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Rift Valley fever in West Africa: A zoonotic disease with multiple socio-economic consequences

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ABSTRACT

Rift Valley fever virus (RVFV) is an arbovirus that causes Rift Valley fever (RVF), a zoonotic disease that mainly affects domestic and wildlife ruminants and humans. The first epidemic in North-Western and West Africa occurred in Senegal and Mauritania in 1987, two countries where RVF is now endemic. Slaughterhouse workers, farmers, herders and veterinarians are at high risk of exposure to RVF. Beyond the health threat, RVF is considered to cause major socio-economic problems, specifically in developing countries where livestock farming and trade are important economic activities. Indeed, the mortality rate linked to RVF infection can reach 95–100% in newborns and young animals. In West Africa, livestock production is a key factor for food production and for national economics. Epizootics caused by RVF can therefore have serious socio-economic consequences by impacting multisectoral economics, the psycho-social health of pastoral communities, and food security. Improving prevention strategies against RVF, including vaccination, enhancing knowledge of RVF and correcting any inappropriate behaviors by populations of endemics areas, as well as better monitoring of RVF ecological factors are effective ways to better foresee and control outbreaks of RVF and its socio-economical side-effects in countries at high risk of occurrence of the disease.

1. Introduction

Several arthropod-borne viruses (arboviruses) including dengue virus (DENV), chikungunya virus (CHIKV), West Nile virus (WNV) and yellow fever virus (YFV) are endemic in Africa and represent a heavy burden for the countries concerned [1]. The geographical distribution of these viruses is closely linked to the distribution of their biologically competent vectors as well as to environmental and climatic factors that favor their distribution [2]. Rift Valley fever (RVF) is a zoonotic arbovirosis that mainly affects ruminant livestock but also humans [3]. The RVF virus (RVFV), an arbovirus that belongs to the family *Phenuiviridae,* genus *Phlebovirus* [4].

RVFV has been responsible for numerous epidemics and epizootics in Africa, particularly in North Western (Mauritania) and Western Africa (Senegal) with a first epidemic that occurred in the two countries) in 1987 [5], Eastern (Egypt, Kenya, Tanzania) and Southern Africa (Mozambique, Namibia, South Africa) as well as in islands in the South-West Indian Ocean (Madagascar, Comoros archipelago) [6–10]. Until 2000, the circulation of RVFV was limited to Africa, after which the first cases outside the African continent were reported in Saudi Arabia and Yemen [11]. RVF was long considered to be a veterinary problem before gradually becoming a major public health problem upon the occurrence of the largest severe epidemic 1977 in Egypt [6]. Beyond being a health threat, RVF causes serious economic problems specifically in developing countries where livestock breeding and trade are two major economic activities. In 1951, epizootics of RVF in South Africa caused nearly

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100,000 deaths among sheep [12]. It is therefore crucial that low-income countries, including several countries in Northern and Western Africa, set up surveillance programs to better foresee outbreaks in the animal and human sectors to enable better management of the disease and of their socio-economic side-effects in a One Health context.

2. Occurrence of RVF in West Africa

As early as 1912, cases of enzootic hepatitis, one of the main symptoms of RVFV infection, had already been reported in sheep long before the first description of clinical cases in sheep, cattle and humans in Kenya in 1930 [13]. Since then several epidemics and epizootics of RVF have been notified but only in sub-Saharan Africa until the 1990s, when the virus spread outside the African continent [10,14]. RVFV is now endemic in several countries in North-Western Africa [15] (Fig. 1). Data suggest that the first outbreak of RVF in North-Western Africa occurred in 1987 in Senegal and Mauritania during floods in the lower Senegal River delta [5]. However, serological surveys of animal samples in Burkina Faso and Senegal between 1985 and 1987 showed that the virus was already circulating in West Africa by then [16–18].

Mauritania is one of the countries in North-Western Africa that has experienced most of the reported outbreaks of RVF. In 2010, 30 human cases and 26 animal cases (goats, sheep and camels) were reported and a role for camel species (*Dromedarius camelus*) in local virus amplification was suggested for the first time [19,20]. In 2015 and again in 2020, respectively 31 and 78 cases of RVF in humans were confirmed [21,22]. Even more recently, in 2022, 47 human cases were documented including 23 human deaths [23]. Seven species of mosquitoes known to be RVFV vectors belonging to three genera (*Culex* spp., *Aedes* spp., *Mansonia spp*), were detected in Mauritania [22]. In Senegal, RVFV has been repeatedly reported in humans, livestock, and mosquitoes [24–29], especially in the Sahelian and Sudano-Guinean zones. Senegal confirmed 11 human RVF cases during an outbreak in 2013–2014 and 75% of the animals analyzed during this period tested positive for anti-RVF IgG [30]. Gambia reported an outbreak affecting humans and animals in 2002–2003, before reporting a single isolated case in 2018 [31,32]. In Burkina Faso, analysis of 520 samples collected from cattle, goats and sheep between 2005 and 2007 revealed an RVF specific antibody prevalence rate of 7.67% [33]. In 2017, a sporadic case in Mali as well as an outbreak in Nigeria were reported [34,35]. In 2016, Niger experienced its first RVF epidemic with 399 suspected cases reported, including 17 confirmed cases [36]. The epizootics that occurred in West Africa showed that the most affected animals were camelids, sheep, cattle and goats [20,33,36].

3. Routes of transmission

RVFV, an enveloped single-stranded negative sense RNA virus comprising three segments (large segment (L), medium segment (M) and small segment (S)) [49] is transmitted to humans and animals either by the bite of an infected mosquito or by aerosol exposure through body fluids, blood and tissues of infected animals [50,51]. The vectors mainly involved in the transmission of RVFV are blood-sucking mosquitoes (*Culex, Aedes, Mansonia, Anopheles*) [52] More than 65 species have been identified as potential vectors of RVFV with varying levels of competence [52], most of the mosquitoes concerned belong to the genus *Aedes* and *Culex* [52]. Vertical transmission of RVFV is described in the vector, notably of the *Aedes* genus, and *Aedes* eggs are able to resist several years to desiccation and hence potentially contribute to the endemicity of RVFV [52,53]. Laid infected eggs may therefore survive the dry season

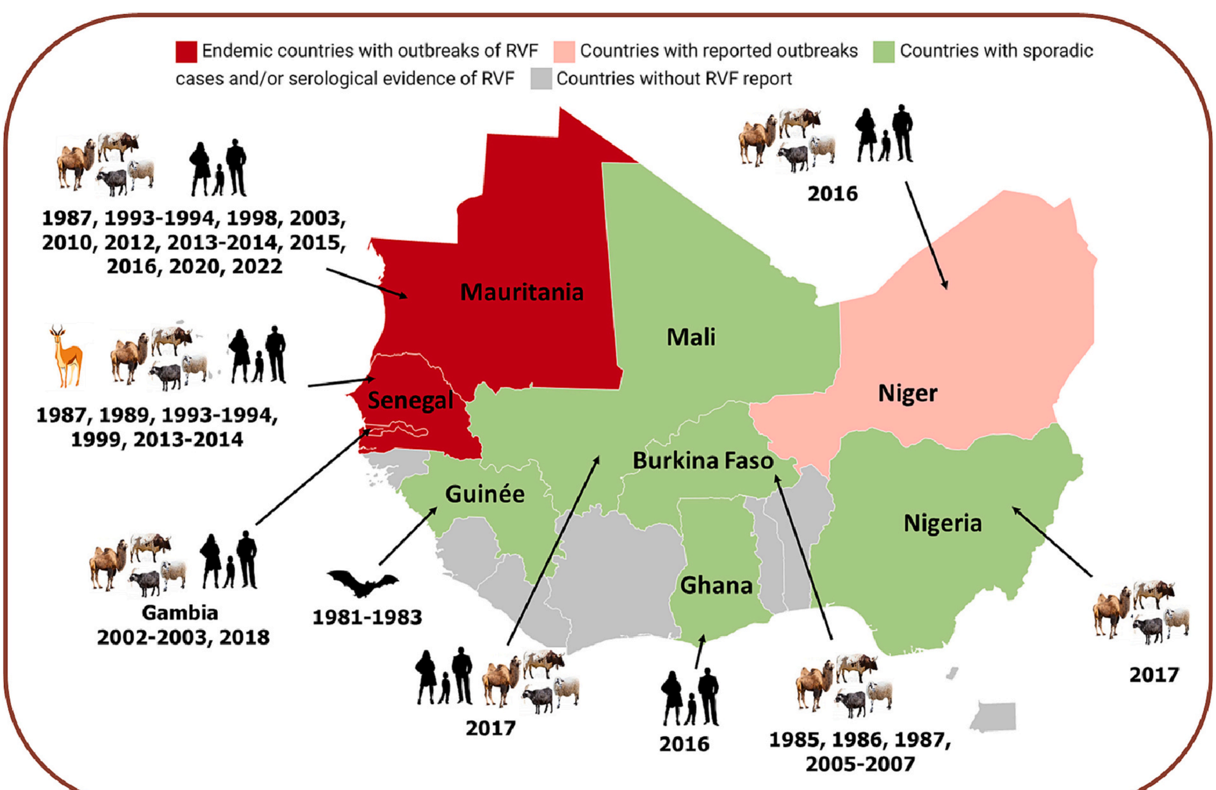

Fig. 1. Geographical distribution of RVF in North-Western and West Africa. Countries that are endemic with RVFV notified epidemics are colored red; countries with sporadic cases and/or serological evidence of RVFV circulation are colored green; countries that have reported some outbreaks of RVFV are colored pink; and countries where no data are available on RVFV are colored gray; The dates are the years RVF cases were reported in the species in which the diagnosis was made. Map adapted from [5,16,17,19,22,23,29–33,35–48] (Map was made with Datawrapper.de). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and hatch during the following rainy season, providing infected adult mosquitoes ready to bite [54]. Climatic factors, such as rainfall or flooding that lead to massive hatching of RVFV infected eggs, can cause immediate epizootics via massive infection of livestock [55]. Other arthropods, including biting midges, ticks and sandflies have been described as mechanical vectors of RVFV [52]. In West Africa, the virus was isolated from *Culex antennatus* in Nigeria in 1967 and 1970, from *Aedes dalzieli* in Senegal in 1974 and in 1983 from *Aedes furcifer* and *Aedes cumminsii* in Burkina Faso [24]. The species *Aedes vexans*, *Culex poicilipes* and *Culex quinquefasciatus* have been shown to be competent vectors for transmission of RVFV in Senegal [56]. Apart from domestic livestock which are the most frequently infected animal populations, wildlife animal species including antelopes, giraffes, African buffaloes, black rhinoceros, African elephants, and some species of bats and rodents appear to be involved in RVFV transmission cycle [54,57–61]. However, ruminants are the amplifying hosts of RVFV [62] (Fig. 2). Two potential maintenance mechanisms of RVFV in the environment leading to RVFV emergence have not yet been elucidated: the first is vertical transmission of RVFV in *Aedes* mosquito species playing both vector and reservoir roles, notably in dry regions. The second is an unknown sylvatic cycle combining a reservoir specie(s) of wildlife mammals and one or more vector(s), notably in regions with abundant wildlife [54]. Thus, environmental factors, including rainfall, wildlife diversity and the density of hosts and reservoirs, vector species, and animal movements play a key role in the emergence of RVF epizootics [55,63–66].

In animals, transmission most often occurs through a mosquito bite rather than through direct contact [67]. Experiments carried out with sheep with acute RVFV infections and immunocompromised sheep showed no transmission of the virus to the latter [68], but direct transmission between goats has already been demonstrated [69] and vertical transmission has also been demonstrated in cattle and sheep [70–72]. Studies have shown that there is strong viral replication in the placenta of rodents and sheep [70,71,73]. The main mode of transmission in humans remains direct contact with body fluids, blood and tissues of infected animals that occurs mainly during the slaughter of infected animals, the handling of sick animals during veterinary procedures and the consumption of undercooked or raw animal products [64,74,75]. No cases of direct horizontal human-to-human transmission have been reported to date [67]. Cases of vertical transmission have been reported in some patients, as well as efficient replication of RVFV in human placental explants, but the threat of RVFV to pregnant women and their newborns remains uncertain [70,76–78].

4. Clinical manifestations

4.1. In animals

Several domestic and wildlife animals species have been identified as susceptible hosts to RVFV: ovine, caprine, bovine, cameline species [19,59,60,79,80]. The clinical picture of the disease in animals varies with the species and ranges from highly susceptible to resistant, depending on the age of the animal, younger animals being more severely affected [81,82]. Clinical manifestations include fever, anorexia, weakness, apathy with an increase in the amplitude of respiratory movements (hyperpnea) [83–85]. Some animals develop diarrhea, sometimes bloody runny nose and jaundice [86]. The mortality

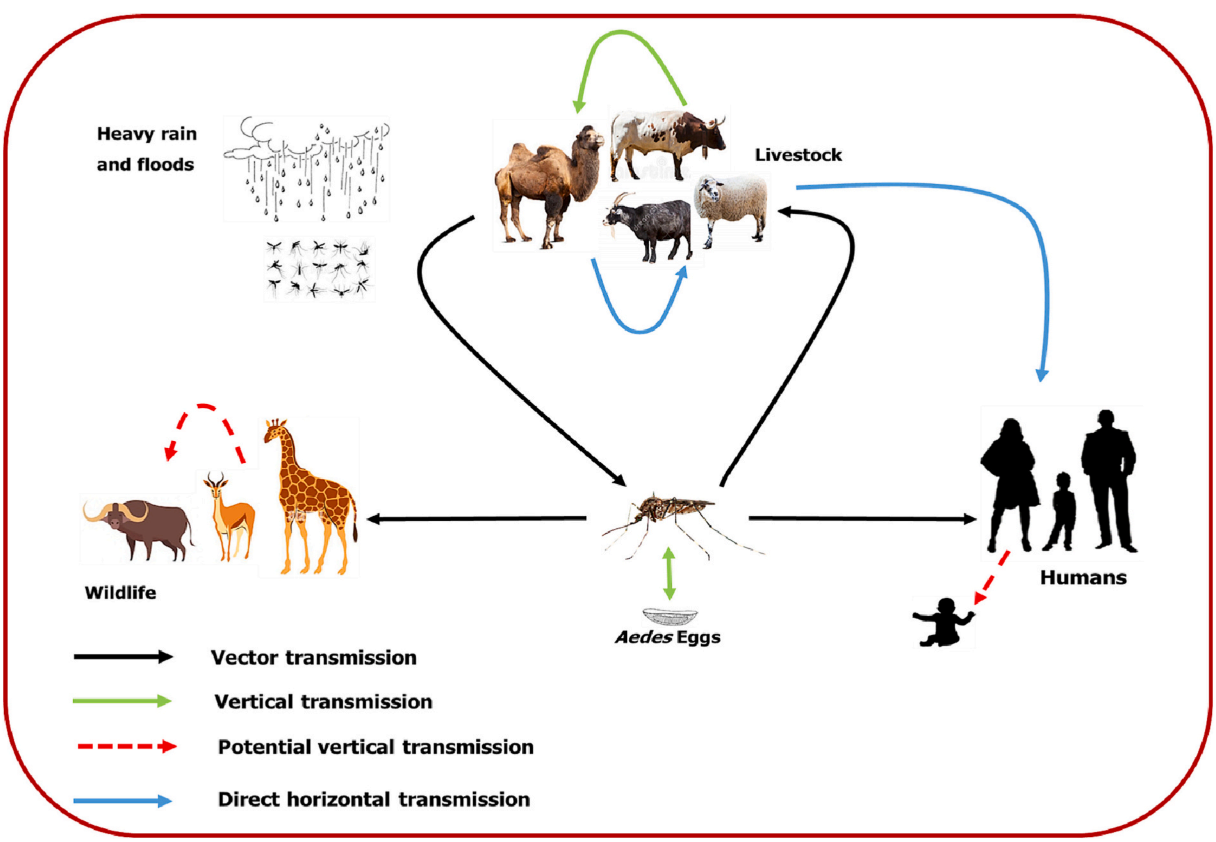

Fig. 2. Transmission cycle of RVFV showing the known transmission routes: (i) Direct transmission (by contact) among livestock (blue arrow); (ii) Humans are infected via two routes, vector-based transmission (mosquito bite) (black arrow) or direct contact transmission (exposure to the body fluids, blood and tissues of infected animals) (blue arrow); (iii) Vertical transmission in vectors (trans-ovarian transmission), in animals (transmission from a pregnant female to her offspring) and in humans (mother-to-child transmission) (green arrow); (iv) The enzootic cycle involves wildlife reservoirs potentially infected by specific mosquito species; (v) Potential vertical transmission in wild animals (dashed red arrow) (Figure was made with PowerPoint 2019 software). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

rate can reach above 90–100% in newborn and young lambs [64,86]. In these animals, death can occur as soon as two days after the onset of the disease. Although they are also infected by RVFV, adult animals seem to be more resistant to the disease (20–30% mortality) [3,86]. RVFV replicates in the liver of animals, causing liver damage and hemorrhages resulting in bloody diarrhea [64,81]. Sheep and goats are more likely to die than cattle [86,87]. Cattle show less severe symptoms, with an adult mortality rate of 5–10%, but in calves, the rate varies from 10 to 70% [3,87]. The most striking sign during RVF epizootics is the wave of abortions that occurs in livestock, with high mortality in younger animals [3]. The abortion rate can reach 100% in pregnant ewes at any time during gestation [3,88,89]. In wildlife, the disease is most often asymptomatic, although cases of abortions have been reported in some species [58,90,91].

4.2. In humans

In humans, the disease is mostly asymptomatic but can evolve into serious forms leading to death [3,92]. The case fatality rate is between 0.5% and 2% but may be higher in some outbreaks [7,93,94]. For instance, in North-Western and West Africa, case fatality rates ranging from 9 to 32% have been reported in outbreaks in Niger and Mauritania [14,22]. The incubation period is 2 to 6 days after exposure to RVFV [95] and the majority of patients develop asymptomatic forms or mild symptoms such as fever, flu syndrome, nausea and digestive disorders. However, 5–20% of symptomatic patients develop severe hepatic, hemorrhagic, neurological or ocular forms [3,62]. In all species, RVFV replicates primarily in the liver [96,97] causing hepatic necrosis, jaundice and hemorrhagic disease [6,98]. However, less than 5% of these patients develop hemorrhagic forms such as epistaxis, gingivorrhagia and hematuria with a very high mortality rate [95] and death usually occurs one to two weeks after the onset of hemorrhagic syndromes [99]. Moreover, neurological damage has been reported in 1–5% of cases but may be higher: in the 2020 epidemic in Mauritania, 38% (30/78) of the persons infected by RVFV developed neurological signs [21,22,95,100]. Neurological damage generally occurs 1 to 4 weeks post infection and sometimes after 60 days post infection [95]. Linked to meningo-encephalitis, neurological manifestations are dizziness, visual hallucinations, stiff neck, memory loss, tremors or convulsions, and can lead to definitive sequalae, coma or death [3,101]. Ocular complications occur in 10% of the infected human population [95] and lead to decreased vision, photophobia, retinitis and retro-orbital pain [101]. In some cases, there is retinal hemorrhage and definitive blindness [101]. Ocular symptoms occur within 2–7 days and may persist for up to 2 weeks after onset of illness [101]. Finally, in some patients, RVFV infection also causes acute renal failure with an increase in serum creatinine and urea revealed upon biological examination [102,103].

5. Populations at risk

The risk of exposure to RVFV infection is related to their activities and to the environment. Activities involving animals increase the risk of infection due to the close contact between human beings and infected animals, which is the main transmission route of RVFV to humans. Thus, people working in slaughterhouses, farmers, people living in livestock raising areas, laboratory workers and veterinarians constitute a population at risk. Handling meat from RVFV-infected animals exposes slaughterhouse workers to the risk of RVFV contamination and these people are more exposed to the risk of contamination by RVFV than other populations [104,105]. Because their activity involves handling infected or dead animals or infected samples, veterinarians, laboratory workers and farmers can also be exposed to risks of contamination [74,106–108]. In addition, farmers and people who live in endemic and pastoral areas are permanently exposed to mosquito bites, another possible transmission route of RVFV [109,110]. Furthermore, the consumption of unpasteurized milk or meat from sick or dead animals by populations in endemic areas exposes these populations to risks of contamination [111,112].

In West Africa, agriculture is the leading sector of employment and employs more than 60% of the active workforce [113], suggesting that a significant population in West Africa is at risk of exposure to RVFV. Indeed, in 2012, during RVF outbreaks in Mauritania, it was reported that 99% of the infected human population originated from rural areas and all were involved in agro-pastoral activities, as was the case in 2020, when 60% of the confirmed cases were farmers [22,114]. Likewise, during the 2016 RVF epidemic in Niger, pastoralists were the most affected population: 34% of the total number of cases and 85% of the total number of deaths [36].

6. Multidimensional impacts of Rift Valley fever

By impacting livestock and human health, RVF also represents a multidimensional socio-economic threat (Fig. 3) [115]. The socio-economic consequences vary with the country and depend on the importance of pastoralism in the country's economic system. For example, the 2007 outbreak of RVF in Kenya induced a 48% drop in national production compared to the 14% loss caused by the outbreak of RVF in Yemen in 2000 [115]. Pastoralism plays an important role throughout Africa and is crucial for some economies like in the Horn of Africa [115–117]. For example, in Kenya, livestock represents 90% of income and in Sudan, the livestock sector employs 40% of the population [116,118].

➢ *Multi-sectoral and multi-scale economic disturbances in Africa*

Given the few economic assessments that are available during RVFV outbreaks, economic studies have mainly used mathematical approaches i.e. modeling and simulations [115]. At the individual and household scale in pastoral communities, livestock is the main source of both income and food (red meat and milk) [119,120]. Thus, livestock mortality and abortions represent a significant monetary loss for individual producers by reducing their activity and meat trade in the short term. The secondary effects linked to the presence of the disease can last for several generations of animals by disturbing herd dynamics thereby becoming a long term problem [117].

At community scale, disruption of red meat markets and of the milk trade can disturb all the livestock marketing chains by stopping or delaying sales, and hence affecting all the actors of the downstream marketing chain including producers, slaughterhouses, traders and butchers, but also associated non-agricultural sectors [118,121]. Indeed, at community scale, the occurrence of RVF leads to a reduction in rural livelihoods and in the value of agricultural products (crops, milk and meat, animal, fruits, vegetables), and affects large parts of the local economy. In Kenya, a cross-sectional household survey showed that 70–92% of pastoral households depend on the income they get from the sale of livestock [118,122].

Linked to the disruption of the community-based economy, RVF outbreaks also have an impact on the national and global economy [115,117,118]. Indeed, disruption of the livestock marketing chain and the fall in the sale of red meat and derived animal products also impact urbanized areas by reducing household supplies and interrupting livestock-related urban industry and auxiliary services: reduced activity, increased unemployment, and decreasing incomes. These impacts on urbanized areas then lead to a decrease in non-agricultural sectors (trade, transport, tourism, petroleum) and finally to significant financial loss at national scale [115–118,121,123]. For example, it was estimated that the 2007 RVF outbreak in Kenya led to a loss of US$ 32 million [118]. Moreover, RVF results in bans on livestock trade not only at the national, but also at an international level for countries with international animal trade like in the Horn of Africa [124–126]. Imports of animals and fresh meat from countries or zones not free of RVF (epizootic or inter-epizootic periods) are complicated by the

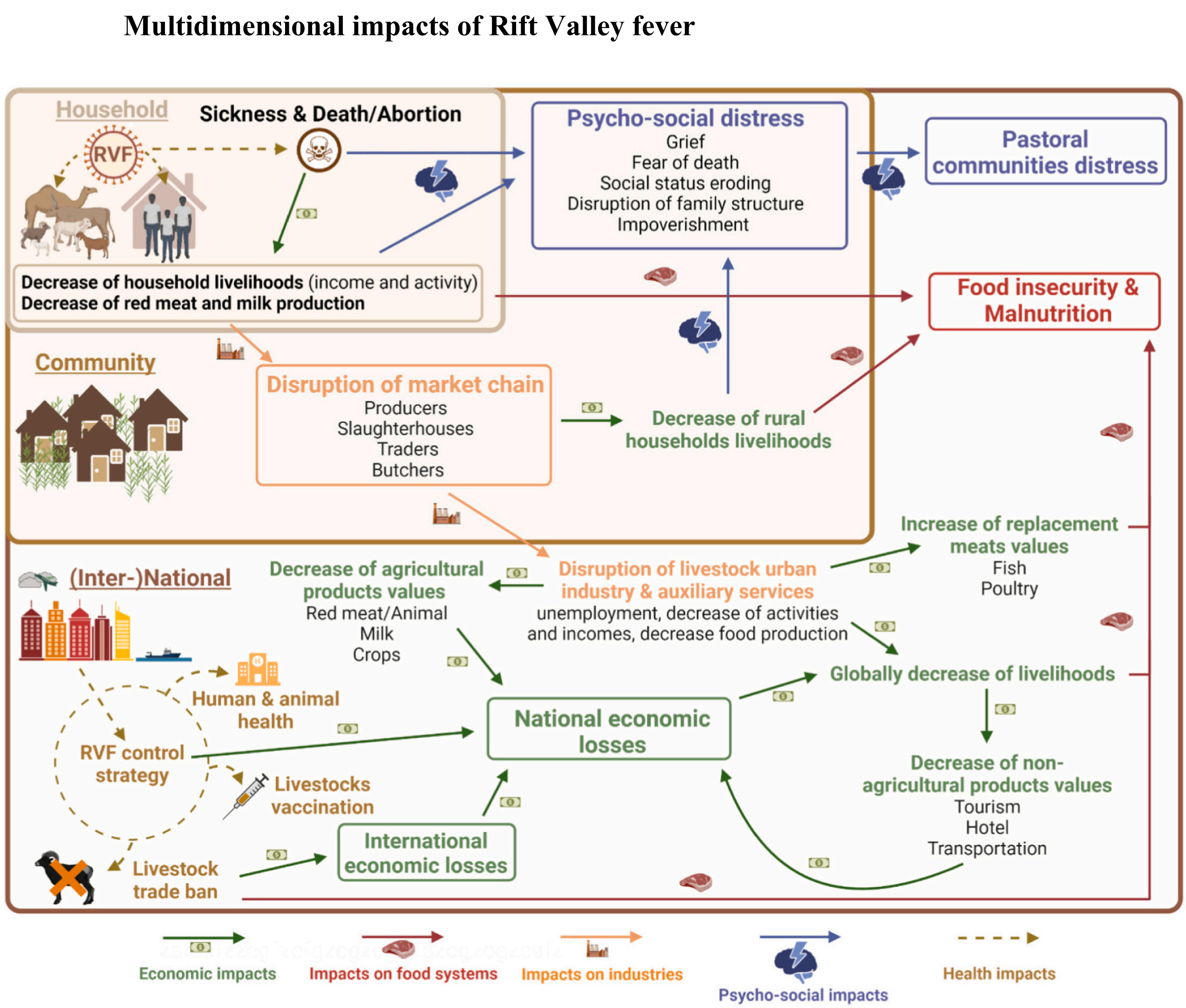

Fig. 3. Schematic representation of the multidimensional socio-economic effects of RVF at household, community and international scales. The colour code distinguishes impacts on the different sectors: the orange arrow with a factory symbol for the livestock industry, the purple arrow with a brain symbol for the psycho-social effect on the population, the red arrow with a red meat symbol for food systems, the green arrow with a US dollar, symbol for economic impacts and finally, the dark yellow dashed arrow for the health impact of RVFV (pathology, control strategy). The boxed texts represent the major impacts of the sector according to the colour code and the scale (Figures was made with BioRender.com). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

recommendations of the WOAH Terrestrial Animal Health Code. This code complicates trade in animals or animal products by making it necessary to obtain an international veterinary certificate justifying the absence of infection in the animals (vaccination status, quarantine, absence of symptoms, transport conditions, …) or in the meat (approved slaughterhouse, post-mortem examination, etc.) [127]. Likewise, public health, healthcare and national RVF control measures have a significant impact on the country's economy. The cost of managing human and animal deaths, the care required by human and animal RVF (treatment, hospitalization, veterinary care) and the control measures (control of animal movements and trade, livestock vaccination strategies) entail significant costs for the national economies of the affected countries. The status of being endemic for RVF can involve long-term economic costs due to irregular and recurrent RVF outbreaks as well as to unexpected costs for disease control [115,128].

➢ *Psycho-social impact and food security threat in Africa*

The occurrence of RVF can lead to significant psycho-social distress in pastoral communities. Indeed, for RVF diseased households, grief over the death of family members or close relatives, the fear of death and of the loss of livestock and/or production have been described as important deleterious psychological factors [111,121,129]. In addition, impoverishment and the decrease in rural household livelihoods were perceived by pastoral communities as major threats of RVF outbreaks [111,121,129]. Not only diseased families feel psychological distress due to RVF threats, many individual inhabitants of pastoral areas, from livestock farmers to people in non-livestock sectors, also suffer from similar symptoms [121]. For some communities, livestock farmers' status is associated with pride, prestige and influence, and, during an RVF outbreak, ruminants at risk temporally loose their economic, nutritional and social value. Thus, in addition to the potential impact on family structure and impoverishment, means the social status of most livestock farmers in RVF epidemic areas is seriously eroded resulting in psycho-social distress for pastoral communities [111,119].

Finally, the food security of populations is seriously affected during outbreaks of RVF. Associated with the drop in food production, loss of rural and urban household livelihoods, an increase in the price of alternative sources of meat to compensate for the lack of red meat, and disruption of the food system disruption caused the ban on animal trade leads to significant food insecurity and particularly, to malnutrition [111,118,119,121,122]. Reports on the RVF outbreak in Kenya in 2020 showed that the consumption of meat declined and that a high proportion of people did not reach the minimum dietary score and consumed insufficient protein rich food [122].

➢ *West Africa, an area with potentially high socio-economic impacts*

Despite the numerous epidemics and epizootics experienced by several countries in West Africa, to date no studies have been undertaken to assess the psycho-social impacts and economic losses caused by RVF in these countries. Based on total animal production in Africa as a whole, West Africa represents 23% of cattle production, 25% of sheep production and 44% of goat production. According to the Food and Agriculture Organization of the United Nations (FAO-UN), West Africa had 76 million heads of cattle and 279 million small ruminants in 2019 [130]. In Niger for example, the annual production of all animal species combined was US$ 315 million [131]. In many West African countries, the livestock sector represents approximately 44% of the agricultural gross domestic product (GDP), the sector is a crucial source of income for the poorest populations and provides employment for young people in semi-rural areas [132]. Given the importance of pastoralism in West African economies, and the psycho-social, health, food security and economic threats of RVF at national scale, RVF represents a major threat for West African countries. It is thus crucial to assess the potential impacts of RVF on the national economies in order to prioritize efficient disease and resource allocation for surveillance and control in these countries. It is also crucial to understand the psycho-social consequences of RVF in West Africa to be able to support populations efficiently during outbreaks thereby limiting large-scale psycho-social distress [115,133].

7. General treatment and prevention

As is the case of most arboviral diseases, no effective specific RVF treatment is available for either humans or animals. Management of human cases of RVF consists of general supportive therapy with symptomatic and non-specific treatments [95]. The prevention of RVFV in animals is an effective way to limit the occurrence and transmission of RVFV to humans [134]. Vaccination of animals can limit the occurrence, spread and impacts of the disease [134–136]. Some authors who studied the 2018/2019 outbreak of RVF in Mayotte, reported that the immune status of livestock was correlated with RVF re-emergence [135]. Several RVF vaccines for animals have been developed, some of which are available commercially, but no RVF vaccine is authorized for humans. World Health Organization (WHO) recommends vaccinating animals against RVF with the live-attenuated type of vaccine in endemic areas to prevent epizootics [62,137–140]. However, in many endemic countries lack clear vaccination policies and strategies, livestock vaccination is not routinely advised [138,141].

In addition to vaccination, other prevention strategies can limit the (re)emergence of RVF in ruminant livestock and human populations at risk. Firstly, livestock infection could theoretically be prevented through control of competent RVFV vectors, but it appears that the great diversity of competent vectors with distinct ecological behaviors makes this strategy unrealistic [52]. However, vector ecology and risk areas can be surveyed and forecasts produced using high-resolution SPOT-5 satellite images [142]. Given the important role of climatic factors in the occurrence of RVF, defining areas at risk using ecological and environmental factors (intensity, frequency of rainfall, type of vegetation) will help to better predict RVF epizootics in livestock [111,122,143,144].

Socio-economic factors also play a determining role in RVFV transmission [145], and human behaviors and habits could be improved to better prevent RVFV transmission to humans. Firstly, professional populations at risk of RVFV infection, including veterinarians, farmers and slaughterhouse workers, need to (i) be better informed and trained to recognize the specific clinical signs of RVF and (ii) wear the recommended personal protective clothing and use appropriate equipment in any suspected cases of RVF [95]. Indeed, during a cross-sectional survey after the 2007 RVFV outbreak in Tanzania, only 24.3% of farmers reported using protective clothing and equipment to handle sick or dead animals [112]. Secondly, improving knowledge of RVF and correcting unsuitable behaviors in all at-risk populations appears to be an efficient way to prevent or limit the occurrence of RVF [146]. Several studies in East Africa have shown that populations in RVFV endemic or non-endemic areas have variable but limited knowledge concerning RVF that can act as barriers to the adoption of protective measures or control strategies. Misconceptions or insufficient knowledge about RVF, notably about the clinical manifestations of RVF, routes of transmission or RVF ecological risk factors, are significant but variable factors in different countries or regions [112,119,121,145]. For example, studies conducted after the 2007 RVF outbreak in Tanzania highlighted significant variability between individuals and between different regions in the country: from 1.3% to 50% of interviewees were cited as being knowledgeable about RVF [112,121]. These misconceptions are often described as a key factor in the transmission of RVFV to humans in some populations. Likewise, even though populations have experienced several outbreaks, they continue their inappropriate dietary habits (consuming milk or meat from dead animals), living with animals, and ways of dealing with animal sickness (i.e., the farmers treat the animals themselves instead of a veterinarian) thereby multiplying the risk of human transmission [112,119,121,129,145]. Several ways of raising public awareness about RVF have been recommended for the control of RVF throughout the African continent and are therefore valid for West Africa.

Controlling legal or illegal movements of animal and trade in animal products in endemic areas bordering other countries is of great help in limiting the spread of RVFV [117,121]. Illegal animal trade between mainland Africa and the island of Mayotte was reported to be the main cause of RVF re-emergence that led to the outbreak of RVF in Mayotte in 2018/2019 [123]. Improving prevention, the control strategies and the infrastructure of the health system are among the main ways to avoid future RVF outbreaks. The limited diagnostic capacity, lack of an emergency plan and of intersectoral coordination limit the efficiency of prevention and control measures [117,121]. In addition, national control measures led to the isolation of diseased pastoral communities thereby encouraging mistrust of the formal healthcare system [129]. It is thus crucial to improve communication between national health systems, international medical personnel, and pastoral communities not only to ensure correct application of prevention and control strategies, but also to limit psycho-social distress in diseased populations [129].

Lastly, multidisciplinary research on RVF in the context of a One Health approach will help foresee and alert RVF outbreaks: animals, humans, and the environment (vectors, climate, etc.) are all part of the RVFV transmission cycle [116,136,147]. Characterization of the enzootic maintenance mechanisms of RVFV in the wildlife and entomology sectors, as well as the use of mathematical models that include ecological factors, vectors and host parameters, will in turn, enable better characterization of RVF emergence, maintenance and circulation in endemic or non-endemic areas, within and potentially outside Africa [3,118,147–150]. In this sense, some countries in North-Western Africa, like Mauritania, have already drawn up a national plan to promote early detection of RVF outbreaks. This plan include (i) the environmental factors that define regions at risk of introduction or exposure through quantitative risk analysis [144] and (ii) the animal health component with serological monitoring campaigns of sentinel herds in these regions during the season when the animals are at risk of exposure to RVFV [22]. Furthermore, in response to the 2016 RVFV outbreaks in West Africa, notably in Niger, a multidisciplinary program has been set up by FAO-UN and West African countries [151]. The aim of the project "Preparation of a regional program for Rift Valley fever prevention and control in Benin, Burkina Faso, Mali, Niger and Nigeria", is to design regional strategies to better prevent and control RVF outbreaks using a One Health Approach. The program is already underway in Senegal and Mauritania and includes (i) mapping of regions at risk of animal movements and that contain risky ecological factors, (ii) international collaboration with sharing of expertise and knowledge, (iii) public and professional awareness-raising and (iv) the creation of an emergency plan. Since 2004, this multidisciplinary approach has also been used at a global scale in the 'Global Framework for the Progressive Control of Transboundary Animal Disease (GF-TADs), set up by FAO-UN, WOAH with the participation of WHO [141,152]. The aim of this program is to improve the prevention, detection and control of animal diseases including RVF and to identify gaps, enhance diagnostic capacities and explore difficulties that could be responsible for the absence of surveillance programs in a particular country.

8. Conclusion

RVF, a serious animal and human public health problem, is now endemic in several countries in West Africa where cattle breeding and trade are of major economic importance. These countries contain a high proportion of at-risk populations and are exposed to huge economic losses due to epidemics/epizootics caused by RVF. RVF is also a threat to human health, to the psycho-social status of pastoral communities and to the food security of countries in North-Western and West Africa. Further in-depth studies are needed to better measure the socio-economic consequences of RVF for the different populations. The best disease control strategy remains the protection of livestock and the definition of clear vaccination strategies that can be applied in practice, and the identification and implementation of effective ways of forecasting and controlling epidemics in countries at high risk of RVF occurrence. Improving the education of professionals who work with livestock, reducing misconceptions about RVF and correcting inappropriate behaviors in local populations are potentially effective ways of controlling RVF outbreaks. Given the link between the health of the environment and that of both animal and human hosts in RVF outbreaks, we recommend affected countries promote control strategies based on a One Heath approach. Indeed, several environmental factors characterize the emergence, maintenance and outbreaks of RVF, and it is crucial to identify exactly which factors are involved to better forecast the emergence and/or outbreaks of RVF. As human epidemics and their side effects are directly linked to animal epizootics, it is important to protect livestock not only to limit the side-effects of RVF outbreaks on human health, but also to improve the monitoring and care of animal epizootics. Sentinel herds should be used in at-risk regions and livestock workers' knowledge needs to be improved to prevent or at least reduce the dissemination and the direct/indirect impacts of RVF outbreaks on animal and human health. Prevention must apply to all compartments of the disease transmission cycle to prevent emergence and to provide efficient care in the case of re-emergence of RVF.

Declaration of Competing Interest

None.

Data availability

No data was used for the research described in the article.

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