (UK) (2,382,869), Italy (2,067,487), Spain (1,893,502), and Germany (1,687,185). In Germany, the number of deaths was 384

Table 2 COVID-19 statistics in several leading coronavirus countries as well as authors' countries Brazil, Germany, Italy, Saudi Arabia and Egypt as of February 28, 2021 compared to the global situation (Onder et al. 2020)

Item	Global average	USA	India	Brazil	Russia	France	Italy	Germany	Saudi Arabia	Egypt
Total confirmed cases	81,159,096	19,346,790	10,266,674	7,561,550	3,131,550	2,530,400	2,067,487	1,687,185	362,601	181,829
Cases per million population	10397	58449	7440	35583	21459	38766	34195	20137	10415	1799
Total recovered	79,367,850	19,011,006	10,122,936	7,368,869	3,075,124	2,466,699	1,994,458	1,655,078	356,387	140,460
Total recovered, % of confirmed cases	97.8	98.3	98.6	97.5	98.2	97.5	96.5	98.1	98.3	77.25
Deaths	1,791,246	335,784	148,738	192,681	56,426	63,701	73,029	32,107	6,214	10,639
Deaths per million population	230	1015	108	906	387	976	1208	384	179	104

Worldwide updated COVID-19 situation till 11 March 2021 (source, European Centre for Disease Prevention and Control: <https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases>)

Table 3 Total cases and deaths due to COVID-19 around the globe

Continent	Total cases	Total deaths	Five countries reporting most cases	Total cases	Five countries reporting most deaths	Total deaths
Africa	3 979 222	105 783	South Africa	1 520 206	South Africa	50 647
			Morocco	486 223	Morocco	8 682
			Tunisia	238 017	Tunisia	8 225
			Egypt	186 503	Egypt	10 995
			Ethiopia	166 138	Algeria	3 013
Asia	22 129 625	365 751	India	11 229 398	India	157 853
			Iran	1 681 682	Iran	60 594
			Indonesia	1 379 662	Indonesia	37 266
			Israel	803 260	Pakistan	13 227
			Iraq	726 548	Iraq	13 572
			United States	28 988 762	United States	524 979
America	52 235 301	1 249 895	Brazil	11 051 665	Brazil	266 398
			Colombia	2 278 861	Colombia	60 598
			Argentina	2 154 694	Argentina	53 121
			Mexico	2 130 477	Mexico	190 923
			Russia	4 333 029	Russia	89 473
Europe	38 756 104	876 229	United Kingdom	4 218 520	United Kingdom	124 501
			France	3 904 233	France	88 600
			Spain	3 160 970	Germany	71 934
			Italy	3 067 486	Italy	99 785
			Australia	29 037	Australia	909
Oceania	59 280	1 228	French Polynesia	18 459	French Polynesia	140
			Guam	7 751	Guam	133
			New Zealand	2 049	New Zealand	26
			Papua New Guinea	1 670	Papua New Guinea	16
Others	705 cases have been reported from an international conveyance in Japan. 6 deaths have been reported from an international conveyance in Japan					

per million, showing the lowest number as of February 28, 2020 (WHO 2020a; Worldmeters 2020).

COVID-19 was first detected in Brazil on February 25, 2020, making it the first Latin American country to report a case of the novel coronavirus (WHO 2020a). Since then, the number of infections has risen drastically; today, Brazil is the Latin American country with the highest number of confirmed COVID-19 cases (COVID-19 situation update worldwide 2020; Montanez 2020a), with over 7,561,550 (Onder et al. 2020). The first death due to this disease was registered on March 17, 2020 (COVID-19 situation update worldwide 2020), and approximately 3 months later, the number of fatalities surpassed 50,617, with 594,108 recoveries (Montanez 2020b; Scalzaretto 2020). As of December 31, 2020, the number of deaths reached 192,681 cases (Onder et al. 2020, showing cumulative increase over time. The number of cases and deaths has probably been underestimated.

An experiment by the Imperial College (London, UK) about the spread rate of COVID-19 in 48 countries showed

Brazil at the top. Large cities such as São Paulo and Rio de Janeiro are currently the top hotspots. Still, there are signs that infections are spreading into minor cities with insufficient numbers of ventilators and intensive care beds (Montanez 2020b; Scalzaretto 2020). While the World Health Organization (WHO) has suspended chloroquine trials in Brazil, the Health Ministry has issued a reference for the public health system to use the medicine in COVID-19 patients from the very early phases of the disease onward. This directive is contrary to recommendations from medical associations (Ficetola and Rubolini 2020; Montanez 2020b; Scalzaretto 2020).

The influence of the COVID-19 pandemic on the environment

The environmental effects of the COVID-19 pandemic have received relatively little attention. Still, this growing interest after the outbreak of 2nd and 3rd waves of COVID-19 and

recently outbreak in India (WHO 2020b): The positive and negative impact of COVID-19 on the total environment, ecological sustainability, and earth systems have not yet been discussed. This pandemic has led to unexpected consequences, such as forced reductions in demands for industries, transportation systems, and all businesses due to public confinement; these declines have caused carbon emissions to drop. For example, in New York, air pollution has fallen by almost 50%. In China, emissions have shown a 25% decrease, and in Europe, nitrogen dioxide emissions dropped over Italy, Spain, and the UK (Ficetola and Rubolini 2020). Other positive influences include clear skies, wild animals roaming streets, clear water in the canals of Venice, Italy, and decreasing pollution elsewhere, particularly industrial areas (Capovilla 2020; Corrigan 2020; Ruiz 2020).

One of the other effects of the COVID-19 pandemic has been a drop in coal and oil consumption worldwide, a phenomenon that has contributed to a large-scale decline in air pollution (IEA 2020; Saadat et al. 2020). While this reduction is essential for environmental health in general, it also benefits individuals who contract COVID-19. Indeed, areas with higher air pollution have presented markedly higher mortality rates from COVID-19 (BBC News 2020).

The repeal of single-use plastic bans, a phenomenon that has translated into a heightened demand for bottled water, personal protective equipment (e.g., masks for individuals who must venture into public), plastic bags, and packaging (Tenenbaum 2020). Medical waste and the trash from personal protective equipment, such as gloves and masks, are also on the rise (Zambrano-Monserrate et al. 2020). Some fast food and retail chains have banned the use of reusable cups and food containers (Peszkó 2020). Thus, the oil industries have produced more plastics to mitigate financial losses (Van der Made 2020). The generation of inorganic and organic waste has been increased due to the consumer's demand for online shopping and home delivery, and trash recycling has been reduced in many countries because of the concerns about the hazard of SARS-CoV-2 spreading in recycling centers (Zambrano-Monserrate et al. 2020).

It is possible that a virus can persist in drinking water, but COVID-19 has not been observed in drinking water supplies; based on present data, the hazard to water supplies is low. However, according to the WHO (2020b), studies of surrogate coronaviruses have indicated that the virus could remain infectious in water contaminated with feces for days to weeks. The influence of the COVID-19 pandemic on the environment is illustrated in Fig. 2.

The impact of the COVID-19 pandemic on the poultry economy

Poultry producers have been affected by the COVID-19 pandemic, but the influences vary substantially from one area to

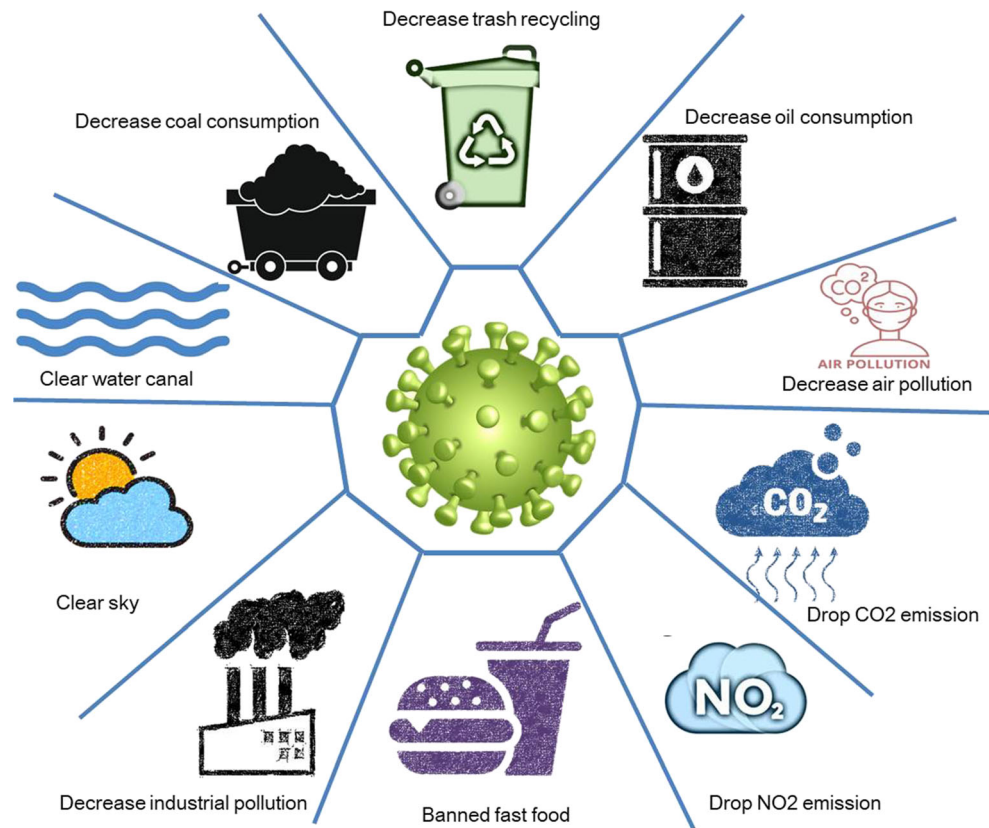
another. Indeed, each country differs concerning how the disease progresses. In a study performed in England and Spain (Clements 2020a), producers indicated a recent increase in product demands, with 17.4% mentioning that the rise had been marked. Nevertheless, this situation has not been universal because 37% stated that requests had dropped, with 28% indicating that the reduction had been considerable. In addition, there has been increased acceptance to perform work over the Internet in favor of live production; 17% of respondents stated that farms had used fewer laborers. Over 14% of respondents revealed that the pandemic had rejuvenated a switch to fully automatic slaughtering plants. According to 8% of respondents, the issues caused by the COVID-19 pandemic have encouraged them to hasten their plans for automatization (Clements 2020b).

In poultry, significant efforts have been made to restrict the avian infectious bronchitis virus (IBV) which is part of the genus *Gammacoronavirus*; it is not transmitted to humans. In addition, SARS-CoV and COVID-19 are from the same group and use the same ACE2 host cell receptor, and thus SARS-CoV does not infect or cause disease in poultry. This finding suggests that poultry are unlikely to serve as a reservoir for SARS coronaviruses (Hafez 2010).

The immune system of human and avian species varies greatly and thus vaccination protocols, the appropriate vaccine virus serotype, and applications are different (Hafez 2005; Torremorell and Bender 2020). The production of human vaccines is essential to safety and wellbeing. Poultry production has not been at risk to the global spread of SARS-CoV (Hafez 2010). Recent data have indicated that it is not associated with poultry or poultry products, and chickens are not susceptible to intranasal infection by the virus (Friedrich-Loeffler-Institut 2020a, 2020b; Schlottau et al. 2020). All swabs and organ samples, and contact birds remained negative for COVID-19 RNA, while infected fruit bats and ferrets were susceptible to the infection; the symptoms were stronger in ferrets than fruit bats (Friedrich-Loeffler-Institut 2020a). Additionally, Shi et al. (2020) stated that cats and ferrets are highly susceptible to COVID-19, dogs have a low risk, and livestock, including chickens, pigs, and ducks, are not vulnerable to the virus. Improved poultry resistance to COVID-19 based on enhanced hygiene, biosecurity, and immunity would provide additional benefits for producers (Hafez 2010). It is recognized that vitamins C, B6, and E and minerals such as zinc and magnesium have played and will continue to play vital roles in sustaining immune function during the COVID-19 pandemic (CSIS 2020).

The economic pressures induced by the COVID-19 pandemic can be seen from different points of view. For example, the pandemic has increased unemployment. Restaurants chains and retailers are trying to fulfill their obligations to their employees while attempting to keep their businesses solvent (Rahman et al. 2020). In addition, the conditions in poultry

Fig. 2 The influence of the COVID-19 pandemic on the environment



processing plants exacerbate the risks due to the proximity on the line, cold and humidity. Most of the workers do not have access to paid sick time or adequate health care, and because of the low wages, they have limited reserves to enable them to leave steady employment (CNN 2020).

The COVID-19 pandemic has had a huge impact on farmers and food suppliers in several ways. First, there are not enough people in slaughterhouses to process the poultry, and farmers are being forced to euthanize their stock. Recently, about 2 million chickens in Delaware and Maryland were humanely killed because processing plants are short-staffed (CNN 2020). Nonetheless, poultry is not affected by COVID-19 (Berkhout 2020) and do not transfer it to humans, and the animal feed industry has been influenced by the cessation of slaughterhouses (Brown and Fu 2020), restaurants, and fast-food chains around the world to avoid contamination among workers and consumers. The closure of processing facilities may ultimately cause the depopulation of millions of animals (chickens, pigs, and cattle) (McDougal 2020). Third, biosecurity is the main line of defense that each breeder, hatchery, and poultry owner has against diseases. Improvements in biosecurity practices will help workers remain safe. Personal and facility cleanliness and avoiding transporting contaminated

material such as chicken manure are essential (Benjamin 2020; Montanez 2020a).

Meat and eggs

Workers in meat and poultry slaughterhouses have had to keep working during the COVID-19 pandemic. Therefore, their work situations in the slaughterhouses and zones, where they must remain near coworkers and directors, may considerably increase their possible exposure risk to COVID-19. In addition, workers in meat and poultry slaughterhouses may be infected through respiratory droplets in the air and/or from touching dirty surfaces or objects such as workstations, break room tables, or tools (CDC 2019).

Despite the COVID-19 pandemic, global food prices have remained stable. According to the Center for Strategic International Studies (CSIS 2020; Galimberti 2020), global prices only dropped 4.3% from February to March 2020 due to the demand for contractions amid lockdowns and quarantines (Welshans 2020). The need for poultry meat and eggs has increased at the retail level due to confinement. The retail market for poultry meat was amplified by nearly 75% during the panic buying phase, which took place in the first few weeks of the crisis; however, this demand has returned to normal levels. Demand for eggs has increased by 20–35% in England (NFU 2020).

The European Poultry Producers Association (AVEC) has observed a 10–30% reduction in broiler slaughtering in European Union (EU) member states (AVEC 2020). Furthermore, poultry prices have declined around 20% since the beginning of March 2020, reversing the trend in EU poultry meat prices from December 2019 to the beginning of March 2020 (ANCO 2020). This evolving EU market situation is being compounded by the closure of export markets for poultry producers in EU member states (AVEC 2020). Poland is one of the countries suffering the most. In the United States of America (USA), which exports a lot of chicken meat, the global export estimates for the chicken meat market have been cut due to emerging risks from the COVID-19 spread (USDA 2020). China's agriculture ministry has stated that the supply of chicken and egg losses of US\$14.3 million (Clements 2020a, 2020b).

Egg prices have increased dramatically during the lockdown as consumers have started to change their behaviors and habits. Consumers had stockpiled necessary food items, including milk, eggs, and bread, to prepare for potential quarantines. Still, as lockdowns were introduced and people had to stay at home, actual consumption increased. People no longer eat out, so the demand for eggs is shifting from the foodservice sector to the retail channel, as consumers are cooking more meals at home (ANCO 2020). Egg consumption has also increased to replace more expensive protein forms in households that are seeing a decline in their income because of COVID-19-related job losses.

Hatcheries

The impact of the pandemic on poultry hatcheries has also been strong. The lockdown and the consequent limitation to the international poultry market have decreased the request for eggs to be used for incubation. Some governments have banned the import of poultry meat mainly to protect their internal market; this action has reduced general chicken placements by 15–25% (De Lange 2020). In Italy, several hatcheries have been forced to euthanize chickens and then reduce the number of incubated eggs (Tuttoggi 2020). If eggs are regularly sent to a hatchery, one way to reduce the number of incubated eggs is to prolong their storage at low temperatures. However, in the long term, this approach can harm hatchability and chick quality. Consequently, it might be better to reduce the number of eggs that enter hatchery, an action that is possible by culling old flocks and inducing forced molting in young flocks (De Lange 2020). Nevertheless, this approach reduces the cost of 1-day-old chickens: in Italy, the price has dropped by 35%.

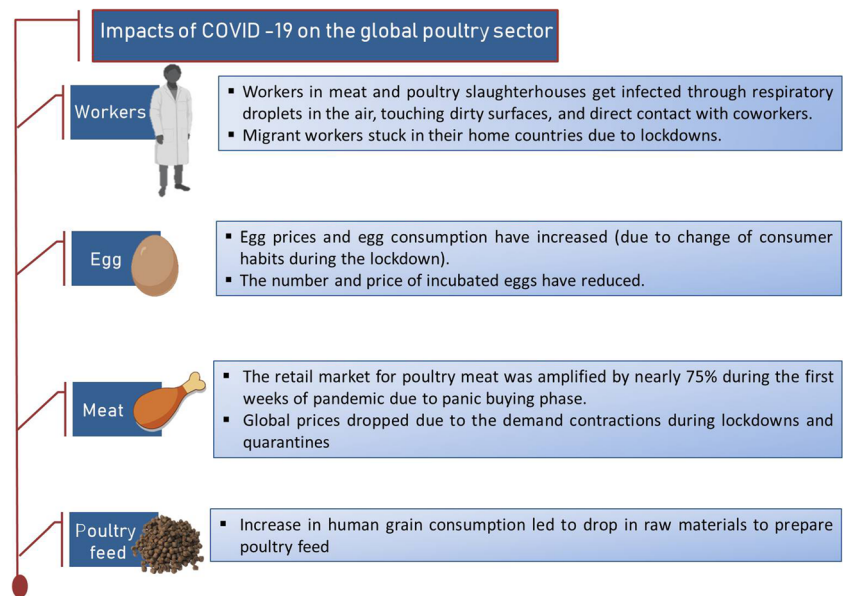
Feed and food security

The availability of raw materials to prepare poultry feed has been strongly reduced by the COVID-19 pandemic in almost all countries, although the reasons are variable. The main ingredients in poultry feeds are corn and soybeans. The primary producers of corn are the USA, China, Brazil, and Argentina; the same countries also produce the most soy, albeit in a different order: the USA, Brazil, Argentina, and China. Thus, many countries around the world, dependent on imports for these raw materials, have had substantial problems in procuring the ingredients to prepare poultry feeds. In addition, about 65% of the net annual production of wheat, corn, and soybeans is used in the feed industry for farm animals, while the remaining 35% is used to meet human needs (All About Feed 2020a, 2020b). Thus, even though there has been an increase in grain consumption for human use, it has been unable to compensate for the losses tied to lowering animal feed production use (All About Feed 2020b; Berkhout 2020).

Furthermore, some agricultural sector activities are connected to migrant workers, who are stuck in their home countries due to lockdowns. Hence, the feed industries have lost a significant portion of their workforce (All About Feed 2020a). These factors have significantly impacted the global poultry sector (The Poultry Site 2020; Poudel et al. 2020).

Another possible risk in the next future is the concern about food safety and security. Even though it has been well established that poultry does not host COVID-19 and thus cannot transmit it to humans (Shi et al. 2020), most concerns are about intensive animal production that could amplify the threats of disease spread and emergence. The likelihood of outbreaks of high-impact animal diseases is elevated by the quarantine of many animals in limited zones, narrowed genetic diversity, and thus the increasing turnover of animals (CDC 2019; Tomley and Shirley 2009). Currently, there is no evidence that COVID-19 can be transmitted by food; however, the transmission is possible if an infected person touches food and another one, within a short time, touches the same food and then her or his mouth or eyes (CDC 2019; BfR 2020). Furthermore, the persistence of the virus at frozen temperatures has not been well described (CDC 2019), but other coronaviruses (e.g., MERS and SARS-CoV-1) can continue to pose a risk for up to 2 years in a frozen state (Hafez and Attia 2020). Thus, this pandemic must push poultry production to achieve several goals. First, the industry must move toward intensive production sustainability, especially by using modern technologies (precision poultry farming) or increasing extensive meat and egg production techniques. Second, the health and immune status of farmed poultry must be improved to increase their disease resistance. Third, feeding

Fig. 3 Impacts of COVID -19 on the global poultry sector



strategies must improve the content of poultry products of bioactive compounds that can stimulate the human immune defense (Parrish et al. 2008). Finally, high hygienic standards should be ensured through the entire food chain, from farm to fork. Impacts of COVID -19 on the global poultry sector is briefed in Fig. 3.

International poultry trade

The COVID pandemic might also substantially impact the international poultry trade over the next several months. For example, in the EU, many poultry meat (around 850,000 tons) is imported from developing countries, mainly Brazil, Thailand, and Ukraine, every year. Those imports are mainly destined for the foodservice market. However, to not lose their rights in the EU Tariff Rate Quota system, these countries continue to export poultry meat, even though the EU market does not demand it at the moment. Thus the meat is stored until the HORECA (hotel, restaurant, café) chains reopen. This action will result in a significant oversupply of poultry meat on the EU market in the weeks and months to come, with dangerous consequences on the price and quality of the products and future trade. On top of that, avian influenza outbreaks in Eastern Europe continue to hit hard in some countries (Poland, Hungary, and Romania). This issue has resulted in the closure of export markets in developing countries, driving this meat intended for exports back on the EU market and adding to the crisis (AVEC 2020; Parrish et al. 2008).

In conclusion, the possibility of poultry being infected by COVID-19 is remote, given that there is only a 60% genetic similarity between humans and chickens (Warren and Sawyer 2019). However, proper handling of animal products and safety measures should be taken during

marketing and handling as a general role for all food supplies. Moreover, the possibility of the existence of COVID-19 in feedstuff and feed is not likely due to high temperature and pressure during feed processing. In addition, the impact of the COVID-19 pandemic on the various poultry sectors such as slaughterhouses, broiler industry, table egg industry, hatcheries, and international poultry trade were favorable for the egg industry and adverse for the other sectors. Therefore, biosecurity, hygiene, and immunity have been and will remain the front line of defense during the COVID-19 pandemic. Therefore, developing and enhancing the current biosecurity measurements is essential to face the new emergence of diseases and overcome the unseen enemy after spreading the 2nd and the ongoing 3rd wave of COVID-19.

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Decalarations

Ethics statement As a review, this section may not be applicable.

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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