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The Socio-Economic Impact of Controlled and Notifiable Wildlife Diseases in the Southern African Development Community (SADC) States of Africa

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Abstract

The African continent is endowed with abundant wildlife, which attracts a vast majority of international and national visitors and with them foreign revenue. Eco-tourism therefore remains one of the most significant contributors to the economies of many developing countries in Africa. However, these financial reserves are continuously threatened by the emergence of endemic and/or exotic diseases that compromise both the wildlife and livestock industries of such countries. Livestock farming is a way of living for many people in many African countries especially in the Southern African Development Community (SADC) states and outbreaks of viral disease, whether endemic or exotic, results in the imposition of stringent food-safety regulations by lucrative foreign markets, thus preventing the export of animals and/or animal products from these regions. This paper aims to highlight the specific social and economic consequences on both the SADC regions as well as selected developing countries in the north of Africa, that are imposed by two viral diseases, Foot-and- Mouth Disease (FMD), a devastating disease that affects the livestock industries worldwide and Avian Influenza Virus (AIV), an exotic viral disease of birds, which not only affects the poultry industries globally, but also has the potential of causing a pandemic. The SADC states can greatly enhance its chances of reducing poverty and building rural economies by addressing the strategies that deal specifically with these two wildlife diseases and in doing so, develop necessary policies that will aid in the assessment and prevention of future outbreak situations.

Keywords: Wildlife; Livestock industries; Exotic viral disease; Rural economies; Cloven-hoofed animals; Endemic disease; Socio-economic impact

Introduction

Over the past two decades, wildlife based ecotourism has rapidly expanded on a global scale and remains an important source of foreign revenue for many developing countries. Almost all countries within the Southern African Development Community (SADC) states have an income stream that is derived primarily from ecotourism [1]. It therefore becomes imperative to thoroughly assess the sustainability of the wildlife industry, particularly in these developing countries. The wide spectrum of disease (endemic and/or exotic) that exists within wildlife impedes export and trade and thus contributes toward crippling rural economies of many African countries. For the purpose of this review, the socio-economic impact of two diseases, i.e Foot-and-mouth disease (FMD), an endemic disease of cloven-hoofed animals and Avian influenza virus (AIV), an zoonotic disease of birds, will be discussed. A controlled animal disease is any animal disease in respect of which any general or particular control measure has been prescribed while for a notifiable disease, it is required by law to report the occurrence or identification of such disease to responsible government authorities. FMD and AIV fall in both categories of classification in all SADC member states and are listed as such within the OIE guidelines [2]. Although these two diseases do not enjoy the monopoly of wildlife diseases, they are relevant examples to illustrate the burden that wildlife diseases can impose on communities if not controlled appropriately. It is hoped that by discussing the clinical, biological and socio-economic impact of these diseases, inferences and parallels on similar infectious diseases affecting both wild and domestic animal hosts can be drawn. A comprehensive list of wildlife/domestic host diseases with a potential to disrupt animal health patterns and pose a threat as emerging diseases is both humans and animals is discussed in other work [3,4].

It is worth noting that legal frameworks and responsibilities for wildlife disease investigation and reporting are not clear in most African countries [5,6]. An extensive list of legislations passed in several SADC states that include Botswana, Mozambique, Namibia, South Africa and Zimbabwe, have been comprehensively discussed and listed in the work by Bekker et al [7]. From the list one can deduce that different legislations and policies exist for different countries and that a coordinated effort within the region does not necessarily occur. The impact of disease outbreaks within the SADC states such as the Democratic Republic of Congo (Table 1, [8]) is an indication that wild life disease control policies either do not exist or are inadequately implemented within certain regions. Furthermore the incidence of disease outbreaks and the reduction in the number of animals destroyed and/or slaughtered as result thereof (Table 2, [8]), indicate marginal success in the implementation of control policies in countries such as South Africa, Zimbabwe and Botswana. The fact that the number of outbreaks recorded between 2007 and 2010 remains constant, highlights the difficulty in eradicating and/or adequately controlling such diseases, especially in the absence

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Country	Outbreak	Cases	Deaths	Destroyed	slaughtered
Angola	123	4,863	748	566	45
Botswana	228	984	500	-	-
D R Congo	74	59,748	45,906	-	760
Lesotho	96	1,636	161	1	-
Malawi	32	8,881	7,589	55	9
Mozambique	148	3,824	586	256	10
Namibia	538	3,294	893	4	2
Swaziland	239	1,408	260	15	2
Tanzania	334	13,937	4,391	-	-
South Africa	2,986	49,726	13,193	6,009	-
Zambia	985	34,603	10,701	-	-
Zimbabwe	3,534	22,936	4,650	32	1
Total	9,317	205,813	89,578	6,938	829

Table 1: Summary of disease outbreaks in SADC region [8].

Parameter	2007	2008	2009	2010
Diseases	76	69	63	72
Outbreaks	9,018	7,499	5,454	9,317
Cases	550,759	673,354	100,538	205,813
Deaths	374,071	210,513	43,984	89,578
Destroyed	8,841	5,937	1,803	6,938
Slaughtered	9,300	1,316,721	194	829

Table 2: Summary of the state of animal health from 2007 to 2010 in SADC [8].

of a common regional policy. Recent debates [9] on free agriculture trade within the SADC region indicate a willingness to coordinate and encourage agricultural trade within the region. We therefore envisage the possibility of a coordinated disease control policy applicable for the entire SADC region, which would result in the social and economic upliftment of the communities involved. However, disease control within wildlife and responsible authority allocation is currently ill defined at best, in the majority of SADC countries. Further complexity is added by the fact that free-ranging wildlife do not easily lend themselves to manipulation such as diseases surveillance and vaccination. The result is a lack of active research in the field of wildlife disease diagnostics; hence tests and vaccines that are developed for domestic animals have mostly not been tested in the wildlife and are therefore necessarily effective for wildlife disease control. Wildlife therefore remains an effective reservoir for transboundary diseases, which not only affect other wildlife species, but domesticated animals also thus leading to massive socioeconomic losses in the country concerned.

A high proportion of African countries have game reserves coupled with pastoral nomadic methods of livestock farming. In countries where wildlife boundaries are clearly demarcated, such as South Africa, there is still a high degree of activity between wildlife and livestock at this boundary interface. Alternative methods are thus needed to control the spread of disease between wildlife and domesticated animals [10]. Failure to implement effective control strategies may result in severe economic losses and social disruption, as the livelihoods of most rural pastoral communities are reliant on the wellbeing of their livestock. Further damage to the economy could result from the loss of valuable wildlife due to disease, leading to reduced revenue from depressed tourism patronage. Therefore, the activity as well as the intensity of activity at the wildlife/livestock interface requires innovative control strategies that will permit the country concerned to market its livestock, wildlife and animal products, profitability. This includes a greater understanding of disease virus profile within the wildlife stocks as well as proper implementation of prevention and control mechanisms that are adapted to the region of choice.

As an example, SADC countries with an exception of South Africa, Botswana and Namibia are generally endemic for FMD. As a result there is an unmitigated, permanent ban on the export of most livestock commodities from Southern Africa and the African countries in general, to lucrative European and Asian markets that are free of the disease. FMD is an endemic disease in Africa that is generally maintained in the free-ranging wildlife populations, particularly buffalo. Avian influenza on the other hand, can be regarded as an exotic disease as it was introduced into the local poultry largely through migratory birds and ducks [11,12]. The costs incurred from both diseases can have an undesirable impact on livestock populations and agriculture. Additional costs are a consequence of mitigation or control efforts, losses in trade and other revenues such as tourism as well as impacts derived from the emergence of pandemics as in the case of a zoonotic outbreak of avian influenza. Visible direct costs include death in young stock, reduced livestock growth, reduced milk production and abortion. Some of the invisible costs include reduced fertility, which necessitates the requirement for larger numbers of breeding animals thus translating to higher production costs and costs incurred for eradicating the disease from animals. Drugs, labour, vaccines, surveillance and forgone revenues are difficult to estimate for both AIV and FMD as these are dependent on the livestock density and the efficiency of the mitigation measures implemented by the responsible authorities [12,13].

Wildlife and Transboundary Diseases

Transboundary animal diseases are diseases that cause damage or destruction to farmers' property, may threaten food security, injure rural economies, and potentially disrupt trade relations. Viral diseases that include amongst others, Foot and Mouth Disease (FMD), African Swine Fever (ASF) and Avian Influenza (AI), periodically affect the South African commercial agriculture sector and the SADC region in general. The absence of suitable disease surveillance and monitoring technologies, coupled with inadequate diagnostic facilities at the pen-side, are the major obstacles in controlling these important agricultural diseases [14]. In the SADC context, the absence of efficient control and prevention strategies at the borders of each member state enables the rampant movement of both animals and their associated diseases across geographical regions. This further complicates the epidemiology and eradication of diseases such as FMD. It is therefore critical to control wildlife linked transboundary diseases more effectively as a region rather than as respective countries in an economically attached region.

Foot-and-Mouth Disease (FMD)

Foot-and-mouth disease virus (FMD) infects a number of wildlife species and in the Southern African landscape and the epidemiology of the virus is greatly influenced by the role of wildlife, particularly the African buffalo (*Syncerus caffer)* in maintaining and spreading the disease to susceptible domestic animals [10,13,15-23]. Individually infected buffalo are able to retain FMDV for at least five years, while the virus can persist for up to 24 years in an isolated herd

[16]. In contrast, cattle are only able to maintain the virus for up to 3.5 years after infection [24]. In the Kruger National Park (KNP) in South Africa, buffalo calves become infected with all three SAT serotypes and individual animals are able to maintain more than one serotype during its lifetime. These serotypes are therefore constantly evolving in buffalo populations in Southern Africa giving rise to the extensive intratypic variation currently observed for these SAT types [21]. Buffalo calves become acutely infected with FMDV at three to eight months of age when their maternal antibodies wane. Once infected, they are able to excrete virus in large amounts thus infecting other animals such as impala, which have been implicated to be intermediate hosts. Acutely infected impala and other antelope species are unable to maintain a carrier status, but it has been suggested that they are able to spread the virus to cattle outside the KNP by penetrating the cordon fences commonly used to separate livestock from wildlife [25]. This is only limited to the vicinities closer to the KNP borders and for areas closer to other game reserves and farms with infected buffalos. We suspect the same pattern may be repeated throughout the SADC region.

Avian influenza (AIV)

Wild aquatic birds such as ducks, geese, gulls and shorebirds are carriers of various influenza A subtypes [26,27]. Although all bird species are thought to be susceptible to influenza A viruses, some domestic poultry species such as chickens, turkey and guinea fowl are known to be highly vulnerable to such infections. In susceptible birds, avian influenza is transmitted in a number of ways, including contact with contaminated nasal, salivary or fecal material from infected birds [28]. Indirect transmission via virus contaminated water and formites have also been reported. Some studies have shown the incidence of avian influenza outbreak to coincide with the increased population of migratory ducks in the same region [29]. Open domestic poultry markets have also been implicated in the spread of avian influenza in the past, although the waterfowl species have been identified as the well-characterized reservoir of different subtypes of avian influenza [30]. Part of the difficulty with exotic diseases such as avian influenza and particularly with regards to rural flocks, is the challenge in forming physical barriers to disease, mainly as a result of the financial implications associated with erecting such bio-containment infrastructures [31].

Economic impact of wildlife transboundary diseases

The costs associated with animal disease can change as societies and economies evolve, making it important to monitor such changes in order to respond in a timely and appropriate manner [32]. Following an outbreak, a country has its supply of beef and related products in case of FMD, or poultry and related commodities in case of AIV, negatively affected through morbidity and mortality. International economic impact to the affected region follows as the trade bans are imposed from the respective international trade partners thus further depreciating the economic prospects of the diseased country. Additional economic depression can be observed following the spillover effects such as tourism restrictions following the implementation of remedial action to contain and eradicate the outbreak. Financial compensation is usually the route most national livestock administrators follow to both boost outbreak control compliance by farmers and to facilitate quick recovery of the affected sector. This flow of finance is usually not adequately budgeted for and therefore negatively impacts the country's budget allocation. Even when a pre-arranged cost sharing method between the public and the private sector exists, the local economic depression following an outbreak does place an unusually large burden on the country concerned. For African countries whose budgets are relatively small, the effect of an outbreak in a region, which was previously a disease free zone, is significantly large in comparison to the total GDP of the country [33].

Foot-and-Mouth Disease (FMD)

Foot-and-Mouth Disease is internationally regarded as the most important economic viral disease of domesticated livestock, which has the potential to spread rapidly through susceptible animal populations. Despite the low mortality rates in susceptible animals, outbreaks of FMDV have a significant impact on the productivity, and therefore the livelihood of resource-poor farmers. Since livestock are highly important in the agriculture-based economy of many of the Southern African Development Community (SADC) member states, trade and quarantine restrictions negatively impacts the national economies of such states, by blocking rural income generation, job creation and most importantly compromising food security. Despite the accumulation of extensive knowledge of the disease as well as the availability of vaccines, attempts at eradicating FMD have remained unsuccessful. An understanding of the epidemiological complexities of FMD has therefore refocused the emphasis on control rather than eradication. As an example, it has been estimated that an investment of 19.6 million US$ in the reduction of losses linked to cattle morbidity and mortality in Sudan would result in revenue generation equalling US$ 40.5 million [32].

Avian influenza (AIV)

Avian influenza is considered one of the most important transboundary animal diseases to have emerged with such a significant impact on human health. The disease has been recognized as a highly lethal viral disease of poultry since 1901 [34]. Sporadic outbreaks of avian influenza in South Africa have had significant impact on the poultry industry. According to the Ostrich Business Chamber, South Africa is the foremost supplier of ostrich products to the international market, accounting for up to 67% of exports with revenue of approximately US$ 120 million annually. The recent outbreak of the highly pathogenic H5N2 strain of avian influenza resulted in the immediate ban on all exports of ostrich products to the European Union. This placed the industry under immense financial strain and inevitably resulted in job losses of approximately 20,000 people directly employed by the industry.

In April 2011, the South African ostrich industry was severely affected by an outbreak of avian influenza. Highly pathogenic avian influenza (HPAI) H5N2 was detected on eight commercial ostrich farms in the Oudtshoorn and Uniondale areas in the Western Cape Province. Concerns of a potential outbreak of the HPAI in domestic poultry and the awareness of the pandemic potential of these viruses, led to the rapid, preventative slaughtering of more than 50,000 birds and a suspension on all exports of poultry products, equating to US$ 140 million in export losses. This drastic action was necessitated since phylogenetic studies have indicated that new subtypes are derived from genetic re- assortments between the LPAI isolates from wild birds and those traditionally found circulating in the poultry and ostrich populations in South Africa. The diversity of avian influenza virus, and its potential to continuously evolve, is the primary factor driving the requirement for

(a) The implementation of stringent biosecurity measures at the farm level to control movement of flocks and prevent virus dissemination;

(b) The development and use of sensitive, cost-effective and rapid diagnostic tests, which can be used for outbreak surveillance to assist in the management of this disease;

(c) The eradication of the disease by culling infected flocks [35].

In developing countries, the implementation of some these containment strategies are not always feasible and therefore other approaches, which include the use of vaccines to manage clinical disease, prevent human infection and ultimately maintain food security, have been adopted [36]. Avian influenza vaccines have been successfully used in the control of HPAI in domesticated poultry and captive birds in countries that include Asia, Europe, Africa and South America and have since improved the livelihood of many rural communities in developing countries [36-38].

In the Nigerian study based on the AIV 2011 outbreak, 80% of the workers from the affected farms lost their jobs while 45% of employees from unaffected farms also lost their jobs as the ripple effect of the outbreak costs followed. The Ghanaian study reflected similar values in that about 75% of the employees lost their jobs. One can therefore extrapolate high unemployment related to an AIV outbreak within the local region of the outbreak in Africa [39]. Current state of veterinary services and preparedness levels in developing countries, especially in Africa, pose a real and present threat to the prevention and control of an AIV outbreak. Smallholder poultry systems tend to have a medium to low-level biosecurity and animal mortality is higher than in intensive production systems where biosecurity tends to be higher. Financial risk is however higher for commercial farmers due to high density of poultry in their settings.

Social impact of FMD and AIV in SADC

Livestock plays a critical and varied role in the economies of SADC states. At household level, livestock provides food, income and is generally regarded as an asset, while at a national and regional level it contributes to food security, trade and GDP [8,40]. It follows then that the negative disruption of wealth and exacerbation of poverty through animal diseases within rural communities will impede the general social way of life. Examples include the ability to pay dowry through cattle as a traditional method of formalities exchanged throughout the Bantu nations of the SADC region. In certain parts of SADC, crop cultivation requires the use oxen to plough the fields. An outbreak of FMD during the main planting season can disrupt crop cultivation and threaten the social way of life due to increased poverty levels. The majority of SADC communities wherein most of the game parks and reserves are situated are mainly rural communities. Their livelihood is largely dependent on crop and livestock agriculture. Small stock traders are particularly vulnerable since an avian influenza outbreak would devastate their trade through local and regional ban on poultry trade. It is well established that one of the major obstacles in implementing proper biosecurity primarily for rural or communal livestock is the absence of adequate biosecurity measures. This is primarily as a result of the prohibitive costs related to the implementation of such biosecurity infrastructures. An outbreak of either FMD or AIV within a rural community in a SADC region does not only alter the social economy by diverting national funding to control the outbreak, but changes in the livestock and/or flock herds drastically affects the general day to day lives of rural communities.

Clinical disease and transmission

Foot-and-Mouth Disease (FMD)

Foot-and-mouth disease (FMD) is a highly contagious, acute vesicular disease affecting cloven- hoofed animals (cattle, sheep, pigs, goats, buffalo and various other wildlife species). The disease is endemic in most developing countries in particular Africa, Asia and South America. The causative agent is a positive-sense, single-stranded RNA foot-and-mouth disease virus (FMDV) classified in the genus *Aphthovirus* within the family *Picornaviridae* [41,42] The 140S virion of FMDV consists of a single stranded RNA genome, approximately 8.5 Kb in length, enclosed within an icosahedral capsid made up 60 copies each of four structural proteins (VP1, VP2, VP3, VP4) [41,42]. The mutation rates of these RNA viruses are inherently high due to the lack of RNA polymerase proof reading mechanisms [43,44]. As a result, FMDV exists as seven distinct serotypes (O, A, C, Asia-1, SAT 1, SAT 2 and SAT 3) that reflect significant genetic and antigenic variability [45-47]. The Southern African serotypes (SAT1-3) are endemic to sub-Saharan Africa but several different epidemiological clusters, based on the distribution of the serotypes and topotypes, evaluation of animal movement patterns and impact of wildlife and farming systems, have been identified for the African continent [48]. The South SADC countries, i.e. Swaziland, Lesotho, South Africa, Botswana and Namibia have segregated wildlife areas that harbour African buffaloes known to be infected, asymptomatically, with FMD virus serotypes SAT-1, SAT-2 and SAT-3. These SAT-serotypes have thus been shown to co- circulate in the various designated clusters along with the Euro-Asiatic (O, A and C) serotypes [49-52]). The SAT viruses differ significantly from each other with respect to geographical distribution, incidence of outbreaks in domesticated livestock as well as infection rates in wildlife species ([17,53,54]. Within the SAT viruses there are at least eight topotypes within SAT-1, 14 in SAT-2 and six within SAT-3. The SAT-1 viruses are commonly found circulating in buffalo herds, while SAT-2 viruses appear to be the most widely distributed serotype in sub-Saharan Africa and are frequently associated with outbreaks of the disease in livestock [54,55]. It has thus been suggested that the different SAT types may have differential abilities in crossing the species barrier, which relates to the varying degrees of pathogenicity among species [56].

The perplexing epidemiology of FMD is dependent on a number of factors that include amongst others virulence of the viral stain and its ability to produce lesions; the stability of the viral particles in different environmental conditions; the immunological status of the host and its ability to respond to infection and environmental factors that can provide geographical barriers that either prevent or promote the dissemination and transmission of virus [14]. FMD is a highly transmissible disease and infection generally occurs via the respiratory route requiring as little as 20 $TCID_{50}$ of virus particles to become established in cattle [57,58]. Transmission is also possible through abrasions on the skin or mucous membranes, however in such instances 10,000 times more virus particles are required for successful infection [57,58]. The clinical outcome of the disease may vary among the host species considered and the infecting virus strain. In domesticated animals such as cattle and sheep, fever and viraemia usually start within 24-48 hours after infection, followed by progressive spread of the virus to different organs and tissues and finally presenting as secondary vesicles, generally on the feet and tongue [42,59-61]. Excreted virus has been also been detected in the milk, semen, urine and feces of infected cattle [58]. In cattle, the incubation period is usually between 2 and 14 days depending on the infection dose and route of infection. Pigs on the other hand are much less susceptible to aerosol infection than cattle and require as much as 6000 $TCID_{50}$ of virus to establish infection [62,63]. They therefore usually become infected either by eating food contaminated with FMDV or by coming into direct contact with infected animals [62,63]. The incubation period is much shorter (approximately two days) and they are able to excrete far more aerosolized virus particles than both cattle and sheep [56,64].

Avian influenza (AIV)

Avian influenza virus (AIV) is classified as a type A influenza virus that belongs to the *Orthomyxoviridae* family. These viruses have a spherical virion with numerous spherical glycoprotein projections, a helical nucleocapsid and a genome consisting of 8 segments of single-stranded negative-sense RNA that code for 11 viral genes [65]. Type A viruses are classified on the basis of the antigenic properties of two surface glycoproteins, hemagglutinin (HA) and neuraminidase (NA) (World Health Organization Expert Committe, 1980). Thus far, sixteen hemagglutinin (H1-H6) and 9 neuraminidase (N1-N9) subtypes, occurring in various different combinations (i.e H1N1, H5N1 and H7N7) have been identified [66-70].

Influenza A viruses are continuously evolving primarily due to the lack of proofreading activity of the viral RNA polymerase during replication of the genomic RNA segments [71]. The high level of antigenic point mutations introduced into the HA and NA surface proteins are responsible for the annual influenza epidemics and the associated mortalities [72,73]. Antigenic shift caused as a result of the segmented nature of the influenza virus genome, is a second mechanism of virus evolution [74]. Due to their surface location, however, genes that code for the HA and NA proteins are likely to be under immense selection pressure by the host immune system and are therefore expected to continuously evolve. The reassortment of viral segments leads to the production of novel progeny viruses for which no pre-existing immunity exists and the new viruses are thus able to escape the host immunity. When sufficiently infectious, the emergence of these new viral strains is the most common cause of influenza pandemics [75-77].

Influenza viruses infecting poultry can be divided, according to their virulence, into two categories. The highly pathogenic avian influenza viruses (HPAIV) cause a systemic infection with high mortality rates (100%) and the low pathogenic avian influenza viruses (LPAIV), which cause localized infections that result in mild respiratory diseases in poultry [78]. Although there are many subtypes of the virus, the H5 and H7 subtypes are generally associated with high pathogenicity, with the prevailing theory that HPAIV variants evolve from subtypes of LPAIV in domestic poultry by mutation or recombination events [79,80]. The transition from low pathogenicity to high pathogenicity is governed by the insertion of basic amino acids into the haemagglutinin cleavage site, which then causes systemic viral replication and acute generalized disease in domesticated poultry [81-85]. Other avian influenza strains lacking this multi-basic cleavage site are considered LPAIV and are perpetuated in nature in wild bird populations [86-88].

Avian influenza viruses generally infect the cells that line the respiratory and intestinal tracts of birds and are excreted in high concentrations in their faeces. Transmission of the virus between birds is considered a complex process dependent on the viral strain, bird species and certain environmental factors [89]. Studies have shown that virus concentrations of up to $10^{8.7}$ mean egg infectious doses (EID) per gram of faeces could be detected from infected ducks [90]. In addition, these viruses were shown to remain infective in contaminated lakes or ponds for up to 30 days at low temperatures thus leading to the transmission of avian influenza via the faecal-oral or possibly the faecal-cloacal route [91,92]. It has been further suggested that depending on environmental conditions, the virus could most likely also over winter and remain a source of infection during the warmer spring seasons [93].

Prevention and Control of Disease

Foot-and-Mouth Disease (FMD)

In Southern Africa, the control and prevention of FMDV is based on (a) the implementation of effective physical barriers (i.e fencing) that separates wildlife from livestock; (b) routine vaccination of cattle in high risk areas exposed to infected buffalo populations; (c) movement control of susceptible animals and animal products and (d) surveillance to monitor outbreaks [20,94-96]. The OIE recognizes fencing as an acceptable method for establishing FMD disease free zones in southern Africa. However, these physical barriers are often subject to both environmental and human pressures such as flooding; breakage due to wildlife and damage from theft [95]. Relying on fencing alone increases the risk of FMD transmission between wildlife and livestock and vaccination therefore currently remains the main tool for the control of the disease in livestock, particularly in endemic areas [97,98].

The current FMD vaccines used worldwide are chemically inactivated whole-virus preparations, typically formulated using the water-in-oil adjuvant and with a potency of at least 3 PD_{50} (protective dose) [98,99]. These formulations increase the humoral immunity, which is known to be the most influential factor in preventing FMD [98,100]. Although the use of inactivated vaccine preparations have been successful in controlling and reducing the number of FMD outbreaks in many parts of the world, there have been considerable concerns and limitations regarding its use in preventative control programs. Due to the antigenic variability of the virus, current vaccination preparations often confer low levels of cross-protection following supplementary vaccinations. Other limitations include the difficulty in adapting some viruses to cell culture, thus slowing the introduction of new vaccine strains, reducing vaccine yield and potentiating through prolonged passage, the selection of undesirable antigenic changes [101,102]. Furthermore, vaccination does not induce sterile immunity and animals may still be able to infect non-vaccinated animals and may also become persistently infected and lastly, the current vaccines are relatively expensive, especially for the small and subsistence farmer [24,103-

105]. Towards developing vaccines with improved efficacy and coverage, continuous monitoring of the field isolates is required to determine the applicability of existing vaccines and the emergence of novel epidemiological situations [98]. Inactivated vaccines induce short-lived immunity and it is recommended that naïve animals receive two initial vaccinations (a primary and secondary dose) 3-4 weeks apart followed by re-vaccination every 4-6 months to prevent spread of disease within populations [106]. However, in the African environment this may differ for different manufacturer's depending on the potency of the vaccine and some manufacturer's recommend five vaccinations per annum. The FMDV particle is also known to be relatively unstable with respect to both temperature and pH, and this has a considerable impact on the shelf life of vaccines, particularly in developing countries where the maintenance of cold-chains is sometimes not possible [107]. To that end, reverse genetics approaches for producing infectious cDNA clones into which the insertion of novel capsid genes that confer increased capsid stability and/or adaptation to cell culture, are currently being explored for a number of FMD serotypes [108-110].

Other factors of concern include

(a) the requirement of high containment facilities for handling live viruses for antigen production and the associated risks of virus escape into the environment

(b) the production of FMD antigens in large-scale suspension or monolayer cell lines, which potentially results in lower antigen yields due to the inability of certain serotypes and subtypes to adapt to cell culture

(c) the presence of nonstructural viral proteins in vaccine preparations that complicate the distinction between vaccinated and infected animals

(d) the inability to produce rapid protection against challenge by direct inoculation thus potentially exposing susceptible, vaccinated animals to infection prior to the development of their adaptive immune response and

(e) the possibility of creating a carrier state in vaccinated animals following an FMD infection [98]. While these concerns are being addressed in the development of novel vaccine technologies, alternative control strategies reviewed by [111] include subunit or peptide vaccines, live attenuated vaccines and empty viral capsids. Although much less potent than whole inactivated virus particles, peptide vaccines have been shown to induce either partial or in some cases full protective immunity following the administration of multiple vaccine doses [112,113]. Baculovirus-derived virus-like particles or adenovirus-vectored vaccines for delivering interferons or FMDV capsid proteins have both been shown to be highly immunogenic [114-116]. Although vaccines are considered to be the most important factor in the global control of FMD, the high levels of genetic diversity observed for the different virus serotypes limit the possibility of developing a single vaccine approach. For these reasons vaccination campaigns should be performed regularly based on the

a) epidemiological circumstances and risk of disease spread

b) value and life expectancy of species and

c) economic status of the country.

The interval between vaccinations is ritical to prevent a "window of susceptibility" and where the continuous or sporadic presence of virus in carrier animals is present.

Avian influenza (AIV)

The diversity of avian influenza virus, and its potential to continuously evolve, is the primary factor driving the requirement for

(a) the implementation of stringent biosecurity measures at the farm level to control movement of flocks and prevent virus dissemination

(b) the development and use of sensitive, cost-effective and rapid diagnostic tests, which can be used for outbreak surveillance to assist in the management of this disease and

(c) the eradication of the disease by culling infected flocks [35].

In developing countries, the implementation of some these containment strategies are not always feasible and therefore other approaches, which include the use of vaccines to manage clinical disease, prevent human infection and ultimately maintain food security, have been adopted [36,117,118].

Currently available commercial vaccines for the control of avian influenza are inactivated whole virus AI vaccines. These vaccines have mostly been used to control low pathogenic avian influenza (LPAI) as well as high pathogenic avian influenza (HPAI) outbreaks [119-121]. Although these vaccines have been shown to be safe and efficacious against AIV, they have several disadvantages that include cost of production, laborious method of administration and lack of long-term immunity, which in turn necessitates booster vaccinations. The use of these vaccines further complicates diagnosis making it impossible to differentiate infected from vaccinated animals therefore leading to continuous shedding of the virus in the field [122]. Furthermore, biohazards associated with manufacturing these vaccines and low vaccine yields generated from using embryonated fowl eggs has reduced the efficacy of these vaccines [123,124]. In an attempt to overcome some of these limitations, several different vaccine technologies have been developed, which has been extensively reviewed [125]. Briefly, they include (a) inactivated whole viruses developed using reverse genetics approaches [126-129]; (b) *in vitro* expressed HA protein in either cell cultures (eukaryotic, yeast or plant derived), bacterial (*E.coli*) or insect derived viral vectors (baculovirus) [130-132]; and (c) *in vivo* expressed HA proteins using live bacterial or viral vectors (eg. Fowl poxvirus, vaccinia virus, rous sarcoma virus and adenovirus) [133-136].

Despite the availability of different AII vaccine technologies, there are several critical aspects that need to be considered when selecting the appropriate vaccination program. One such concern is the emergence of antigenic drift within the viral population, which results in the occurrence of modified viruses that can escape the immune response of the vaccine strain. It is therefore essential that suitable control programs be implemented such that correct seed viruses are selected for the development of vaccines that enable the detection of field exposed flocks. Other aspects include the reliance on adequate monitoring and surveillance systems being in place to ensure the early detection of and rapid response to AI infections [36,137].

Conclusion

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Livestock trade contributes about 15% of global agricultural trade, of which more than 80% of exports are from developed countries [10]. This presents a favourable economic potential for the SADC states in particular and Africa in general, should the endemic status of FMD be managed effectively to create disease free zones. In Africa, the diverse wildlife species attracts local and international tourism, which forms the lifeline for income generation for developing countries. The communities around the wildlife reserves and the nomadic cattle herding practices where livestock and wildlife interact facilitate the transfer of viral diseases to livestock. This adds complexity to both disease control and to determining the loss of revenue for countries where both livestock and wildlife play an integral part. It is clear that effective disease control is beneficial for both the wildlife/conservation sector as well as the livestock based export industry, although emphasis has been placed primarily on disease control within the livestock industry. Surveillance of migratory birds is limited even though ducks are the known to be the main reservoirs for the transmission of avian influenza. Similarly, although African buffalo are the known to be the maintenance host of FMD, factors that contribute to the transmission of the virus to livestock remain unknown.

Developing countries, with specific emphasis on the African continent, have an obligation and need to improve the socio-economic outlook of the resource-poor communities, by reducing the levels of poverty and implementing applicable national development plans. The trade relevance of both AIV and FMD and in the case of AIV, its zoonotic capacity, has a major impact on the economies of developing countries. Investment in controlling and preventing the spread of disease has significant financial benefits that usually outweigh the costs incurred during outbreak situations. As an example highlighted in the Agra study, an investment of USD 1 towards the implementation of a disease prevention strategy resulted in the generation of revenue to the value of USD 12 [32]. However, it should be noted that the actual revenue generated from effective and efficient prevention measures will depend on the prevailing conditions within the disease outbreak region, which include the animal density levels, the intensity of export activity as well as the market size of the region.

For exotic diseases such as AIV, the outbreak is best addressed by focussing on the domestic host by test-slaughter and mass vaccination, respectively. Preventing contact between infected domestic animals and wildlife is desirable, but not always feasible in many African countries. Some industries such as the South African ostrich business sector has, by its nature animals that are in themselves semi domestic, hence the biosecurity becomes much more difficult to implement or police. When an exotic disease becomes established in a free ranging wildlife population, the control options become considerably limited and frequently unpopular, since the culling of valuable wildlife remains the main option for control.

Based on the AGRA report [138], about 25% of African countries have no program for control of viral disease despite the high incidence of zoonotic and non-zoonotic epizootic diseases. This situation is compounded by the dire lack of qualified personnel to fulfil this role. Furthermore, the lack of sophisticated technical resources in many SADC regions prevents the accurate, timely detection and reporting of FMD outbreaks. The socio-economic challenges of the African continent will continue due to weak investments in animal health, the lack of scientific capacity, improper implementation and/or lack of awareness of policies and general weak governance of food safety due to competing national demands. Access to high-end markets depends on disease control options that include

(a) maintaining zones recognized as FMD-free from which livestock may be exported without the requirement for vaccination

(b) the creation of containment zones with high levels of regulation and biosecurity thus favouring compliance with export regulations

(c) commodity-based trade, which enables the trading of processed products that precludes the possibility of virus dissemination and

(d) managing the disease and focusing on local trade rather than export.

Thus, regardless of the access strategies being sought after the implementation of effective disease control programmes within the SADC regions remains imperative for both livestock production and revenue generation.

It is therefore imperative that the wildlife disease control is further addressed before the SADC states can see the full economic potential for being endowed with both wildlife and livestock sectors. It is through proper management, effective legislation and increased wildlife diseases research that the agriculture based economies can improve and thereby lift the social well being of the communities within SADC nations. By maximising the revenue generated from these interrelated sectors, long- term sustainable earnings in foreign currency will potentially reduce poverty through local job creation. The wildlife disease detection, prevention and control will become increasingly relevant since most of the diseases that affect wildlife seem to show only mild symptoms while they show devastating clinical effects to livestock and poultry as demonstrated by FMD and AIV, respectively. Although the economic impact of wildlife diseases is easier to measure imperially, the social impact and the disruption to the way of life in many native communities within SADC states, is usually not reported as a direct link to animal disease outbreak such as FMD and AIV. Social cohesion, due to wealth accumulation through livestock and the absence of disease, could be an added advantage of properly controlling animal diseases in the most vulnerable rural communities.

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