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Review paper

Tackling African swine fever and highly pathogenic animal diseases for sustainable meat production and food security

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ABSTRACT

The purpose of this article is to review the impact of the current international geographical distribution of African Swine Fever (ASF) and other transboundary swine diseases and their consequences. Moreover, the aim is to discuss the importance and modalities of their prevention and control, based on international standards of the World Organisation for Animal Health (WOAH, founded as OIE in 1924) and the Resolution on Global Control of ASF, adopted by 182 Member countries in 2019.

Highly pathogenic swine diseases have multifaceted impacts on food security and rural development. These impacts are driven by factors such as reduced meat production, price volatility, trade disruptions, economic losses in rural areas, decreased livelihoods, investment uncertainty, changes in rural infrastructure, and, for some of them, potential zoonotic characteristics. Understanding these dynamics is crucial for creating effective preventive and control strategies and measures to mitigate such consequences on food security and rural development in affected regions. Scientific research and evidence-based policy measures, as promoted by WOAH, are essential to address these challenges comprehensively.

Regional and international collaboration for identifying and coordinating the management of ASF is crucial for their effective prevention and control. In Europe, the WOAH plays a vital role in this mechanism, collaborating with 53 Members and partners to support the control and eradication of ASF and promote the implementation of international standards and best practices. National ASF strategies should follow these examples, with a focus on legislation enforcement and capacity building, in close collaboration with all stakeholders, to introduce effective prevention and biosecurity measures, official controls, traceability of swine commodities, wild pig management, and awareness programs.

Collaboration, cooperation and learning from best practices will contribute to better tackling these challenges and ensure sustainable disease control, meat production and food security.

1. Introduction

Livestock production is vital for human health and nutrition, food security, rural development, poverty reduction and sustainable agriculture (*Randolph et al.*, 2007). However, livestock diseases significantly affect the sustainability of livelihoods among impoverished communities while a key challenge is the limited access to quality veterinary and other services, technical capacities, funds, and relevant information about preventing and treating these diseases (*Heffernan*, 2009). The growth of the human population has multiple influences on swine health and its management, leading to a higher pork demand among consumers, consequently boosting the global pig population. More and more people are com-

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ing into direct or indirect contact with livestock and wildlife, either in proximity or in terms of geographical presence, thereby amplifying the potential for disease transmission, including those with zoonotic potential (*Vonderohe et al.*, 2022). These instances underscore the necessity of constructing a comprehensive global perspective on swine pathogens to bolster preparedness and comprehend the dynamics of their emergence and dissemination.

The expanding, intensifying, and centralized nature of pig production has given rise to unique challenges in porcine health management and public health, potentially impacting the sustainability of swine farming (*Maes et al.*, 2020). These challenges predominantly arise from the sheer volume of pigs confined within limited spaces, providing fertile ground for pathogen proliferation. Viral and bacterial propagation risks are compounded by environmental and physiological stressors, like heat stress or weaning, which can weaken the immune system, overall health, and welfare of animals. The existing disease issues are further complicated by escalating antibiotic resistance levels, making it more challenging to manage bacterial diseases that were once treatable with antibiotics (*Davies*, 2012; *Mathew et al.*, 1999; *Muurinen et al.*, 2021; *Vonderohe et al.*, 2022).

Infectious diseases represent a significant obstacle to pig production, and the global expansion of the swine industry has played a role in the emergence and dissemination of pathogens. The pig sector, characterized by its vast size and varying biosecurity levels, is vulnerable to transboundary animal diseases (TADs) like African swine fever (ASF), Classical swine fever (CSF), foot-and-mouth disease (FMD), porcine reproductive and respiratory syndrome (PRRS), porcine epidemic diarrhea (PED), with devastating economic impact (*De Vos et al.*, 2003; *Meuwissen et al.*, 1999; *Nedić et al.*, 2011; *Plavsic et al.*, 2009; *VanderWaal & Deen*, 2018). These diseases, facilitated by legal and illegal international trade, perpetually endanger swine health, diminishing livestock productivity and quality. Such outcomes extend beyond producers, impacting broader socioeconomic well-being. Even if some infections have low mortality, they negatively impact the immune system of animals, which might be more susceptible to bacterial coinfections, many of which have harmful potential (*Saade et al.*, 2020). Trade restrictions, often accompanying disease cases, impose significant economic burdens, particularly on exporting nations. Veterinary control measures, including depopulations, compound these costs, bearing additional economic, social and political consequences.

Moreover, some pig diseases have impact on public health, while various factors contribute to the rise of zoonotic infections in humans, such as the density of pig farms and population, inadequate hygiene and biosecurity conditions on farms, in transport or hunting practice, the pathogen's characteristics, professional contact with pigs, inadequate sanitation practices. The significance of livestock pathogens for public health was emphasized by the H1N1 "swine flu" pandemic in 2009, originating from influenza A viruses discovered in swine populations *(Smith et al.*, 2009). Other highly pathogenic zoonotic viral pathogens, such as Ebola and Nipah viruses, are limited to specific geographical localization, but have potential for more severe consequences (*Haddock et al.*, 2021; *Uddin Khan et al.*, 2013). The intensified interaction among humans, livestock, and wildlife will likely lead to new zoonotic viral pathogens that could threaten both swine and human health. Swine-related zoonoses frequently result in significant economic consequences due to the potential threat posed by new pathogens to humans, decreased public interest in pork consumption, mandatory culling of swine herds, and the imposition of international trade restrictions (*Uddin Khan et al.*, 2013).

The more significant the impact of animal diseases on agricultural production, the more evident the need for rigorous prevention and preparedness measures *(Brown et al., 2021; Plavšić et al.*, 2019). TADs, including ASF, with their potential to cause economic, trade, and food security crises, necessitate international cooperation for their control and management *(Plavšić et al.*, 2019). A comprehensive epidemiological understanding of entry mechanisms of these diseases is vital to ensure stakeholder preparedness, prevent pathogen introduction to farms via diverse pathways, and enable effective outbreak detection, rapid response, and effective control. Unfortunately, numerous countries, particularly those in the developing world, face a deficiency in crucial veterinary and diagnostic capacities, leading to a lack of clarity concerning the origins of primary outbreaks, the transmission pathways, and the inability for rapid containment. Recent cases of ASF spreading in Europe and Aasia, and outbreaks of FMD, CSF and PED in other regions, underscore the challenge of identifying index cases despite heightened risk and alert levels (*Huang et al.*, 2013; *Moennig et al.*, 2003; *Pharo*, 2002; *VanderWaal & Deen*, 2018; *Zhou et al.*, 2018).

2. Pig production

The worldwide pig industry plays a crucial role in providing animal protein, with pork being the most consumed terrestrial meat, making up over 36% of global meat consumption and showing steady growth (*Drew*, 2011; *FAO*, 2014). An apparent contrast marks the pig production landscape: on the one hand, there are traditional small-scale farms driven by subsistence, and on the other hand, there are industrialized operations that are vertically integrated (*Plavšić et al.*, 2019). Despite the growing importance of large-scale pig farming in meeting the demand for pork, a significant number of pig producers (around 43% of the worldwide pig population), are involved in small-scale, backyard type of farms, producing pork products mainly for own consumptions (*Robinson et al.*, 2011). In rural settings, pig farming is an essential source of meat and cash income, having an efficiency in using household food waste, providing manure for fertilization, and serving as a financial safety net. However, smallholder pig farming is typically not a primary source of income, leading to limited investment in housing facilities, biosecurity measures, and adoption of new technologies. This disparity between commercial and backyard farmers is especially evident in efforts to prevent and control diseases. The backyard sector, which is characterized by low biosecurity levels, outdated practices, and poor adherence to animal health regulations, plays a significant role in the introduction, spread, and persistence of most pig diseases, particularly ASF, CSF and FMD, including in countries with a considerable share of world's pig population (*Costard et al.*, 2013a; *Kedkovid et al.*, 2020; *Postel et al.*, 2019; *Vergne et al.*, 2017).

3. African swine fever

ASF, a severe haemorrhagic disease with a nearly 100% fatality rate in infected domestic pigs, has recently emerged as a global concern for food security following its devastating impact on swine production in several countries (*Dixon et al.*, 2020; *Kukielka et al.*, 2017; *Plavšić et al.*, 2019; *Turlewicz-Podbielska et al.*, 2021; *VanderWaal & Deen*, 2018; *Vergne et al.*, 2017; *Zhou et al.*, 2018). It poses an immense challenge for control due to its ability to cause asymptomatic infections, resulting in carrier animals capable of spreading the virus to new herds and wild boar. Additionally, it can persist in tick vectors for over five years and is difficult to diagnose. Efforts to create a safe and efficient vaccine have proven unsuccessful thus far.

ASF poses a complex epidemiological challenge, given its persistent adaptation and global spreading across diverse ecosystems, affecting different swine populations, while utilizing various transmission mechanisms. The survival of the ASF virus (ASFV) within a given ecosystem depends on various ecological factors, including the dynamics of wild host populations, vectors, soil conditions, and the characteristics of livestock production systems. These factors collectively influence the density of host and vector species and the nature of their interactions (*Costard et al*., 2013b).

ASF represents the most significant threat to the potential sustainability of global swine production and will probably continue to do so until an effective control strategy, supported by the availability of an efficient, potent, and safe vaccine, is developed. In the battle against ASF, it is imperative to recognise that control efforts must extend beyond the major responsibilities of specific sectors and encompass all key players, ideally using a "whole-of-society approach" (WoS), promoted by public health sectors during Covid-19 crisis (*Ortenzi et al*., 2022). This approach means that ASF control is not solely a technical challenge but a collective responsibility that requires active participation and commitment of practically all stakeholders, from farmers, food business operators, and professional services to consumers, hunters, and the overall community. By uniting efforts across all segments of society, a robust defence system against ASF should be built to safeguard both swine populations and the broader ecosystem in which they exist (*Maes et al.*, 2020; *Ortenzi et al.*, 2022; *Turlewicz-Podbielska et al.*, 2021; *VanderWaal & Deen*, 2018; *Vonderohe et al.,* 2022).

4. Control of African swine fever

4.1 International standards

In the context of ASF prevention and control, strict adherence to international standards is imperative. Although control of ASF is feasible, success requires regional and global coordination (*Park et al.*, 2020; *Plavšić et al*., 2019). WOAH Terrestrial Animal Health Code provides the harmonised international standards for mitigation of zoosanitary risks, including through zoning, compartmentalisation and application of risk-based trade measures *(WOAH Resolution No. 33: Global Control of African Swine Fever*, 2019; *WOAH Terrestrial Animal Health Code*, 2023) .

4.2. Global initiatives and international collaboration

In 2019, WOAH proposed its Membership the development of a strategic framework for the sustainable control of ASF, while ensuring economic growth, food security, and safe trade of swine commodities. All 182 Members unanimously adopted Resolution No. 33 on Global Control of African Swine Fever at the 87th General Session of the World Organisation for Animal Health (WOAH) after the comprehensive presentation and profound discussions among Delegates. It acknowledged the complexity of ASF and the need for multisectoral cooperation and highlighted the importance of collaboration between the Food and Agriculture Organization of the United Nations (FAO) and the WOAH in managing animal health risks related to ASF under GF-TADs mechanism (General Framework for Progressive Control of Transboundary Animal Diseases). The Resolution also emphasized the roles of Member countries, FAO, and WOAH in global ASF control, emphasizing the importance of adopting and implementing national control programs, risk communication, transparency in disease notification, and adherence to international standards (*WOAH Resolution No. 33: Global Control of African Swine Fever*, 2019).

4.2.1 GF-TADs Framework — global level

The GF-TADs is a joint initiative of the WOAH, and FAO, which combines the strengths of both organisations to achieve agreed common objectives. Initiated in May 2004, GF-TADs serves as a facilitative platform dedicated to strengthening global and regional collaborations in combating TADs. Its core objectives include enhancing capacity-building efforts and supporting establishing programs tailored to address specific TAD control priorities at both global and regional levels.

The GF-TADs initiative for the Global control of African Swine Fever is designed to address strategic challenges, foster partnerships, enhance prevention and preparedness measures, and reduce the negative impacts of ASF. The GF-TADs platform encourages regional alliances and synergizes with existing control strategies for other transboundary animal diseases. The initiative provides a structure for global ASF control, establishing a theory of change translated into a logic framework. This framework outlines outputs and indicators for three objectives: i) improve the capability of countries to control ASF using WOAH standards based on the latest scientific knowledge, ii) establish an effective coordination and cooperation framework for the global control of ASF, and iii) facilitate business continuity.

4.2.1 GF-TADs Framework — regional level

Following leadership from global level, regional offices of WOAH and FAO, in collaboration with relevant stakeholders, developed an efficient regional mechanism, to identify and coordinate management of regional activities, including priority TADs. In Europe, WOAH is providing role of Secretariat of this mechanism, in close cooperation with FAO and EC, current elected chairmanship. Among other priority animal diseases, ASF is recognized as one with critical importance for its Membership, covering 53 Member countries and partners in Europe. Since 2014, an operational Standing Group of Experts for ASF (SGE ASF) has been in place. It aims to build up closer cooperation among countries affected by African swine fever, thereby addressing the disease in a more collaborative and harmonized manner across Europe. The SGE ASF is a unique opportunity to engage affected countries into a fruitful regional dialogue and increased transparency. The GF-TADs offers the ideal framework to discuss common and harmonized mitigation measures based on scientific and technical grounds only. On top of the formal members of the SGE ASF (the countries in Europe affected by ASF), representatives from any other country in Europe and beyond are welcome to attend as observers.

4.3 National control strategies

National ASF strategies should follow these standards and best practices, enforce legislation, and collaborate with all stakeholders. Members should enhance technical capabilities, use scientific knowledge, and engage national stakeholders, since a collaborative approach is crucial to prevent further spread of ASF. To formulate robust and effective control strategies, it is essential to understand the potential for ASFV transmission within the domestic pig population, and within a wild boar reservoir, as well as at the interface between wildlife and domestic pig production. Currently, the primary methods for ASF control, proven in many regions, involve containment measures and stringent biosecurity practices (*Turlewicz-Podbielska et al.*, 2021).

Nonetheless, it is of utmost importance to carefully assess the risk factors associated with ASF and tailor control strategies accordingly, a task that presented significant challenges in certain regions during the current epizootics in Europe and Asia. A comprehensive categorization of risk factors associated with ASF was proposed, classified into twelve distinct categories, encompassing various aspects of ASF epidemiology. These categories include ASF virus characteristics, biosecurity, disease control measures, environmental factors, pig husbandry practices, movements of animals and associated materials, network connections within the swine industry, pig-related attributes, societal influences, surveillance activities, vaccination considerations, and wildlife management practices. By systematically organizing these risk factors, authors offered a valuable resource for understanding, assessing, and mitigating the spread of ASF, facilitating more informed decision-making and improved preparedness strategies within the swine industry and stakeholders (*Bergmann et al*., 2022).

4.3.1. Control strategies in domestic pigs

Effective prevention and control of ASFV is a complex task involving numerous stakeholders within the pork food system. National Veterinary Authorities (VA) are crucial in designing and implementing policy instruments, such as legislation, regulations and guidelines, disease surveillance programmes, and outbreak response procedures. These policies often need to pay more attention to socioeconomic, cultural, behavioural, or political factors, leading to limited stakeholder acceptance and reduced effectiveness. Consideration of stakeholder behavioural responses and feedback loops between policy instruments is essential. For instance, prohibiting food waste feeding may drive farmers to seek alternative protein sources, potentially from illegal means, thereby impacting the effectiveness of control measures. It is noted that well-resourced Veterinary Services (VS) can more effectively enforce compliance and the pork value chain stakeholders more readily accept and implement control measures. Achieving this requires a deep understanding of relevant socioeconomic factors and knowledge about effective incentives, often needing more social science research and technical capacity-building. Additionally, the availability of specific tools and information, such as farm registration, animal identification and traceability and the spatial distribution of farms and pig flows, will support VA in developing effective control and prevention policies for ASF (*Barnes et al.*, 2015a; *Dixon et al.*, 2020; *Hidano et al.*, 2018; *WOAH Terrestrial Animal Health Code*, 2023).

The prevention of ASFV introduction is a critical focus for VS and the pork industry due to the challenges in controlling and eradicating ASF in affected areas. This prevention strategy targets countries, regions, farms, and local wild boar populations. It involves implementing farm-level biosecurity measures, movement control and inspection activities to deter the legal and illegal importation of infected pigs, pork products, or food waste. Awareness campaigns are vital to reduce risky behaviours among travellers between affected and non-affected areas. The effectiveness of biosecurity measures depends on the local socioeconomic context and the policy instruments. Cooperation with hunters and adaptation of gaming methods involving local hunting grounds and forestry authorities may provide insights into achieving adequate knowledge to impose preventive measures (*FAO Anim. Prod. Health*, 2010; *Jurado et al.*, 2018; *Merrill et al.*, 2019).

Surveillance is paramount in the control of the spreading of ASFV, aiming to early detect outbreaks at sources, and enable swift responses to prevent its spread. Extended survival period of the virus in the environment and pork products, necessitates early detection to contain its transmission effectively. Passive and active surveillance components play roles in early detection, with passive surveillance being crucial for domestic and wild pigs. It relies on farmers and other stakeholders in the pork food system to report suspect cases. Farmers, in particular, must be capable of recognizing clinical ASF symptoms and be willing to report them promptly. Detection often occurs when multiple pigs exhibit symptoms, usually two weeks or more after the initial case. Active surveillance involves diagnostic testing of live or dead pigs for the virus, primarily, and antibodies, secondarily. Routine virus testing in slaughterhouses and at large pig farms can increase ASFV detection probabilities *(Dixon et al., 2020; Guinat et al., 2016; Halasa et al.*, 2016; *Hoinville et al.*, 2013; *Stärk et al.*, 2006).

Responding to an ASF outbreak is multifaceted, particularly in complex pork food systems. Recommendations for response strategies emphasize the importance of tracing potentially infected contacts both forwards and backwards to identify the source and potential spread of the virus. However, conducting these activities can be highly challenging, especially in some countries and regions, which might be amplified when some of the contacts involved in transmission have illegal or informal backgrounds. Establishing

protection and surveillance zones with strict restrictions on pig movement and ASFV investigation activities around an outbreak is essential. Decision-making regarding preventive culling pigs at risk of infection is intricate, involving considerations about farms in direct or indirect contact, whether to cull only those on the affected farm, a part thereof, or those on neighbouring farms within a certain radius. These decisions must account for various epidemiological, economic, cultural or social factors, as extensive culling and carcass disposal can spread the infection further if not implemented properly (*Guinat et al.,* 2016; *Halasa et al.,* 2016; *Honhold*, 2011; *te Beest et al.*, 2011).

Moreover, the mental distress experienced by farmers, veterinarians and field staff during culling operations adds another layer of complexity. Developing an integrated, locally adapted perspective based on best international practices can ensure effective outbreak response policies. Still, it is a significant challenge for national and local disease control authorities, particularly in low- to middle-income countries (*Hall et al.*, 2004; *Makita et al.*, 2015).

The role of vaccination in ASF control and prevention policies is a critical consideration. Future ASF vaccines should be integrated into comprehensive control and prevention strategies tailored to national or local pig production system considering economic and social contexts, human behaviour-related risk factors and responses to control measures. However, vaccines alone cannot replace the necessity for high-level biosecurity measures and behavioural change among all swine value chain stakeholders to restrain ASFV transmission effectively. A significant concern is the premature use of vaccine candidates driven by ASF's severe socioeconomic impact, highlighting the need for thorough effectiveness evaluation before their deployment (*Borca et al.*, 2020; *Brake, 2022a*; *Chen et al.*, 2020; *Dixon et al.*, 2020; *Urbano & Ferreira*, 2022).

Financial compensation to farmers following culling constitutes a pivotal policy instrument, positively influencing the inclination of farmers to notify disease cases. This instrument ranks among the most crucial tools accessible to Veterinary Authorities. It holds particular significance not only in effective prevention but also in the early reporting of ASF cases. A comprehensive socioeconomic analysis must underpin financial compensation schemes to ensure their effectiveness; otherwise, they could incentivise farmers to tolerate outbreaks or deter them from reporting suspected ASF cases due to concerns about potential financial losses (*Barnes et al.*, 2015b).

4.3.2. Control strategies in wild boar population

In ASF-affected countries within the European Union, most ASFV incursions have been traced back to the introduction of the virus into wild boar populations, either through anthropogenic sources or infected wild boar movement. These infected wild boar populations serve as a reservoir of infection for domestic pigs and result in trade restrictions. To achieve ASF-free status by WOAH, based on self-declaration, Belgium and the Czech Republic successfully applied control and eradication strategies since the virus introductions primarily affected wild boar populations at specific points. These strategies included the establishment of zones, including infected, buffer, and control zones, as quickly as possible. In the Czech Republic, the infected zone with fences was physically isolated to reduce the risk of natural disease spread among free-ranging wild boars and demarcate restricted areas. While using fences for ASF control in wild boar populations is subject to debate, they can likely limit wild boar movements, acting as a barrier to virus spread. Feeding and hunting bans were imposed in the infected and buffer zones to minimize disruptions to affected and at-risk populations. Efficient wild boar carcass surveillance systems were developed to detect and remove infected carcasses effectively. In the control zone, stringent wild boar depopulation strategies were recommended to reduce wild boar densities with minimal disturbances. Collaboration with hunting communities and relevant authorities played a pivotal role in achieving successful outcomes. The European Commission (EC) is now advocating for adopting these measures in other EU countries. However, it is essential to note that their application may require significant adjustments in accordance to ecological, epidemiological, and social contexts (*Abrahantes et al.,* 2017; *Dixon et al.,* 2020; *Jori & Bastos*, 2009; *More et al.*, 2018; *Nielsen et al.*, 2021).

5. The impact of ASF on the swine industry

The ongoing epidemiological situation with ASF poses a real threat to the global pig industry (*Costard et al.*, 2013a; *De Vos et al.*, 2003; *Zhou et al.*, 2018). Effective strategies for managing ASF outbreaks are paramount to safeguard the future of the pig industry and prevent adverse consequences on a local, regional, or global scale. Existing guidelines and recommendations for developing ASF control strategies, namely those adopted by WOAH Member countries, are available. As the disease has

already spread across many European and Asian countries, this section addresses critical issues related to ASF control based on the Global Framework for ASF control under the GF-TADs umbrella (*Dixon et al.*, 2020; Park et al., 2020; *Plavšić et al.*, 2019).

The success of ASF control largely depends on how farmers and stakeholders perceive and manage risk, highlighting its crucial role. Firstly, there is a critical need to closely monitor small-scale farms practicing swill feeding and lacking adequate biosecurity measures or even prohibiting them in the highest-risk areas. Backyard holdings can be significant sources of ASF infections in previously unaffected areas. The pathways for ASFV transmission to these holdings are diverse and may involve swill feeding, contaminated fomites, vehicles or other equipment, accompanied with movement of humans and animals. Although the risk of ASFV introduction to larger farms implementing robust biosecurity measures is generally low, it escalates when the viral circulation in the surrounding farms and environment increases, particularly in the case of backyard pig holdings. Therefore, it is highly recommended that affected countries implement policies to standardize biosecurity level on pig farms, properly control those with inadequate biosecurity, and consider compartmentalization or zoning to mitigate the risk. With complementary awareness-raising campaigns, availability of governmental subsidies to improve biosecurity measures could significantly decrease risks of spreading ASF and other diseases (*Kedkovid et al.,* 2020).

Efforts to prevent the introduction of viruses into farms through feed and feed ingredients represent a important aspect of biosecurity management, even for commercial pig farms (*Dee et al.*, 2018). Previous studies have demonstrated the extended survival of various swine viruses in these products. For instance, ASFV's half-life in different feed or feed ingredients ranged from 9.6 to 14.2 days under conditions simulating trans-Atlantic shipment (*Stoian et al.,* 2019). Recent reviews have outlined key principles to mitigate virus transmission through pig feed, including heat treatment (e.g., pelleting feed at higher temperatures), chemical mitigation (e.g., treating feed with formaldehyde and propionic acid), and managing storage periods based on virus half-life data. The effectiveness and practicality of these strategies for various swine viruses warrant further investigation and clarification (*Kedkovid et al.*, 2020).

Although many countries have moved beyond the peak of severe ASF outbreaks and are now in the endemic stage with increasing pork prices (e.g. in Asia), the temptation to expand pig production should not overshadow the persistent effects of ASF. The importance of maintaining biosecurity cannot be overstated, and there is a continuous need to educate farmers and those involved in the supply chain to prevent a reintroduction of ASF (*Bergmann et al.,* 2022; *Kedkovid et al.,* 2020).

Cooperation is a crucial factor in shaping the future of the pig industry. Given the suspected transmission of transboundary diseases through the illegal trade of pigs and pork products, improved cooperation among neighbouring countries is essential (*Nilubol et al.*, 2012). This type of transmission can occur across geographically isolated areas or over large distances, as demonstrated by the recent introduction of the CSF virus into Japan and the transmission of PED virus from Asia to North America via contaminated fomites (*Davies*, 2015; *Postel et al.*, 2019). Concerning ASF, we should understand that unless the problem in Africa and Asia is properly addressed, the virus may re-emerge. Therefore, cooperation should not be limited to neighbouring countries but extend further, potentially facilitated by initiatives from international organizations like the GF-TADs mechanism (*Park et al.,* 2020; *Plavšić et al.,* 2019).

An efficacious ASF vaccines, urgently required and coupled with robust biosecurity practices, are pivotal for the future of pig production. Recent advancements in the development of vaccine candidates demonstrate promising results in safety and efficacy (*Borca et al.*, 2020; *Chen et al.*, 2020). There are several reasons for tempered optimism that current and forthcoming ASF vaccine candidates can progress from discovery research to product development while effectively fulfilling the stringent regulatory criteria: vaccine purity, potency, safety, and efficacy. Among the five primary approaches to developing ASF vaccines, namely inactivated, naturally attenuated, laboratory-passaged attenuated, recombinant subunit, and recombinant gene-deleted modified live vaccines (MLV), the prospects for first-generation vaccine product licensure are most promising with ASF recombinant gene-deleted MLV candidates soon (*Brake*, 2022b). Ideal vaccine candidates may serve as marker vaccines, valuable for disease control programs like DIVA (differentiating infected from vaccinated animals). However, avoiding overemphasizing vaccination at the expense of other essential control measures, notably biosecurity and animal movement restrictions, is crucial. Lessons from previous disease control efforts in some countries, such as those targeting CSF or pseudorabies

virus (PRV), highlight the pitfalls of relying solely on vaccination. Although effective vaccines for some diseases exist, inadequate surveillance and control measures have allowed endemic diseases to spread (*Luo et al.*, 2014; *Sun et al.*, 2016). Furthermore, the potential rise in non-standardized vaccine production units due to increased demand raises concerns about vaccine safety and efficacy, mirroring challenges seen in CSF control (*Luo et al.,* 2014). Therefore, a holistic approach is imperative for effective disease management in pig production combining vaccination with stringent biosecurity and surveillance.

6. Discussion

Learning from the experience with pandemic diseases and extracting it to the case of ASF control, national, regional, and global policymakers should advocate for comprehensive control strategies encompassing the entirety of government and society. The WoS approach in ASF control, extends its scope beyond governmental bodies, involving a wide array of relevant stakeholders, including professional health services (veterinary, environmental, forestry and agriculture authorities), farmers, hunters, and traders, individuals, families, communities, intergovernmental organizations, religious institutions, civil society, academia, the media, voluntary associations, and, notably, the private sector and industry.

Establishing an efficient regional coordination mechanism for the management of priority TADs is crucial for their effective prevention and control. In Europe, the WOAH plays a vital role in this mechanism, collaborating with 53 Members and partners, namely EC and FAO, to support the control and eradication of ASF and promote the implementation of international standards and best practices. National ASF strategies should adhere to these examples, focusing on the enforcement of legislation, collaboration with all stakeholders, and enhancing technical capabilities, scientific knowledge, and risk communication. A collaborative approach is crucial to prevent the spread of ASF, with Member Countries enforcing WOAH's international standards at the local level. This includes risk-based prevention, biosecurity measures, traceability, official controls, wild pig management, and awareness programs.

Effective prevention and control of ASF require the involvement of various stakeholders within the pork production system. National VA play a crucial role in designing and implementing policy instruments, which should consider socioeconomic, cultural, behavioural, and political factors to ensure stakeholder acceptance and effectiveness. Strict adherence to WOAH international standards is imperative in ASF prevention and control. Regional success stories, like those in Belgium and the Czech Republic, underscore the importance of coordinated efforts and tailored strategies to combat ASF effectively.

Impact of ASF on food security, include several major changes: *1. Decline in meat production*: ASF substantially affect meat production, with a pronounced impact on the swine industry. The disease's high mortality rate among swine herds frequently results in a significant reduction in pork availability, a critical source of protein in many regions. Sometimes, entire herds must be culled to mitigate the outbreak, exacerbating the supply shortage. *2. Price fluctuations*: Diminished meat production reduction because of ASF outbreaks can lead to price volatility, rendering this protein source less accessible to vulnerable populations, especially those with limited incomes. Such price volatility can engender food insecurity among poor communities. *3. Disruption of trade*: ASF outbreaks often trigger trade constraints on pork and pork-related products, locally and internationally, which disproportionately affect exporting nations. Trade barriers impede the flow of pork into international markets, potentially disrupting global food supply chains and affecting food security in both exporting and importing countries. *4. Transition in consumer preferences toward alternative protein sources*: In response to the reduced availability of pork or because of ASF epidemics, consumers may shift their preferences toward alternative protein sources, such as poultry, fish, or plant-based proteins. However, heightened demand for these alternatives could increase prices, undermining food security through various channels.

African Swine Fever and similar TADs have far-reaching consequences on rural development, including various aspects, such as: *i) the economic consequences* (rural areas heavily reliant on swine production suffer substantial economic losses due to disease outbreaks, encompassing mortality, reduced production, and surge effects on related industries such as feed production, transportation, and processing); *ii) decreased livelihoods* (swine farming is a crucial livelihood source for numerous small-scale farmers in rural regions where disease outbreaks jeopardize these livelihoods, compelling individuals and families to seek alternative income sources, often challenging to find in rural settings): *iii) investment uncertainty* (ASF introduce uncertainty into the swine industry, making it less

appealing for investment, while the fear of recurrent outbreaks and potential financial losses discourages both local and foreign investors from engaging in the swine sector, hindering rural community growth and development) and *iv) infrastructure and services* (regions heavily dependent on swine farming often modify rural infrastructure and services to support this industry; when outbreaks occur, causing industry contraction, infrastructure and services like processing facilities, transportation networks, and veterinary services may become underutilized or obsolete, impacting overall rural development); *v) social impact* (swine farming plays a pivotal role in the social fabric of rural communities, tightly interwoven with their way of life; the stress and social disruption resulting from disease outbreaks can have enduring psychological and social consequences on individuals and rural communities, further affecting rural development).

7. Conclusion

The ongoing global epidemiological situation with ASF presents a significant and persistent threat to the swine industry worldwide. The consequences of uncontrolled ASF outbreaks are profound locally, regionally, and globally. Addressing global challenges in animal health and welfare, particularly highly pathogenic diseases like ASF, requires a collaborative effort on an international scale.

The GF-TADs represent an efficient mechanism to address the challenges ASF and other TADs, for its Membership, particularly in Europe. The establishment of the SGE ASF in Europe in 2014 has facilitated closer cooperation among countries grappling with disease, promoting a harmonized and transparent response to disease across Europe. Through cooperation, coordination, and scientific collaboration, this framework represents a significant step toward achieving effective control and prevention strategies for ASF on a global scale.

Developing a national control strategy for the control of ASF and other TADs, requires a multifaceted approach, which should include: i) Implementing robust surveillance systems to monitor disease prevalence and promptly detect outbreaks, involving both passive and active surveillance, ii) Promoting stringent biosecurity measures within the swine production system to minimize disease introduction and spread, including practices such as controlled access, disinfection, and quarantine protocols, iii) Evaluating and regulating hunting practices, which can contribute to disease transmission, which particularly covers biosecurity hunting practice, and iv) Developing and implementing effective control measures, including rapid alerts and response system, culling infected animals, and movement restrictions. The development of a high-quality vaccine for ASF is a high-priority research area.

Activities relevant to control measures include training and education of farm staff, hunters, and veterinary personnel, including disease recognition, passive surveillance and particularly biosecurity measures. In addition, rapid response teams and specialized units should be ready to contain outbreaks through culling, disinfection, and safe disposal of infected animals. International trade policies should be designed to support disease-free meat and animal product exchanges while ensuring compliance with WOAH standards.

Practical strategies for managing ASF outbreaks, based on WOAH standards and best practices shared by GF-TADs, are imperative to safeguard the future of the pig industry and mitigate these adverse effects. One of the key priorities is the close monitoring of small-scale farms, especially those employing risky practices such as swill feeding and lacking adequate biosecurity measures. Backyard holdings can be significant sources for initiating ASF outbreaks in previously unaffected areas. Affected countries should standardize farm practices, regulate farms with inadequate biosecurity, and consider implementing compartmentalization or zoning measures to mitigate risks.

Farmers' and stakeholders' perceptions and risk management play a pivotal role in the success of ASF control efforts. While some countries have moved past the peak of severe ASF outbreaks and are experiencing increasing pork prices, the importance of maintaining biosecurity practices must not be underestimated. Continuous education and awareness campaigns are essential to prevent the resurgence of ASF. Given the potential transmission of transboundary diseases through the illegal trade of pigs and pork products, enhanced cooperation among neighbouring countries is imperative.

By working together and learning from successful experiences, the global community can better tackle these challenges and ensure sustainable meat production and food security for all.

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