Review article

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AFRICAN SWINE FEVER: A BIOSECURITY CHALLENGE FOR DOMESTIC PIG PRODUCTION IN SERBIA

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Abstract

African swine fever (ASF) is currently the most important challenge for domestic pig production worldwide. The virus reached Eurasia in 2007, and is today affecting more than half of European Union member countries. Among Western Balkan countries, Serbia suffered the first case of ASF in a backyard holding in 2019. Since then, numerous outbreaks in domestic pigs and wild boar have been reported throughout the country despite the efforts of the veterinary authorities to control the disease. The lack of an effective vaccine is one of the main constraints, and the only currently available option to prevent further ASF infections is the application of strict biosecurity measures. Regarding biosecurity, backyard pig producers and smallholding farmers in Serbia have substantial gaps in the knowledge and fail to comply with safe production behaviour that favours the spread of ASF virus. In the currently prevailing smallholder and backyards farming systems, farm biosecurity is largely non-existent. The aim of this review was to identify specific ASF-risks factors in the current pig production system and gaps in biosecurity measures related to the human activities recognised as social and cultural identity in Serbia. Moreover, the main risk factors for ASF spreading and transmission at the domestic/wild boar interface, biosecurity practices in different production systems, and possible future control measures and awareness campaigns are discussed.

Key words: African swine fever, domestic pig production, Serbia

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AFRIČKA KUGA SVINJA: BIOSIGURNOSNI IZAZOV ZA PROIZVODNJU DOMAĆIH SVINJA U SRBIJI

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Kratak sadržaj

Afrička kuga svinja (AKS) je trenutno najvažniji izazov za domaću proizvodnju svinja širom sveta. Virus je prvi put utvrđen u Evroaziji 2007. godine, a danas je prisutan u više od polovine država članica Evropske unije. Među državama zapadnog Balkana, Srbija je 2019. godine potvrdila prvi slučaj AKS u jednom seoskom gazdinstvu. Od tada se beleži pojava brojnih žarišta u populaciji domaćih svinja i divljih svinja širom zemlje uprkos preduzetim kontrolnim merama. Nedostatak efikasne vakcine je glavno ograničenje i jedina trenutno dostupna opcija za sprečavanje daljih infekcija je primena strogih mera biosigurnosti. Što se tiče biosigurnosti, proizvođači svinja u seoskim gazdinstvima i mali farmeri u Srbiji imaju značajne nedostatke u znanju i praksi i imaju različita rizična ponašanja koja mogu da doprinesu širenju AKS. U postojećem sistemu malih gazdinstava i dvorišta, biosigurnost se uglavnom ne primenjuje. Cilj preglednog rada je identifikacija specifičnih faktora rizika od AKS u postojećem sistemu proizvodnje svinja i nedostataka u biosigurnosnim merama koji se vezuju sa ljudskim aktivnostima, a koji su prepoznate kao svojevrsni društveni i kulturni identitet u Srbiji. Pored toga, analizirani su glavni faktori rizika od širenja i prenošenja virusa AKS između populacije domaćih i divljih svinja, praktičnih biosigurnosnih mera u različitim proizvodnim sistemima i mogućnosti kontrolnih mera i kampanje podizanja svesti.

Ključne reči: Afrička kuga svinja, proizvodnja domaćih svinja, Srbija

INTRODUCTION

African swine fever (ASF) is a viral disease of domestic pigs and wild boars that currently represents a major threat to the swine industry worldwide (Sanchez-Vizcaino et al., 2013; Bellini et al., 2021). The disease was first reported in Kenya in 1921, and several intercontinental transmissions have

occurred since then (Sánchez-Cordón et al., 2018; Ståhl et al., 2019; Liu et al., 2021). Within European continent, the first ASF incursion was reported in Portugal in 1957 (Boinas et al., 2011). It took until 1995 to officially eradicate the disease from the continent, with the exception of Sardinia Island, where ASF is still endemic from 1978 to this day (Cappaia et al., 2018). In 2007, a new introduction of the highly virulent genotype II of African swine fever virus (ASFV) was reported in Georgia, the Caucasus (Rowlands et al., 2008). Despite all preventive measures, in early 2014, ASF reached the territory of European Union (EU) with the first case reported in Lithuania followed by other Baltic countries (Blome et al., 2020; Malakauskas et al., 2022). Since then, disease has continuously been spreading, and it reached Asia (2018) and the Americas (2021), which identified ASF as the worst livestock pandemic of this century (Liu et al., 2021; de la Torre et al., 2022). Today, 15 years later, ASF is progressively spreading each year to the territories of new countries on 4 different continents. Indeed, at least two new countries have become affected each year in Europe: Czech Republic and Romania in 2017, Hungary, Bulgaria, Belgium in 2018, Slovakia and Serbia in 2019, Greece and Germany in 2020, Italy and Northern Macedonia in 2021. Only two countries (Belgium and Czech Republic), both with only wild boar population affected, have regained an ASF-free status (Schulz et al., 2019; Sauter-Louis et al., 2021; Sauter-Louis et al., 2022). The geographical expansion of ASF continues (Zani et al., 2019; EFSA, 2022), but there are a number of important differences reported regarding disease spreading in the different parts of European continent (EFSA, 2019; de la Torre et al., 2022). Excluding the Sardinia Island, from 2014 up to the end 2020, there have been 6037 ASF outbreaks in domestic pigs and 39,970 ASF notifications in wild boar across 12 EU countries (ADIS, 2021). Indeed, in 2014 when ASF arrived in the Baltic States and Poland, it became endemic in the wild boar population (Zani et al., 2019; Malakauskas et al., 2022). Wild boar has been the main affected species in all countries except for Romania, where most notifications occur in domestic pigs (Andraud et al., 2021; Ardelean et al., 2021). Also, on the other side of the world, by November 2021, China had reported 203 cases of ASF and culled in total 1.193 million domestic pigs (Liu et al., 2021). Today in Europe, except for Hungary, Belgium and the Czech Republic where ASF occurred only in wild boar, both domestic pigs and wild boars are affected (Lamberga et al., 2020; EFSA, 2022). Generally, the total number of reported wild boar cases in Europe has increased from year to year, whereas the number of outbreaks in domestic pigs has been limited (Chenais et al., 2018; Chenais et al., 2019a). However, in the European south-eastern countries, ASF is severely affecting small-scale domestic pig holders and backyards (Zani et al., 2019; Andraud et al., 2021; Ardelean et al., 2021). Indeed, in this part of Europe,

the observed epidemiological ASFV pattern is different and mostly associated with the characteristics of the domestic pig sector with large percentage of backyards with low levels of biosecurity where pig keeping represents an important source of livelihood and a traditional heritage (Chenais et al., 2019b; Gervasi and Guberti, 2021).

Since at present there is no treatment or vaccination, prevention and control of ASF rely on biosecurity measures (Jurado al., 2018; Bellini et al., 2021). It is well known that ASF virus can be transmitted to domestic pigs and wild boar through direct and/or indirect contact with infected animals, contaminated fomites and through the ingestion of contaminated meat products (Olesen et al., 2020; Bellini et al., 2021). The virus is highly resistant to environmental conditions and can persist in contaminated fomites and meat products for several months, contributing to the disease spread (Mazur-Panasiuk et al., 2019; Beato et al., 2022). In many cases, the exact route of introduction into domestic pig herds cannot be determined, but most introductions are attributed to indirect virus transmission (Ståhl et al., 2019; Olesen et al., 2020). However, in the current epidemic involving domestic pigs and wild boar population in Europe, disease transmission is frequently driven by human activities (EFSA, 2019). Indeed, the specific influence of humans and social, cultural factors on ASF epidemiology today is increasingly recognized (Jurado al., 2018; EFSA, 2022). It is important to mention that ASFV is the only known DNA virus that can be transmitted by vectors (Mazur-Panasiuk et al., 2019; Olesen et al., 2020). Thus far, only soft ticks of *Ornithodoros* spp. have been found to facilitate ASFV replication (Ståhl et al., 2019). The first documented case of ASFV isolation in ticks (*O. erraticus*) was recorded in Spain in the 1960s (Boinas et al., 2011). Since then, eight *Ornithodoros* species have been found to be involved in the ASFV transmission (Blome et al., 2020). However, a new type of ASFV that can infect hard ticks and transmitted from female adults to the first generation larvae was discovered in China. However, the conducted studies did not confirm that hard ticks are able to transmit ASFV to susceptible pigs (Liu et al., 2021). Other insects that may mechanically spread virus have also been reported, for example, the stable flies. In the study by Olesen et al. (2018), it was demonstrated that blood-feeding flies are capable of transporting infectious virus for at least 12 hours. Therefore, flies may play a role in the introduction of ASFV to pig farms, even those with high biosecurity (Liu et al., 2021; Štukelj et al., 2021). Indirect spread by vectors could help explain the introductions into large high-biosecurity farms and the seasonal pattern of transmission seen in domestic pig farms in EU countries (Estonia, Latvia) (Jurado et al., 2018; Olesen et al., 2020).

In this review, we explored the pig production systems in Serbia and identified specific ASF-challenge risks in biosecurity measures related to human activities recognised as social and cultural identity. Also, the main risk factors of disease spreading and transmission at the domestic/wild boar interface, the importance of biosecurity in different production systems, and control efforts that require further attention in awareness campaigns are discussed.

OVERVIEW OF ASF SITUATION IN SERBIA (2019-2021)

In 2019, ASF was for the first time detected in domestic swine backyard population in central part of Serbia (Milićević et al., 2019). Following the first one, several outbreaks were confirmed in the villages of one municipality. Disease outbreaks were registered in the next 2 months in the backyard domestic pig population. According to the epidemiological investigation, almost all cases were firstly detected as health disorders in sows (anorexia, abortion, death) (Polaček et al., 2021). However, the last outbreak in 2019 was confirmed in another region, at the border with Romania in the south-east area of Vojvodina province (Petrović et al., 2021). The distance between the first and the last outbreaks was estimated to about 185-190 km. According to the results of epidemiological investigations, it was concluded that these outbreaks represent most probably two separate introductions from a neighbouring country - Romania (Polaček et al., 2021). In Europe, the long distance ASF transmission has been associated with the disposal of infected waste, meat or meat products in wild boar habitat, for example, in the Czech Republic, where the closest ASF cases were about 400–500 km away (Jurado et al., 2018; Bellini et al., 2021). Similarly, in 2017, in Romania, the first detection of ASF was confirmed in a domestic pig backyard, and contaminated Ukrainian meat products were suspected as the most likely source of ASFV (Zani et al., 2019). Subsequently, the Romanian domestic pig sector was affected with more than 3800 outbreaks from 2017 to 2020 (Ardelean et al., 2021). According to the results of epidemiological investigation in Serbia, it has been suggested that ASFV was most probably brought in with the different meat products from the affected neighbouring country - Romania (Milićević et al., 2019; Nešković et al., 2021; Polaček et al., 2021).

At the beginning of 2020, new cases of ASF outbreaks were registered in the south-eastern region of Serbia in a wild boar population. From then on, there have been continuous outbreaks in domestic pigs and wild boars along the country border with Romania and Bulgaria (Petrović et al, 2021; Polaček et al., 2021). At the beginning of 2021, a disease outbreak was confirmed in domestic pigs but for the first time on a large commercial pig farm, near the

border with Romania. The first clinical signs were notified in the gestating stable: high fever and mass abortions in pregnant sows, regardless of gestation stage were detected (Nešković et al., 2021). Similar findings were reported in the ASF outbreaks on a commercial pig farms in other countries (Lamberga et al., 2020; Liu et al., 2021). Afterwards, ASF was spreading to numbers of smallholdings and backyards and wild boars in different localities in the south-eastern and central part of Serbia. Additionally, in 2021 the ASF was detected 2021 in the wild boar population in the immediate neighbouring area with Romania, South Banat region of Vojvodina Province. This was the first case of ASFV confirmation in wild boar population located in one organised enclosed hunting ground (Petrović et al., 2021). From then on, ASF is continuously present in the south Banat, in backyards population located in several villages and wild boars located in open hunting grounds. The epidemiological situation in Serbia is somehow different comparing the EU countries (Chenais et al., 2018): the occurrence of ASF in wild boars seems to have a strong connection with the presence of the virus in backyards and immediate environment in/around villages. Indeed, in the most cases ASF occurred in wild boars located in areas which have previously been declared as an infected area, i.e., the first cases in domestic pigs were firstly notified (Polaček et al., 2021).

THE ORGANISATIONAL STRUCTURE OF DOMESTIC PIG PRODUCTION SECTOR IN SERBIA

In the Western Balkan region, the existence of highly variable pig farming system was reported (Prodanov-Radulović et al., 2015; EFSA, 2019). Considering the situation in Serbia, the main and highly important difference as compared to the EU member countries is related to the structure and organisation of domestic pig sector (Prodanov-Radulović et al., 2020; Prodanov-Radulović et al., 2020b). Serbia has the highest pig density of all countries in the Balkan region, with a total population of 2.7 million pigs (EFSA, 2019). However, the estimated number of pigs has fluctuated over the years, and nowadays it shows constant decreasing. Based on the official data, there were 2,983,102 pigs in 2020, and from that number 1,260,970 were in Vojvodina Province (Polaček et al., 2021). The official data of the Veterinary Directorate differ from the above due to the fact that only marked individuals are recorded in the database. However, in terms of percentage, over 50% of the domestic pig population is located in production units with very low or no biosecurity measures (Prodanov-Radulović et al., 2020a; Polaček et al., 2021). According to the official data, more than 40% of the people live in rural areas, and 36% of the total population is poor or at risk for poverty (EFSA, 2019). The above data indicate

that this could be the actual percentage of human population oriented towards extensive pig production sector. Serbia has started to harmonise the legislation related to animal diseases with the EU, but it is still ranked among the most vulnerable for disease outbreaks in Europe (EFSA, 2019; EFSA, 2022).

In the EU, pig farms are classified into three categories: non-commercial farms (pigs kept only for fattening for own consumption and neither pigs nor any of their products leave the holding); commercial farms (sell the pigs or move pig products off the holding) and outdoor farms (pigs kept temporarily or permanently outdoors) (Bellini et al., 2021). Rather than taking into account the farm size, this classification considers the commercial attitude of the holdings. In this way, it controls two important facts: the risk of ASF spreading by trading pigs and the risk for the farm of being exposed to source of infection (EFSA, 2019; EFSA, 2022). However, the pig farming in Serbia include five different pig production holdings: commercial pig farm (industrial pig production); family farm of type A (farm with more than 10 animals and high level of biosecurity); family farm of type B (farm with more than 10 animals and low level of biosecurity); backyards (few animals/less than 10 pigs kept mainly for self-consumption, with a low or total absence of biosecurity) (Prodanov-Radulović, et al., 2020; Prodanov-Radulović et al., 2021). Finally, the last type includes free-range and semi-free-range pig keeping, where domestic pigs often share the habitat with wild boars (Prodanov-Radulović et al., 2015; Polaček et al., 2021). From the aspects of domestic pig population density, farms are present through the whole country territory, with the highest densities in northern parts (Vojvodina Province) along the borders with Romania, Hungary and Croatia (Prodanov-Radulović et al., 2018; Prodanov-Radulović et al., 2020a). Beside industrial pig farms, backyards and smallholdings are a kind of traditional family type units. Indeed, in some parts of the Vojvodina region (especially in Srem and Mačva district), domestic pigs are dominantly managed under a backyard and smallholdings system (Prodanov-Radulović et al., 2015; Prodanov-Radulović et al., 2020b). Certainly, the key biosecurity measures are not easy to implement in this type of farming system (Chenais et al., 2019b; Polaček et al., 2021). According to the epidemiological investigations, the majority of the extensive units are incompletely or only partially fenced, and access of other persons is not controlled. The introduction and purchase of new animals (piglets, breeding animals) does not imply quarantine measures and health controls. Moreover, due to stables' construction characteristics, the vehicles that transport food or animals to the slaughterhouse have to enter directly the farm perimeter (Prodanov-Radulović et al., 2017a). The most important risk factors that promote the introduction and spread of the ASFV

are multiple: poor farming practices and low biosecurity, introduction of purchased pigs from internal trade with no quarantine measures, human activities and factors often related to society and the cultural background of the farmers (EFSA, 2019; Zani et al., 2019).

BIOSECURITY CHALLENGE IN COMMERCIAL PIG PRODUCTION SECTOR IN SERBIA

Despite the fact that all the mentioned different pig production units are highly diverse, according to the Serbian Law, they are in the category of commercial holdings. Actually, anyone who has a registered pig holding (regardless of number/type of production) and carries out the official pig labelling can obtain the necessary veterinary health certificate and sell pigs on the country market (Prodanov-Radulović et al., 2015; Prodanov-Radulović et al., 2020a). Of course, the actual commercial production implies intensive pig production from farrow-to-finish and/or farrow-to-piglets or fattening only. Lately, the commercial fattening units can be found quite frequently in the villages, where weaned pigs imported from ASF-free EU member countries are placed (Prodanov-Radulović et al., 2017a; Prodanov-Radulović et al., 2020b). Within the actual pig unit classification, there are substantial differences in only one classified group, i.e., in the commercial pig holdings. In general, the true commercial pig farms include the classical pig farm structure according to the technological pig production process. Again, there is a difference between old types of pig holdings (built in the period 1970-1980s) and farms built after 2000, where the breeding pigs imported from EU are mainly located. The number of these farms is actually small, and they are usually a part of the regional companies (Prodanov-Radulović et al., 2020b). On the other hand, there are commercial pig holdings, which in were earlier owned by the state (socialist model of governance). In the 1990s, farms were privatized but the new owners have not been obligated to invest in the modern concept of biosecurity. Indeed, today we have examples of a large production system, with capacity from 450 to 1300 sows that is still managed by the old type of farrow-to-finish production system. Some of the biosecurity measures that we know today, which are essential for sustainable pig production, are not possible to be implement without major investments (Prodanov-Radulović et al., 2020a; Prodanov-Radulović et al., 2021). Indeed, the external biosecurity measures cannot always be applied in these systems (entrance the transport vehicles in farm perimeter, farm workers with direct contact with the backyard population, entering the different sources of food for employees) (Prodanov-Radulović et al.,

2021; Polaček et al., 2021). The problem of transport vehicles stands out, and the situation is similar on most of the farms, i.e., the vehicles enter the farm perimeter (animal feed transport, public rendering services, slurry transport and transport to the slaughterhouse). Nowadays, a major problem from the biosecurity aspect is the lack of workers. It is very difficult to find workers who do not have domestic pigs in their backyards or have any kind of contact with domestics and/or wild boar after working time (Prodanov-Radulović et al., 2017b; Nešković et al., 2021; Angeloni et al., 2022). So, the request for workers not have any contact with domestic pigs outside of their employment is very difficult to implement.

In Serbia, the biosecurity measures are not officially required by the Law, and are only specified in a form of general recommendations. Indeed, in the latest Government Instruction for ASF it is only requested that commercial and family farms need to have officially written and implemented biosecurity plan. However, this does not include the details what the biosecurity plan needs to include (Polaček et al., 2021). In the EU member countries, formal biosecurity plans are generally focused on commercial holdings that exceed a specific size defined by the national legislation (Bellini et al., 2021). Regardless of the type of production, high levels of farm biosecurity are considered the most important tools for preventing introduction of ASFV. Biosecurity measures on farms and especially at the farm entrance (thorough cleaning and disinfection and personal protective equipment) have an important role in any type of pig production (Bellini et al., 2021; Beato et al., 2022). Lamberga et al. (2020) recently described an ASF outbreak at a large commercial pig farm in Latvia, where the weakest points identified were the entrances of the farm. The other risk factors identified in this study are similar as the present ones in Serbia: different vehicles entering the farm perimeter and the possibility that farm employees were involved in activities linked to wild boars (Lamberga et al., 2020). Pig farms need to pay special attention to the infrastructure construction of the staff entrance and sanitary lock (Jurado et al., 2018; Lamberga et al., 2022). The tenacity and resistance to inactivation of ASFV are important aspects that make external biosecurity control hard to manage. It is well-known that ASFV survives for 11 days in faeces at room temperature, one month in contaminated pen, 18 months in blood stored at 4 °C, and several years in frozen meat (Mazur-Panasiuk et al., 2019; Štukelj et al., 2021). Effective disinfection against ASFV can only be achieved when recommended concentration of disinfectant is used and contact time is ensured (De Lorenzi et al, 2020; Liu et al., 2021; Beato et al., 2022).

BIOSECURITY CHALLENGE IN BACKYARD AND SMALLHOLDER PIG PRODUCTION IN SERBIA

Rearing domestic pigs in backyards is a common and traditional practice in the south-eastern countries of Europe (EFSA, 2019; Zani et al., 2019; Andraud et al., 2021). Smallholdings and backyards represent about 60% of the domestic pig holdings in Serbia. In the villages, mixed backyard farming systems are common, with different livestock (pigs, sheep, cattle, chicken) and cropping systems, and with a focus on subsistence farming (Prodanov-Radulović et al., 2015; Prodanov-Radulović et al., 2017a). The primary purpose for keeping pigs is regular family meat supply but also an extra income. The majority of households have one or two sows together with the piglets and fatteners (Polaček et al., 2021). The designation 'backyard holding' stands for a quite heterogeneous family-run small-scale pig farming system with low biosecurity (Zani et al., 2019; Mutua and Dione, 2021; Ardelean et al., 2021). In EU countries, this type of holdings is classified as non-commercial pig sector with farms including 10 pigs per holding (Bellini et al., 2021). Backyard farms with their low biosecurity standards are considered prone to ASF introduction and thus are of particular interest in disease prevention and control (Sanchez-Vizcaıno et al., 2013; Zani et al., 2019; Mutua and Dione, 2021).

In backyards and smallholders, pig feeding strategies depend on feed resources availability and the ability of farmers to buy ingredients. In these systems, domestic pigs frequently have access to swill (i.e., the kitchen leftover food from owners and restaurants) (Chenais et al., 2019a; Mutua and Dione, 2021). According to the law, swill feeding is banned in Serbia; however, it is difficult to control in practice. Similarly, swill feeding was banned in the EU in 2002, but the epidemiological studies of ASF outbreaks have shown that this practice is still used (Boklund et al., 2020). Such practices can facilitate ASFV spread, as happened in 2012, when ASF was introduced in Ukraine due to the use of contaminated pork products in swill feeding (EFSA, 2019; Bellini et al., 2021). In general, swill is considered to be the most likely source of ASF introduction in Georgia (de la Torre et al., 2022), Bulgaria (Zani et al., 2019) and Romania (Ardelean et al., 2021). Swill feeding represents an important risk for indirect ASF transmission because of the long term survival of the virus in pig meat (Bellini et al., 2021). The ASFV can survive in chilled meat or carcasses for up to 6 months, and at 4 ˚C even for two years. Similarly, virus can survive for long periods of time in smoked and salted pork products (Sanchez-Vizcaıno et al., 2013; Sánchez-Cordón et al., 2018).

The existence of breeding animals in the backyards (gilts, sows, boars) is highly-risky situation in the extensive production system. Moreover, in Ser-

bia, breeding boars are frequently found in the small-scale holdings, and they are moved around for breeding purposes (Prodanov-Radulović et al., 2015; Polaček et al., 2021). The critical point from this aspect is animal loan practices, i.e., sharing of boars for natural mating in several villages (Mutua and Dione, 2021). This can be significant risk factor contributing to the transmission of ASFV through direct pig-to-pig contact (Olesen et al., 2020). The aforementioned specific circumstances are likely to contribute to the introduction and establishment of ASFV in Serbian vulnerable pig production system thus promoting the disease spreading. On the contrary, according to the EU regulations, sows or boars cannot be held on non-commercial farms for mating purposes (Cappaia et al., 2018; Bellini et al., 2021).

Another important risky activity in backyards and smallholdings is related to home-slaughtering practice. Backyard pigs are mostly slaughtered at home, usually before Christmas or whenever new meat supplies for family are needed (Polaček et al., 2021). Home-slaughtering is considered as a feature of non-professional pig production, which is a known constraint to ASF control (EFSA, 2019; Bellini et al., 2021). Such practices contribute to the spread of ASFV due to improper disposal of offal, often in the immediate environment of the village, and the use of slaughter waste for feeding other domestic animals in the yard (dogs, cats). Finally, home-slaughtering could be a driver for the spread of the other infectious and zoonotic diseases (Petrović et al., 2019; Petrović et al., 2022). However, home slaughtering of domestic pigs is allowed in Serbia.

It is well-known that implementation of biosecurity is a key to successful pig production in an ASF-endemic environment (Bellini et al., 2021; Gervasi and Guberti, 2021). Several studies have recommended training of pig farmers on biosecurity measures as a means of mitigating ASF. In a specific smallholder pig sector such as Serbian, additional costs for application of biosecurity, availability of funds are key barriers to adopt better practices (Polaček et al., 2021; Angeloni et al., 2022). In the current systems, farmers rely on cheap biosecurity and animal management measures to sustain their pig production; however, these practices are not sufficient to stop ASF transmission (Andraud et al., 2021; Ardelean et al., 2021). Relevant stakeholders need to be educated about implementation of biosecurity measures in an effort to mitigate the risks (Mutua and Dione, 2021). Further, backyards could facilitate the introduction of ASFV from wild boar population to domestic pigs and vice versa (Gervasi and Guberti, 2021). Low biosecurity farms and the human factor that creates link to wild boars around the villages are deemed to be the most dangerous combinations for the spread and persistence of ASFV in domestic pig sector (Nešković et al., 2021). Indirect contact through visiting the yard by the

neighbours or via shared different mechanical equipment or vehicles cannot be excluded. Thus, direct or indirect contact to contaminated fomites, which entered the stable via human activities, is regarded as the most likely source of infection (Zani et al., 2019; Bellini et al., 2021). In the case of ASF outbreak in one backyard, the whole village needs to be regarded as one epidemiological unit. The clinical phase starts usually after an incubation period of about 3–5 days (Blome et al., 2020), which would be the earliest time point during the ASF infection when the owner might suspect that one of his pigs is sick. In the backyard context, detecting suspect animals depends nearly exclusively on the pig owner. However, ASF could remain unreported for longer period due to a constant supply of susceptible pigs (Liu et al., 2021). The slow spread of the disease from pig to pig hampers early disease detection as it leads to initially low mortalities (Schulz et al., 2019).

Outdoor keeping, semi-free range or free range pigs is common in some regions in Serbia (Prodanov-Radulović et al., 2015). This type of pig keeping represents one of the weakest links in the biosecurity chain and the biggest risk factor for ASF introduction. The interaction between wild boars and pigs can prolong ASFV circulation, as observed in Sardinia (Cappaia et al., 2018). The free-ranging pigs can act as a bridge in transmitting ASFV between wild boars and domestic pigs (Sauter-Louis et al., 2021; Ardelean et al., 2021). Above all, allowing domestic pigs to roam freely is a concern, for not only ASF but also for diseases of public health importance (Petrović et al, 2019; Petrović et al., 2022). In the EU, concerning current ASF situation, the EU Commission has banned outdoor keeping of pigs as the main strategy to avoid ASF spread (EFSA, 2022).

Serbia has a central geographical position in the Balkans (EFSA, 2019), surrounded by the ASF positive countries on three sides: north, east and south (Hungary, Romania, Bulgaria, and recently North Macedonia) (EFSA, 2022). The global dimension of the current epidemic shows that all countries are at risk: human-mediated dispersal to domestic or wild boar populations can occur at any time and to any country, regardless of the distance from on-going infections (Chenais et al., 2018; Chenais et al., 2019a; de la Torre et al., 2022). Cooperation among countries and information exchange plays a key role in better understanding ASF epidemiology, and in implementing timely and appropriate preventive measures.

CONCLUSION

Pig production in Europe is highly heterogeneous with different biosecurity standards. However, in the pig systems like the one in Serbia, farmers rely

on cheap biosecurity and animal management measures, which are often not sufficient to prevent or control ASF. Farmers still have significant knowledge gaps in view of ASF and practice various risky behaviours that might favour disease spread. The ongoing practices of natural mating, home-slaughtering and swill feeding can be identified as main challenging biosecurity risk factors.

ASFV has a history of more than 100 years worldwide. It is anticipated that it will continue to threaten the pig industry in countries around the world for a long time in the future. Our work reviewed the main risk factors involved in the introduction and spread of ASF in Serbia and this information can be relevant in assessing the risk level of different holdings in order to plan specific preventive measures. We can conclude that different types of risks affect different types of farming systems, and they need to be considered when preparing a biosecurity program. In the future, the study with insights into the ASF knowledge of backyard farmers can be helpful to identify predominant risky practices carried out by them. These insights may help to better understand the role of backyard farmers in the ASF epidemic in Serbia and to improve future evidence-based policies, including the development of new public awareness activities.

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JPR and MJ made substantial contributions to conception and design of the review, wrote the main part of the article; BB and JM helped in formatting and translating the text, and were involved in drafting of the manuscript, VP revised the manuscript critically and gave the final approval of the manuscript to be published.

Competing interest

The authors declare that they have no competing interest.

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