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Is the COVID-19 pandemic impacting on the risk of African Swine Fever virus (ASFV) introduction into the United States? A short-term assessment of the risk factors

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Summary

African swine fever (ASF) is a contagious disease with high mortality in domestic and feral swine populations. Although it is not a zoonosis, its spread may have severe socio-economic and public health consequences. The activities of veterinary services are essential for controlling ASF outbreaks within a country, but also for diminishing its threat of spread to neighbouring countries, and for recognizing its entry into countries that are currently free. ASF requires quick responses and permanent monitoring to identify outbreaks and prevent spread, and both aspects can be heavily undercut during the COVID-19 pandemic. This paper analyses changing patterns of the main drivers and pathways for the potential introduction of ASFV into the United States during the COVID-19 pandemic, including international movements of people, swine products and by-products. Data on commercial flights and merchant ships was used as a proxy to indirectly assess the flow of illegal products coming from ASF affected countries. Results from this study highlight a decreasing trend in the legal imports of swine products and by-products from ASF affected countries (Sen's slope = −99, 95% CI: −215.34 to −21.26, p-value < 0.05), while no trend was detected for confiscations of illegal products at ports of entry. Additionally, increasing trends were detected for the monthly number of merchant ships coming from ASF affected countries (Sen's slope = 0.46, 95%CI 0.25–0.59), the monthly value of imported goods ($) through merchant ships (Sen's slope = 1513196160, 95%CI 1072731702–1908231855), and the monthly percentage of commercial flights (Sen's slope = 0.005, 95%CI 0.003–0.007), with the majority of them originating from China. Overall, the findings show an increased connection of the United States with ASF affected countries, highlighting the risk posed by ASF during a global public health crisis.

KEYWORDS
African Swine Fever Virus, COVID-19 pandemic, global connections, transboundary disease, United States

1 | INTRODUCTION

African Swine Fever (ASF) is a contagious haemorrhagic viral disease of domestic and wild pigs, causing substantial economic losses to pig farming in the affected countries. It is one of the most important pig diseases due to the severe socioeconomic consequences for affected countries. For example, a study modelling the global impact of a major ASF outbreak in China, showed that this would cause an increase of pork prices by 17%–85% , along with other domino effects, such as increases in prices of other meats due to increased demand, decrease in feed prices, and decreased availability of animal source foods, which are fundamental for human health nutrition (Mason-D'Croz et al., 2020). As such, ASF is one of the most important emerging infectious diseases in the swine industry, causing major veterinary, economic and food production concerns due to its continued outbreaks and global spread (Gaudreault et al., 2020). Underlining its importance is the fact that it is a notifiable disease according to the World Organisation for Animal Health (OIE) (OIE, 2021a). Specifically, ASF was listed in the ex-list A which included transmissible diseases that have the potential for very serious and rapid spread, irrespective of national borders, with a great impact on the international trade of animals and animal products (https://www.oie.int/en/what-we-do/animal-health-and-welfare/animal-diseases/old-classification-of-diseases-notifiable-to-the-oie-list-a/).

The epidemiology of ASF is complex with different epidemiological patterns of infection occurring in Africa, Europe and Asia due to the presence of wild hosts and vectors, environmental conditions, human behaviour and characteristics of the viruses circulating in the regions giving rise to a wide range of clinical forms (Gallardo et al., 2015). Since there are no commercial vaccines currently available against ASFV (Sang et al., 2020), control measures are limited to testing and mass slaughtering of infected and in-contact pigs. Also the implementation of high biosecurity standards are critical to protect swine populations, however, these are more likely to be applied in intensive rearing farms than in small and backyard production (Danzetta et al., 2020). Laboratory diagnosis of ASF consists of detection of the virus and immune responses, using a variety of commercially available tests (Gallardo et al., 2019), and guidelines for diagnosing and reporting have been developed by the OIE (OIE, 2019). At the time of revising the paper (March 2021), the disease is continuing to spread across Asia and Eastern Europe at a worrying rate, with millions of pigs being culled to halt its spread (Table S1). In addition to animal health concern, the disease has a large impact on international exports of pig products and on producer prices in the domestic markets (Niemi, 2020). The impact is highest in countries with a significant commercial pig industry.

The United States is the world third-largest producer of pork and pork products (12,843 tons of pork produced in 2020), thus the entrance and spread of ASFV would have a huge socio-economic effect. In 2020, the value of U.S. pork exports to the world increased by 11% from the prior year, with China, Japan and Mexico being the top trade partners. The reason of the U.S. export growth is mainly driven by the strong global demand for pork product due to decreased Chinese production resulting from ASF (USDA, 2021a). The United States has never had a case of ASF and there are strict import requirements to prevent any form of ASF to enter into the country. The U.S. trade regulations appear under the Code of Federal Regulations Title 9 Animals and Animal Products.[1] The Animal and Plant Health Inspection Service (APHIS) maintains a list on animal health statuses of countries regarding specific animal diseases (Animal Health Status of Regions[2]), including ASF. No pork or pork products may be imported into the United States from any ASF affected country reported in this list. With regards to the ASF affected areas in Europe, APHIS agreed to follow the restricted zone established by the European Union (EU) (EU 2021/605[3]) unless there are specific reasons to do otherwise: these reasons are justified by a risk assessment. Other import exceptions include pork or pork products prepared in approved establishments and accompanied to the United States by an original certificate stating that all the requirements of the Federal Meat Inspection Act (21 U.S.C. 601 et seq.[4]) and regulations thereunder (9 CFR, chapter III, part 327[5]) have been met. Given the important economic consequences expected if ASFV is introduced, several works assessed the risk of ASFV entry into the United States, suggesting that the risk of the disease reaching the U.S. borders is higher through smuggling of pork products than the legal importations (Brown and Bevins, 2018; Herrera-Ibatá et al., 2017; Jurado, Mur et al., 2019; Jurado, Paternoster et al., 2019; USDA APHIS VS S&P CEAH, 2019)

Illegal swine products and by-products may be imported by sea and air freight containers, passenger baggage, and post plus courier (Wooldridge et al., 2006). However, complete information for all the routes is difficult to obtain, and risk analysts usually decided to focus only on 1 pathway. For instance, Jurado et al. (2019) quantified the risk of ASFV entry through swine products illegally imported into the United States by air passengers' luggage, without considering other routes of introduction such as maritime containers, land or mail shipments, where the volumes of smuggled products are more likely to be higher. A similar work was conducted by Sugiura et al. (2020) who assessed the risk of ASFV entry in Japan through pork products illegally brought by air passengers from China. Noteworthy, this work has been recently updated within the context of the COVID-19 pandemic, highlighting the importance of recalculating the risk of foreign animal diseases (FADs) during a global public health crisis (Sugiura, Kure et al., 2020).

Indeed, the COVID-19 pandemic could have affected several aspects of the ASFV entry pathways into ASF free countries. Since December 2019, ASF has been continued spreading into new areas due to the diffusive nature of the virus (Supporting information). This further spread could have been facilitated by the difficulties in animal diseases prevention and control due to the COVID-19 lockdown (FAO, 2020a). The measures undertaken to mitigate the pandemic have restricted movement of people indirectly causing an economic crisis. The latter, compounded by a high demand of laboratory supplies for human COVID-19 diagnosis and research, has probably also affected the capacity of veterinary laboratories to fulfil their mandate. Additionally, official international disease reporting could have been disrupted due to logistical issues and constrains faced by countries (Figure S1, Figure S2). Timely and accurate reporting allows to prevent

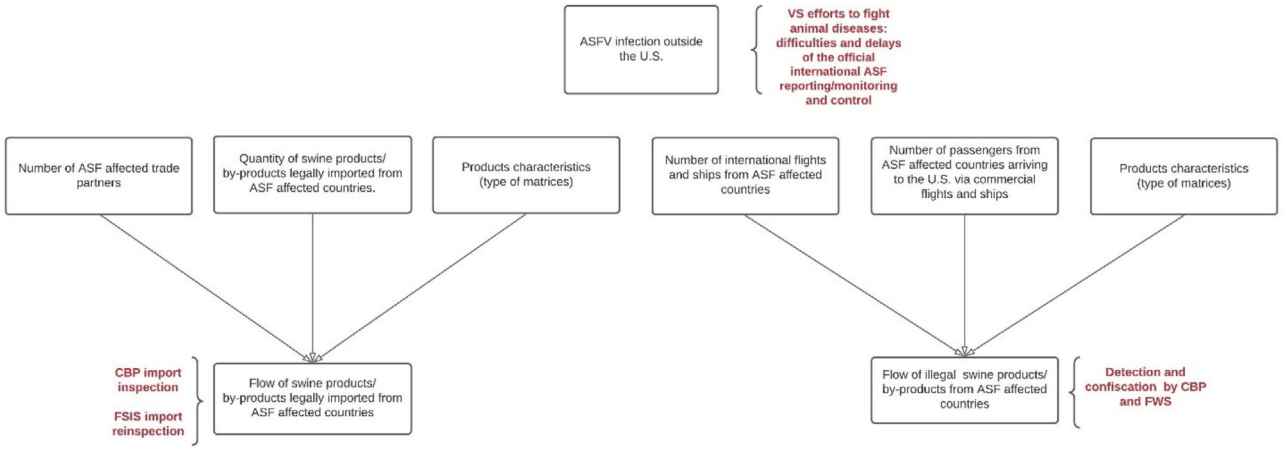

FIGURE 1 Summary of the components that should be considered to evaluate changing patterns of the main drivers and pathways for the potential introduction of ASFV into the United States during the COVID-19 pandemic. The key points hit by the COVID-19 are presented in red.

the entry of ASFV from affected areas. Thus, the lack of knowledge of animal health status in certain areas could have heightened the risk of ASFV entry through swine products/by-products legally imported. Conversely, the risk of entry is expected to be reduced when considering that the COVID-19 pandemic has negatively affected the world meat trade with a global decline of meat imports and a decrease of meat prices (FAO, 2020b). Similarly, the risk of ASFV entry through smuggling of pork in passengers' luggage could have decreased due to the reduction of the number of people travelling. However, the number of import/export inspectors has fallen worldwide (OECD, 2020), thus the border controls could have been compromised. Considering all the above, this study aims to investigate changing patterns of the main drivers and pathways for the potential introduction of ASFV in the United States during the COVID-19 pandemic.

2 | MATERIALS AND METHODS

2.1 | Main drivers and pathways for the potential introduction of ASF into the United States

Figure 1 shows the main drivers and pathways for the potential introduction of ASF into the United States through the legal and illegal imports of swine products and by-products. For the illegal importation, the number of international flights, ships and passengers from ASF affected countries are relevant indicators as they are assumed to influence the risk of illegal import.

Considering that ASF control measures are required both before departure and on arrival to effectively prevent the disease transmission across borders, the main stakeholders influencing the risk of ASF entry into the United States are identified as following (depending on the different national institutional structure additional stakeholders, not listed here, may be relevant too):

- National Veterinary Services (VS) (governmental bodies/laboratories) of ASF affected trade partners and countries from which illegal products originate: personnel involved in animal disease monitoring and surveillance activities responsible to prevent the export of ASFV infected products.
- The U.S. Department of Homeland Security Customs and Border Protection (CBP): CPB officers authorize the formal entry of shipped goods which has filed appropriate entry documents (entry manifest, permits, veterinary certificates, etc). They are also responsible for the confiscation of illegally imported products and specimens from domestic livestock species.
- The Food Safety and Inspection Service (FSIS): FSIS reinspects and approves incoming shipment import.
- The U.S. Fish and Wildlife Service (FWS): FWS is responsible for the confiscation of illegally imported wildlife and wildlife products.

2.2 | Overview of the data required

A time window between January 2019 and February 2021 (roughly 1-year pre-COVID and 1-year of COVID-19 pandemic) is used to identify changing patterns of the main drivers and pathways for the potential introduction of ASFV in the United States. The most updated information (January 2019–December 2020) was used for data on the number of passengers arriving in the United States through commercial flights, and the number of departures performed from ASF affected countries. The ASF affected trade partners and countries from which illegal products originate were identified based on the disease status (presence or absence of ASF) obtained from the OIE-WHAIS system considering the ASF first occurrence reported by the country (OIE, 2021b). Further details are provided in the Sections 2.2.1 and 2.2.2.

2.2.1 | Flow of swine products/by-products legally imported from ASF affected countries

Data on imported swine products and by-products was obtained from the USDA Global Agricultural Trade System (GATS) (USDA,

2021b). GATS database contained the quantities (MT[6]/pieces) and value ($) of imported products by month and country of origin. Considering that the risk for swine products and by-products to be infected/contaminated and maintained infectious ASFV depends on the type of matrix (EFSA AHAW Panel, 2014), we divided data in four main categories: frozen, fresh or chilled, processed and raw hides and skins (not pre-tanned). Fully tanned and processed hides and skins were not included, as not representing a risk (Ministry of Agriculture and Forestry, 2008). Since the unit of measure of raw hides and skins (pieces) differs from the other products (MT), they were not included in the quantitative analysis. The information on ASF affected trade partners was used to build six time series: (i) monthly number of ASF affected trade partners, (ii) monthly quantity of swine products and by-products imported from ASF affected countries, (iii) monthly percentage of swine products and by-products imported from ASF affected countries over the total quantity of swine products imported, (iv) monthly quantity of fresh or chilled swine products and by-products imported from ASF affected countries, (v) monthly quantity of frozen swine products and by-products imported from ASF affected countries, and (vi) monthly quantity of processed swine products and by-products imported from ASF affected countries.

2.2.2 | Flow of illegal swine products/by-products from ASF affected countries

The flow of illegal swine products/ by-products from ASF affected countries was assessed using: (i) data on illegally imported domestic swine products and by-products confiscated in the United States ports of entry obtained from the Agricultural Quarantine Activity Work Accomplishment (WADS), (ii) data on wild suids products confiscations obtained from the Law Enforcement Management Information System (LEMIS) database. Access to these databases was provided by the CBP and FWS personnel, respectively. As data retrieved from WADS was not homogeneous (e.g., some records described the products in kilograms other as number of confiscated packages), the target of the analysis was the "event" intended as the record of a single confiscation. The information was used to build three time series: (i) monthly number of ASF affected countries of origin, (ii) monthly number of events from ASF affected countries recorded by CBP, (iii) monthly percentage of events from ASF affected countries over the total number of events recorded by CBP. Additionally, the following relevant indicators (parameters related to the risk of ASFV entry and for which data is available) were considered: (i) commercial flights and air passengers from ASF affected countries arriving in the United States obtained from the T-100 International Segment database (United States Department of Transportation. Bureau of transportation statistics., 2021), (ii) value of international U.S. imports of goods ($) from ASF affected countries retrieved from the United States Trade Online (The U.S. Census Bureau, 2021). The information on the number of merchant ships and marine passengers from ASF affected countries arriving in the United States was not easily accessible. Thus, these factors were not assessed (even if included in the pathways presented in Figure 1) and the value of imports of goods was used as a substitute indicator for the maritime connections between the United States and countries where ASFV circulates. With regards to the airfreight transportations, five time-series were built: (i) monthly number of ASF affected countries of origin, (ii) monthly number of passengers from ASF affected countries, (iii) monthly percentage of passengers from ASF affected countries over the total number of passengers, (iv) monthly number of departures performed from ASF affected countries, and (v) monthly percentage of departures performed from ASF affected countries over the total number of departures performed. Data on merchant ships was organized as following: (i) monthly number of ASF affected countries of origin, (ii) monthly value of international U.S. imports of goods ($) from ASF affected countries, (iii) monthly percentage of international U.S. imports of goods ($) from ASF affected countries over the total imports.

2.3 | Time-series analysis

The Sen's method was used to determine whether there was a positive or negative trend in the time-series with a significance level alpha set at 0.05 (Sen, 1968). This method computes linear trend in time-series, which can be presented as an upwards/positive or a downwards/negative trend. It has many advantages (e.g., data does not need to conform to any particular distribution) that have made it very useful in time series analysis in different fields (Fanelli, Perrone et al., 2021; Fanelli, Tizzani et al., 2021; Marques da Silva et al., 2015). All the time series were formatted into a time-series object using the ts () function in the R software 3.5.2 (R Core Team, 2018).

3 | RESULTS

Out of 15 time-series analyses performed only 6 were significant and are presented in Table 1 Details are provided in Sections 3.1.1. and 3.1.2.

3.1 | Flow of swine products/by-products legally imported from ASF affected countries

Seven trade partners (28.57%) were identified as ASF affected. These were China, Germany, Hungary, Lithuania, India and Poland (further details in Figure S3 and Table S2). In this study Italy was considered as free of ASF, although the disease is endemic in Sardinia Island (Franzoni et al., 2020). The situation of Sardinia differs from that in other territories due to the long lasting endemicity of the disease since 1978, thus the EU banned swine export from Sardinia (Decision 2014/709/EU) and a strict control is applied to the animal products movement from the Island. The total imports of swine products from ASF affected countries was 98960 MT, corresponding to 11.22% of the total imports during the study period. Details on the monthly number of ASF affected trade partners and the quantity of swine products and by-products imported are shown in Figure 2.

TABLE 1 Significant trends of time series on risk factors of ASFV introduction between January 2019 and February 2021

Time series	Sen's slope	95%CI	*p*-Value
Quantity of swine products and by-products imported from ASF affected countries	−99	[−215.34; −21.26]	0.009
Quantity of imported frozen swine products from ASF affected countries	−112.63	[−211.97; −31.90]	0.006
Percentage of departures performed from ASF affected countries over the total number of departures.	0.005	[0.003; 0.007]	0.0001
Number of ASF affected countries of merchant ships origin	0.46	[0.25; 0.59]	1.083e-08
Total value of international U.S. imports of goods ($) through merchant ships from ASF affected countries	1,513,196,160	[1,072,731,702; 1,908,231,855]	1.547e-06
Percentage of international U.S. imports of goods ($) from ASF affected countries over the total imports.	0.007	[0.005,0.009]	2.067e-07

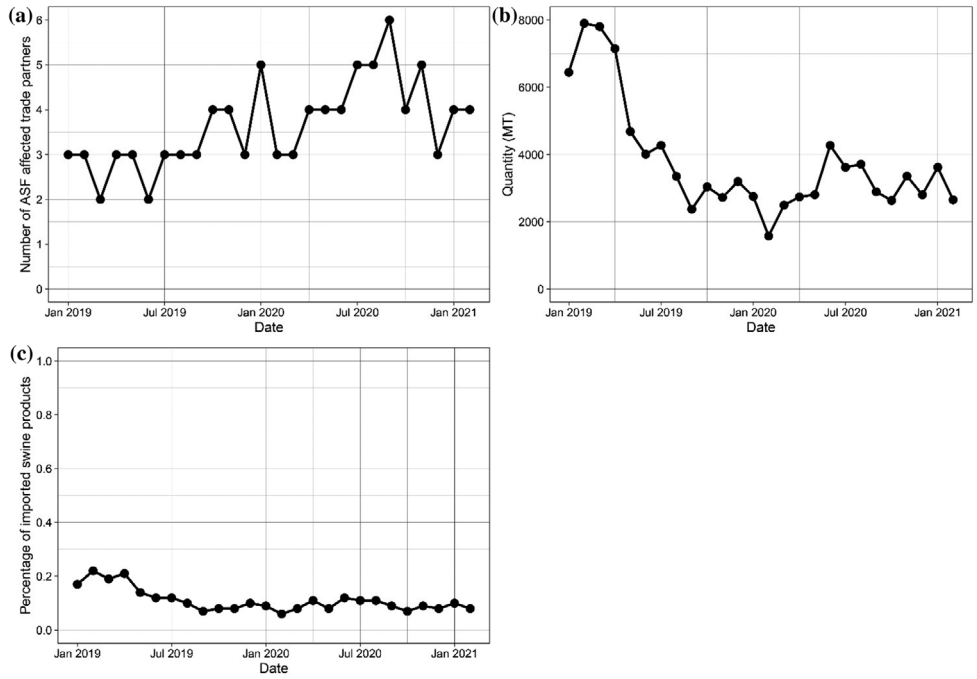

FIGURE 2 Monthly U.S. imports between January 2019 and February 2021: (a) number of ASF affected trade partners, (b) quantity of swine products and by-products imported from ASF affected countries, (c) percentage of swine products and by-products imported from ASF affected countries over the total quantity of swine products imported. *Please note that raw hides and skins are not included in the charts.*

Figure 3 shows the monthly U.S. imports of swine products and by-products according to different matrices from ASF affected countries between January 2019 and February 2021. The time-series analysis using Sen's method shows a significant decreasing trend in the quantity of swine products and by-products imported from ASF affected countries (Sen's slope = −99, 95%CI: −215.34 to −21.26, p-value < 0.05). This is mainly due to a significant downtrend of the quantity of imported frozen products as shown in Figure 3b (Sen's slope = −112.63, 95%CI: −211.97 to −31.90, p-value < 0.05). No significant trend was detected for the imports of fresh or chilled and processed products (Figure 3a,3c). The last import of fresh or chilled meat was in July 2019.

With regards to raw hides and skins not pre-tanned, only 14 pieces were imported during the study period. Specifically, five pieces from South Africa in December 2020 and nine pieces from Zimbabwe in October 2020. ASF is endemic in South Africa, while it is epidemic in Zimbabwe which reported the last recurrence in 2019 (OIE, 2021b).

3.1.1 | Flow of illegal swine products/by-products from ASF affected countries

Between January 2019 and February 2021, there were 840 records of swine products and by-products confiscated by CBP at ports of entry

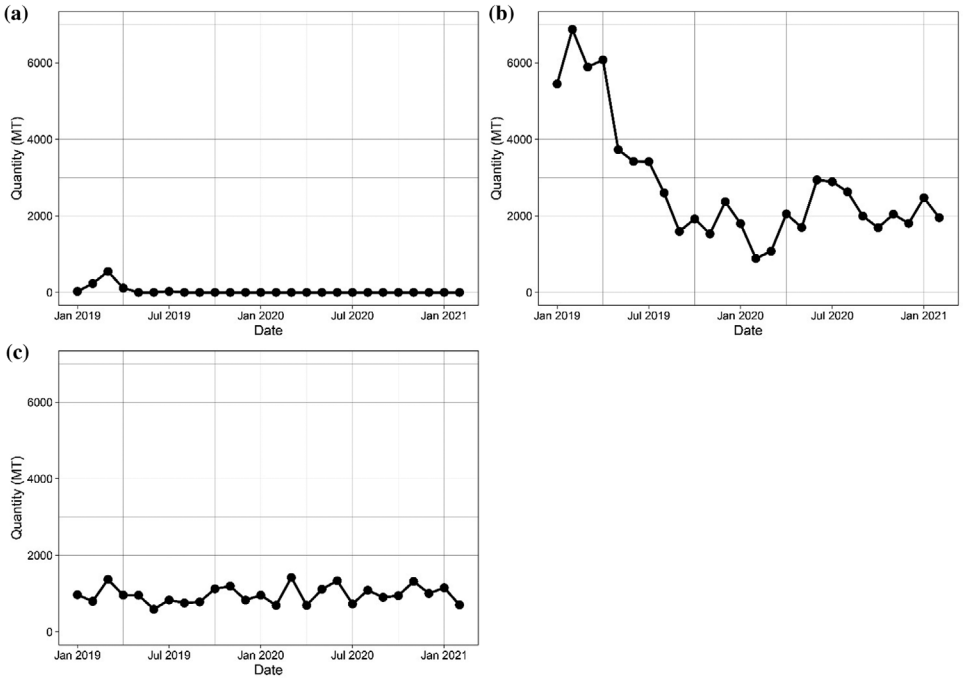

FIGURE 3 Monthly U.S. imports of swine products and by-products according to different matrices from ASF affected countries between January 2019 and February 2021: (a) fresh or chilled, (b) frozen, (c) processed.

(Supplementary material: Figure S4). Out of 55 countries of origin, 19 were (34.5%) ASF affected[7] (Table S3) which accounted for 316 confiscations (37.6%). Table 2 shows the number of events per ASF affected countries of origin. China represents the ASF affected country from which the majority (71%) of the illegal products originate.

Figure 4 shows the monthly U.S. data on illegal swine products and by products between January 2019 and February 2021. Neither the number of ASF affected countries of origin or the number of events from ASF affected countries show a statistically significant trend using the Sens' method (p-value > 0.05, Table S4). A peak of confiscations was detected in September 2020, when 92 events from ASF affected countries occurred. Out of these, 90 were records of swine products and by-products from China.

Considering the confiscation of illegally imported wild suids products retrieved from the LEMIS database, there are only 10 records originating from seven different countries. Among these, three products were from ASF affected countries. These include two trophies of warthog from Zambia and tusks of a wild suid from Cambodia.

The monthly data on U.S. commercial flights between January 2019 and February 2021 are described in Figure 5. The analysis of air transportation from ASF affected countries showed no significant trend using the Sens' method considering the number of passengers transported (Table S6) and the number of departures performed by international commercial flights (p-value > 0.05, Table S8S). When normalized with the total number of departures, the monthly percentage of departures from ASF affected countries noted a slightly significant increase (Sen's slope = 0.005, 95%CI 0.003–0.007), with a peak in May 2020 when 25% of the flights performed to the U.S. originated from ASF affected countries (Figure 5d). In this month, most of the commercial

TABLE 2 Number of events (confiscations by CPB at ports of entry) between January 2019 and February 2021 per ASF affected country of origin

Country	Number of events
Belgium	2
Bulgaria	1
Cameroon	1
China	224
Germany	22
Hong Kong	12
Hungary	3
India	2
Kenya	1
Republic of Korea	5
Russian Federation	1
Lao People's Democratic Republic	10
Latvia	10
Lithuania	2
Moldova	2
Nigeria	3
Poland	9
Togo	1
Vietnam	5

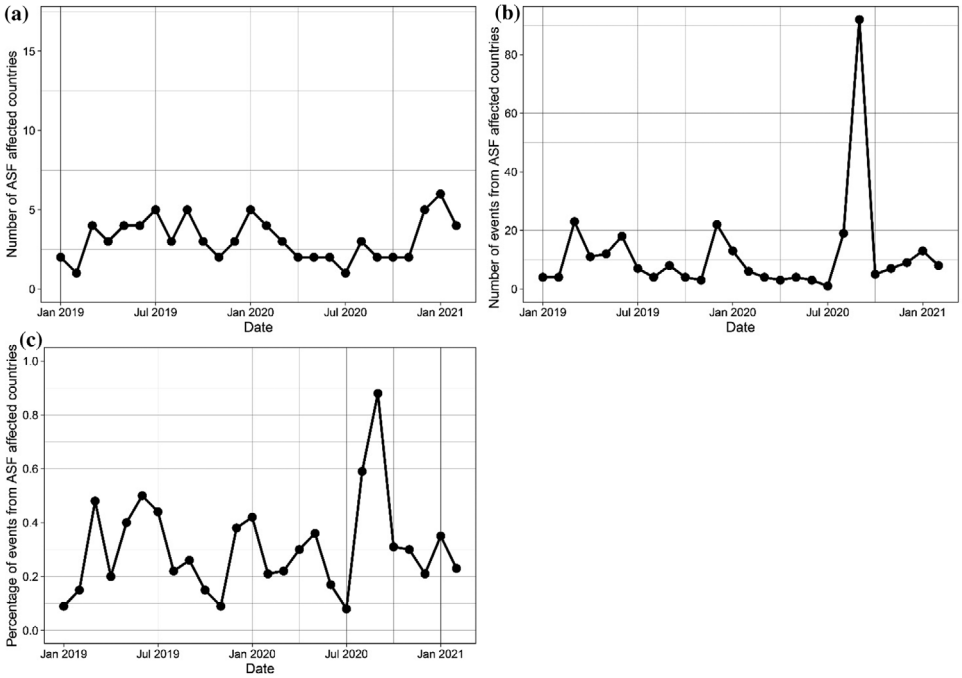

FIGURE 4 Monthly U.S. data on illegal swine products and by products between January 2019 and February 2021: (a) number of ASF affected countries of origin, (b) number of events from ASF affected countries recorded by CBP, (c) percentage of events from ASF affected countries over the total number of events recorded by CBP.

flights from ASF affected countries came from China (43%), followed by South Korea (33%) (Table S7).

The U.S. international routes of merchant ships included 24% (56/234) of ASF affected countries (Table S9), with the highest import values from China (18%), followed by Germany (3%). Statistically significant uptrends (p-value < 0.05) were detected in all the time-series (Figure 6). The increase was particularly high for the total values of imports from ASF affected countries (Sen's slope = 1,513,196,160, 95%CI 107,2731,702—1,908,231,855). The number of ASF affected countries of origin increased from 41 in January 2019 to 51 in January 2020, remaining stable at 52 from May 2020 to February 2021 (Sen's slope = 0.46, 95%CI 0.25–0.59). The percentage of international U.S. imports of goods ($) from ASF affected countries over the total imports slightly increase over the study period (Sen's slope = 0.007, 95%CI 0.005–0.009).

4 | DISCUSSION

This paper analyses changing patterns of the main drivers and pathways for the potential introduction of ASFV into the U.S during the COVID-19 pandemic, including international movements of people, swine products and by-products. Results from this study highlight a significant decreasing trend in the legal imports of swine products and by-products from ASF affected countries, while no significant trend was detected for illegal confiscations at borders. Nevertheless, the analysis of the indicators used to indirectly assess the flow of illegal products coming from ASF affected countries showed an uptrend in the number of ASF affected trade partners, percentage of flights departures and trade via merchant ships from ASF affected countries.

If done in compliance with the official regulation (e.g., appropriate heat treatment, controls in place etc) the risk of ASFV introduction through the legal importation of swine products and by-products from ASF affected countries is considered to be low. It is worth mentioning that the analysis performed not only reveals a downtrend in the total amount of swine products and by-products imported, but also a decreasing import of frozen products from ASF affected countries. This is important because the risk for different matrices to maintain infectious ASFV at the moment of transportation varies from very high for frozen meat to negligible for meat cooked for 70°C for 30 min (EFSA AHAW Panel, 2014).

The ASF affected U.S. trade partners identified in this study reported the implementation of zoning to control ASF, and China declares to apply also the compartmentalization (OIE, 2021, Table S5). The zoning principle consists in defining a geographic area to contain ASF outbreaks. The areas outside of these control zones are disease-free zones. This implies that all pork production businesses within the disease free-zones must operate at a high biosecurity standard, and do not have parts of their business outside the disease-free zone (OIE, 2018). Conversely, compartmentalisation consists in a single or multiple connected facilities dealing with pig populations free of ASF whereas ASF is assumed to be present in the rest of the country. Compartments adopt high biosecurity standards required to control ASFV, thus they are mostly implemented by single companies that have integrated production processes (Cowled et al., 2019). ASF control measures reported by the countries to the OIE are accessible through the

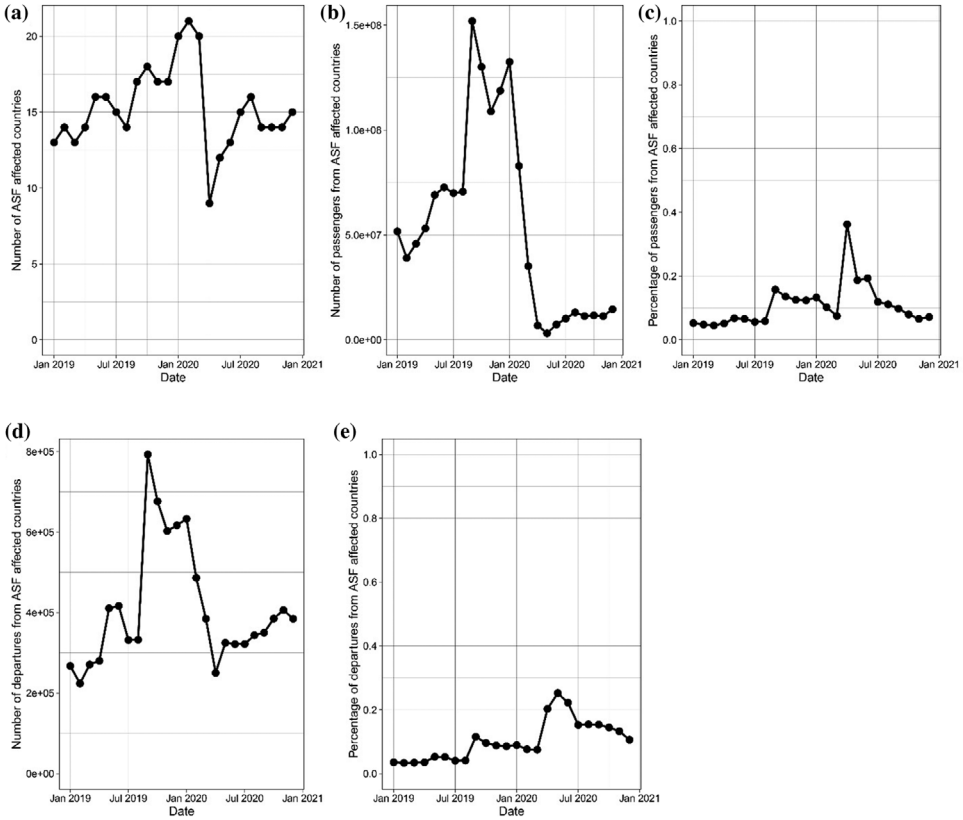

FIGURE 5 Monthly data on U.S. commercial flights between January 2019 and February 2021: (a) number of ASF affected countries of origin, (b) number of passengers from ASF affected countries (c) percentage of passengers from ASF affected countries over the total number of passengers, (d) number of departures performed from ASF affected countries, (e) percentage of departures performed from ASF affected countries over the total number of departures.

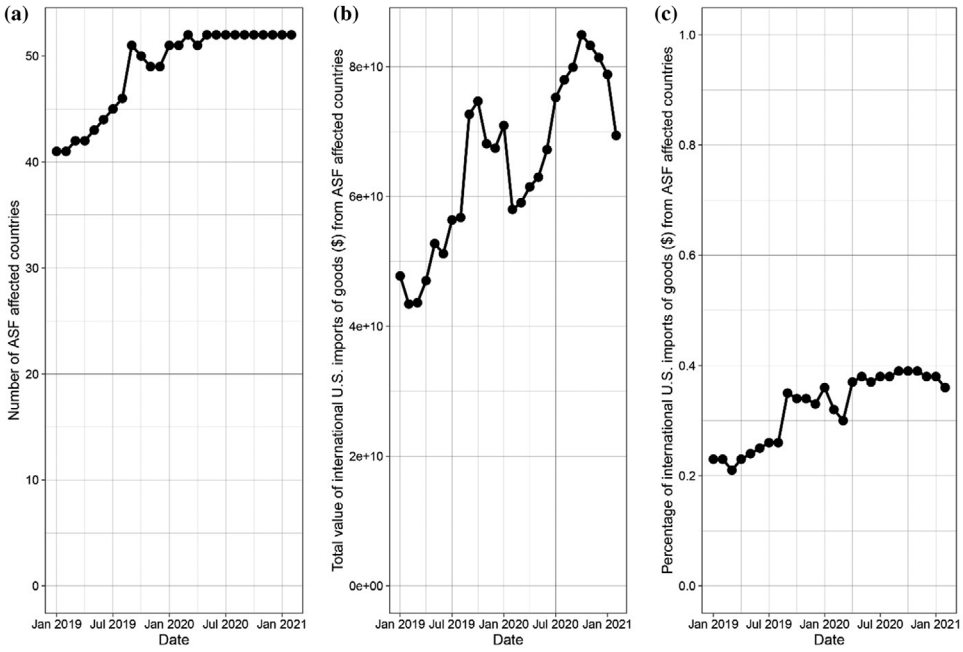

FIGURE 6 Monthly data on U.S. imports through merchant ships between January 2019 and February 2021: (a) number of ASF affected countries of origin, (b) total value of international U.S. imports of goods ($) through merchant ships from ASF affected countries, (c) percentage of international U.S. imports of goods ($) from ASF affected countries over the total imports.

OIE-WHAIS database. The information is available till 2019/2020 but data is missing for some periods due to delays in reporting (e.g. India). Some U.S. trade partners (e.g., Poland) had difficulties in timely reporting ASF outbreaks during 2020 (Supplementary material: Figure 1S). This delay may be due to various intrinsic and extrinsic factors, including the COVID-19 emergency. The COVID-19 related disruption of the functioning of the national veterinary services, like many other services, is plausible (FAO, 2020a; Gortázar & de la Fuente, 2020). The activities of veterinary services are essential for early detection and controlling ASF outbreaks within a country, and consequently to reduce the risk of further spread to neighbouring countries. Although it is only a hypothesis, we suggest that the COVID-19 pandemic has severely affected the control and surveillance of animal diseases. ASF requires quick responses and permanent monitoring to identify outbreaks and prevent spread, and both aspects could have been heavily undercut during the COVID-19 pandemic.

It is believed that the illegal importation of swine products and by-products from ASF affected countries represents the main source of ASFV introduction into free areas. Several risk assessments have been performed focusing on the flow of smuggled swine products from ASF affected countries (Jurado, Mur et al., 2019; Sugiura, Lei et al., 2020; Wooldridge et al., 2006). During the COVID-19 pandemic, a dramatic decline in the ASF entry risk into Japan through this route was reported, and attributed to a decrease in the number of air travellers from China (Sugiura, Kure et al., 2020). In this study, no changing trend was detected in the monthly confiscations of swine products from ASF affected countries at the U.S. port of entries. However, a peak of confiscated swine products and by-products from China was recorded in September 2020. This result should be interpreted considering that the analysis was based on all information of illegally confiscated swine products and by products at borders arrived by freight (both air and sea), mail, and passenger baggage. Indeed, despite the COVID 19 pandemic had disruptive effects on the airline industry, with a significant reduction in the number of business and leisure air travel (Bartle et al., 2021), the mail package volume significantly increased over 2019 levels in 2020 (U.S. Postal Service, 2021). In particular, the large number of events recorded in September 2020 might be due to the Chinese Moon Festival, which occurred on 1st October. If compared with the records of 2019, when Chinese supplies were plenty available in the United States, the records of confiscation of swine products and by products from China in 2020 almost doubled (from 77 in 2019 to 137 in 2020). The disruptive role of COVID-19 in this trade pattern is not clear. In the United States, the infectivity of smuggled swine products and by products is unknown as they are immediately destroyed after confiscation. Nevertheless, smuggled products from China detected by the Animal Quarantine Service (AQS) of Japan were found to be ASFV positive, highlighting the risk of ASFV introduction by such route into ASF free countries. (Kondo et al., 2020). In the pre-pandemic period, Jurado et al. (2019) suggested that the risk of ASFV introduction into the United States through smuggling of pork products increased substantially since the spread of the disease into regions of Asia, with most of the risk coming from China. Results from this study highlight that, considering its strict controlled and uncontrolled connection, China still poses one of the major risks for ASF entry into the United States.

Only a small percentage of illegally imported products is generally detected at the ports of entry, as a results of a limited inspection workforce and budgetary restrictions over time (Brown & Bevins, 2018). Nevertheless, the National Pork Producers Council (NPPC), which represents the U.S. pork industry, continuously supports the CBP activities at borders to prevent the ASFV entry. During the COVID-19 pandemic these efforts have been maintained, and funding for new agricultural inspectors at land, air and sea ports was authorized by then President Trump to reinforce the border control activities (NPPC, 2020; Wagstrom, 2020). Strengthening border controls may help tackle the challenges posed by the COVID-19 pandemic to prevent FADs introduction. This is particularly important considering that the percentage of departures performed by commercial air carriers from ASF affected countries has increased during the last 2 years. Nevertheless, this result should be interpreted considering the lack of information on the number of passengers from ASF affected countries with no direct flights to the United States. Thus, it does not provide a complete picture on the air transportation to the United States as many countries, including the ASF affected, are connected to major hubs (e.g., Amsterdam, Frankfurt or Paris-Charles de Gaulle) rather than by direct flights. The COVID-19 pandemic had a large impact on the air transport system, causing an overall reduction in freight and passenger travel. Specifically, it led to a reduction in the amount of passenger flights and belly cargo, requiring an increase in the number of flights that carry cargo only (Bartle et al., 2021). However, determining the impact of the COVID-19 crisis on the air freight transport is complex, considering that the capacity demanded for some goods has increased, while the demand for others has lapsed. In this study, only the departures performed and passengers from ASF affected countries were evaluated. This should be considered when interpreting the results presented. A high percentage of trade routes from ASF affected countries was also detected. This is not surprising as goods are generally produced in regions where the cost of labour is low (e.g., Asia).

In line with the commercial air transportation, increased trends in the number of ASF affected countries of origin of merchant ships and goods (in value-$) transported were also observed during the COVID-19 pandemic. This is of relevance as the waste disposal from international ships has historically been one of the most important ways for ASFV introduction into free areas (Mur et al., 2012). No information was available for the movements of passengers and number of merchant ships, but it was considered the dollar value of the goods imported. This provides a realistic information of the changes in volume between years, assuming that the type of goods imported from each country per each port is more or less homogeneous in time. Additionally, this study is based on two consecutive years, with limited variation of dollar inflation (Table S10). Under these assumptions, the increasing trend seems to be due to a real increase in imports rather than a price increase. It is important to consider that the increased number of trade partners that are ASF affected is also due to the fact that some countries already trading with the United States became ASF countries during the study period (e.g., India).

One limitation of this study is that it does not investigate the risk of ASFV introduction into the United States via third countries from the Central and Southern parts of the American Region that were considered ASF free at the beginning of the pandemic. During the processing of the manuscript, ASFV entered the Dominican Republic (01/07/2021, https://wahis.oie.int/#/report-info?reportId = 37116) where it is currently spreading. The United States already prohibits imports of swine from the Dominican Republic due to the presence of Classical Swine Fever. Nevertheless, the presence of ASF in the Americas is of concern, increasing the risk of entry into the United States. The reason of the entry into the Dominican Republic is still not known. It may be supposed that the COVID-19 pandemic could have derailed the border controls, surveillance and preparation for emergencies especially in areas where the pandemic is complicated by internal political dynamics, poverty and inequality (Pablos-Méndez et al., 2020). Additionally, in contrast to the United States, national veterinary services in Latin America do not have dedicated and trained staff to perform specialized activities such as risk analysis (e.g., the Performance of Veterinary Services (PVS) in Brazil (OIE, 2014)). Therefore, once entered in the Americas, a regional spread of ASFV is likely to occur.

It is important to highlight that this study analyses only some of the drivers and pathways for the potential introduction of ASFV into the United States during the COVID-19 pandemic. Indeed, there are other factors that might be associated with the introduction of the virus in free countries. For instance, animal feed imported from ASF affected countries (either legally or illegally) is considered a matrix able to contain and maintain infectious ASFV in some cases (moderate risk) (EFSA AHAW Panel, 2014). Additionally, this study does not evaluate the e-commerce pathway due to the scarcity of harmonized and public data. Products contaminated with ASFV can also be purchased online by private. This warrants special consideration as the COVID-19 pandemic has seen growth in the market share of trade and retail taken by e-commerce (United Nations, 2021). All these factors can be considered as potential limitations of this study.

Another important limitation of this work is the lack of data on the effect of COVID-19 pandemic on ASFV surveillance activities outside the United States, and the border control activities of the CBP and FSI at ports of entry, which was not possible to evaluate with detailed figures. Further studies should be performed to compare baseline (pre-COVID-19) ASF surveillance and border control activities with the current pandemic situation to examine the resilience to cope with potential ASFV introduction. This should be best done through surveys or by performing experts knowledge elicitation (EKE). Given that ASF control measures are required both before departure and on arrival to effectively prevent the disease transmission across borders, two questionnaires should be developed. The first should be administered to a group of experts from ASF affected trade partners in order to evaluate the efficiency of national veterinary services activities in the pre-COVID-19 and during the COVID-19. The experts should be identified based on their involvement in animal disease monitoring and surveillance activities, and their expertise on ASF. Each expert should be asked to assess the capacity of ASF surveillance and control during the COVID-19 pandemic in their countries. The second questionnaire should be focused on the U.S. border control measures and should be administered to experts from U.S. governmental bodies. Specifically, the questions should consider: (i) capacity to work on animal health activities at farm level (difficulties to maintain good biosecurity, movement restrictions limit farmers' capacity to reach out to their veterinarian), (ii) disease surveillance activities (outbreak investigation and disease reporting disrupted due to logistical issues), (iii) laboratory diagnostics (shortages of lab reagents and reduced intensity of lab testing for animal diseases), (iv) control of imported foods (sampling and analysis of food), (v) reallocation of veterinary staff to national COVID-19 emergency response teams.

5 | CONCLUSION

In conclusion, this study highlights an increased connection of the U.S. with ASF affected countries during COVID-19 pandemic. The findings presented did not aim to provide an estimate of the risk of introduction of ASFV in the United States. but they point out important aspects to be considered when performing a risk assessment during a global public health emergency. The long-term consequences of this pandemic on countries capacities to control and prevent ASF are still unknown. Nonetheless, it remains fundamental to ensure that the ASF risk is not underestimated. In this sense, a risk assessment that includes EKE and covers all the aspects influencing the ASFV risk of introduction into the United States is necessary to inform polic makers and international agencies on the risk posed by ASF during a public health emergency status.

Lastly, the circulation of ASFV in the Dominican Republic represents a great risk for the whole Americas Region. The disease is likely to further spread in the highly interconnected Caribbean Islands, given the socio-cultural context of this area, the important movements of ships, flights, and population of emigrants from Dominican Republic. Therefore, an increased surveillance effort at borders of every American country is needed to assure early detection of ASFV and rapid reaction.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICAL STATEMENT

Ethics approval was not required for this study.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

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ENDNOTES

[1] https://www.ecfr.gov/cgi-bin/text-idx?SID=9babc721e6ebd9cdc085a3396f1c97ce&mc=true&tpl=/ecfrbrowse/Title09/9cfr94_main_02.tpl
[2] https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-and-animal-product-import-information/animal-health-status-of-regions
[3] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L:2021:129:TOC
[4] https://uscode.house.gov/view.xhtml?path=/prelim@title21/chapter12&edition=prelim
[5] https://www.govinfo.gov/content/pkg/CFR-2012-title9-vol2/pdf/CFR-2012-title9-vol2-part327.pdf
[6] MT: Metric Tons
[7] The number of events from ASF affected countries was computed considering the ASF first occurrence reported by the countries to the OIE. For instance, the first occurrence of ASF in Germany is on 09/09/2020. Illegal products from Germany confiscated by CBP before September 2020 were not considered.

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