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Introduction

COVID-19 pandemic—how and why animal production suffers?

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Key words: coronavirus, livestock, SARS-CoV-2

Nearly a year ago, a novel coronavirus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), named COVID-19, emerged on the world stage. In the ensuing months (to November 2020), the COVID-19 virus has infected 48,947,235 people and resulted in 1,237,417 human deaths (Johns Hopkins University of Medicine Corona Virus Resource Center, 2020). As country by country has succumbed to the pandemic, economic effects have been devastating. Job losses, shortages in production, and lockdowns have resulted in a severe economic challenge for most governments. The International Money Fund (2020) estimated that, by May 2020, government interventions to fight COVID-19 have exceeded $9 trillion dollars (both for fiscal support and loans). One of the critical effects of the pandemic has been a negative impact on agricultural food production and distribution. This issue of Animal Frontiers will investigate the problems of pandemics and, specifically, COVID-19 on global animal agriculture.

Global animal pandemics have been a frequent occurrence and have yielded some notable strategy developments, but there is much remaining to be learned and applied. Perhaps the experience gained from the previous pandemics (e.g., the SARS-Pandemic 2002/2003 and the MERS epidemic 2012), as well as the current pandemic can serve as models to assist in the development of approaches to handle future pandemics. Shi et al. (2021) have examined the impacts of various swine disease pandemics and discuss the methods employed in which government, industry, veterinarians, and scientists have worked together to prevent and manage animal pandemics. Furthermore, the appearance of the COVID-19 pandemic in addition to the existing animal pandemics in some countries has further exacerbated the impacts of COVID-19 on animal agriculture.

As the COVID-19 pandemic moved across the planet, there were differing effects of the disease on different countries and industries that, in turn, were often managed in different ways. Pig production in Europe was impacted by two concurrent pandemics, African Swine Fever and COVID-19. The negative effects were associated with decreased demand for pork in Europe and an inability to export products to other countries. The reduced demand for products resulted in an elevated pig population on farms in Europe and elsewhere (Millet et al., 2021). In Australia, the panic buying of meat products by consumers and the COVID-19 infections in processing plant workers slowed processing capacity. In addition, there was a decreased demand for meat products from restaurants and the simultaneous closure of national borders that reduced the export of products. These events created a cumulative effect to increase on-farm animal populations and increased costs to farmers (D’Souza and Dunshea, 2021). In the United States, a similar consequence to the COVID-19 pandemic was observed. The large increase in farm swine numbers presented a challenge to the industry (Tokach et al., 2021). In an effort to avoid mass euthanasia of excess animals, producers, industry, and scientists worked together to develop management and nutritional approaches to delay the entry of swine to processing plants to wait until market conditions recovered.

Along with most other countries, Argentina faced the pandemic by ordering a strict nationwide quarantine and severe restrictions on human contact as a means to prevent the spread of the virus. Argentina has had a little disruption in animal agriculture, in part because of the ability to move beef products from traditional markets to other countries (Arelovich, 2021). However, the economic conditions in Argentina have worsened and this may yet have a consequence for animal agriculture. Similar to many countries, the United States faced an abrupt decrease in the foodservice sector, coupled with overpurchase of goods by concerned consumers and a subsequent disruption in supply chains that were unable to respond quickly to the crisis (Peel, 2021) (Figure 1). The effect of COVID-19 infections in the workforce served to reduce cattle processing leading to more shortages for consumers (Peel, 2021). COVID-19 also impacted economics in China. China implemented travel restrictions, which had serious effects on the normal supply of

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Materials, sales, and transportation and eventually caused disruptions in supply chains in and outside of China (Ding et al., 2021). The prices for livestock and meat rose by 80.8% and pork prices rose by 122.5%. In addition, the global effects of COVID-19 produced severe disruptions to the normal import and export of animal feed and products. Similarly in Ghana, COVID-19 resulted in severe disruptions in importing protein, as well as effects on feeding, management, and disease control (Obese et al., 2021). One consequence was a shortage of feed ingredients for animals. This has all led to an increase in prices for meat and other products in Ghana and a lowered profit margin for farmers (Obese et al., 2021). Although milk and cattle processing were unaffected in the Czech Republic, the closure of farmers’ markets, restaurants, and schools, like in many other European countries, have impacts on foodstuff and cattle prices (Brzakova et al., 2021). Moreover, the quarantine has reduced available farm labor producing additional complications. The result is a need for government supports for farmers and slaughterhouses.

Investigation of the effects of the pandemic on specific segments of the animal industry has revealed a number of consequences of the COVID-19 pandemic. The breeding industry faces problems from decreased breeding records and reductions in government supports (David, 2021). In the genetics area, the effects are not yet known (Gandini and Hiemstra, 2021) but, clearly, in both breeding and genetics, there were disruptions in education, mobility, restrictions of movement of goods and supplies across borders, disruptions in international trade, and the need to work from home and away from critical interactions with colleagues (Semianer and Reimer, 2021). Likewise, the pandemic had a little direct effect on camel production, though secondary effects, such as workers becoming infected or shortages of labor across national borders were certainly an issue (Nagy et al., 2021).

Although all countries have experienced significant illness and death of their citizens, market disruptions, business

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**Figure 1.** Meat section of a local grocery store showing the lack of meat for sale, March 14, 2020.

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closures, and job losses, not all countries have faced the same consequences to animal agriculture. In addition to the direct impacts on animal production and industries, there were also consequences, such as university closures, reduced research, funding issues, scientific society meetings canceled, etc. The articles in this issue of *Animal Frontiers* both describe the similarities between countries’ responses to COVID-19 and highlight some differences in strategies developed by different countries to deal with the pandemic, particularly in regard to animal agriculture. As this issue is compiled, some countries are emerging from the pandemic, while others are entering a second wave of infections. It is hoped that these articles may provide an accounting of the impacts on animal agriculture, as well as suggest strategies to employ in future epidemics.

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Feature Article

Of pigs and men: the best-laid plans for prevention and control of swine fevers

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Introduction

John Steinbeck drew the title of his novel “Of Mice and Men” from a line in a Robert Burns poem “To a mouse”: “The best-laid plans of mice and men/Go often awry.” Unlike John Steinbeck who used the title to mirror the characters who were struggling during the Great Depression to the mouse whose nest was accidentally destroyed by the poet (Burns 1785), we chose this line to emphasize that the best-laid plan can go wrong in infectious disease control and prevention. Here, we will discuss the contributing factors behind the global successes and failures in the prevention and control of swine fevers—classical swine fever (CSF) and African swine fever (ASF).

Swine Fevers (Classical Swine Fever and African Swine Fever) are not Swine Flu

Swine fevers and swine flu are different diseases caused by completely different viruses. However, swine fevers and swine flu are often regarded as the same disease by the public. This is in part due to the 2009 H1N1 influenza pandemic where the human influenza virus contained genetic segments from the swine influenza virus (Neumann et al., 2009). Swine flu and human flu are caused by negative-strand RNA viruses (influenza A virus). In contrast, CSF and African swine fever are caused by a small positive-strand RNA virus (CSF virus, CSFV) and a large double-strand DNA virus (ASF virus, ASFV), respectively. To date, no evidence suggests that ASFV and CSFV can infect humans, even though they often cause lethal infection in pigs of all ages. Various inactivated swine flu vaccines with different levels of efficacy are used on swine farms all over the world. On the other hand, safe and efficacious modified live virus (MLV) vaccines (such as the C-strain vaccine) have contributed to the successful control of CSF in many countries (Luo et al., 2014; Blome et al., 2017). But there is no safe and efficacious vaccine for ASF.

Vaccines and Diagnostics: Technological Tools for Infectious Disease Control and Prevention

Vaccines are the most cost-effective tools for animal infectious disease control and prevention in disease-endemic regions.
Based on the nature and/or production method of antigens, vaccines can be classified into five different categories: 1) tissue-derived vaccines (inactivated or live) with little or no antigen purification; 2) inactivated vaccines in which pathogens are inactivated by the chemical methods after they are processed from cell culture or fermentation systems; 3) MLV vaccines with naturally or genetically modified attenuated live microbes; 4) subunit vaccines in which the antigens are purified from native pathogen cultures or recombinant expression systems; and 5) nucleotide (DNA and RNA) vaccines in which partial genetic segments from the pathogens are used to directly induce antigen expression in the immunized animal or incorporated into microbial vectors for antigen expression and delivery.

The selection of a certain type of vaccine for field use in animal disease control and prevention should be based on its safety and efficacy profile and cost-effective analysis, not how the vaccine is produced. The first three categories (tissue-derived, inactivated, and MLV) of vaccines have been used in the field since the late 1800s and the last two categories of vaccines (subunit and nucleotide) were developed with new technologies in the last few decades (McVey and Shi, 2010). For many infectious diseases, one or more of the five types of vaccines have been developed with robust and efficient manufacturing processes. Therefore, safe and efficacious vaccines are affordable and available for use in various animal populations.

In addition to vaccines, diagnostics are also essential tools for animal disease control and prevention. For antigen/pathogen detection, antigen capture antibody enzyme-linked immunosorbent assay (ELISA), real-time quantitative polymerase chain reaction (PCR), lateral flow assay (LFA), and a fluorescent antibody test (FAT) are routinely used in a laboratory setting. Various forms (indirect, Sandwich, and competitive) of ELISA have been developed to detect antigen/pathogen-specific antibodies in animals after vaccination or infection. Virus neutralization assays (and surrogate assays like hemagglutination inhibition) are still very useful for characterizing antibody responses.

Diagnostics that can differentiate infected from vaccinated animals (DIVA) are crucial tools for animal disease control and eradication. DIVA assays are extremely useful for the control of a newly emerging infectious disease or a foreign animal disease as they can enable the “vaccinate-to-live” strategy by which vaccinated animals can be raised and processed for food production and consumption and/or international trade. Genetic DIVA assays are designed to identify the genetic difference between a vaccine antigen and a virulent field pathogen. Serological DIVA assays target the difference in host immune response to the vaccine strain (after vaccination) and virulent field strain (after infection).

**Classical Swine Fever/Hog Cholera**

*What is classical swine fever?*

Pigs with CSF, also known as hog cholera, have clinical signs such as high fever, loss of appetite, lethargy, and high mortality rate. CSF/hog cholera was first reported in the Ohio river valley in the 1830s, and it still causes significant economic losses to the swine industry in Asia and presents a significant agricultural security threat to CSF-free countries such as the United States. CSF is probably one of the earliest swine viral diseases identified by animal disease researchers in the early 20th century. It was the United States Department of Agriculture (USDA) scientists Emil Alexander de Schweinitz and Marion Dorset who first demonstrated in 1903 that the highly contagious hog cholera was caused by a virus (not a bacterium) and hogs that survived from the infection were immune from future infection (Lofflin, 2009).

**CSF control and its impact on animal health regulation in the United States**

Hog cholera/CSF caused devastating losses to American swine producers since the late 1800s. According to USDA’s historical data, “Outbreaks in 1886, 1887, and 1896 each killed more than 13% of the Nation’s hogs; more than 10% died during the 1913 outbreak. The disease was still costing producers $50 million a year in the early 1960’s” (USDA 2019). Around the beginning of the 20th century, smoke rising aloft from the burning of dead pigs on farms across the prairies of the Midwest was the heart-breaking evidence of CSF destruction. It is not an overstatement that CSF was the most destructive disease of swine in the United States for more than a century (1830 to 1970).

Although the eradication of CSF from the United States in 1978 was a great success story, one must remember that many important pieces of research were carried out before the 17-yr effort (1961 to 1978), with the support from the pork industry as well as State and Federal governments. After the initial federal ban (1963) on interstate shipment of virulent CSF virus or of feeder pigs and breeding stock vaccinated with CSF vaccines, use of MLV vaccines and inactivated vaccines continued until banned in 1969 (Lofflin, 2009; USDA, 2019). Most of the control policies were developed based on the early CSF research findings of USDA scientists and veterinarians. Injection of hyperimmune anti-CSF serum plus CSF virus was used as a routine CSF control method for decades until CSF vaccines with reasonable efficacy were developed in the 1950s. Large scale field trials involving thousands of swine farms were conducted to evaluate the field efficacy of anti-CSF biologies (vaccines and antiserum products). The plans and policies for CSF eradication in the United States were developed based on the knowledge regarding how the CSFV was transmitted. Other significant contributions included clinical trials with anti-hog cholera serum products, various inactivated CSF vaccines and MLV vaccines, and the development of fast and accurate diagnostic methods for CSF.

Actions and governmental regulations associated with CSF control in the United States played an important role in the development of animal health policies in general. Since the discovery that pigs injected with hyperimmune serum could be protected from CSF virus challenge in 1907 (USDA, 2019),...
anti-hog cholera serum production and processing plants mushroomed in Kansas City and the rest of the Midwest (Lofflin, 2009). Interestingly, pigs were not only an important food source for ordinary Americans 100 yr ago, they were also very important to the politicians. Then-President Woodrow Wilson attended National Swine Show (Figure 1A), and his Secretary of the U.S. Food Administration Herbert Hoover believed that food would help the U.S. win World War I and started a national campaign for greater swine production (Nebraska, 2020). He said in 1917: “We need a ‘keep-a-pig’ movement in this country, and a properly cared for pig is no more unsanitary than a dog. Every pound of fat is as sure of service as every bullet, and every hog is of greater value to the winning of this war than a shell.”

Given the social and economic importance of pork production in the United States at the beginning of the 20th century, perhaps it was not a surprise that one of the earliest anti-hog cholera serum plants in the Kansas City area was created by Mason Peters, a lawyer and former U.S. congressman in Kansas (Kansas, 1914). He saw the potential of this biological product (Figure 1B). Mason Peters “was one of the most active in the original research work for the practical use of this remedy to combat hog cholera.” Equally amazing is that an academic institution like Kansas State Agricultural College also owned and operated an anti-hog cholera serum plant from 1908 to 1948 (Dykstra, 1952). The transgenerational significance of that serum plant location is obvious as the “Serum Plant Road” on Kansas State University campus today leads to USDA’s National Bio and Agro-defense Facility (NBAF) in which research related to CSF will continue (Montgomery, 2019).

Furthermore, the Virus-Serum-Toxin Act, which enacted federal regulation of veterinary biologics in 1913, was passed largely because of public concerns over the safety and efficacy of veterinary vaccines from Europe and hog cholera products being produced and marketed across the country (USDA, 2020). The new law required the USDA to ensure that veterinary biologics (vaccines, bacterins, antisera, and similar products) sold in the United States are pure, safe, potent, and efficacious.

The successful eradication of CSF in the United States was the result of a determined and comprehensive approach including 1) more than 60 yr of scientific research and development on CSF virus and the disease management tools (antiserum products, vaccines, and diagnostics); 2) science-based regulatory decisions from all levels of government; and 3) the public and private partnership of all stakeholders related to the swine industry. We can summarize the best-laid plan in CSF prevention and control (the U.S. story) as:

1. Know your enemy (the disease and pathogen) through supporting innovative research.
2. Develop and implement science-based governmental policies at both state and federal levels.

Figure 1. Pigs were important animals to the President and other politicians 100 yr ago. Shown are two advertisements in The Poland China Journal (January 10, 1917) that depicted the relationship between pigs and politicians in the early 20th century. (A) President Woodrow Wilson at the National Swine Show in 1916. (B) Former U.S. Congressman Mason S. Peters and his six sons formed the National Serum Company with seven serum plants around Kansas City.
3. Ensure the cooperation of all stakeholders of the pork industry including pig producers, animal health companies, veterinarians, and regulatory agencies.

**Why CSF is still endemic in Asia and how can it be eradicated in the future?**

It has been clearly demonstrated that CSF can be eradicated with less ideal tools (vaccines and diagnostics) in a country with large and intensive swine production systems. Nevertheless, CSF remains one of the most devastating diseases of swine in many other large pork-producing countries such as China, Vietnam, Thailand, Japan, South Korea, and the Philippines. This phenomenon is intriguing as these countries have produced or have had access to the C-strain CSF vaccines that are affordable, available, safe, and efficacious against all known genotypes of the CSF virus.

With the development of better vaccines and faster and more accurate diagnostic assays over the last 20 yr, CSF endemic countries have more and superior technological tools for CSF control and eradication than the United States did in 1960 to 1978. Subunit vaccines based on CSFV structural protein E2 have been marketed since the 1990s and newer versions of E2 subunit vaccines have also been now manufactured and marketed by different companies in Asia (Blome et al., 2017; Gong et al., 2019). One of the distinct advantages of E2 subunit vaccines is their intrinsic capability of differentiating vaccinated from infected animals in which infected pigs would produce antibodies against other CSFV structural proteins such as E\textsuperscript{NS} (Madera et al., 2016; Wang et al., 2020).

The C-strain MLV vaccine is an attenuated live virus and can provide complete protection against wild-type CSFV with the onset of effective immunity just 5 d after vaccination (Graham et al., 2012). The only drawback of this vaccine is that it is difficult to differentiate pigs vaccinated with C-strain from pigs infected with field strains of CSFV. This shortcoming may be overcome soon because a C-strain CSFV E\textsuperscript{NS}-specific monoclonal antibody (mAb) has been recently generated by our group (Wang et al., 2020). A cELISA is being developed to differentiate pigs vaccinated with the C-strain vaccine from pigs infected with wild-type CSFV or unvaccinated pigs, based on the observation that the latter two groups of pigs do not produce antibodies that can compete with this C-strain E\textsuperscript{NS}-specific mAb. This is an example of a positive DIVA marker.

With the help and guidance from the Food and Agriculture Organization (FAO) and the World Animal Health Organization (OIE), many if not all CSF endemic countries in Asia have developed national policies for CSF control and eradication (China, 2012; FAO and OIE, 2014). Thus, it is not the lack of technological tools and/or government policies that have hindered the eradication of CSF in these CSF endemic countries. Because the C-strain vaccine can be cost-effectively produced and marketed or freely distributed to swine producers in China and other Asian countries, lack of resources (vaccines) does not seem to be the major constraint to control CSF, which is often the case in tackling a major disease epidemic such as the COVID-19 (McMahon et al., 2020).

There is no doubt that CSF outbreaks can be effectively controlled by routine and high coverage vaccination with the C-strain vaccine, but the success of this approach requires government support in providing sufficient and qualified field veterinarians and establishing an effective disease diagnostic and epidemic information network. More importantly, the government at all levels (central and local) should provide sufficient technical support and financial compensation to swine producers whose pigs might have to be culled due to localized CSF outbreaks. Furthermore, government, industry associations, and the media can also play an important role in raising public awareness that CSF can and should be eradicated soon. Without an effective eradication plan, CSF will continue to negatively affect general consumers due to pork price increase and overall inflation when pork production is disrupted by disease outbreaks.

Thus, the eventual eradication of CSF from CSF endemic countries may depend on whether and when all stakeholders of the pork industry can form a real partnership and work cooperatively for the same goal. To make this partnership effective, pork producers and animal health companies also must equally contribute to control and eradication efforts. These efforts will include strict compliance with government regulations on vaccination and animal movement; eliminate production, marketing, and use of CSF vaccines when a vaccination ban is placed in effect in the final stages of a CSF eradication plan.

**African Swine Fever**

**What is African swine fever?**

Although CSF and ASF share similar clinical signs such as high fever, loss of appetite, lethargy, and high mortality rate, these two diseases are caused by two distinct and unrelated viruses. The CSFV is a small (12.3 kb) RNA virus with only four structural proteins, while the ASFV is a large DNA virus (170 to 190 kb genome) with more than 50 structural proteins (Schulz et al., 2017). Since ASF was first reported in Kenya, ASF research has been the focus for only a few laboratories in Europe after its first emergence in the 1960s. The re-emergence of ASF in east European counties since 2007 sparked more interest in ASF research (Borca et al., 2016), the urgency for and the intensity of ASF research are increased significantly worldwide only after the ASF outbreak was first reported in China in 2018 (Zhou et al., 2018). Since then, ASF outbreaks have occurred in many other pork producing countries in Asia including Vietnam, South Korea, Cambodia, Laos, the Philippines, and Indonesia (Figure 2). More recently, ASFV has been detected in wild boars in Belgium and Germany (USDA, 2020). Because there are significant knowledge gaps about ASVF and ASFV–host interactions, it is no surprise that safe and efficacious commercial ASF vaccines have yet to be developed.
Was an ASF outbreak in China/Asia inevitable?

Three conditions might explain why ASF research in China was not a priority before 2018: 1) limited preparations for ASF research—there were very limited high containment (biosafety level 3) research facilities in China that were available for animal studies on foreign animal diseases such as ASF; 2) false security—CSF and foot and mouth disease (FMD), two highly contagious and devastating swine viral diseases are largely controlled in China via mass vaccination; and 3) false optimism—because ASF has been largely eradicated in Europe in the 1990s, it was not hard to imagine that ASF could be controlled quickly by culling pigs infected with ASF virus. Consequently, research on ASF as a foreign animal disease was not carried out as a priority in China to develop the tools essential for the prevention and control of ASF.

Before the rapid spread of ASF in China that was first reported in August 2018, policymakers in China were aware of the serious threat of ASF and had implemented an ASF-specific national policy—“Technical Specification for Prevention and Treatment of African Swine Fever” in 2015 (China, 2015). Based on online public reports (https://finance.huanqiu.com/article/9CaKnJY1uN and http://www.cpwnews.com/content-23-9199-1.html), the General Administration of Customs of China (GACC) and the Ministry of Agriculture (MOA) organized several ASF-specific emergency response drills in northern provinces and cities including Inner Mongolia, Hebei, Beijing, and Tianjin in 2016 and 2017. The risk of importing transboundary animal diseases associated with the “One Belt One Road” Initiative (BRI) was highlighted as the rationale behind these exercises.

Although no direct evidence that ASFVs were introduced to China via commercial activities of the BRI, there are two intriguing relevant observations: 1) the first ASF outbreak was likely started in mid-June (confirmed on August 2, 2018) on a swine farm in the outskirts of Shenyang (Zhou et al., 2018), the provincial capital of Liaoning Province; and 2) on June 11, 2018, the first convoy of six trucks and two buses supplying fruits and vegetables returned from a 25-d round trip from Dalian, China to Novosibirsk, Russia. Shenyang is 400 km from Dalian and a likely stop on the road from Novosibirsk to Dalian (https://www.sohu.com/a/238415268_267831?f=index_pagerecom_417). However, what happened next was puzzling: the second ASF case was confirmed 12 d later in Zhengzhou (http://www.xinhuanet.com/fortune/2018-08/16/c_112321884.htm), which is 1300 km south of Shenyang.

It is even more troubling and puzzling that tens of millions of pigs were lost due to ASF outbreaks all over China and some...
of its neighboring countries in less than 1 yr. These losses probably eclipsed the total number of pigs lost on the entire planet to ASF over the previous 90 yr. ASF meetings in China were often packed with hundreds of swine producers with the hope to find a miracle weapon to control or prevent ASF on their farms (Figure 3). Without the help of a safe and efficacious commercial ASF vaccine, swine producers in China and the rest of Asia have quickly recognized the importance of biosafety and biosecurity in swine production over the last 2 yr.

**How to develop a successful plan for ASF prevention and control?**

After ASF outbreaks started in China, swine producers quickly learned that, unlike CSF or FMD that could be effectively controlled by mass vaccination, there is no commercial ASF vaccine in the world. Without a tool to implement a “vaccinate-to-live” policy, millions of pigs were culled in the early days of ASF outbreaks in China. Although this control measure seems to be in line with OIE and FAO guidelines, the losses and disruption it created soon became unbearable for at least two reasons: 1) the social and economic impact associated with the huge increase of pork price in a few months after the number of pigs available for the market was reduced quickly and dramatically, and 2) the environmental risk associated with disposing of thousands of pigs on farms in a short period of time.

Without an available safe and efficacious vaccine, swine producers quickly realized that they have to significantly improve biosafety and biosecurity measures on farms to prevent the introduction of ASFV, and use “targeted culling—pull the bad tooth” to remove ASFV infected pigs from the facility to avoid further disease spreading and to preserve the herd. “Reopening” some of the infected farms for production became possible after carrying out intensive disinfection of the infected facility. In addition, significant changes have to be made in biosafety practices to minimize the risks associated with many factors associated with swine production. These risk factors include culled pigs, lagoons, pigs and feed purchased from outside suppliers, selling pigs to others (trucks and personnel from outside vendors), drinking water, boots and coveralls, insects, rodents and pests on farms, swine semen, and use of veterinary pharmaceuticals and vaccines. Implementing policies to incentivize employees to follow biosafety rules and remodeling the current facility for better biosafety control are also common practices for many swine operations. However, many of these changes are very costly and can only be effectively managed by well-funded large operations. Nevertheless, various “Reopening” or “Re-grow” plans have been developed and tested to raise pigs before a highly efficacious vaccine is available.

If a successful plan for ASF prevention and control could be developed, it should resemble the plan that facilitated the U.S. eradication of CSF more than 40 yr ago. Briefly:

1. **Know your enemy (the disease and pathogen) through supporting innovative research.**
   Invest strongly and continuously in research related to ASFV, ASFV–host interaction, point-of-contact diagnostics, safe and efficacious vaccines, swine farm biosafety and biosecurity risk management systems, and high containment facilities that are suitable for ASF research.

2. **Develop and implement science-based governmental policies at both state and federal levels.**
   Develop and implement science-based animal disease outbreak emergency management policies that will encourage the full participation and support of pork producers and consumers: swine farmers, pork processing plants, and the public. These policies must consider: 1) what will happen if the government does not compensate swine producers for their loss due to ASF outbreaks? 2) how can swine farmers properly cull/dispose of thousands of pigs in a short period of time?, and 3) how do the processing plants/slaughter-houses deal with ASFV positive products?

3. **Ensure the cooperation of all stakeholders including pig producers, animal health companies, veterinarians, regulatory agencies, social media, and the public.**
   Because the public is a significant stakeholder of the pork industry, it is not enough to tell the public that ASFV does not infect people. Instead, the swine industry should educate the public that ASF outbreaks affect the livelihood of many parts of the society including swine producers, workers on the farm, grain and feed producers, pork processing plants, grocery stores, truck drivers, animal health companies, restaurants, international and regional pork/grain/feed importers and exporters, and all consumers of pork products. Animal health companies should only manufacture and sell safe and efficacious ASF vaccines, and swine producers should only use au-

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*Figure 3.* ASF meetings for swine producers were held frequently in China during the first half of 2019. Shown here was an ASF meeting at Nanning, China on March 20, 2019. While 500 people pre-registered, 800 swine farmers and animal health professionals showed up at this “Protect Pigs from ASF and Survive” meeting. The focus of this meeting was on-farm practices that can minimize the biosafety and biosecurity risks associated with swine production. Photo courtesy of Mr. Yuanfei Gao of Yangxiang Group, the organizer of this ASF meeting.
Future Prospective

CSF and ASF are swine viral diseases with high consequential social and economic impacts in endemic countries. Successful prevention and control of ASF and CSF requires not only safe and efficacious vaccines and fast and accurate diagnostic tools but also science-based government policies that ensure the cooperation of all stakeholders of the swine industry. Science and technology alone are not enough without the effective partnership of the public.

Despite recent devastating outbreaks of ASF and CSF in Asia, the countries of North America and Europe demonstrated decades ago that ASF and CSF can be eradicated with proper government policy and adequate scientific and technological tools. The world has indeed changed since then, notably with ever-increasing high-density swine production and globalization, which demands more innovative approaches to solve new problems:

1. What is the best way to cull/dispose of thousands of pigs in a short period of time in a restricted area to take into consideration of animal welfare, economic and environmental impact, and technical feasibility?
2. Because large quantities of various disinfectants are used to inactivate the ASFV on swine farms, the negative impacts of these biosafety measures on environment, food safety, and human health should be carefully investigated.
3. The transboundary nature of emerging and re-emerging high consequence animal infectious disease threats requires global cooperation not only in outbreak management, but also in research for a broader biomedical, social, and ecological understanding of disease systems.

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Conflict of interest statement. The authors declare that there is no conflict of interest.

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Authorized ASF vaccines. Veterinarians should employ only field tested, effective immunization, and biocontrol practices. Additionally, ASFV positive products should not be produced, transported, sold, or consumed by anyone. Swine production security is a “weakest-link in the chain” problem. Therefore, the only way to achieve long-lasting security of the system is to improve the strength of the weakest link through full cooperation and regulatory compliance among all stakeholders.
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Feature Article

How two concurrent pandemics put a spoke in the wheel of intensive pig production

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Key words: African swine fever, COVID-19, pigs

Introduction: The Pig Chain as an Example of Efficiency Optimization

At the time of writing, the global COVID-19 pandemic is happening in conjunction with the African swine fever (ASF) pandemic (Blome et al., 2020). Both pandemics have proven to be a challenge for pig production. Intensive pig production is an example of a cost-efficient production system, namely an optimized meat chain with highly specialized links. It includes genetic, pharmaceutical, and feed companies, pig producers, transportation companies, slaughterhouses, processors, and retailers (Rodriguez et al., 2013). Over the years, genetic selection, optimized feeding, and improved farm management practices have decreased the inputs per kilogram of pork (Patience et al., 2015). Industrial slaughterhouses and processors have also optimized their processes. Characterized by high efficiency, the European pork production chain has maintained its position as the largest exporter of pork and pork products at competitive prices in spite of high labor costs (Popescu, 2020). However, industrial pig production as a concept has been challenged (Sorensen et al., 2006). The current double pandemic has revealed not only that the industrialization of pig production is an issue of consumer perception but also that risk factors are inherent to the system. These recent pandemics, like other unexpected events in the past, have revealed the vulnerabilities inherent to the system that we highlight here.

Vulnerability of the Pig to Pork Chain in Times of Pandemics

Prices on the world market are volatile and subject to external factors although local calamities may be balanced out by global supply and demand. The ASF crisis has had a clear impact on pork prices: in European countries with positive cases, prices dropped quickly because of an export ban to countries outside Europe, such as China. In contrast, the massive outbreak of ASF in China led to a shortage of pork on the world market, with price increases in other parts of the world (Mason-D’Croz et al., 2020). This may have stimulated farmers to inseminate more sows or invest in larger farms as expected according to the cobweb theorem (Ezekiel, 1938). With a 9- to 10-month period between insemination and slaughter, the pig chain cannot adapt quickly to an increasing or decreasing demand. This became painfully clear during the COVID-19 pandemic:

Implications

• Intensive pig production is an example of a cost-efficient production system: an optimized meat chain with highly specialized links.
• External factors, such as the COVID-19 and African swine fever pandemics, are having an immense impact on the chain and farmers’ income.
• These crises may exacerbate societal concerns about industrialized production, especially when linked with poor animal welfare and the risk for future pandemics.
• Transition from a supply-driven to a demand-driven market may result in more sustainable business models.

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with the closure of restaurants and the ban on group events, the demand for pork decreased (European Commission, 2020). Additionally, large slaughter and processing plants (mainly in the United States) had to close due to COVID-19 outbreaks and labor shortages because of quarantine measures, leading to a shortage in slaughter capacity (McEwan et al., 2020). As a result, not all pigs could be brought to the slaughterhouse as planned. This has led to overstocking, reduced production efficiency, and eventually even euthanasia of pigs on farm. Outbreaks of COVID-19 in slaughterhouses and meat processing companies also occurred in a number of European countries, particularly in Germany. This raised awareness of the poor working conditions of meat workers across Europe, especially because the sector depends to a large extent on migrant and cross-border workers. Closed borders also caused labor shortages during the COVID-19 pandemic (European Federation of Food, Agriculture and Tourism Trade Unions, 2020). Most outbreaks in European slaughterhouses have been small in comparison to those in the United States. Prices did rise again after confinement measures against COVID-19 were progressively lifted (European Commission, 2020). Nevertheless, the events raised awareness of the sector’s dependency on sufficient slaughter capacity.

**Biosecurity in Intensive Pig Production**

The high stocking density in intensive animal farming makes biosecurity a key factor. Biosecurity measures can be more easily implemented in intensive compared to extensive systems (Maes et al., 2019). As such, the risk of contracting diseases such as ASF is probably lower in intensive systems, as indicated by the higher prevalence of ASF outbreaks in backyard and small-scale herds (Costard et al., 2015). While modern intensive pig farms focus on strict biosecurity, high population density dramatically increases the risk of the rapid spread of disease if biosecurity measures fail. Biosecurity measures can reduce the impact of diseases such as ASF but some endemic diseases cannot be prevented in areas of high pig density and can only be controlled by vaccination programs or destocking and repopulation (Sørensen et al., 2006). Pig production is also considered a potential risk factor for future human pandemics, in particular those caused by influenza viruses. Pigs are susceptible to both avian and mammalian influenza viruses, and pig farms are, therefore, considered as potential “mixing vessels” for new viruses with the potential to cause human pandemics (Kahn et al., 2014; FAO, 2020). Still, with high biosecurity measures, the risk of contact between pigs and (wild) birds is probably either absent or low in intensive pig production and risks occur most from pig/human contact. Pigs have experienced influenza outbreaks from human origin, but so far only one case of influenza transmitted from swine to humans has been reported to cause an influenza pandemic in humans (Trovão and Nelson, 2020).

To date, strict biosecurity has resulted in increased control of several pathogens but full control of pathogens is impossible. Intensive pig production may especially be vulnerable to airborne viruses with potential risk for causing human pandemics (Davies, 2011; VanderWaal and Deen, 2018).

**Farmer Income in a Supply-Driven Market**

Specialization in the pig to pork production chain can be considered as an example of the treadmill theory (Levins and Cochrane, 1996). According to this theory, technological innovations are a driving force behind the growing scale of operations: with the introduction of new technologies (e.g., better management and better genetics), early adopters benefit from the reduced costs of production for an initial period. However, this temporary benefit declines as increasing numbers of farmers adopt the technology, leading to increased production and outputs, followed by a decrease in output prices. As a result, profitability declines and farmers are urged to adopt the technology to reduce their production costs under the current market conditions in order to stay in business (Levins and Cochrane, 1996). Indeed, intensive pig production is characterized by efficiency improvements, large numbers of pigs, and relatively small and volatile margins. Thus, small differences in pig prices and market disruptions have large effects on farmer income. As the number of slaughter pigs is determined almost a year ahead, and the pig production chain can be considered to be a supply-driven market, a sudden disruption, such as slaughterhouse closures, caused by the COVID-19 pandemic may have a major impact not only on the received price per pig but also on the cost of production because of decreased feed efficiency with higher slaughter weights (Van den Broeke et al., 2020). In particular, for “Protected Designation of Origin” products, a specific weight range is requested and deviations may lead to price penalties and inefficiencies along the chain (Parma Ham Specifications, 1992). Farmers have little room for short-term adjustments. One possible measure is to slow down growth rates, thus extending the time required to reach slaughter weight. Despite the higher feeding cost because of decreased feed efficiency, with possibly also a negative effect on the nutrient excretion to the environment, this option may be the only viable alternative. It may also be the best option for
animal welfare if slower growth is obtained by adapting the diet rather than through management measures, such as water restriction (for more information on this strategy, see Tokach et al., 2021). Optimal space allocation is traditionally one of the key factors in efficiency optimization. More pigs occupying the same space decreases the fixed cost per pig (Powell et al., 1993). Only in small segments—in niches that can be considered demand driven—are farmers paid extra for giving their pigs more space, mostly in light of improved welfare.

Animal Welfare

Good animal welfare is a prerequisite for society and animal welfare concerns have been increased since the 1960s (Maes et al., 2019). This concern has become even more apparent during a pandemic. In the case of ASF or other infectious diseases that need to be eradicated, a major focus is to eliminate the pigs on infected farms to prevent the disease from spreading to other farms. Consumers were particularly outraged about the practice of burning and burying live pigs in China during the ASF crisis (Loeb, 2019). Many risk factors are associated with on-farm killing of animals, both during the handling and moving of pigs before slaughter and during the slaughter process itself (EFSA Panel on Animal Health and Welfare et al., 2020). Societal acceptance of pig production clearly depends on the perception of extreme care for humane handling of animals during rearing and slaughtering and the transparency regarding these procedures. If a drop in slaughter capacity prohibits pigs from reaching the slaughterhouse in a timely way, there is an evident risk of overstocking, with concomitant welfare problems and disease risks. On-farm killing of healthy animals is a last resort that has serious implications for all three pillars of sustainability but keeping pigs on farm may not always be possible. The pig chain is, therefore, obliged to find strategies to avoid these bottlenecks in the future.

Conclusion

The pig to pork chain—with its highly specialized and optimized links—is an example of a cost-efficient production system. Maximizing stocking density within legal limits and process optimization lead to minimal costs per animal in the farm or per carcass in the slaughterhouse. Recent pandemics show the vulnerability of this pig chain as a whole and, especially, the potential risk exposure of the farmers and their animals. External factors, such as disease outbreaks or reduced slaughter capacity have an immense impact on the farmers’ income. At the same time, these crises may augment societal concerns about industrialized production, especially when a crisis is linked to poor animal welfare and the risk for future pandemics. The awareness of these risks should be a driver toward a transition in the pig chain from a supply-driven to a demand-driven market with a built-in flexibility to anticipate market requirements. To allow flexibility, more housing space and higher slaughter capacity will be necessary. This will imply higher costs per unit of production and will require cooperation throughout the chain with clear arrangements between all partners in the chain. This must finally result in sustainable business models and a fair income for each partner in the value chain. A high level of optimization and specialization can still be useful in the future, but the focus should shift to optimal instead of maximal production.
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Feature Article

Impact of COVID-19 on the Australian pork industry

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Key words: Australia, COVID-19, pork, quarantine

The Australian summer, November 2019, started with our focus on bushfires and their impacts on both regional and urban Australia, and this continued into the new year. Southern Australia bore the brunt of these ferocious bushfires with devastating consequences on many regional communities. The southern Australian major cities were also affected albeit at a very different level, with extreme smoke pollution confining much of the population indoors for a few weeks at a time. Domestic air travel in Australia was disrupted, people were forced to work from home, and, unfortunately, we also witnessed a consumer behavior that few had witnessed previously, panic buying, with items like toilet paper and face masks and commodities like long-life milk, rice, flour, and meat being stockpiled by consumers, resulting in ‘rationing’ of these items by retailers. But few foresaw what was about to confront us in 2020.

Like the rest of the world, we started seeing increasing media coverage of COVID-19 in January 2020. Some in Australia were aware of the severe acute respiratory syndrome-associated coronavirus epidemic in 2003 and, more recently, the Middle East respiratory syndrome coronavirus epidemics. Most thought the impacts of the new coronavirus would largely again be localized epidemics with few cases spread outside these regions. But all that changed as we saw this incredible spread of COVID-19 globally, resulting in Australia effectively shutting its borders to all visitors in March 2020.

The Australian pork industry, a relatively small industry by global standards with 270,000 sows, produces approximately 5.3 M slaughter pigs annually. The pork processing sectors consists of seven export-accredited sites that slaughters and processes approximately 85% of the national slaughter pigs. The Australian pork industry is unique in that it has been a closed genetic herd since late 1980s and does not allow fresh pork imports. All imported pork in Australia, mainly boneless hams and middles, must be cooked prior to sale. The Australian pork industry is spread across all Australian states with the major supply chains operating nationally.

At the start of 2020, the Australian pork industry was very much focused on African Swine Fever (ASF) and its spread across China and other parts of Asia, including Timor-Leste. As an industry, we were on high alert as numerous illegal pork products seized and destroyed by Australian authorities at airports from predominantly Asian travelers were

Implications

• Australia as an island was able to quickly respond to a pandemic such as COVID-19 by closing international and domestic borders to reduce the introduction of COVID-19 and an introduction of lockdown procedures.
• Hotel quarantine of returning travelers was very effective in reducing the introduction of COVID-19 to the community. However, breakdown in training and adequate use of PPE resulted in a second wave emanating from hotel quarantine in one jurisdiction (Melbourne), which was controlled by very strict lockdown.
• Introduction of federal government support for employees form businesses impacted by COVID-19 reduced the social impacts of COVID-19 although gaps occurred.
• The COVID-19 pandemic and associated lockdown resulted in some stockpiling of essential items, including meat.
• During the initial lockdown when restaurants and food service were closed, there was an initial surplus of pork, in particular, premium cuts. However, ongoing lockdowns resulted in an increase in household demand for pork, particularly roasts and mince. Food service has rebounded since lockdowns were removed.
• The decline in air travel and increased freight costs has reduced both exports and frozen imports of pork. The latter generally makes up a substantial proportion of processed pork products and this has been picked up by domestic production.

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found to contain ASF viral DNA material. Come March 2020, with its borders effectively closed and social distancing rules affecting both urban and regional Australia, we saw significant impacts of COVID-19 on the pork industry. For starters, the risk posed by visitors bringing in ASF via contaminated pork products was significantly diminished by the COVID-19 border closures.

Australia’s response to COVID-19 was rapid with the closure of international borders and mandatory hotel quarantine for returning travelers. Non-essential workers worked from home from mid-March and various levels of lockdown were introduced across the country. By global standards, Australia had very low rates of infection during the first wave and appeared to have things well under control in May 2020. However, a second wave arose primarily in Victoria when COVID-19 escaped from the quarantine hotels as a consequence of quarantine breaches. This second wave appears to have been controlled and, on 26 October 2020, there were zero cases of COVID-19 in the state of Victoria from approximately 15,000 tests performed in the previous 24 h.

One of the immediate impacts as a consequence of COVID-19 social distancing was the decline in the domestic food service pork volumes. Data from Australian Pork Limited’s foodservice tracker, which gauges Australian consumer activity, shows the percentage of people eating out of home—for either lunch or dinner on a given day—dropped from around 29% before March to as low as 16% in April. Surprisingly, the food service industry has rebounded back strongly to 27% for August 2020. While some of this can be attributed to the easing of some of the COVID-19 social distancing restrictions, much of this has come about with many restaurants reconfiguring their business from dine-in venues to take-away meal service only.

The border closure in March 2020 and the subsequent decline in air travel resulted in increased airfreight costs (>200%) to service our chilled carcass export markets in Singapore and Hong Kong. Freight volumes to Singapore and Hong Kong were marginally affected in April 2020 but have since recovered (Figure 1). While there was some Federal Government support for airfreight, this was insufficient to fully support the increased costs and the reduced options for air cargo.

Accompanied by these market shifts, we saw domestic retail trade increase markedly with consumers again resorting to panic buying. Interestingly, the latest data confirm Australian pork year-on-year growth of 20.6% in volume and 27.5% in value (http://porknews.com.au/documents/pasteditions/APN1020.pdf). This has been driven by household demand, especially for roast pork and mince, and helped by the increase in Australian pork being sourced for small goods. Retail fresh pork also remains competitively priced compared to other animal protein options.

The Australian Bureau of Statistics shows that pork imports to Australia have dropped significantly (Figure 2). The pork vacuum created by African swine fever across global

Figure 1. Monthly and moving annual total (MAT) volume of Australian pork exports. https://mcusercontent.com/1b6b935b82a4a431aa5f157a/files/d07fe095c22-41b8-ea60198bacd/Import_Export_Jul_Report.pdf.
markets has seen large volumes of European Union and North American pork being directed away from Australia.

Pig production in Australia, like many other countries, relies on foreign labor and with border closures in Australia and both the Philippines and New Zealand has seen a significant labor shortage and numerous vacancies for on-farm jobs. This is likely to continue until at least March 2021. Within Australia, state border closures have had some impact on the supply of both breeding animals and semen delivery. In most instances, these impacts have been easily overcome with the transfer of animals and semen at border transition sites but have resulted in increased distribution costs. The supply of feed ingredients similarly has not experienced significant delays, but we have again seen the freight costs of these ingredients increase.

Thankfully, we have not had to euthanize any pigs as a consequence of slaughter and processing facilities closures due to COVID-19. To date, only one of Australia’s seven pork abattoir processing facilities have had to close their facilities due to workers testing positive, and this was for a few weeks. However, there were at least two red meat processors who had outbreaks of COVID-19 in Victoria (see below). The livestock processing sectors in Australia were very proactive in developing and implementing their COVID-19 management plans. The costs, however, to maintain business continuity has come at a significant price, with some of the larger pork processing facilities with over 800 workers across multiple shifts reporting increased costs in the vicinity of AUSS700,000 (personal communication). The Australian Federal Government introduced a Jobkeeper program (https://www.ato.gov.au/general/jobkeeper-payment/) that allowed companies that had experienced a substantial decrease in income to keep staff on the payroll through a Government grant and this greatly assisted some of the meat processors impacted. The Government also increased (doubling in some cases) the Jobseeker payments for people seeking work (https://www.servicesaustralia.gov.au/individuals/services/centrelink/jobseeker-payment). While these initiatives were largely successful and certainly assisted many people across the community, there were some unintended consequences. For example, some processors and other agricultural industries were sometimes unable to fill unskilled positions because the magnitude of the benefits was a disincentive to work for some people.

Some states and territories of Australia have been very successful in quashing COVID-19 with the strategy often relying on tight border closures both internationally and between states. This has presented issues for staffing in particular for those processors and businesses located close to the border. Another possible consequence as we enter hay and grain harvesting season is the possibility that harvesting contractors who often move south with the season may not
be able to cross some state borders. It is envisaged that there will be some relaxation of borders to minimize these impacts. Another concern for the agricultural sector in general is that many of the labor-intensive jobs, such as fruit picking, are traditionally performed by backpackers. With the closure of international borders, it is unknown who will perform these jobs.

While social distancing restrictions in most Australian states are easing, the Australian pork industry continues to keep its COVID-19 management plans active and in place. However, the second most populous state Victoria, particularly metropolitan Melbourne, experienced a second wave of COVID-19 with 99% of the infections being traced back to security breaches in hotels where incoming travelers returning from overseas were required to quarantine for 14 days. Victoria, unlike other jurisdictions, used private security contractors with inadequate training in infection control and the use of PPE. Unfortunately, these contractors often worked more than one job and lived in large households with other workers, including some in the meat processing and food distribution sectors, as well as the aged care sector. Reluctance to be tested and enter isolation until test results were received and concerns about not being able to work further increased the spread of COVID-19 in Victoria. As a consequence, the Victorian State Government has implemented strict lockdown protocols in an attempt to control this spread, which still remains in place up until late October. The meat processing sector in Victoria were forced to operate at approximately 70% of normal capacity for about 2 months and will not be back to full capacity until at least November 2020.

One of the other consequences of the COVID-19 pandemic and border closures is that many aspects of research and development have been heavily affected both on farm and at the processor level. Collaborative national research and development programs, particularly those focused on red meat and pork eating and carcass quality have been seriously delayed and will continue to be delayed well into 2021. Other research that relies on the sourcing of abattoir materials, such as embryos or rumen fluid and possibly tissues, for biomedical research have been hampered by tight biosecurity within abattoirs.

Unfortunately, the increase in the second and third wave human infections globally will likely see the industry implement these plans for the rest of 2020. To date, 2020 has been a difficult year for the Australian pork industry but the industry can be well pleased with its effort and its resilience in the face of a devastating COVID-19 pandemic.

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Feature Article

Slowing pig growth during COVID-19, models for use in future market fluctuations

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Implications

• COVID-19 resulted in significant challenges for swine production in the United States and globally due to temporary limitations of harvest capacity at swine processing facilities.
• The U.S. swine industry worked collaboratively to discuss, evaluate, and disseminate strategies to reduce the growth rate of pigs in order to avoid pigs growing past a stage where processing facilities could no longer accept them.
• A combination of management and nutritional approaches has been extremely effective in restricting pig growth rate in response to the COVID-19 pandemic—namely feeding reduced protein diets, increasing stocking density, and ambient temperature, among others.

Key words: COVID-19, reduced growth, swine

Introduction

COVID-19 has provided global challenges to almost every industry. Among these challenges were positive cases of COVID-19 in employees at swine processing facilities, leading to temporary, or extended, shutdown of the facilities (Millet et al., 2020). In the United States, processing capacity is closely aligned with the number of pigs produced such that packing facility shutdowns or slowdowns rapidly results in a backlog of pigs needing to be harvested. Thus, there was no place for the pigs to go that were ready for market. Swine processing under federal inspection began to decrease in late March 2020 (Figure 1; USDA, 2020). The lowest weekly harvest occurred from April 27 to May 2, 2020, which represented a decrease of approximately 45% of normal slaughter capacity.

In the late finishing stage, pigs typically gain 800 to 1,000 g/d. Thus, each day they were held resulted in approximately 1-kg heavier pigs. Processors have maximum allowable market weights because their facilities are not able to accommodate extremely heavy pigs. The maximum weight varies by the processor but is typically around 145 to 155 kg in the United States. During the COVID-19 pandemic, an increase in swine carcass weight was observed in response to this reduced harvest capacity (USDA Agricultural Marketing Service, 2020). Producers were quickly faced with a dilemma with few options and none of them good.

One option was to allow pigs to continue to grow, knowing that they would quickly be beyond the maximum allowable weight, not be accepted by the processor (whenever they were able to process pigs again), and have no value. The second option was to euthanize the pigs as they became too heavy, which, besides the economic ramifications and logistical difficulty, carries an enormous emotional toll. The third option was to slow the growth of the pigs with the hope that the processing plants would eventually reopen. This third option became the preferred choice for the majority of the swine industry if the extra finishing space needed to keep the pigs indefinitely was available.

The question then became: how do you slow the growth rate of the pigs? As an industry, considerable research has been conducted to find ways to increase the growth rate of pigs; however, very little research has focused specifically on methods to reduce pig growth rates. This is particularly true for pigs in late finishing. An additional challenge that needed to be overcome was related to facility design. In the United States, facilities have automated feeding and watering systems to allow pigs to have constant access to feed and water to promote growth and are not designed for restricting feed consumption.

Universities, feed companies, the National Pork Board, and others responded to producer needs by providing data-driven recommendations on strategies that producers could consider implementing in their facilities (DeRouchey et al., 2020, Hostetler, 2020; Patience and Greiner, 2020). Iowa State University was one of the first to respond to the industry need. They altered an ongoing study to test some potential options in...
individually housed pigs, which gave many the encouragement needed to try fairly drastic diet changes (Gabler et al., 2020). Iowa State University, National Pork Board, and many others hosted webinars to discuss processing capacity, slowing pig growth, and euthanasia options. Producers, veterinarians, nutritionists, and others shared their experiences and thoughts openly. These combined resources were critical to provide essential information for producers.

The exact requirement on how much pig growth needed to be slowed depended on the producer, but immediate and dramatic reduction in growth was required for pigs already close to market weight. The need for slowing down younger pigs was less known because of the huge uncertainty of how soon processing plants would be able to be back online and how long it would take to get through the backlog of pigs. Thus, the application of slow down methods for young pigs was more varied. For many, the response with younger pigs was just a shift from maximizing profit to minimizing loss (shift from formulating for maximum margin over feed and facility cost to formulating for minimal feed cost per unit of gain). For heavy pigs, the need for a dramatic reduction in growth led to the consideration of many options.

**Options Considered**

**Nutrition**

Remove growth-promoting feed additives. An obvious first step to lower growth rate was to remove any feed additive included in the diet for growth promotion. These included ingredients such as copper, ionophores, acidifiers, enzymes (other than phytase), and mycotoxin binders. Producers implemented this option, but reductions in growth were only marginal with the removal of these products, especially in the late finishing pig.

Reduce dietary energy. Including high-fiber ingredients in the diet and removing any added fat will lower dietary energy and growth rate (Nitikanchana et al., 2015). When fed high-fiber diets, pigs increase feed intake in an attempt to meet their energy requirement; however, if the fiber concentrations are high enough, the pig cannot physically consume enough feed and, thus, pig growth is reduced (Kyriazakis and Emmans, 1995). The neutral detergent fiber level in the diet needs to exceed 20% to have an appreciable impact on growth rate (Patience and Greiner, 2020). Unfortunately, economical fiber sources were not available and, in many cases, simply not available at all. Ethanol byproducts are often the highest fiber ingredients available in the United States and most ethanol plants were closed during this time period and, thus, their byproducts were not available or cost effective. Thus, this option was not available to many. However, producers that were using added fat in late finishing removed it immediately to lower diet energy and feed cost.

Reducing the dietary electrolyte balance. Including ingredients in the diet that greatly lower the electrolyte balance (negatively charged dietary ions [Cl⁻] subtracted from positively charged dietary ions [Na⁺, K⁺]) makes the diet unpalatable to the pig and is highly effective at reducing feed intake (Patience et al., 1987). The most common ingredient used for this purpose is calcium chloride, but other ingredients can have a similar effect. Although some research exists, predicting the exact response to altered acid–base balance remains difficult (Haydon et al., 1990; Patience and Chaplin, 1997; Holt and Walker, 2011). The use of products to alter acid–base balance can be expensive, greatly increases water usage, and, therefore, carries some risk if water availability is a concern. Some producers may have chosen to use this strategy; however, it was on a limited basis because of the cost and low availability of calcium chloride during the pandemic.

Altered amino acid balance. Reducing the ratios of some amino acids, such as tryptophan, valine, or isoleucine, relative to lysine is known to reduce feed intake and growth rate (Gonçalves et al., 2018; Cemin et al., 2019). The growth rate is particularly impacted if the leucine to lysine ratio is also high in the diet (Cemin et al., 2019). Diets with high leucine concentrations can be easily produced when corn byproducts from ethanol production are available; however, as stated previously, ethanol byproducts were in short supply during the pandemic. Thus, this method had little practical use. Another strategy that was discussed was significantly increasing the addition of specific amino acids to generate a wide excess, most notably DL-methionine, which has been shown to greatly reduce intake and growth when added at very high inclusion levels (Edmonds and Baker, 1987; Edmonds et al., 1987). However, excessive dietary DL-methionine was not widely implemented in the 2020 COVID-19 pandemic.

Low-protein (amino acid) diets. Reducing dietary protein (all amino acids) greatly reduces the growth rate of pigs. Feed intake is not impacted as much; thus, feed efficiency dramatically worsens. Under normal circumstances, this option is not preferred because the cost per unit of gain increases dramatically even though diet cost is reduced with the reduction in the...
protein content. The COVID-19 pandemic was not a normal situation. Cost per unit of gain is not a very useful metric when you do not want pigs to gain weight. The cost per day to feed the pig becomes a more important metric. Low-protein diets reduced the daily feed cost per pig. Thus, low-protein, corn-based diets were used by the majority of swine producers. Experiments by Iowa State University showed the effectiveness of this approach at reducing pig growth rate (Gabler et al., 2020). Multiple feed companies conducted similar studies to validate the approach. An experiment was conducted at Kansas State University to evaluate feeding a lysine-restricted diet or a corn-vitamin-trace mineral diet for different periods of time in finishing pigs (Rao et al., 2020b; Figure 2). The lysine-restricted diet was formulated to contain 75% of the lysine concentration in the control diet. This diet reduced pig performance but not to the extent achieved with a corn-vitamin-trace mineral diet, which contained about 25% of the lysine concentration of the control diet. This data, as well as multiple other research trials by swine production systems, allied feed industry, and academia, documented that growth rate could be significantly reduced with manipulation of the diet.

Management
Reducing floor space. Pigs require a minimum amount of space directly related to their body weight (Gonyou et al., 2006). If these space requirements are not met, the growth rate will be reduced. As pigs went beyond their intended market weight, the growth rate was naturally reduced to some extent because pigs started to become limited on space availability. Increasing the number of pigs per pen to limit floor space can also reduce the growth rate. This was done to some extent with younger pigs to allow heavy pigs more time in barns; however, it was not done with heavyweight pigs because of potential welfare concerns.

Increasing barn temperature. Increasing temperature above the thermoneutral zone of the pig results in reduced feed intake and growth rate (Renaudeau et al., 2011). Hot temperatures are a natural consequence in the summer and result in the seasonality of pig growth rate and market weights. The pandemic did not occur in the hottest months of the year and, therefore, decreased ventilation rates would have been required to increase temperatures in the barn. Reducing ventilation to increase temperature carries risk because gasses can increase in the facility posing a health danger. In addition, in order to be effective, barn temperature would need to be increased significantly to have enough impact on feed intake and growth rate. Increased barn temperature may have been implemented by some farmers but not the majority of the industry.

Restricting feed access. Restricting access to feed will reduce intake and growth rate and does not result in poorer feed efficiency. Thus, on the surface, this option would appear to be ideal. However, true restriction in feed intake is difficult to accomplish in most finishing barns in the United States because all pigs typically have free access to dry feed in either a mash or pelleted form. Tightening the feeder opening limits feed intake but, by itself, does not greatly reduce pig growth. Reducing feed access to a greater extent by blocking access to one or more of the spaces in a multi-space feeder or allowing pigs to have access to feed for only certain hours of the day or every other day was considered by some producers to reduce feed intake, but worries about increased pig-to-pig aggression limited its application. A few producers allowed pigs from neighboring pens (e.g., across an aisle) to share a single feeder in one of the pens instead of having access to the feeders in both pens. However, these methods would also increase pig-to-pig aggression and require changes in barn management and were not widely implemented.

Restricting water access. A pig’s water intake is directly related to feed intake (Patience, 2012). Thus, reducing water access will reduce feed intake. However, limiting water access for pigs is risky because water shortage can lead to salt toxicity. Because pig barns have water systems with a limited number of water devices that are shared by pigs, providing access to water for only certain hours of the day would fail to lead to fighting whenever the water became available. Thus, this option was not used by producers and in general is not recommended due to the potential negative impacts on animal welfare.

Producer application and lessons learned. COVID-19 left many swine producers with limited options. They were faced with either mass euthanasia of pigs or finding a way to slow the growth rate immediately. Producers pivoted quickly to adapt to the crisis. Diets with reduced amino acids were adopted as the easiest nutritional strategies to implement what would have an immediate impact on reducing the growth rate. Because a dramatic reduction in growth rate was required, pigs that were at or near market weight were placed on a lowered protein diet containing only corn, vitamins, and minerals. The “corn” diet met all of the vitamin and mineral requirements of the pig but was below amino acid requirements for rapid growth. The vitamins and minerals were maintained in

Figure 2. Body weight change relative to control (black horizontal line) when pigs initially 90 kg body weight were fed 1) the control diet for 28 d and then switched to corn-vitamin-trace mineral diet for the final 16 d, 2) fed a lysine-restricted diet for the entire 44 d study, and 3) fed a lysine-restricted diet for the first 28 d of the study followed by a corn-vitamin-trace mineral diet for the final 16 d. The control, lysine-deficient, and corn-vitamin-trace mineral diets contained 0.7%, 0.5%, and 0.18% digestible lysine, respectively. Adapted from Rao et al. (2020b).
the diet because it was unknown how long the diet would need to be fed and a deficiency in these nutrients that may impact the health or welfare of the pigs was not desired. The “corn” diet was fed in mash form by most producers. The diet slowed the growth rate by 50% or more from normal levels. Reducing the protein sources reduced the cost of the diet such that feed cost per pig was reduced on a daily basis compared to feeding a normal diet, although the impact was minor and did little to offset the major financial impact that COVID-19 had on pig farmers. For pigs that were not near market weight, less dramatic reductions in amino acid concentrations were used depending on the farm and their marketing prospects.

The corn diet was fed for anywhere from 1 to 8 wk, but was fed for 3 to 4 wk for the majority of situations. As would be expected, pigs fed this type of diet had more backfat and less muscle than if they would have been fed a normal diet. However, coupled with strategies like tightened feeder adjustment, it was effective at holding the majority of pigs long enough for them to reach normal processing channels. A concern expressed by producers was that the amino acid-deficient diet would increase aggression and vices. Fortunately, vices and aggression were not reported by anybody that fed this diet in mash form; however, anecdotal reports indicated some vice problems when the corn diet was fed in pelleted form.

Some pigs that were fed the corn diet were switched back to a typical finishing diet prior to marketing as processing space became available. These pigs exhibited compensatory gain greatly improving growth rate and feed efficiency when switched to normal diets (Gabler et al., 2020; Rao et al., 2020a; Figure 3).

The COVID-19 pandemic caused tremendous financial loss and emotional stress for many people around the globe. The crisis also brought out the best in people in the swine industry. Genuine care and concern for pig farmers and the welfare of the pigs under their care resulted in collaboration between universities, feed companies, other allied industry suppliers, and the National Pork Board resulting in data-driven solutions to lessen the impact of the crisis. Whether the strategies used will be the model for future market fluctuations remains to be seen, but the cooperation and communication within the industry can serve as an example of people coming together to help each other in a time of need. Conflict of interest statement. None declared.

Potential Strategies to Reduce the Growth Rate of Pigs in Response to Reduction in Processing Facility Capacity

Nutritional
- Remove all growth-promoting feed additives
- Reduce dietary energy
- Reduce dietary electrolyte balance
- Altered amino acid balance (branch chain amino acids, excessive DL-methionine)
- Deficiency of amino acids (widely used during 2020 COVID-19 pandemic)

Management
- Reducing floor space
- Increasing barn temperature
- Restricting feed access
- Reduced water access (not recommended)

Figure 3. Body weight change relative to control (black horizontal line) when pigs initially 89 kg body weight were fed 1) the corn-vitamin-trace mineral diet for 14 d and then switched to control diet for 30 d, 2) the corn-vitamin-trace mineral diet for 21 d and then switched to control diet for 23 d, and 3) the corn-vitamin-trace mineral diet for 28 d and then switched to control diet for 16 d. The control and corn-vitamin-trace mineral diets contained 0.7% and 0.18% digestible lysine, respectively. Adapted from Rao et al. (2020a).

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Feature Article

Facts and thoughts on how the COVID-19 pandemic has affected animal agriculture in Argentina

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Implications

• On March 20, 2020, a strict nationwide quarantine was announced. The number of infected people and deaths grow daily, and the general impact on welfare and economy is notorious.
• Supply chains have suffered because of national and regional lockdowns, but auctions and direct sales of beef cattle sustain their activities; however, COVID-19 had a negative economic impact on livestock trade fairs and shows.
• Specific protocols have been issued and strictly followed. Thus, the feed industry, slaughterhouses, and transportation have kept providing their services.
• Overall, COVID-19 restrictions per se have not substantially affected animal agriculture in Argentina.

Key words: animal agriculture, Argentina, COVID-19

Sociopolitical and Economic Context in Argentina

Describing Argentina’s political and socioeconomic context in which the COVID-19 pandemic evolved is necessary to weigh the disease’s potential impact on animal agriculture. Argentina is the eighth largest country in the world (2,780,400 km²). Presently, the population exceeds 45,000,000 people (National Institute of Statistics and Census of Argentina; INDEC, 2010); however, about 40% of the population is concentrated in Buenos Aires (CABA, 203 km²) and its metropolitan area (AMBA, 3833 km²). AMBA is a very heterogeneous region with both wealthy and extremely poor large regions. However, CABA assets are political, economic, technological, and cultural power, with minor, but also highly relevant, areas of poverty. CABA was historically the metropolis of Argentina’s middle class. The remaining 60% of the population is unevenly distributed across the 23 provinces of the country with the same problems of middle-class degradation, as well as poverty. In December, 2019 after the national elections, President Mauricio Macri transferred the administration to the elect President Alberto Fernandez (AF).

Regardless of the administration change, Argentina has a structural high inflation rate, increased poverty, and a large external debt. As an example, the inflation rate for 2019 was 53.83% and, up to August 2020, it was 40.67% (INDEC, 2020a), showing no prospective to decrease in the short term. This indicator reflects the fragility of the economy. The impact of the pandemic increased the pressure over the health system and aggravated the economic and social situation.

In this context, on March 20, the government announced the initiation of a strict quarantine to confront COVID-19, even though the outbreak at that time was negligible. There were logical reasons for the decision, such as improving health infrastructure and delaying community spread of the virus. Essential activities were announced and nonessential canceled. These measures were welcome by the citizens for the first 2 months, and President AF’s approval was high. Since then, social fatigue, lack of income, sense of uncertainty, and an inevitable increase in the infection rate and death toll led many to question government mandates related to COVID-19.

Now, 6 months later, schools, research facilities, and universities are still closed, interurban buses and commercial flights never circulated, people can only go to the banks with an appointment, numerous small and large business are broke, the unemployment rate has climbed up, real salary and pensions cannot match up the rise in inflation, and the U.S. dollar exchange rate is increasing permanently in an informal market, while the Central Bank keeps losing its reserves. The government does not seem to have an economic and development program in progress; besides a productive dialogue between officialism and opposition about the real needs of the society does not exist. This situation is increasing social restlessness and deepens the fracture of Argentine society.

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The highly populated areas, such as CABA and AMBA, have been the most severely affected initially; however, in the last few weeks, the COVID-19 expanded and increased everywhere. By mid-October 2020, restrictions still continue and Argentina is in the seventh place in the world in COVID-19 total reported cases with a death toll of 2.6% in those infected. The gross national product (GNP) exhibits an interannual variation (August, 2019–2020) of −19.1%, one of the biggest falls in history. Although economic activity in many countries has declined in the second quarter of 2020, Argentina’s situation is more difficult because 25 out of the last 30 months have shown a decrease in the inter-annual GNP.

Status of Major Animal Commodities

With some exceptions and despite all these burdens, agribusiness seems almost intact, even growing in productivity and trade. This can be attributed to the impetus and positive attitude that characterize this sector—a sector that cannot afford to stop. Fortunately, mostly agribusiness activities are recognized as essential and, thus, exempt from COVID-19-related restrictions on operations and movement. The Ministry of Agriculture, Livestock and Fisheries (MAGYP, 2020a) developed COVID-19 protocols for different agricultural productions.

Beef industry indicators

The monthly beef production, exports, and domestic market consumption averaged across 2017–2019, compared with the first semester of 2020 (MAGYP, 2020b), are shown in Figure 1. Neither COVID-19 restrictions nor economic context seems to affect beef production or exports. A detailed report from Argentine Beef Promotion Institute (IPCV A, 2020) indicated that the volume of beef production for the second quarter of 2020 shows an interannual expansion of 7.3% compared with the same period in 2019. In the first 5 months of 2020, more than 25% for the beef demand was from China but, in June, it fell below 20%; this makes it difficult to predict exports volume. However, the meat that was not exported to China was compensated by a considerable purchase from the United States.

Beef cattle, with a stock of more than 54 million heads, is the most relevant animal product in Argentina due to cultural significance and eating habits. When affordable, consumers prefer beef over other meats. In Figure 1, we can observe a decrease in beef consumption per capita for the first semester of 2020. This can be attributed to an increase in retail prices, low incomes, and job loss, undoubtedly aggravated by the COVID-19 pandemic. Retail prices, as of June 2020, grew at a year-on-year rate of 52.6%, significantly above the general inflation rate of around 42.8%. Still, 74% of the beef produced supplies the domestic market, and the remaining 26% go to exports (IPCV A, 2020). Argentina’s total exports for the first semester of 2020 reached 27.336 million USD, with a great collapse in the interannual variation of the oil-petrochemical and automotive sectors, among others (INDEC, 2020b).

However, exports in U.S. dollars for the main agribusiness sector (soybeans, corn, and wheat), with a proportional participation of 21.5%, showed a positive interannual variation. Beef and leather made up a significant 5.9% share of U.S. dollars income. Despite the increase in metric tons (MT) exported compared to 2019, in US dollars, beef had a low interannual variation of −3.9% probably because international prices plunged 23%.

Other meat products indicators

Argentina’s “protein basket” per capita is made up of 50.9 kg of beef, 43.9 kg poultry, and 14.5 kg pork for a total 108.4 kg per year of a variety meats (Brusca, 2020). Although, in Argentina, there is about 15 million head of sheep, their meat consumption is negligible; some estimates indicate only about 1 kg per capita annually. Poultry and pork production and domestic market consumption average across 2017–2019 and the first semester of 2020 (MAGYP, 2020c,d) are shown in Figure 2. Reported interannual variation (January–July, 2019–2020) indicates that production was +2.3% and +5.5%,
consumption +2.9% and −1.3%, and exports −1.3% and +66% for poultry and pork meat, respectively. It looks like the increase in poultry meat accounted for the decrease in beef consumption. The dramatic increase in exports from the pork industry was mainly because of Chinese demands, but the increase also shows the growth of this industry in Argentina. Currently, the African Swine Fever outbreak in Europe is an unfortunate fact; nevertheless, it can open a new business opportunity for the Argentine pork industry. Consequently, up to date, COVID-19 restrictions do not seem to affect the variables presented here for the poultry and pork industry.

**Dairy industry indicators**

Fluid milk production and consumption exhibited an almost sustained fall since 2010, parallel with the drop of GNP per capita (−17%) up to 2019. A moderate but sustained increase in fluid milk production for the first semester of 2020 compared to the mean of the period 2017–2020 can be seen in Figure 3, as well as April–May peak for total sales (MAGYP, 2020c).

Numerous other products, such as yoghurts and cheeses, are produced by the dairy industry in Argentina, but those more expensive and, unfortunately, might not be as accessible to many people with the lowest income. Compared to the first half of 2019, exports of powdered milk and cheese were 63,809 and 19,707 MT, a total of +51.3% and −24.6%. Different variables, other than COVID-19, seem to have influenced production and export fluctuations within the dairy industry.

**Supply Chains**

From the very beginning of the pandemic, the circulation of people was limited, but essential supplies were somewhat guaranteed. As in other parts of the world, more and more activities have been allowed as the pandemic has continued. However, businesses did not open up evenly in the country, and there are differences in the duration and strictness of the protocols—and bottlenecks—because of national and regional (provinces) lockdowns. Fernando Canosa (Livestock Consulting at GANADERO, professional service, personal communication, 2020), a nationally recognized beef cattle consultant, stated “…our livestock sector is actively working, the animals continue to produce, gestate and calving, and those who have to re-breed continue to do so. What worries are the province closures, with permits that are often useless. This is a serious threat to production by preventing the transfer of inputs, products, contractors, professionals and entrepreneurs, etc. If the situation is not resolved quickly, future production is at stake.”

**Animal Farming and Trade**

Except for inconveniences in obtaining some specific supplies or social distancing, no reports indicate that COVID-19 has affected operations inside farms. A national survey among members of the Regional Consortium for Agricultural Experimentation (CREA, 2020), a group for agricultural entrepreneurs, indicated that around 15% of members had difficulties commercializing their production because of COVID-19 restrictions, and this ranged between 7% and 29% of members.
depending on their type of production and area of the country. A clear majority (85%) said that they were “unchanged.”

In general, regular commercial auctions and direct sales of beef cattle sustain the flux of heads to maintain the dynamics of production systems and the supply of meat. Online auctions have also been held for years. For in-person auctions, specific protocols have to be followed for those with attendance. As an example, the Ministry of Agrarian Development of the Province of Buenos Aires (MDA, 2020) approved specific protocols for cleaning and disinfection, and it made recommendations for the transport, loading and unloading of animals, and in the physical space of the fair auction (MDA, 2020).

Despite these measures, COVID-19 has had a very negative economic and social impact on livestock trade fairs and shows, which are of economic relevance and very popular around the country. The Palermo Rural Exposition at CABA, the most important show in Argentina that attracts thousands of people every year, was suspended before its 134th edition and rescheduled for 2021. The 136th National Exposition of Livestock, at Bahía Blanca, and other traditional annual exhibitions were conducted on schedule but without the public. At Bahía Blanca, exposition was restricted to beef cattle only and held without the industrial and commercial exhibit; however, the shows could be followed through online streaming. Some other customary shows at a smaller scale were either conducted with limitations or suspended according to diverse criteria and regional COVID-19 trends.

The feed industry was also declared essential. According to Cecilia Inchausti (CEO at CRECER FEEDS, Tornquist, Argentina, personal communication, 2020), a regional leader in feed manufacturing, they suffered delays the first 2 wk after national quarantine was initiated; thereafter, permits were issued and transportation became more regular, at least in the areas they cover with their business. They also adopted precise work protocols to protect their operators, as well as to ensure continuous production. They are working in teams that do not cross each other and, if they have a COVID-19 case, the whole team is isolated and the other team takes over the job. Most of the problems they face are more related to the economic and financial uncertainty than to the pandemic itself. Inchausti believes that these facts are true for most of the feed industry.

**Slaughterhouses: Outbreaks of COVID-19**

The evolution of the COVID-19 pandemic is of great concern for slaughter houses and packing plants, which are in high alert for COVID-19 around the globe. In Argentina, a strict protocol was issued by SENASA (MAGYP, 2020a) and is applied at all plants. Only two plants were suspended by mid-September 2020, and there were six plants that temporarily self-excluded due to COVID-19 cases among employees. Four of these plants are for poultry, three for beef, and one for pork. So far, very few plants have been affected, but some people expect that the number of workers infected may rise as the virus advances.

Although there is no evidence that COVID-19 can be transmitted through food, slaughterhouses became a real bottleneck because the workers are at a high risk of being infected. Besides the concern for their health, difficulties marketing products, worker absence, and sanitary controls could slow or stop production.

**Education, Research, and Extension**

All educational institutions, from kindergartens to universities, have been closed for the last 6 months. The National Institute of Agricultural Technology has research stations all along the country; an institutional protocol has affected sites to different extents. Their extension activities are being intensively carried out online. Universities stay closed and activities are mostly reduced to teaching online. Overall, on-going projects are allowed to proceed with specific permits, but new projects have been temporarily canceled, particularly those that require the interaction of multiple individuals and intensive lab activity.

However, commercial labs remain productive. For example, the U.S. Department of Agriculture has established an agreement with an Argentine pharmaceutical company to be one of its suppliers of antigens and vaccines for a new bank created to reinforce protection measures against foot-and-mouth disease (Valor Carne, 2020).
So far, COVID-19 restrictions per se have not substantially affected animal agriculture in Argentina, but restrictions have changed our sociopolitical and economic situation, which, in turn, has somewhat impacted productivity and trade variables. However, different results could be seen in the next months or year since the pandemic is highly dynamic. Our expectations for the future can be defined by one word: “uncertain.”

Although the country’s poverty rate increased to 40.9% of the population—and we have seen the impact of COVID-19 on wages and job loss—the consumption of animal products (except for milk) seems to be stable. It makes sense that some consumption is sustained by the portion of the population that maintains purchasing power, plus government emergency assistance programs, which were added to the many already existing (INDEC, 2020c).

Conflict of interest statement. None declared.

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Feature Article

Beef supply chains and the impact of the COVID-19 pandemic in the United States

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Implications

- This article describes the initial impacts of COVID-19 on beef supply chains and beef product markets. An overview of major beef market segments of retail grocery, food service, and exports is provided, including a focus on ground beef markets.
- COVID-19 caused massive and unprecedented impacts on beef supply chains for food service and retail grocery.
- The shutdown of food service and the corresponding surge in retail grocery demand provoked a first wave of product shortages due to bottlenecks and rigidities in food service and retail grocery supply chains.
- A second wave of impacts resulted from COVID-19-induced reductions in cattle slaughter and beef production. This resulted in additional product shortages in retail grocery.
- COVID-19 revealed both the efficiencies and rigidities of specialized food service and retail grocery supply.
- Dramatic and varied market price reactions across beef product markets helped rebalance markets and restore equilibrium.

Key words: beef supply chains, COVID-19, food service, retail grocery

Introduction

One of the many factors that make the U.S. cattle and beef industry an extremely complex set of markets is the disassembly of the beef animal into thousands of different products. These products are marketed in a vast array of final markets including retail grocery, food service and exports (Clark, 2019). In the United States, food expenditures prior to COVID-19 consisted of two, roughly equal market channels: food service, representing 54% of expenditures, and retail grocery, representing 46% of expenditures (USDA-ERS, 2020). The unprecedented impacts of COVID-19 revealed to producers, processors and consumers, efficiencies as well as vulnerabilities of beef industry supply chains. The COVID-19 impacts occurred in two different but overlapping waves beginning in mid-March 2020 with the majority of impacts over by late-June. However, economic ripples continued for many weeks thereafter.

Beef packers provide the animal harvest and the primary fabrication of beef carcasses into wholesale products. Typically, packers fabricate several hundred basic wholesale products, which are marketed as several thousand products representing unique customer specifications. Subsequently, the majority of wholesale beef products move through a diverse and specialized set of further processing activities that further expand the set of products by several thousand additional products into largely separate supply chains. Following sections provide a brief overview of beef market sectors to better understand the impacts of COVID-19 on beef markets.

Retail Grocery Sector

Retail grocery is responsible for a large amount of beef sales and grocery sales are generally recognized as the main driver of total beef sales. Retail grocery typically sells a core set of products that is rather broad but also has considerable flexibility to adjust and feature different products when market conditions are favorable. Many supermarkets no longer have butchers or do any meat cutting in the store. Some independent stores and at least one regional grocery chain are exceptions to this. The majority of supermarkets receive case-ready product from further processors, many of which are owned by major packing companies. Further processing for retail grocery involves cutting, packaging, and labeling for retail, including ground beef retail packaging. Ground beef is discussed separately in more detail below. Retail grocery increasingly may include premarinated, ready to cook “meal kits” or similar value-added products. Retail grocery uses almost entirely fresh beef products with beef features following a standard calendar in which advertising and purchasing are planned several weeks to several months in advance.

Food Service Sector

Food service includes facilities sometimes referred to as HRI, meaning hotels, restaurants, and institutions (hospitals, hospitals,
schools, etc.). Restaurants represent a wide range of establishments including quick service restaurants (QSR or fast food), fast casual, cafeterias/buffets, casual dining, midlevel, and fine dining. Individual restaurants or chains typically have limited and fixed beef product needs that are very specific and quite rigid. Collectively, restaurants utilize a wide range of beef products from ground beef to Prime steaks. The majority of food service beef products originate from further processing facilities in which products are trimmed, sized for portions, tenderized, marinated or otherwise processed according to specifications. Food service further processing often produces additional beef products as primal and subprimals are further fabricated into multiple products including bench trim that is used for cooked ingredients in other processed products. Although most food service facilities use fresh beef products, some restaurants may utilize frozen portion-control steaks or other products that can be thawed on demand.

**Ground Beef**

Ground beef represents an estimated 45% of total U.S. beef consumption (Ishmael, 2020) and plays a singular and uniquely important role in the U.S. beef industry in both retail grocery and food service sectors. Retail grocery establishments market large quantities of ground beef in a variety of forms and packaging. Ground beef for retail grocery is commonly part of supply chains that specialize in case ready products and processing specifically for grocery. For retail grocery, ground beef is typically made from fresh domestic meat products, frequently sourced from muscles and trimmings from specific primals as supermarkets often market ground beef with carcass references such as ground chuck, ground round, ground sirloin, etc.

Ground beef for food service is typically provided by specialized grinders that utilize a diverse set of inputs including fresh 50% (or similar) fatty trimmings, fresh lean trimmings or muscles from fed slaughter, fresh or frozen cow/bull lean trimmings, and frozen imported lean trimmings. Margins are razor thin in food service, especially in QSRs that feature dollar menus, etc. and ground beef formulation is subject to intense cost scrutiny. Though there is some potential overlap in input sources for food service and retail grocery ground beef, the resources used for each tend to be largely separate.

**Exports**

Beef exports frequently originate with packers that produce export products according to unique specifications that are typically different from domestic products; or from exporting companies that may do additional fabrication/processing for export. Growing exports in recent years and expanded demand for specific products have significantly changed domestic markets. For example, various chuck products are popular in some Asian markets and have increased prices relative to other products and changed seasonal price patterns. Food service grinders, that can and have used these chuck items in ground beef now find that these products are effectively priced out of the ground beef market. Most exports are frozen and products are typically staged in cold storage prior to shipment.

**Imports**

The United States has long been a major beef importing country, despite being the largest beef producing country and a major beef exporter. Beef imports are driven by the demand for lean trim to support ground beef production with over 70% of imports estimated to be processing beef. It is estimated that imported lean trimmings accounts for over 25% of the total trim used for ground beef production in the United States. Imported beef also includes some muscle cuts from Canada and Mexico. Beef trade with Canada includes some bilateral trade of similar products that are economically motivated by north–south transportation efficiencies (compared to east–west shipping in both countries). Beef imports from Mexico have grown dramatically in recent years and largely represent retail grocery and food service products targeted to Hispanic markets in the United States.

**COVID-19 Impacts**

**Food service shutdown**

The first wave of impacts, which began in mid-March, resulted from the near total shutdown of food service. Abruptly, food demand at retail grocery nearly doubled. The surge in retail grocery demand was further aggravated by panic buying as consumers attempted to stockpile food at home. Retail grocery demand quickly overwhelmed the retail grocery supply chain resulting in localized and temporary shortages in retail stores. It is important to recognize that there was no actual shortage of product during the first month of the shutdown, but rather bottlenecks in the supply chains. Figure 1 shows beef production was above year earlier levels until April. It became quickly apparent that food service and retail grocery supply chains are very specialized and as a result somewhat inflexible. Food service processors are not equipped to package and label products for case-ready retail sale; and in many cases, distribution systems are largely separate.

The shutdown affected various beef products differently according to their primary use. Table 1 shows that the initial impacts were price decreases for products heavily used in food service, for example, tenderloin (IMPS 189A), brisket (IMPS 120A) and ribeye (IMPS 112A). Simultaneously, products used at retail, especially products that support retail ground beef, that is, chuck and round products (IMPS 114A, 116A, 168, 170) saw immediate price increases (Table 1). Over a period of weeks, adjustments eventually allowed some food service processors, distributors and retailers to adapt to retail grocery demand. Creative solutions included some restaurants, experiencing no, or greatly reduced, foot traffic, selling raw product direct to consumers, either from existing inventories when the shutdown occurred, or because they still had access to food.
service supply chains. QSR recovered somewhat quicker than full service restaurants because of the availability of drive-thru service, which further reduced some of the retail grocery burden. Full service restaurants developed or emphasized take-out, curbside and delivery options, often with a limited menu. Adjustments to the limited food service channel continued through April and May and, to some extent, for many weeks thereafter.

The contrasting impacts in retail grocery and food service ground beef supply chains are demonstrated in Figure 2, which shows weekly prices for chucks (IMPS 113C) and fresh 50% trimmings. In the first few weeks after the shutdown of food service, markets for ground beef sources showed diverging price impacts. From early March to early April, the price of beef chuck clods (IMPS 114A) and chuck rolls (IMPS116A) increased sharply, driven by sharply higher retail grocery demand for ground beef (Table 1). Simultaneously, the price of 50% lean trimmings, used primarily for food service ground beef, decreased nearly 39%, to 18-yr lows. After another 4 wk or so, arbitrage and adjustments re-established the normal price relationships between these beef product markets. Most beef wholesale markets increased to record levels in April and May (Table 1) due to the supply disruptions in beef packing, although tenderloin (IMPS 189A) did not reach record high levels because the product is heavily dependent on food service demand (Table 2), which remained severely reduced.

Figure 1. Beef production, federally inspected weekly.

Packing plant disruptions

The second wave began in April when COVID-19 affected the labor force of harvest and processing installations and severely reduced output. Never before have so many packing and processing plants been affected simultaneously by reductions in capacity. Some harvesting plants completely shut down for up to 2 wk and others curtailed output due to labor force reductions. Cattle slaughter decreased weekly through the month of April, reaching a peak reduction of 34.8% down year over year the end of April, and then slowly recovered through May. Total beef production over a 9-wk period of these effects was down 17.9% compared to the same period 1 yr earlier (Figure 1). This reduction in beef production resulted in real, though temporary, shortages of product that looked to many consumers like more of the same conditions as the initial shutdown in March and early April. The beef supply disruptions were exaggerated by the continuing limitations in the food service sector and the added demand continued to stress the retail grocery supply chain. Over several weeks, additional adjustments were made to help food service supply chains support retail grocery including more bulk packaging and, in some cases, temporary exemptions from some labeling requirements.

Retail beef prices, which reflect retail grocery prices (as opposed to food service), responded as expected but with some difference in timing. The monthly retail all-fresh beef price increased modestly in April before spiking higher in May and June. The May all-fresh price jumped to $704.50/cwt, up 18.7% over the January and February average pre-COVID level of $593.60/cwt and 19.3% higher year over year. The all-fresh retail price peaked in June at $738.20/cwt, up 26.2% compared to June 2019 levels. Retail beef prices decreased in July and August, albeit more slowly than wholesale beef prices, and remained higher year over year in August. An important market function is to use higher prices to ration demand when supplies are limited and thus avoid shortages. In this situation, the dramatic rise in retail beef prices helped to ration limited beef supplies in the March to May period but the magnitude of the shock and supply disruptions overwhelmed rising prices and led to temporary, sporadic product shortages in retail grocery.

The impact on and perception of consumers to these two waves of impacts was similar due to the lack of product in grocery stores in both cases. The reality of those impacts was very different—one due to bottlenecks and rigidities in the supply chain and the other the result of actual reductions in product
availability. The combined impacts of the shutdown and packing plant disruptions were unprecedented volatility in beef product markets. Table 2 shows numerous and varied impacts on selected beef product markets. For example, the shutdown of food service caused beef tenderloin (IMPS 189A) to drop to record low levels in April, reaching a weekly low that was down 49% from the 2019 average level (Table 2). Many wholesale beef prices reached record high levels in May because of the supply shortages. Some products, such as the chuck clod (IMPS 114A) and inside round (IMPS 168) briefly reached levels nearly three times the average 2019 price for those products (Table 2). Perhaps most dramatic was the price of fresh 50s trim, which dropped to an 18-yr low in early April before jumping to a record high 5 wk later. The May price peak for fresh 50s trim was over 3.5 times higher than the average price level in 2019 (Table 2).

The focus of this article is on beef products and supply chains from packers downstream. However, upstream cattle production is broadly part of the beef supply chain and cattle markets were significantly affected by the packing plant disruptions in April and May and beyond. The reductions in packing plant operations effectively cleaved beef product markets from cattle markets for several weeks. During this period, beef product markets generally moved in opposite directions from fed cattle markets. The lack of packing capacity created beef shortages that led to immediate and dramatic price spikes for beef products while that same lack of packing capacity created an immediate excess supply of fed cattle relative to packer demand and led to lower fed cattle prices. Many concerns were voiced about the disconnect between fed cattle markets and boxed beef cutout prices when there was, in fact, an unavoidable temporary physical disconnect that caused prices to move in opposite directions above and below the packing level of the industry. Although this was an extremely unusual situation, the market reactions at all levels were exactly what is expected and helped support a remarkably rapid recovery in beef product markets.

Table 1. Wholesale beef price changes, selected products

| Product          | IMPS* | Shutdown impacts % Price change 3/6/20–4/10/20 | Reduced production impacts % Price change 4/10/20–5/8/20 |
|------------------|-------|-----------------------------------------------|----------------------------------------------------------|
| Ribeye 112A      | –17.1 | +80.9                                         |
| Chuck Clod 114A  | +27.1 | +150.7                                        |
| Chuck Roll 116A  | +39.1 | +67.9                                         |
| Brisket 120A     | –15.5 | +105.5                                        |
| Inside Round 168 | +28.4 | +106.2                                        |
| Gooseneck Round 170 | +31.1 | +90.6                                          |
| Loin Strip 180   | +17.8 | +50.7                                         |
| Loin Top Butt 184 | –2.1  | +129.0                                        |
| Tenderloin 189A  | –42.0 | +126.2                                        |
| Fresh 50s Trim   | –38.9 | +720.0                                        |

Data sources: USDA AMS LM_XB 459 and LM_XB 460, compiled by the Livestock Marketing Information Center.

*Institutional Meat Purchase Specifications.

Figure 2. Food service vs. retail grocery ground beef demand.
Major impacts on fed cattle markets extended well beyond June. Reduced cattle slaughter in April and May resulted in a large backlog of fed cattle that took many weeks over the summer and fall to work through. No cattle were depopulated and delayed feedlot marketings resulted in excess supplies of fed cattle that pushed fed cattle price lower into July before recovering into the fall. Delayed fed cattle slaughter resulted in heavier carcass weights, higher quality grading percentages and other lingering impacts on beef supplies and product mixes.

Beef exports also dropped sharply in May and June before recovering in July and by August exceeded year earlier levels. Beef imports spiked higher with a delay, jumping sharply in July and remaining well above year earlier levels in August. Beef imports increased in the summer in response to strong ground beef demand from the recovery of QSR restaurants. Large supplies of fatty trimmings resulting from heavy carcass weight in domestic fed cattle and stimulated additional lean demand.

In 2020, beef in cold storage increased counter-seasonally in March before declining seasonally in April and May, likely as a result of the abrupt loss of food service demand. Cold storage was not available to offset retail grocery product shortages because it consists of the wrong set of products and because the quantity of cold storage holding is small. Monthly beef cold storage inventories averaged 458 million pounds in 2019. This represents less than 1 wk of beef production, which averaged over 513 million pounds per week in 2019. This means that even if all cold storage beef was pulled out at once, it would represent less than 1 wk of beef supply and, as noted previously, would not match the mix of products needed in food service and retail grocery markets.

**Recovery and permanent impacts?**

As noted previously, the majority of the initial COVID-19 shocks were resolved by the end of June. Certainly, there were continuing impacts after June and additional recovery will occur for many months. Ripple effects on beef quality, product mixes, beef exports and imports, and feedlot dynamics will extend beyond 2020. Moreover, at the time of writing in October 2020, the public health crisis and the macroeconomic impacts of COVID-19 in the United States and globally were continuing and could lead to new or renewed impacts going forward. Food service is still significantly diminished with a slow recovery that will last many more months. Clearly, recovery is a moving target as 2020 moves into the fourth quarter.

Many questions have been raised about likely permanent or very long-lasting effects of COVID-19 on food industries, beef supply chains, and the cattle industry. Given the on-going nature of the situation, it is premature to say anything definitive about permanent impacts. There are clear indications of several changes that will affect food industries; including the likely loss of food service establishments (which may rebuild or be replaced over time); changes in travel, especially business travel in a world of Zoom meetings; a larger role for take-out, drive-thru, and home delivery food service; and the extent to which home food preparation results in a long-term reduction in food service demand. Only time will provide the perspective.
to understand the types of changes and long-term impacts on food industries.

COVID-19 also exposed rigidities and lack of agility of beef supply chains to respond to this type of shock. Questions have been raised about the likelihood of fundamental changes to increase the resilience of beef supply chains. Certainly, it seems likely that individual firms may assess some business practices and make some changes. Firms may consider a wider range of procurement practices, such as contracts and other means to enhance both supply reliability and manage price risk. Many firms may devote additional resources to management planning with such things as supply chain mapping and other activities that will help identify supply chain redundancies and contingency plans to reduce the impact of future supply shocks. However, the current structure of food service and retail grocery supply chains evolved in response to efficiencies and economic returns to specialized facilities and have contributed to reducing the cost of food in the United States. Less specialized multifunction facilities that operate simultaneously in food service and retail grocery chains would be less efficient and more costly. Marginal changes in management and operational flexibility to increase the tactical agility of firms are more likely than massive reinvestment in new beef supply chain infrastructure.

Summary

COVID-19 has revealed both strengths and weaknesses in beef supply chains. It has also revealed much about market economics. Under normal, stable market conditions, markets coordinate resource and product allocation with such efficiency and subtly as to be largely unrecognized. Only in the face of abrupt and unexpected shocks are the reactions of markets to rebalance and restore equilibrium revealed. Freely operating markets react with dramatic, sometimes surprising, and confusing responses to massive and unprecedented shock such as COVID-19. Consumers, producers, companies, and policymakers all learned much about how beef supply chains and the market-based economy works as a result of COVID-19.

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1Fabrication of feedlot finished (fed) steer and heifer carcasses produces fatty trimmings, which are mixed with additional lean to produce ground beef. Beef packers may produce and sell a range of trimmings products with varying lean percentages but the most common are fresh 50% lean trimmings (50s).

2Specific beef product references are identified by the corresponding Institutional Meat Purchase Specification (IMPS) product code. IMPS codes are maintained by the Agricultural Marketing Service (USDA-AMS) and are available at https://www.ams.usda.gov/sites/default/files/media/IMPS100SeriesDraft2020.pdf.

3The all-fresh retail beef price is a composite retail grocery price series provided by the Economic Research Service (USDA-ERS) that includes a variety of Choice and other grade beef products to better reflect retail beef purchases. The data is available at https://www.ers.usda.gov/data-products/meat-price-spreads/.

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Feature Article

Effect of COVID-19 on animal breeding development in China and its countermeasures

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Key words: animal breeding, China, COVID-19, sustainable development

Introduction

In 2020, the coronavirus disease (COVID-19) has spread to more than 200 countries and regions and has far-reaching effects on human safety and living standards. In order to stop the spread of the virus and effectively bring it under control, a series of effective measures have been taken by the Chinese government; for example, no one is allowed to go out in different provinces on holidays. However, due to the long epidemic prevention and control period, significant challenges have brought to the development of China’s agricultural industries, including animal husbandry, planting, and agricultural product processing. The objective of this review is to analyze the adverse impact of COVID-19 on the development of animal breeding in China. Then it provides some suggestions to reduce the negative impact and help promote the sustainable and healthy development of animal husbandry to ensure that China can win the battle against COVID-19.

Effects of COVID-19 on the Development of Animal Breeding in China

Since the earliest African pig disease was discovered in China in August 2018, it has spread across the whole country and the regions, which caused the death of large numbers of pigs, a shortage of pork products, and a significant increase in the price of pork and other meat products. This year has seen another outbreak. To prevent the spread of the virus, trade markets were closed, slaughterhouses resumed work with a delay, and transportation was blocked. These factors lead to feeding supply shortage, unmarketable products, and an increase in production and storage costs (Jiang, 2020).

Furthermore, during the COVID-19 epidemic, a large amount of funds were needed for safe isolation and personnel health management, which caused some enterprises to break the capital chain (Liang, 2020). China’s livestock and meat prices rose 80.8% in early 2020, with pork prices rising 122.5%, according to the National Bureau of Statistics (Wei, 2020). However, the production of poultry meat and eggs has increased significantly since last year, with a relative surplus of products and prices falling rapidly after reaching a peak (Figure 1). Therefore, with the implementation of policies such as the resumption of pig production, it is desirable that China’s pig production will basically return to the perennial level by the end of this year.

In order to effectively control the epidemic, China has implemented traffic control for a long period of time, strictly controlling the flow of people and vehicles. On the one hand, this has serious implications on the normal supply of animal husbandry production materials and the sales and transportation of products and even leads to the disruption of the entire industrial supply chain. On the other hand, due to poor antirisk capability and a low level of epidemic prevention, small- and
medium-sized enterprises have some difficulties in continuing to operate after the epidemic (Cai, 2020). In addition, the impact of COVID-19 has fully exposed the shortcomings of China’s animal husbandry industry, with weak regional structure, small environmental bearing capacity, and lack of major grain-producing areas. Therefore, combined with the current development situation at home and abroad, it is extremely urgent to promote the transformation and upgrading of China’s animal husbandry industry structure to the direction of mechanization, scale, and standardization.

Meanwhile, the sudden outbreak of COVID-19 is also a warning for the prevention and control of the disease in China’s animal husbandry industry. This shows that China’s livestock industry does not afford enough attention to animal epidemic prevention and control. Therefore, we should enhance the animal epidemic prevention system, especially the prevention of African swine fever, avian flu, foot-and-mouth disease, and other diseases (Hu, 2020). In addition, we should also improve the immunity of animals, and we should enhance the monitoring and detection technology for major diseases. At the same time, we must accelerate the establishment of a biosafety management system that can be placed in real time, monitored and traceable.

With the global spread of COVID-19, the growth rate and trade scale of the global economy have dropped significantly, and livestock products are in short supply. World meat production in 2019–2020 is expected to achieve 33.5 billion tons, with a reduction of 1.0% over the previous year. This is a sharp departure from the trend of steady growth over the past two decades (Li, 2020). This short supply of animal products in some countries and their measures and technical barriers promoted trade restrictions, which caused difficulties for Chinese soybeans, corn, and other raw materials, as well as difficulty importing meat products. It further increases the tension between the domestic supply and demand, increases the instability of the domestic market, and promotes product price volatility.

Strategies for Responding to COVID-19

Animal husbandry is a major industry related to the national economy and people’s living standard in China. Meat, eggs, and milk are important varieties of people’s “vegetable basket”. Therefore, the COVID-19 epidemic presents both opportunities and challenges to China’s livestock industry. Faced with a series of problems caused by the outbreak of COVID-19, China should ensure the future development of a high-quality livestock industry and comprehensively improve the safety guarantee capability of China’s livestock and poultry products, both from the perspective of long-term development and short-term impact. This provides a basic guarantee for consumers and is essential for winning the battle against COVID-19. It is suggested that, while preventing and controlling COVID-19, decisive measures should be taken in accordance with the law to better ensure the safe production and effective supply of the breeding industry (Figure 2). First, local governments should, on the premise of scientific and safe epidemic prevention and control, guarantee the normal production order of the breeding industry and the circulation of products (meat, eggs, milk, and aquatic products) in accordance with the law. Second, we should do a good job in production management and guarantee an effective and safe supply of animal husbandry products so as to stabilize market prices. Third, it is proposed to improve the immunity of breeding animals. Further attention should be paid to the protection and cultivation of high-quality breeding varieties. Moreover, we need to actively carry out the detection and evaluation of novel varieties that may impact the breeding process. The government should also increase financial investment in aquaculture and speed up the cultivation of more high-end technical talents in the aquaculture industry. Sixth, we should actively respond to international trade restrictions and take a series of measures to strengthen China’s external cooperation in animal husbandry.

Conclusions

In conclusion, novel coronavirus prevention and control in China needs the joint efforts of all Chinese. We should rely on the power of policy macro-control and scientific and
technological innovation to stabilize the production of the livestock and poultry industry and the supply of livestock and poultry products in China. We should also speed up the transformation and upgrading of China’s animal husbandry and promote its development to a higher quality. These countermeasures are hoped to help China better control the COVID-19 epidemic and provide stable material security and maintain social stability.

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Impact of COVID-19 on animal production in Ghana

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Key words: COVID-19, feed resources, input supply, livestock production, lockdown

Introduction

COVID-19 is a highly infectious disease originating from Wuhan, a city in China (Lone and Ahmad, 2020), in November 2019. This virus has, since its emergence, caused widespread damage to the world, including both developed and developing countries. Aside from the health implications of the disease, other important areas, including the agricultural value chain, such as the livestock production sector, has had its share of the effects (Bisson and Hambleton, 2020) given its role in nutrition, livelihood, and food security.

The COVID-19 pandemic has also brought into focus a number of issues, including food safety and hygiene issues, intricately linked to the consumption of the animal resourced foods, the high cost of production on the African continent versus cheaper imports now less available due to global movement restrictions, and the weaknesses in feed, veterinary, insurance, and other supply chains (AU-IBAR, 2020). Like other African countries, animal production in Ghana has not been spared the negative impacts on the activities of stakeholders along the livestock value chain from feed production and supply, communal grazing, sustainable use and conservation, and provision of veterinary services, including artificial insemination, livestock trade, transport, slaughtering, processing, and marketing of livestock products.

These suggest the need for various governments and stakeholders in the West African region, including Ghana, to put in measures to counteract the adverse effects of the pandemic in the livestock subsector and the agricultural sector as a whole. This paper examines the effects of COVID-19 on animal production in Ghana.

Implications

• COVID-19 has affected the importation of animals and livestock products into Ghana with the potential of lowering the consumption of animal protein.
• There has been a reduction in the availability of feed resources and farm inputs for animal production, leading to price increases.
• Animal production activities, including feeding, management, and disease control, have been adversely affected as a result of lockdown due to the COVID-19 pandemic.
• Capacity building programs in animal breeding have had challenges as a result of restrictions, leading to the rescheduling of most programs.

Effects on Food Supply and Demand

The first two cases of COVID-19 recorded in Ghana on March 12, 2020, were imported. Since then, the disease has been spreading in the country. As of October 7, 2020, there are 46,829 confirmed cases, 46,006 recoveries/discharges, and 302 deaths. The active cases now stand at 466 (Ghana Health Service, 2020). On March 30, 2020, there was an imposition of partial lockdown in some parts of the country for 2 wk as the virus began to spread. Decongestion and some market closures (Asante and Mills, 2020) led to shortages of some feed ingredients for formulating livestock feeds, including maize, wheat, soybean, and fishmeal, resulting in price increases of these commodities.

Ghana imports most livestock products from neighboring West African countries, the United States, Brazil, and the European Union. The live animal imports and importation of day-old chicks (DOCs) and parent stock into Ghana are as shown in Tables 1 and 2, respectively. Livestock trade mainly from the Sahel regions of West Africa into Ghana has been severely affected as a result of the closure of the land borders (Asantewa, 2020). For example, the quarantine posts for livestock recorded a decline in the average number of trucks conveying livestock, such as Sanga cattle (Figure 1) from...
Table 1. Live animal imports by species into Ghana

| Year | Cattle | Sheep | Goats | Total | Share of total imports* |
|------|--------|-------|-------|-------|-------------------------|
|      |        |       |       |       | Cattle | Sheep | Goats |
| 2008 | 1,081  | 1,401 | 1,514 | 3,996 | 27.1%  | 35.1% | 37.9% |
| 2009 | 10,119 | 4,987 | 6,098 | 21,204| 47.7%  | 23.5% | 28.8% |
| 2010 | 11,389 | 4,843 | 3,711 | 19,943| 57.1%  | 24.3% | 18.6% |
| 2011 | 9,384  | 2,835 | 2,495 | 14,714| 63.8%  | 19.3% | 17.0% |
| 2012 | 23,622 | 9,840 | 10,008| 43,470| 54.3%  | 22.6% | 23.0% |
| 2013 | 21,131 | 16,738| 16,953| 54,822| 38.5%  | 30.5% | 30.9% |
| 2014 | 20,948 | 22,188| 32,012| 75,148| 27.9%  | 29.5% | 42.6% |
| 2015 | 17,968 | 15,763| 20,004| 53,735| 33.4%  | 29.3% | 37.2% |
| 2016 | 23,575 | 13,854| 16,900| 54,329| 43.4%  | 25.5% | 31.1% |
| 2017 | 32,249 | 47,526| 46,665| 126,440| 25.5%  | 37.6% | 36.9% |
| 2018 | 54,566 | 65,950| 97,703| 218,219| 25.0%  | 30.2% | 44.8% |

Source: Veterinary Services Directorate of Ministry of Food and Agriculture (2018).

*Statistics, Research and Information Directorate of Ministry of Food and Agriculture (2018) (Computed).

Table 2. Importation of day-old chicks and parent stock (numbers) into Ghana

| Year | Broiler | Layer | Turkey | Parent stock |
|------|---------|-------|--------|--------------|
| 2009 | 454,640 | 1,036,872| 6,972 | 58,822 |
| 2010 | 379,643 | 1,422,199| 21,290| 95,016 |
| 2011 | 547,205 | 2,461,140| 9,180 | 9,180 |
| 2012 | 651,112 | 3,227,844| 16,966| 114,344 |
| 2013 | 1,088,865| 4,481,602| 9,286 | 126,288 |
| 2014 | 3,161,144| 602,209 | 6,840 | 18,080 |
| 2015 | 246,948 | 2,573,326| 19,497| 111,692 |
| 2016 | 784,917 | 3,963,705| 13,412| 158,386 |
| 2017 | 724,580 | 5,476,815| 14,945| 86,099 |
| 2018 | 511,960 | 7,130,999| 41,189| 101,871 |

Source: Veterinary Services Directorate of Ministry of Food and Agriculture (2018).

Figure 1. Sanga cattle.

Effects on the Food Supply Chain

Travel bans affected the importation of food into the country, as well as the transportation of farm produce from food-producing areas within the country to market centers. Also, decongestion and closure of some market centers to enforce social distancing among traders reduced food supplies leading to a hike in food prices in most urban markets across the country, especially during the early days of the lockdown (Asante and Mills, 2020; Gakpo, 2020).
A total of 3,579 cattle, 1,985 sheep, and 3,978 goats were imported 3 wk before the lockdown at the Paga animal entry point but were reduced to 1,525 (57%), 780 (61%), and 1,423 (64%), respectively, during the lockdown period (Tasiame et al., 2020). Moreover, the Kumasi slaughterhouse, which is purposely for slaughter and sale of meat, recorded an average slaughter of 725 cattle and 533 for sheep and goats, respectively, 3 wk prior to the lockdown but this reduced drastically leading to increases in the price of meat.

**Effect on Input Supply**

Ghana imports most agricultural inputs from other parts of the world. COVID-19 prevention protocols have reduced access to inputs and services for animal breeding and production. Movement restrictions and disruption of national and international trade routes have curbed farmer access to breeding materials and replacement stocks (e.g., DOCs and semen; FAO, 2020). Most agricultural inputs are now more expensive to import due to the closure of borders and restricted to commercial flights, thus increasing production cost and reducing profit margins of farmers. Additionally, uncertainty and fear have had a negative impact on planning decisions. For instance, when the COVID-19 lockdown was announced by the authorities in Ghana, poultry farmers procured raw materials in advance as farmers were not sure how long the lockdown was going to be and this led to huge losses and there was no market for the finished products as most clients had either downgraded or had closed down completely. According to the Ghana Poultry Farmers Association, supply exceeded demand and this glut in chicken and eggs has been a major loss to the poultry industry. Overall, there have been serious disruptions of income of especially women livestock farmers with serious consequences on household essentials and nutrition. On the other hand, local hatcheries have seen a tremendous increase in the demand for DOCs due to the closure of land and sea borders. Before the pandemic, local farmers were not interested in local DOCs with the perception that products from local hatcheries are inferior to imported ones. At the same time, COVID-19 provides an opportunity to increase the production of selected value chains. Scaling up investment in the government’s Rearing for Food and Jobs (RFJ) Programme has boosted meat and egg production. Under the RFJ Programme, meat processing plants, small scale poultry farmers, hatcheries, and small ruminant farmers have been supported with resources to improve the productivity of their enterprises.

**Effect on Animal Breeding Activities**

The pandemic also resulted in an interruption of breeding programs. The movement restrictions and possible infection of the workforce resulted in a shortage of labor (FAO, 2020). Transhumance and pastoral practices faced challenges with regards to feeding and, hence, halted breeding programs as they may have not been able to provide concentrate feed as required for an intensive system of production. Workers call in sick, while others also avoid work for safety reasons, and all these disrupt program timelines.

The livestock production system in Ghana is predominantly extensive and, therefore, restrictions on the movement of herdsmen and their animals have had significant impacts on feeding and production. Most of the herders are young men hired by cattle owners to take care of their animals throughout the year. Unfortunately, the Ghana National Association of Cattle Farmers reports that, with the outbreak of COVID-19, most of the herders have left to look for other means of livelihood and this has had a major impact on their operations. Movement restrictions have also disrupted transhumance and crippled pastoralists’ ability to feed their animals (FAO, 2020). Reduced access to animal feeds as a result of physical distancing and requirements for additional personal protective equipment has reduced the efficiency of industrial feed enterprises (FAO, 2020). Ruminant livestock keepers have thus resorted to “cut and carry” to feed the animals, which is very expensive for most farmers, leading to malnutrition and disposal of most of their animals sometimes at very low prices.

Services provided by veterinarians to livestock farmers have also been badly affected as a result of the restrictions. Generally, in Ghana, some livestock farmers are unable to access veterinary services for their stock due to the relatively low number of veterinarians and the high cost of services and medicines. Unfortunately, the COVID-19 pandemic has worsened this situation as the few service providers become more expensive and difficult to reach.

**Effect on Capacity Building**

Capacity building programs on animal breeding in Ghana, including sharing of information from research to stakeholders, education on the National Strategic Action Plan on Animal Genetic Resources, and training of field extension personnel have either been put on hold or restricted as a result of the COVID-19 pandemic. Additionally, various stakeholders for animal production have been rescheduled to the year 2021. However, such platforms provide an opportunity for researchers, industry players, farmers, and students in animal agriculture to discuss current issues germane to animal agriculture and share ideas on lessons learned and best practices. Graduate students who were supposed to travel and undertake some laboratory work in connection with their postgraduate research programs in some external collaborating universities have had challenges to undertake these stages of their program. These have serious implications for the training and mentoring of the next generation of animal breeders for Ghana. Although various attempts have been made to train livestock workers via various electronic platforms, these have largely been inaccessible due to power, infrastructure, and internet accessibility challenges.

**Conclusion**

The COVID-19 pandemic has impacted livestock production in Ghana negatively via demand and supply of food, input supply and veterinary services, and animal breeding and husbandry, as well as human and institutional capacity building.
On the other hand, unique opportunities have emerged for stakeholders to support various activities in the value chain whilst ensuring sustainable livestock production and nutritional food security.
Perspective

Impact of COVID-19 on animal production in the Czech Republic

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Key words: animal breeding, COVID-19, Czech Republic, impact of crisis, prices, services

Introduction

The COVID-19 crisis has had a negative impact on macro-economic development in the Czech Republic, with the second quarter of 2020 seeing the most severe downturn since the formation of the Czech Republic in 1993. The Czech Statistical Office recorded a year-on-year decrease in GDP of 11% (CZSO, 2019). The analysis presented here focuses on the impact of the COVID-19 crisis on selected aspects of animal breeding and summarizes the situation up until 1 October 2020.

Impact of COVID-19 Crisis on Animal Breeding

We carried out a short survey analyzing the impact of the COVID-19 crisis on animal breeding in a selection of livestock animals. Based on the outcomes of this survey, we conclude that the crisis has not impacted on data collection, performance recording, or the prediction of breeding values in cattle, sheep, goats, and pigs. Some specific changes, which notably affect cattle milk recording methodologies, were observed. More flexibility was given to milk recording technicians when recording milk yield data at stables, while intervals between tests were extended. Some milk yield data were accepted without factoring in all milk samples due to various technical issues, which led to a slight decrease in the number of milk samples recorded. Restrictions were imposed on visits to organizations involved in milk recording, data processing, and the prediction of breeding values. For instance, restrictions on access to goat milk recording stables resulted in samples being delivered to collection points instead. Strict hygienic rules were introduced at all stables involved in performance recording. At the beginning of the COVID-19 crisis, there was a reduction in the supervision of animal breeding and related services. The survey revealed a major impact on DNA analysis in the areas of parentage verification and genomics. Due to the preference of suppliers to prioritize deliveries to human health laboratories tasked with analyzing Covid-19 virus samples, DNA analysis laboratories encountered problems with purchasing materials and experienced significant increases in costs. The crisis has not had an impact on animal identification and registration or ear tag logistics (Personal communication, Czech-Moravian Breeders’ Corporation) (Figure 1).

Implications

- The COVID-19 crisis has not had a strong impact on animal breeding, identification, performance recording, or genetic evaluation.
- The crisis has affected DNA analysis and basic and applied research.
- Production of raw milk and cattle slaughtering has not been affected by the crisis.
- Impacts on prices have affected farmers, processing companies, consumers, and the international trade in agricultural products.

Impact of the COVID-19 Crisis on Animal Breeding Research and Other Activities

The crisis negatively affected the organization of various breeder events, conferences and exhibitions both nationally and internationally. Many of these events were canceled. Some laboratory providers of animal breeding and veterinary services were enlisted to assist in the analysis of human COVID-19 samples (Biology Centre, CAS, 2020; State Veterinary Administration, 2020). The crisis not only negatively impacted research projects, particularly those that are international in scope, but also created practical issues with regard to sample taking and maintaining contact with breeders.
Increased interest in the scientific aspects of the virus has led to the establishment of a new COVID-19 research center at the Czech University of Life Sciences in Prague. This centre is involved in researching infectious diseases among animals, as well as humans (Votruba, 2020).

Practical Examples of Impacts on Breeders

Several studies carried out by agricultural associations reveal that the crisis has had a particular impact on small farmers reliant on independent production. The almost complete cessation of agritourism dealt a hammer blow to direct sales at these farms. Public farmers’ markets were also required to cease trading and, in some cases, takings dropped by almost 50%. The shutting of restaurants and schools had impacts on the demand for foodstuffs and semifinished goods. For example, sales between beef cattle breeders and schools were immediately affected once restrictions came into force, with breeders compelled to find alternative customers. Not only did demand decrease but also slaughterhouses began to offer lower prices than before the crisis. As a result, the Ministry of Agriculture put in place various supports for farmers and food processing plants. Various large farms encountered labor shortages due to the quarantine, with milking and feeding particularly affected (Czech Beef Breeders’ Association, 2020; Pýcha, 2020).

Trends in Raw Milk Production and Pig and Cattle Slaughtering by Live Weight

A total of 3.1 million tonnes of milk were produced in the Czech Republic in 2019 (CZSO, 2020a). The first half of 2020 saw the biggest annual rise in milk production since 2015, with 1.6 million tonnes of milk produced. Based on this data, the crisis has had no effect on milk production.

In 2019, the production of cattle for slaughterhouses amounted to 167,900 tonnes by live weight. Production of slaughtered cattle grew by 2.6% during the first half of 2020, representing the biggest rise in production for the period 2017–2020 (CZSO, 2020a).

Over recent years, pig slaughterhouse production by live weight has undergone a long-term economic depression nationally. Production at pig slaughterhouses in 2018 decreased from 302,019 tonnes by live weight in 2018 to 286,762 tonnes in 2019 (CZSO, 2019). Production decreased from 152,024 tonnes during the first half of 2018 to 140,148 tonnes by live weight for the first half of 2020. Reflecting a sharp and long-term decline in production, slaughtered pigs amounted to 286,800 tonnes by live weight in 2019. In the first half of 2020, production decreased by 1.2% year-on-year in line with this previous downward trend (CZSO, 2020b).

Impact on Markets, Prices, and Foreign Trade

The restriction measures introduced led to rapid reversals in food demand. The most direct results of these measures were the cessation of public consumption within the catering industry, panic buying at retail outlets, and an overall increase in online shopping. As a part of AC Nielsen Czech Republic’s retail monitoring, we examined the sales of nine foodstuff categories of animal origin at the largest retail chains nationwide, namely pork cuts (ham, shoulder, and neck), drinking milk, yoghurts (white and flavored), butter, chicken, and eggs. In the first quarter of 2020, year-on-year sales grew by between 2% (flavored yoghurt) and 15% (pork shoulder) in seven of the nine categories assessed. Sales of pork ham and neck fell by 25% and 35%, respectively. This sharp decrease was probably reflective of the limited ability of producers to satisfy the feverish increase in demand. In what was a completely unprecedented situation, supplies of various meats and cuts disappeared from retail chains for days at a time or parts of days. In the second quarter, year-on-year sales in seven of the categories assessed increased by between 1% (with pork neck) and 19% (with white yoghurt). Sales of drinking milk and flavored yoghurt remained stable or slightly decreased (AC Nielsen Czech Republic, 2020).

Agricultural commodity and foodstuff prices were not unaffected. With regard to farm, processor, and retail sales, there was a generable variable reduction and, in exceptional cases, stabilization of animal product prices in all three categories between March and June (CZSO, 2020a,b,c). In somewhat simplistic terms, farms were worst affected, with processor prices declining only in some product categories and consumer prices decreased the least. Over the same 4 months, live pig (by 11.8%) and slaughtered cow prices (by 7.9%) fell sharply and rapidly compared to previous periods. In line with usual price volatilities, farm-gate milk and egg prices reduced by 5.6% and 6.8%, respectively (CZSO, 2020c). Processors were paid 11.9% less for pig ham and 0.7% and 0.9% more for beef forequarters and hindquarters, respectively (CZSO, 2020d). Consumers paid 4.2–7.6% less for various pork cuts, 0.6% more for beef sirloin, and 1.4% more for Edam cheese. Butter was 9.8% cheaper in June than in March (CZSO, 2020e).

Figure 1. Dairy cattle.
Concerning foreign trade (Ministry of Agriculture, 2020), live cattle was the most severely affected. Net exports of live cattle, a traditional Czech export commodity, dropped by 14% in quantity and 20% in value year-on-year for the period from March to June 2020. Exports to Turkey and Netherlands in particular fell dramatically. The reduction in net exports of pigs and poultry, however, was less severe. On the other hand, exports of raw milk grew by 9%. The most important destinations are two German processing plants close to the Czech border. The lack of interruption to the supply chain is probably explained by the fact that processors largely use their own vehicles for the transportation of milk products and tend not to rely on hired containers. While a slowdown in certain net imports was observed, this was more the exception than the rule. For instance, although imports of beef, cheese, and butter decreased, net pork imports grew by 14% (frozen pork by 38%) year-on-year between March and June. There was a considerable increase in pork imports from Poland and Belgium. Summed up, the closure of national borders and the consequent disruptions to the availability of trucks and other means of transport did not cause a fatal blow to the sector. Over the same 4-month period, exports and imports of Czech animals and animal products decreased year-on-year by 1% and 0.7%, respectively.

### Conclusion

Although the COVID-19 crisis has had an impact on prices for both customers and producers, no substantial effect on animal breeding has been observed. In terms of the long-term outlook, the crisis may result in the implementation of new distribution channels and encourage self-sufficiency among farmers and producers. It is reasonable to assume that consumer habits may also change over time. A number of new research projects have been established due to the impact of the COVID-19 crisis.
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Perspective

Covid-19 pandemic and its impact on the breeding world

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Implications

• Since March 2020, like all other industries worldwide, the breeding world had to face the COVID-19 crisis.
• Breeding activities belong to essential economic activities being able to continue in some extend services and activities during locked down (for example AI).
• However, it is interesting to look at the changes that occurred during this time.
• Moreover, I invite you to discuss the long-term evolution between actors’ and also breeders’ needs and behaviors.

Key words: animal breeding, biotechnologies, COVID-19, phenotypes monitoring, research on genomics

Introduction

Since the end of 2019, the COVID-19 pandemic, also known as the coronavirus pandemic, has been an ongoing pandemic of coronavirus disease (COVID-19) caused by the SARS-CoV-2 virus. The disease was first identified in December 2019 in Wuhan, China. The World Health Organization declared the outbreak as a Public Health Emergency of International Concern in January 2020, and COVID-19 was recognized as a pandemic in March 2020. As of the beginning of October 2020, more than 35 million cases have been confirmed in the world and the number of deaths attributed to COVID-19 is now over 1 million. Besides this dramatic situation regarding human fatalities, the world has been on hold since March 2020. As a consequence, the majority of our economic and social activities have been deeply impacted.

This article will outline the consequences of this extraordinary crisis on animal breeding activities either during the lockdown period imposed by a large number of countries or in the longer term after the lockdown. In order to cover this topic properly in essential scopes that lead to genetic improvement, the impact of COVID-19 pandemic will be described first on research activities and then on routine activities.

Impact of COVID-19 on Animal Genetics Research

Research activities like conducting studies and experiments but also teaching, writing scientific articles, and discussing new topics adapted very fast and quite efficiently during the period of lockdown. Scientists are already accommodated to the extensive use of a virtual work environment either within international consortia or with remote teaching in different international universities. Therefore, the impact on daily activities was quite limited with almost no interruption in 2020.

However, there were some negative impacts which can be divided into two categories. The first one with an impact in 2020: as almost everyone except the essential activities, such as hospitals, food industry, and security, were on pause, collection of samples in the field and the work within the laboratories have been delayed for a few months. Consequently, many research projects planned in 2020 and for which sampling was an essential activity will be delayed. In Human genetics, together with the research on infectious diseases and the development of new vaccines, the host genetics studies have been boosted.

Will 2020 be a blank year in animal genetics research? Will the gap increase between human and animal genetics? Or will animal genetics research take benefit of all of these new discoveries in terms of biotechnology (turn-around time [TAT] for virus detection, TAT for virus surveillance, and new approaches taking into account the genetic specificities to understand the variation in the severity of COVID-19)?

The second category of impact is much more critical for animal breeding. As the demand for funds for human health has increased dramatically in all countries, this will definitely generate a research funds shortage for other species, such as livestock. Furthermore, in low- and middle-income countries, such as Africa, nongovernmental organizations focus their actions on infectious diseases and vaccine discovery instead of host genetics. Today, there is an urgent need to better understand the genetics of local breeds and local species in order to allow the local population to
overcome the challenges of food security, climate change, and biodiversity for the next decades.

Another consequence that is not visible at this time of the pandemic is the social impact on research teams. Research activities as many other essential economic activities are based on teamwork. One of the key factors of a successful scientific team is the capability to brainstorm together and to exchange different ideas, with different backgrounds and cultural approaches—all this needs social interactions. The first conclusion of remote working during the first half of 2020 coming from different organizations in finances and in web services shows higher productivity of the employees due to the lack of transportation to the office but also a decrease in creativity and a lack of innovative process or solution. Let’s see in the next years the number of new discoveries in the era of genetics all over the world. Will it be as prolific as previous years and will it be comparable to human genetics?

Impact of COVID-19 on Animal Genetics Routine Work

Animal breeding is a very small and concentrated industry with a very well-organized sector and a clear distribution of the tasks: the recording organizations, the AI centers, the breeding companies, and, finally, the breeders/commercial farmers.

The COVID-19 pandemic impacted field activities deeply, at least in the first months: interruption of farm visits for nonessential activities, such as milk recording, type evaluation, bull dams, and bull sire’s recruitment. Except for some extreme situations, such as in North East of France during the peak of the crisis and the urgency to stop the propagation of the virus, AI daily service never stops in Europe. But how to adapt to the different actors of this industry? And what will be the changes?

2020: less phenotypic data collected

Performance data collection in dairy farms is not automated everywhere. So the first direct consequence will be the lack of data collection during 2–3 mo depending on the regions impacting the workflow of milk samples in laboratories specialized in milk analysis: moreover, some of the traits have been collected without the same process of validation or precision (done by the farmer, e.g., for the quantity of milk) and some other traits will not be collected at all (weaning weight in beef cattle) or even postponed to a later age (type classification).

Will this periodic event have any impact on genetic evaluation? It will depend on the seasonality of animal farming in each country and the species. What percentage of the total amount of yearly records will these 3 mo represent?

More farms equipped with monitoring instrumentation

More than the effect on the evaluation of the herds in 2020, the most important impact for performance recording organizations is still not visible. As Jean Monnet said perfectly: “Human accept change only in necessity and they only see necessity in crisis.” We are facing a huge crisis. That is why we will change a lot and some evolution in our practices, habits, and methodologies will speed up dramatically.

Let us take the sector of traits measurements, such as milk recording. The future of farms will be to be well equipped to collect on daily basis and automatically records on performance traits, on health, on behavior. That will be done without any visits of operator. In the first half of 2020, we clearly see an increase in monitoring equipment sales all over Europe, the Middle East, and Africa.

Besides the traditional tools of breeding, did the COVID-19 crisis impact the implementation of genomics in animal breeding? Two factors may have impacted the number of animals genomically tested and when the test has been done. In regions where sample collection is made by third parties, we faced a momentary stop of the collection due to sanitary reasons advocating the farmers to receive no visits on his farm. Most of the time, the samples were stored on the farms and the samples will have been tested later. However, the impact on the breeding program for the sire selection should not be underestimated here. Holstein genetics is a very competitive market internationally. That’s why one-month delay may take away the chance of a bull to become a young genomic bull servicing AI few months later.

Another reason is the new priorities of some genomic laboratories. Even if human and nonhuman sample analysis does not follow the same network of labs, many laboratories dedicated to animal molecular testing, were switching to COVID-19 testing in order to answer the increased demand for PCR-based tests during the pandemic. The priorities were given to the human tests and the traditional animal genomic tests were postponed or delayed. In some regions where animal genomics was in its starting blocks, its implementation will be slowed down (Figure 1).

Figure 1. In the cattle industry, the Montbeliarde breed is a good example of intensive and early use of genomics at a large scale dedicated to breeding and also herd management to secure herd replacement and farm performance.
Conclusion

What can we expect in terms of the breeding landscape after this crisis? We will definitively face an acceleration of the ongoing breakthroughs or mutations within our breeding world. First, due to the financial burden faced by the different countries, subsidies for the animal world, either breeders association or research, will certainly decrease and sometimes even completely stop in order to fund other more important challenges regarding human health and social security. Consequently, the concentration of actors in the breeding world but also withdrawal from the state of certain activities will engage the different stakeholders to adapt quickly in terms of strategy according to the new level of resources. In that context, what will be the picture of the breeding world in 5 yr? How to conciliate the need of keeping biodiversity within species and critical size to run a breeding program with the new biotechnologies? In a few words, the new challenge could be: how to do differently with less?

Second, the use of new technologies, such as livestock monitoring, will be sped up for many reasons: need to manage larger herds with challenging economical deadlines with real-time data and production insight, keeping sanitary security (reduce farm visits) leading to more autonomy, increased traceability, especially beef industry, increased quality of the production, and lowered production costs together with reduced environmental footprint.

Finally, like the Chinese, the concept of crisis can be expressed in two words: once the risk generated is managed, let us work on the opportunities to accelerate the adaptation of the breeding world by integrating more technologies, either biotechnology or IT (big data), in order to deliver not only the right genetics but also the customized service to livestock farms.

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Perspective

Farm animal genetic resources and the COVID-19 pandemic

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Key words: agroecology, COVID-19, farm animal genetic resources, local breeds, typical food product

Since early 2020, the COVID-19 pandemic is deeply affecting human health and is causing a severe worldwide economic and social crisis. The real dimensions of the impacts are yet to be determined and will differ among geographical areas and economic sectors, including agriculture and animal production. Effects are expected to be higher in poorer and more vulnerable countries and population strata.

Farm animal genetic resources (AnGR) refer to the diversity present within and between farm animal species, the diversity that is necessary for facing the current challenges of food production in agriculture and to meet future demands, in the scenario of the ongoing growth of the human population. A specific focus in AnGR management is on the genetic diversity between and within local breeds and on how to stop the erosion that started in the middle of the last century, with intensification and specialization of agriculture. This note proposes some considerations on the possible effects of the COVID-19 crisis on local breed diversity conservation and mitigation measures.

It has been shown that the DNA sequence of the SARS-CoV-2 virus, the agent of the COVID-19 disease, has similarities with other coronaviruses infecting bats, suggesting that this mammal was the original animal reservoir. The next step, still unclear, is that the virus has arrived in humans through an intermediate animal host, the Chinese pangolin (Manis pentadactyla). Given this framework, it should be noted that much attention has been given to the possible interface between humans and the pangolin, the Chinese “wet markets”, and that much lesser consideration is addressed to the wider interface between humans and the bats’ forest ecosystems. The density of contacts between human populations and previously undisturbed forests is recognized to increase the risk of spillovers. This has been documented for HIV, Ebola virus, and other pathogens (Quammen, 2012).

Some features of animal production systems in different areas of the world contribute to enhancing human–wildlife interactions by clearing new forest areas and by pushing small-holding farmers toward the remaining forests. Although the rate of global net forest loss has somehow decreased in this century, in the period 2010–2015, an average of 3.3 million ha of forest was still lost each year for the expansion of agricultural land. This inevitably affects the ecology of the forest systems. The entry of humans into areas formerly inhabited by wild animals may provide opportunities for animal viruses to enter the human community. Moreover, intensive farming has been sometimes claimed to be among factors triggering the COVID-19 pandemic, but no evidence has been brought forward in this respect. However, there is a clear link between the growth and intensification of the global livestock sector and the global loss of biodiversity and between livestock production systems in general and other recent zoonotic pandemics, for example, caused by influenza viruses. More intensive livestock systems are considered to be associated with higher zoonotic risks (Wallace, 2016), although a debate is still open about the relationship between the risks and scale/intensity of systems. In the intensive farming context, high animal densities combined

Implications

• Endangered breeds in fragile socio-economic contexts are particularly exposed to population decline and stochastic perturbations expected following COVID-19 pandemic.
• The interest of richer societies for short food chains, natural food and traceability of products can create opportunities for local breeds production systems in the context of COVID-19.
• National surveys on the breed diversity status following COVID-19 should address negative situations and opportunities.
• COVID-19 has revealed risks, fragilities and inequalities for our food systems. The aim is to build resilience at all levels. Agroecology, which implies to conserve breed diversity, can play an important role.

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with high animal performances and low genetic diversity of the animals, as in intensive poultry and swine production, amplify the risk of emerging and spreading of diseases. Low genetic diversity is associated with the lack of genetic variants providing resistance to the farmed populations against pathogens, with the risk of faster spreading of the disease.

Considering the links between intensive farming and recent pandemics, we should turn this COVID-19 crisis into an opportunity for rethinking animal production including consumers to substantially reduce consumption of animal protein, reconsidering the ecological dimension of animal production systems, aiming for higher standards of “epidemiological sustainability.”

The effects that the COVID-19 pandemic has on the diversity of local breeds, in the short and medium term, are to be determined. Not enough information is yet available. About 30% of the livestock breeds are considered endangered on the basis of their small population sizes (DAD-IS, 2020), although, for 60% of breeds, basic demography is unknown. Besides other threats, endangered breeds are particularly exposed to the effects of population decline and stochastic perturbations that can be expected following COVID-19 pandemic. The weakness of many local breeds, besides their population size, is also often associated with their farming areas or territory, often characterized by particularly fragile socioeconomic contexts, with limited capacity to react to the effects of the pandemic. Emergencies can have a significant effect on farm animal diversity, in particular, because of disruptions to livestock-keeping livelihoods. In addition, emergencies can negatively affect the sustainable management of AnGR.

The restriction of human movements and of people gathering, business closures, and merchandise trade limitations under COVID-19 are proving the vulnerabilities of food chains. Evidence is available for the general livestock farming sector. But how these elements could affect the short food supply chains associated with local breeds is largely unknown. Different pictures are possible. Poor economic farming contexts can be expected to be less affected by the pandemic. Conversely, in richer countries, food chains characterized by local products, gastronomy, and tourism can be expected to be negatively conditioned. However, on the positive side, in such countries, the higher interest of the society for short food chains, natural food, and traceability of products could also create specific opportunities for the local breeds production systems in the context of COVID-19. Some evidence in this direction is observed in Italy, for example, in the Reggiana cattle, a known example of how a typical product can be beneficial to an endangered breed (Gandini et al., 2007). In the 1940s, the population of Reggiana cows was greater than 40,000; however, the number progressively regressed to 550 cows in the early 1980s as Reggiana cows were displaced by Holstein cows with higher milk production. Since 1992, a consortia of dairy producers initiated the production of a branded Parmigiano Reggiano cheese, made exclusively from milk from Reggiana cows. The branded cheese is today sold at premium prices (+45%) compared with standard Parmigiano Reggiano cheese and, since 1992, has been revitalizing the interest in the breed that has gradually increased in cow numbers to 2,700 in 2020. During the COVID-19 quarantine, March–May 2020, direct sales of the branded Parmigiano Reggiano cheese dropped dramatically but, since March, selling via the internet increased consistently compared to previous years. The Historic Rebel cheese, made with local breeds on Valtellina summer pastures, in the

Figure 1. Orobica goats at a farm-based cheese dairy for the Historic Rebel cheese, Italian Alps. How COVID-19 will affect this short food chain?
Animal Frontiers

Development underlines the need to take actions directed at the agriculture sector at all levels. The 2030 Agenda for Sustainable Development calls for system transformations to encounter evolving situations and opportunities. In general, COVID-19 has revealed risks, fragilities, and inequalities for our food systems. During a severe crisis, the real challenge is to promote system transformations to encounter evolving environmental conditions and human needs, avoiding the return to business as usual. The overall aim is to build resilience in the agriculture sector at all levels. The 2030 Agenda for Sustainable Development underlines the need to take actions directed at transformational change. A transition is needed to more sustainable and resilient food systems capable to produce more, with higher socioeconomic benefits and fewer environmental consequences. In the case of AnGR, for example, a stricter separation between livestock systems and nature areas, sometimes advocated to avoid transmission of zoonosis, might result in negative effects on local breed conservation. On the other hand, the integration of biodiversity and environmental values and other ecosystem services in the development of future livestock systems may provide opportunities for increasing breed diversity.

Agroecology is based on applying ecological concepts and principles to optimize interactions between plants, animals, humans, and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system. Agroecology can play an important role in building the resilience of our food system that the COVID-19 pandemic has shown to be fragile. Agroecology implies to conserve biodiversity, including breed diversity, and the ecosystem services on which agriculture depends. There is a need for sustainable and feasible policies to conserve and utilize the existing diversity of local breeds in rural development. Agroecology is not a new concept but is gaining more and more interest worldwide, including governments, research, civil society and producer organizations, international institutions, and the private sector. FAO’s engagement is today adding strength to agroecology. Can the agroecological approach be applied on a global scale? Can it respond to the challenge of food security in the world and at the same time contribute to global climate challenges? These are recurrent questions that today receive positive answers from many experts. Obviously, a complex transition period has to be covered. Today agroecology represents a space for challenging our modern food systems where COVID-19 has revealed risks, fragilities, and inequalities.

A final consideration on animal research: COVID-19 sanitary measures are negatively affecting the interactions necessary for research, development, and dissemination through social distancing and loss of employment. The expected postpandemic economic recession might also result in reductions of the financial commitment to animal research by funding agencies, governments, and the private sector. The field of AnGR conservation has generally received limited financial support. On the contrary, the need for higher resilience in agriculture should call for future financial supports to promote diversification in agriculture and livestock production and to promote the use and conservation of farm animal diversity.

Conflict of interest statement. None declared.

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Perspective

COVID-19: a “black swan” and what animal breeding can learn from it

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Key words: animal breeding, climate change, COVID-19

In economics theory, the “black swan” metaphor (Taleb 2010) is used for a highly improbable and, thus, virtually unpredictable event, which, when it materializes, has a disruptive impact on the markets. The COVID-19 pandemic can be considered as such a “black swan” event, which not only pushed the global economy into dire straits but also had devastating effects on the living conditions on a global scale, including a death toll of currently—October 2020—slightly above a million and many millions more having suffered grave illness. However, was it really so highly improbable and entirely unpredictable that such a pandemic will hit the globe at one stage? When looking at the literature (see, e.g., Jones et al. 2008; Morse et al. 2012; Han et al. 2016), there is a long documented history of zoonoses that turned into a pandemic, with steadily increasing frequency. The U.S. Center for Disease Control and Prevention stated that “… more than 6 out of every 10 known infectious diseases in people can be spread from animals, and 3 out of every 4 new or emerging infectious diseases in people come from animals” (https://www.cdc.gov/onehealth/basics/zoonotic-diseases.html). The intensifying emergence of infectious pathogens is driven by the growing anthropogenic impact on nature and can be attributed, among other factors, to biodiversity loss and habitat degradation (Schmeller et al. 2020), processes which are partly pushed by ever-intensifying livestock production. Many of the risk factors like overpopulation, wildlife markets, and poor hygienic and medical standards are prevalent in developing or emerging countries. Since we live in a highly mobile and globalized world, a local outbreak anywhere in the world, if not immediately detected and consequently eradicated and epidemiological parameters of the causal agent being favorable, has a considerable chance of spreading globally to become a pandemic.

So, all insiders could have been fully aware that a pandemic of major severity might occur at one point of time (just as “the big one” earthquake in the Bay Area will happen at some point) and, at least in theory, plans for such a case were made in many countries. So COVID-19 was not exactly a black swan, although its impact on all aspects of life was very much so, demonstrating that all the emergency plans being developed for such cases, despite being useful to some extent (with a huge variety between countries, though), cannot entirely prevent the adverse effects.

Evidently, the COVID-19 pandemic had a direct impact on the animal breeding industry, with a ban of large meetings making events like animal shows or auctions practically impossible, restriction of mobility of persons and goods (including animals) across borders, but also partly within countries, and forcing people to work from home, which posed an extra hurdle to a direct exchange in teams, etc. Not all affects were exclusively negative, though: by replacing duty travels through video conferences, we all learned that it is possible to organize an exchange with many people from different partners at short notice, which otherwise had to be planned long in advance and with substantial unproductive travel time (and, by the way, a significant carbon footprint). Further effects are indirect in that international trade with animal products partly collapsed, which had a downside effect on livestock production and will have an impact on the demand for breeding products. Compared to other industries (like, e.g., aviation, tourism, or...
event management), however, the effects on the animal breeding industry so far were relatively mild, meaning that COVID-19 regulations made daily business more complicated and possibly less profitable but, by and large, did not threaten breeding companies or organizations to lose their business model in the short term.

But still, the COVID-19 pandemic can be seen as a warning shot across the bows, thus being a good opportunity to reconsider the situation and the level of preparedness for comparable (or even more severe) crises that we may be faced with in the future. In the following, we will suggest and discuss some hypotheses that might be worth considering when making strategic plans in the animal breeding industry. Admittedly, this is done from a personal perspective with a certain bias toward the German situation.

• In a pandemic situation, the livestock industry as a whole, and animal breeding as part of it, may be seen as very critical by the general public.

The majority of severe pandemics are caused by close contact between humans and animals, and the proportion of zoonoses transmitted by farm animals rather than wild animals has steadily increased over the years (see Jones et al. 2008). Therefore, animal breeding as part of animal production will be considered particularly skeptical by the general public as a potential source of zoonosis-associated pandemics. In the worst case of a pandemic caused by a zoonosis transmitted by farm animals, comprehensive documentation and traceability of animals and products is of key importance. Overall, livestock production for diverse reasons has a poor reputation in many Western societies, and events like the current pandemic have the potential to pull production conditions even more into the focus. In the COVID-19 pandemic, slaughterhouses and meat packaging plants proved to be super-spreading platforms, provoking a very critical review of the sometimes actually reprehensible working conditions there. Such circumstances can foster the already existing alienation between the general society and animal production, with long-term consequences, for example, for production standards and market demand for animal products in competition with plant-based diets or meat substitutes. The livestock industry, including the breeding sector, should always be aware that it is under critical and sometimes hostile observation, and anything that potentially deepens this alienation should be avoided.

• “A ‘black swan’ event can have major disruptive effects on various crucial activities of animal breeding programs.”

We now have with the COVID-19 pandemic, a specific case with specific consequences for daily life and business as described above. We have learned that effects can be much more extreme than expected: who would have thought that it is possible to implement—from one day to another—a complete halt of international travel or to put whole countries effectively into a “stay at home” quarantine for weeks or months? We should be aware, though, that another “black swan” may have very different consequences, possibly even more severe or affecting other aspects of life and business. Just to give an example from a rather different realm: shortly before Christmas last year, a major German university was attacked with the malicious computer virus “Emotet.” Despite having a professional cyber security infrastructure in place, the entire computer system had to be shut down—essentially by pulling the plug—and it literally took weeks before at least some of the systems could be gradually restarted. Note that this not only affected scientific work but the entire organization, including personnel administration, student admission, procurement, and bookkeeping, no emails could be sent and received etc. You do not need much fantasy to imagine the devastating impact such a scenario would have on a modern large-scale breeding operation.

• “While it is not possible to be perfectly prepared for all eventualities, there are ways to improve and verify the level of preparedness.”

We are sure all breeding companies have their emergency plans in place, but we should be aware that it will not be possible to be fully prepared for all eventualities. It might be a good opportunity, though, to review these plans now and possibly think of even more extreme scenarios based on the current experience. In the financial world, regular “stress tests” are undertaken, in which a hypothetical scenario mimicking a financial crisis is simulated in a very realistic and detailed way and then banks are assessed as to whether they are sufficiently prepared so that they can handle, and
actually ultimately survive, such a scenario (see, e.g., Upper 2011). It might be a good idea to consider a similar “stress test” approach for breeding companies and see how they would do.

- “Operations striving for maximum efficiency run the risk of high vulnerability, so we should include resilience as a strategic goal of breeding operations.”

As in many other fields of business, breeding programs over the last decades have been continuously pushed toward maximum efficiency. It is taught at universities, including ours, that maximizing genetic progress or better, maximizing breeding efficiency—basically genetic progress per unit of capital input—is the primary objective. High efficiency inevitably comes along with high levels of complexity: think of the complex infrastructure in performance testing and data management but also the complex logistics when it comes to transferring the genetic progress made in the breeding nucleus to the practical farms. In the context of the COVID-19 pandemic, it became evident that high efficiency comes at the expense of resilience, which makes the most efficient, and in “normal times” most successful, enterprises most vulnerable and, thus, more at risk, when shocks occur (see, e.g., the interesting opinion piece of W. J. Galveston in the Wall Street Journal: https://www.wsj.com/articles/efficiency-isn’t-the-only-economic-virtue-11583873155). So, there is an obvious trade-off between efficiency and resilience. But are we not, as animal breeders, experienced in operating with trade-offs between conflicting goals, such as performance and fitness, in breeding? Consequently, we should apply the same basic principles in the design of resilient breeding programs and operations.

The COVID-19 pandemic often is compared with the “Spanish flu” pandemic almost exactly a century ago and, thus, one might hope that it is a “once in a century” event and we might be safe for another century when we have overcome the current crisis. It is needless to say that this view is naïve and unrealistic. Actually, we even know that another “black swan” is steadily approaching, which is global heating (which in our view is the more appropriate term compared to the neutral “climate change”). Global heating itself and the commitment of 189 countries in the 2016 Paris Agreement to limit the CO₂ emissions such that the heating will not exceed 2 °C compared to the preindustrial level will have an impact on the livestock industry that hardly can be overstated (Rojas-Downing et al. 2017). Livestock production will not only be affected in places where environmental changes, like droughts, have a direct impact, but there will be an overall change in the way how businesses can operate everywhere in the world. Each country has a certain emission budget, and it will have to make a decision how to spend it wisely. As we have learned in the current pandemic, governments are prepared to act massively when higher goods are at stakes. The Netherlands, for instance, have decided in 2019 to introduce a 100 km/h speed limit on motor highways and to compensate pig producers to give up their business in order to be able to continue other emission-intensive activities like building houses. Ultimately all products and production processes will be assessed and taxed according to their carbon footprints along the entire value chain. This is going to happen within the next few years or decades, and it likely will have a major effect at least on some segments of the livestock industry. Again, as in the COVID-19 pandemic, this will not be an entirely improbable and, thus, virtually unpredictable event (so, no classical “black swan”), but it still will have disruptive effects in many areas. Livestock breeding should be prepared.

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

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Emerging Infectious Diseases and Human Pandemics

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

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

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

Effect of the Pandemic on the Camel Breeding and Production Sector

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

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

Figure 1. The two main large camelids: Camelus dromedarius and Camelus bactrianus (photo: B.F.).
The hypothesis of cross-immunity between MERS-CoV and SARS-CoV-2 seems to be justified (Yaqinuddin, 2020).

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

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

Figure 3. Camel used for racing in Saudi Arabia (photo: B.F.).
tion of camels to slaughterhouses in the countries where
the camel meat sector is well developed. Dairy plants ex-
perienced shortages with their supply chain of packaging
materials.

3) The health crisis has impacted the consumers’ habits. How-
ever, a different pattern could be observed for camel meat
and camel milk. During the confinement, consumers have
increased the purchase of nonshortly perishable food (paste,
flour, and canned goods). However, perishable items, such
as fresh meat, were less consumed. In contrast, camel milk
consumption was boosted in some countries. Based on sci-
entific information regarding the potential use of llama
immunoglobins for developing therapeutic antibodies
(Dong et al., 2020) and because of the similarity between
lama and camel IgG, the myth that camel milk consump-
tion could boost COVID-19 immunity became a commer-
cial argument. Therefore, the price of camel milk soared
in parallel with high demand, for example, in Kazakhstan
(Figure 4; Konuspayeva, personal communication). Des-
pite transport restrictions, the demand increased also on
international markets. For example, the demand from
China for camel milk produced in Kazakhstan increased
by 20% (http://www.chinadaily.com.cn/a/ 202007/06/
WS5f0288dda310834817257656_3.html).

4) The restriction on international tourism has impacted di-
rectly the camel breeders involved in camel trekking or any
other events including camels (fantasia, festival, and camel
ride). Most of the Sahara festival expected during spring
2020 was canceled as the festival of Saharan cultures at
Amdjarass in Chad. In Gulf countries, where camel racing is
very popular, such events were canceled, then organized with
a limited number of spectators (https://www.thenational.ae/
uae/ coronavirus-camel-races-resume-but-the-majlis-stays-
shut-1.1071394).

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

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

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

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

Figure 4. Increasing demand in camel milk for its suspected immune-protective effect against COVID-19.
dromedaries takes a mild course from asymptomatic to mild nasal discharge (Hemida et al., 2014, 2017; Nowotny and Kolodziejek, 2014). First described in the Middle East in 2012, MERS has appeared in more than 25 countries on four continents (except Australia) since. However, MERS-CoV-specific antibodies have been found in camel blood samples as early as 1992, showing a long-term prevalence of this virus in camels from the Middle East and North Africa (Gossner et al., 2016). Recently, also the transference from dromedary to Bactrian camel has been proven (Lau et al., 2020). The transmission from camel to humans takes multiple ways, airborne (droplet) infection (Dawson et al., 2019; Dudas et al., 2018), camel urine, and food borne through the consumption of unpasteurized milk and raw meat (Gossner et al., 2016). Although humans act as transient and terminal host, the human-to-human transmission rate is low (Dudas et al., 2018). As the consumption of camel milk and meat is on the rise and camel products gain access to wider markets, the impact of camel-associated zoonotic diseases on public health and economy will also grow with increasing urbanization. Recent releases of whole-camel genomes include detailed information on immune response regions (Lado et al., 2020, Fitak et al. 2020, Ming et al. 2020), while ongoing studies aim to understand patterns of immunogenetic diversity in dromedaries in response to MERS-CoV infection (Burger, unpublished data). The knowledge gained with all these studies during and after the SARS and MERS outbreaks has been essential for fighting COVID-19 as the scientific community has been better prepared to deal with the new pandemic. This is clearly shown in the time COVID-19 vaccines are prepared. Normally, it takes 10 years to develop an effective vaccine, while this process might be completed in less than 2 years for COVID-19 (Thanh Le et al., 2020).

Camelids are not only characterized by their remarkable adaptation to harsh climate and production potential but also by their extraordinary immunology and now play an important role in fighting infectious diseases. This is because camelids are the only mammals that can produce homodimeric immunoglobulins consisting of heavy chains only with a light chain in addition to conventional antibodies. The antigen-binding fragment is reduced to a single variable domain of the heavy chain and, thus, reduces the size of the antibody (Arbabi-Ghahroudi, 2017; Ciccarese et al., 2019; Muyldermans et al., 2009), which can be used for biotechnology and clinical applications as so-called “nanobodies.” These nanobodies, due to their small size, have an enormous potential for diagnostic use and therapeutics. New research by several groups (Dong et al., 2020; Hanke et al., 2020; Wrap et al., 2020) has shown that the peripheral blood mononuclear cells of camelids can be used to produce specific nanobodies that effectively neutralizes beta coronaviruses. These nanobodies are excellent candidates for antiviral therapy.
There is no specific impact of COVID-19 on the camel sector compared to what we experience in other livestock sectors or, more generally, the agricultural sector. However, the specificity of the immune system in camelds, and the reputation of camel milk with its true or expected health effects on consumers contribute to the development of camel products through increasing demand. This trend might help to compensate for the losses due to the pandemic.

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The EAAP 2021 meeting will be held in Davos from 30th of August to 3rd of September 2021. The Theme of the conference will be: Scientific solutions to different demands on the livestock sector.

Davos is the highest town in the Alps located at about 1500 metres above sea level.

The Annual Meeting will host scientists and experts from all disciplines of animal science, not only from Europe but also from other countries around the world. The EAAP Meeting provides a platform for scientists and industry experts to meet and acquire new knowledge and to exchange their experiences on the latest research results from many areas of animal science. The many sessions, plenary session, poster presentations and discussions about scientific achievements in livestock production during the Annual Meeting all provide an opportunity to put new ideas into practice. All these activities make the EAAP one of the largest animal science congresses in the world. We hope to welcome more than 1200 participants from more than 50 countries worldwide. More information can be found at www.eaap.org and www.eaap2021.org. In parallel to this outstanding scientific program, we are also preparing an appealing and interesting program of social events, starting with the Welcome Ceremony. These events will also include a Swiss Evening, a Conference Dinner, Technical Tours and a Companion Program.

Given its typical grasslands, livestock farming has always played an important role in Switzerland. Animals and animal products account for 54 percent or CHF 4.9 billion of agricultural production. The self-sufficiency rate in this sector is high— for milk and veal almost 100%, for beef and pork around 90%, and 114% for cheese.

Congress website: www.eaap2021.org
E-mail: info@eaap2021.org
The venue: Davos Congress CH-7270 Davos Platz
Abstract submission Information and guidelines: www.wageningenacademic.com/eaap Submission deadline: March 1, 2021

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doi: 10.1093/af/vfaa061

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Introducing our new President!

On behalf of the CSAS Executive, I would like to welcome Dr. Flavio Schenkel as our new President.

Dr. Schenkel is a Full Professor with research interests ranging from theoretical to applied genetics and genomics in livestock breeding. Current research focuses on the use of genomic information to enhance genetic evaluation of livestock species with emphasis on genomic selection. His research program is supported by industry and governmental funds, including various funding agencies. Since 2006, he is a member of influential industry boards in Canada, including the DairyGen Council of Canadian Dairy Network and the Dairy Cattle Genetic Evaluation Board. Dr. Schenkel was a professor at a Federal University in Brazil from 1993 to 2000, and a Research Associate at University of Guelph from 2000 until he became an Assistant Professor in 2005. In 2009 Dr. Schenkel changed his status to an Associate Professor and in 2014 he became a Full Professor. Since 2013, Dr. Schenkel is the Director of the Centre for Genetic Improvement of Livestock at University of Guelph. In his scientific career, Dr. Schenkel published over 200 peer-reviewed scientific papers and has contributed to formation of several high qualified personnel, including 23 graduate students and 17 post-doctoral fellows. Dr. Schenkel also serves on several international journal editorial boards and maintains strong research collaboration with researchers in Brazil and other countries.

Dr. Schenkel will continue to work to further foster collaboration with sister organizations, including the American Society of Animal Science, the American Dairy Science Association, the Canadian Meat Science Association, the European Association for Animal Production, the British Society of Animal Science and the World Association for Animal Production, to keep our members and our society at the forefront of innovation and knowledge in animal science.

Best wishes,
Canadian Society of Animal Science Executive

Welcome to our new Executive members!

Dr. Younes Miar (Awards Chair)
Dr. Obioha (Obi) Durunna (Western Director)
Dr. Carl Julien (Eastern Director)
Dr. Oscar Lopez Campos (Vice-President)

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