Aquaculture 493 (2018) 123–129

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Review

Tilapia lake virus threatens tilapiines farming and food security: Socio-economic challenges and preventive measures in Sub-Saharan Africa

Y.M.G. Hounmanou[a,b,*], R.H. Mdegela[b], T.V. Dougnon[c], M.E. Achoh[d], O.J. Mhongole[b,e], H. Agadjihouèdé[d], L. Gangbè[d,f], A. Dalsgaard[a,*]

[a] Faculty of Health and Medical Sciences, University of Copenhagen, 1870 Frederiksberg C, Copenhagen, Denmark
[b] African Centre for Health of Aquatic Resources, College of Veterinary and Biomedical Sciences, Sokoine University of Agriculture, PO Box: 3021, Morogoro, Tanzania
[c] Research Unit of Applied Microbiology and Pharmacology of Natural Products (U.R.M.A.Pha), Laboratory of Research in Applied Biology (LARBA), Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, 01 PO Box 2009, Benin
[d] Laboratory of Hydrobiology and Aquaculture (LHA), Faculty of Agronomic Sciences, University of Abomey-Calavi, 01 PO Box: 526, Cotonou, Benin
[e] National Fish Quality Control Laboratory (of Tanzania), PO Box 1213, Mwanza, Tanzania
[f] Laboratory of Research in Aquaculture, Biology and Aquatic Ecology (LaRABEA), The Valley's School of Aquaculture, National University of Agriculture, PO Box 43, Kétou, Benin

ARTICLE INFO

Keywords:
Tilapia
Fish diseases
Aquatic health
Aquaculture
Food security

ABSTRACT

Tilapia is a traditional dish in most countries of Sub-Saharan Africa (SSA). A deadly disease caused by a virus named Tilapia Lake Virus (TiLV) currently threatens tilapia production and fisheries. The objective of this study was to describe TiLV disease, discuss its related socio-economic impacts in SSA, and envisage preventive measures applicable in SSA countries. The methodology was based on an exhaustive search on TiLV in PubMed, Web of Science, Scopus, Google Scholar and ResearchGate. Results revealed that TiLV is an RNA virus causing the disease of up to 90% mortalities in tilapia. It affects all developmental stages, however, tilapia fingerlings and juveniles seem to be more vulnerable. TiLV is transmitted horizontally between infected and naïve fish in the aquatic environment and is a potential trade-influencing transboundary animal disease. The disease is currently confirmed in eight countries such as Ecuador, Israel, Colombia, Egypt, Thailand and Taiwan, India and Malaysia. However, subclinical infections have been detected in the Tanzanian and Ugandan basins of Lake Victoria. Reports show that at least 10 SSA countries have likely imported TiLV infected tilapia fries and fingerlings from hatcheries in Thailand whereby Burundi, Congo, Mozambique, Nigeria, Rwanda, South Africa, Togo, Zambia, Tanzania and Uganda are now suspected infected with TiLV with the two latter recently confirmed. SSA is a newly reported region of TiLV circulation and all tilapia farming countries in the region may have theoretical risk of infection. It poses a major threat to fish supplies and the nutritional status in populations that eat tilapia on a regular basis and likely constitutes a food security issue. Over 150,000 tons of tilapia from tilapia farming and more from the tilapia fisheries with their associated costs could be threatened in SSA due to TiLV. Some control measures recommended by OIE and FAO may not be practical for countries in SSA region, and farmers can hardly comply with biosecurity measures or afford vaccination unless vaccines are thermostable, require no sophisticated technology for administration and are cost-effective to small-scale rural farmers. There is a crucial need for capacity building among farmers and technical personnel on diagnostic procedures and effective remedial action, creation of awareness among farmers on TiLV management and establishment of diagnostic and outbreak response systems. We encourage the creation of a Community-Based Fish Health Insurance funds (CBFHI) among small-scale fish farmers for outbreak prevention and control at local levels.

1. Introduction

Globally, fish represents 16.6% of animal protein supply and 6.5% of all protein for human consumption (The World Bank, 2013). Tilapiines, is a generic term for edible fish of to the family Cichlidae and commonly known as tilapia. They are fast growers, efficient food convertors and disease-resistant (FAO, 2005). These assets render them most suitable for farming and their demand is growing as populations grow (FAO, 2014). Tilapia are farmed worldwide and serve as an important protein source, because of their affordable price, omnivorous

* Corresponding authors at: Faculty of Health and Medical Sciences, University of Copenhagen, 1870 Frederiksberg C, Copenhagen, Denmark.
E-mail addresses: tnc203@alumni.ku.dk (Y.M.G. Hounmanou), adal@sund.ku.dk (A. Dalsgaard).

https://doi.org/10.1016/j.aquaculture.2018.05.001
Received 22 October 2017; Received in revised form 17 April 2018; Accepted 1 May 2018
Available online 03 May 2018
0044-8486/

diet, and tolerance to high-density farming (FAO, 2005; Gomna, 2011). Tilapia represent the second farmed fish species worldwide with an annual production of 4.5 million tons and the current global tilapia trade is estimated at more than USD 7.5 billion (Dinesh et al., 2017).

In Africa, Egypt ranks first and third after China and Indonesia with regard to global tilapia output (Nicholson et al., 2017). Culture of tilapia in Sub-Saharan Africa (SSA) has grown at an annual average rate of 20% over the last decade with about 150,000 tons produced in 2012 (de Graaf and Garibaldi, 2014). The contribution of Sub-Saharan Africa to global aquaculture production remains very small but is increasing significantly; between 2000 and 2008 there was an increase in production from 55,802 to 238,877 tons (Handisyde et al., 2015). Although aquaculture is still recent in Africa and mostly concentrated in a few countries, it already produces an estimated value of almost US$3 billion per year (de Graaf and Garibaldi, 2014).

Most disease reports in tilapia implicate bacterial pathogens, e.g. *Aeromonas hydrophila* and *Streptococcus* spp. with less reports of viral diseases (Aly, 2013). Viral pathogens in tilapia include betanodavirus, iridovirus, and herpes-like virus (Aly, 2013). At the time this paper is being written, eight countries have reported outbreaks of the new viral disease named “Tilapia Lake Virus” (TiLV) disease. The concerned countries are Ecuador (Ferguson et al., 2014), Israel (Eyngor et al., 2014), Colombia (Tsofack et al., 2017), Egypt (Fathi et al., 2017; Nicholson et al., 2017), Thailand (Dong et al., 2017a, 2017b), Taiwan (FIS, 2017), India (Behera et al., 2018) and Malaysia (Amal et al., 2018). Additionally, subclinical infections have been reported in wild and farmed tilapia in the Tanzanian and Ugandan basins of Lake Victoria, being the first report of TiLV from SSA (Mugimba et al., 2018). Studies have demonstrated high mortalities during co-infections with other microorganisms (Amal et al., 2018). Recent studies revealed that tilapia egg, fry and fingerling samples collected from previous disease outbreaks in several tilapia hatcheries in Thailand during 2012–2017 have tested positive for TiLV (Dong et al., 2017a). These records suggest that many countries have been translocating tilapia fry/fingerlings before and after the first indication of TiLV in Thailand (Dong et al., 2017a; Surachetpong et al., 2017). Besides the already confirmed countries, it seems that 43 others, including 10 SSA countries, i.e. Burundi, Congo, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Togo, Uganda, and Zambia, may have imported TiLV-infected tilapia from hatcheries in Thailand and potentially other TiLV reported countries (Dong et al., 2017a). This has led the Food and Agriculture Organization (FAO) to raise alerts and called for awareness and active surveillance of TiLV worldwide (FAO, 2017). In response, two of the suspected SSA countries, Tanzania and Uganda have recently revealed the presence of the virus (Mugimba et al., 2018). Human and animal infectious diseases usually spread fast and often uncontrolled in SSA countries and TiLV has the potential to cause serious socio-economic impact on tilapia farmers and fishers in SSA. This study therefore aimed to review the available literature on TiLV and discuss the potential socio-economic impact and disease control and management challenges faced by SSA countries where disease control is known to be difficult compared to other countries in the world.

2. Material and methods

2.1. Data sources and searches

We conducted a systematic literature review on the global situation of TiLV disease. Scientific reports were identified by searching PubMed, Web of Science, Scopus, and Google Scholar as well as ResearchGate. The initial search was performed in English during 25 June to 25 July 2017 with no time limitation imposed. The search string used was the following: “Tilapia Lake Virus”, “Syncytial hepatitis of tilapia”, “update TiLV”, “alert Tilapia lake virus” “TiLV Africa”, “TiLV developing countries”, “TiLV Sub-Saharan Africa”. Moreover, specific documentation was selected from FAO and WorldFish websites and other literature sources on the socio-economic importance of aquaculture and tilapia farming in Sub-Saharan Africa as well as challenges related to fish health management in SSA countries. Additional search was made during manuscript revision in January and March 2018.

2.2. Data collection and eligibility criteria

For this review, only articles written in English were considered. We first studied titles and abstract of all the articles and retrieved data. Several criteria were used to select eligible studies which included that studies should be conducted on Tilapia lake virus; reports of TiLV in Africa; importance of tilapia farming in SSA; reports on economic aspects of aquaculture in Africa and studies describing biosecurity and disease control challenges in SSA aquaculture. Information about TiLV disease included country of study, risk factors and detection methods of TiLV, clinical manifestations, geographic distribution, epidemiology and etiologic information. We also went through the reference lists of initially retrieved articles to identify relevant papers that were not obtained during the first search. Other papers not related to TiLV disease description were selected from the literature purposively to respond to challenges and prevention strategies for aquatic health management in low-income countries.

3. Results and discussion

3.1. Current research on TiLV

A total of 42 scientific papers, 13 books, reports, and ten webpages were retrieved with the search queries and only 18 were retained and used in the study based on the aforementioned eligibility criteria for TiLV disease description. However, only one of these TiLV studies was conducted in Sub-Saharan Africa. Seven additional current papers on TiLV and trhee general discussion papers have been added during manuscript revision.

3.2. Description of the causative agent of TiLV disease

Tilapia lake virus (TiLV) disease is caused by a virus first known as a novel Orthomyxo-like RNA virus (Bacharach et al., 2016; Del-Pozo et al., 2017; Eyngor et al., 2014). However, it has been later classified into a new unassigned group of its own termed Tilapinevirus (Adams et al., 2017). It is a round to oval enveloped and filamentous/tubular virus of 60 to 80 nm size with negative-sense, RNA genomes of 10-segments and 10,323 kb total length (Dong et al., 2017a; Tattiyapong et al., 2017). The segment 1 of the TilV genome has some sequence identity with the influenza C virus, while the remaining segments possess complementary nucleotide sequences similar to the genome of most Orthomyxoviruses (Bacharach et al., 2016). Genetic information on TiLV can be found through the GeneBank accession numbers provided in the NCBI database and previously summarized by other authors (Jansen and Mohan, 2017).

3.3. Biology of TiLV

The virus is found in fresh and brackish water (OIE, 2017) and have so far been observed only in wild tilapia *Sarotherodon galilaeus*, cultured tilapia (*Oreochromis niloticus*) and hybrid tilapia (*Oreochromis niloticus* & *Oreochromis aureus*) (Bacharach et al., 2016; Eyngor et al., 2014; Ferguson et al., 2014). Thus, TiLV has a narrow host range infecting only tilapiines while other species which are reared with tilapia remain for now unaffected (Dinesh et al., 2017). It is possible that other fish species can be found susceptible since the virus can undergo mutations like the case for example of the epizootic hematopoietic necrosis virus initially isolated from redfin perch but have switched host and caused epizooties in other fish species like sheatfish and catfish or even ornamental fish (Bandín and Dopazo, 2011). Nevertheless, it is still not clear why only tilapiines are infected and what are the specific receptors of the virus in tilapia compared to other fish species. The virus has a multiple tissues tropism including liver, brain, kidney, spleen, gills and connective tissues of muscle (Dong et al., 2017b). However, the central nervous system (brain) and the liver of tilapia remain the main targets of the virus where it probably has its best receptors by inducing viral encephalitis and syncytial hepatitis (Bacharach et al., 2016; Tattiyapong et al., 2017). Nevertheless, the brain and liver surprisingly showed very low infection levels in specimens from Lake Victoria (Mugimba et al., 2018). TiLV affects fish at all stages (Senapin et al., 2018) but disease and mortalities are higher mainly in early developmental stages of tilapia, i.e. fertilized eggs, yolk-sac larvae, fry and fingerlings (Del-Pozo et al., 2017; Dong et al., 2017a; Tattiyapong et al., 2017). It is reported that higher mortalities were seen among fish weighing 1 to 50 g, whose immunity is still low, while adults or larger sized tilapia seems to resist the virus (Surachetpong et al., 2017). The affected age group brings suspicions of possible vertical transmission and this requires further investigation. Additional questions to be resolved also include the replication cycle and pathogenesis of the virus to understand its infection process, specific receptors involved and immunology. Recent studies prove that adult tilapia can have asymptomatic infections of TiLV with probably low viral loads or require additional susceptibility/risk factors to manifest the disease (Mugimba et al., 2018; Senapin et al., 2018).

Some strains of tilapia have lower levels of mortality (10–20%) compared to other strains (Ferguson et al., 2014) and this gives hints on existence of genetically resistant strains among tilapia populations to TiLV (OIE, 2017). Moreover, other authors have reported the absence of further outbreaks in ponds where epidemics have already occurred, reinforcing the idea of acquired resistance (Eyngor et al., 2014). Such information gives hope for vaccine development and for gene profiling for the promotion of genetically improved tilapia strains that are resistant to TiLV. However, the possibility of vaccination might not be effective because TiLV mostly causes disease among early very young tilapia whose immune system is not well developed.

3.4. Mode of transmission of TiLV

The main transmission route of TiLV is horizontal giving a high likelihood for disease transmission via water and transport of live fish (Liamnimitr et al., 2018; OIE, 2017). A recent study was able to prove that naïve fish get TiLV from infected fish via mucus of the infected fish, which contain infective doses of the virus (Liamnimitr et al., 2018). Studies from Thailand reported genetic similarities with the prototype Israeli strains (Senapin et al., 2018). Moreover, TiLV identified in Lake Victoria were similar to strains reported in Israel and Thailand (Mugimba et al., 2018). This poses the risk of cross-country and potential cross-continents spread of the virus. Since adults may have asymptomatic infections as apparently healthy adults were positive for TiLV (Mugimba et al., 2018; Senapin et al., 2018), it may be that the immune system of adult tilapia makes them resist the disease's manifestations and they are therefore, in most cases, asymptomatic carriers that pass the virus to their offspring. Furthermore, the occurrence of low viral load and detection of viral nucleic acids in the absence of disease, mostly among adults may be ascribed to variability in pathogenicity of the virus as observed in infectious salmon anemia virus ISAV (McBeath et al., 2014). It could also be attributable to possible latent infection among adult tilapia like the case of Koi herpesvirus (KHV) in carp, where the virus may reactivate following stress induction (Eide et al., 2011). All these suggestions remain to be clarified in further studies.

Intrinsic characteristics of the virus are not yet well known, so the contribution of indirect transmission by fomites remains unclear (OIE, 2017). Infected populations of fish, both cultured and wild, remain the sole reported reservoirs of the virus but the original source of TiLV is not established (Dong et al., 2017a; Ferguson et al., 2014). The most important risk factors are associated with stress (Ferguson et al., 2014). Risk factors have been predicted to be production-related whereby the incidence of TiLV increases in farmed tilapia with, lower body weight at the time of transfer to on-growing ponds, lower water temperatures, high DO_2, high stocking density and increased numbers of production cycles in the same ponds per year (Kabuusu et al., 2017).

3.5. Clinical manifestations of TiLV disease

Natural and experimental infections of tilapia by TiLV display the same clinical signs that reflect the tropisms of the virus. In some literature TiLV disease is regarded as a syncytial hepatitis because of its liver related symptoms (Del-Pozo et al., 2017; Ferguson et al., 2014). However, other authors reported liver and brain affected symptoms in TiLV infected fish (Dong et al., 2017b; Tattiyapong et al., 2017). Tiredness, endophthalmitis, skin attritions, congestions in kidney and brain inflammation are some other symptoms (Dinesh et al., 2017). General clinical manifestations of TiLV disease include discoloration, skin abrasions and ocular alterations like opacity of the lens (cataract), ruptured lenses with swelling of the eyeball and sometimes perforated cornea and shrinkage and loss of ocular functioning in severe cases (CGIAR, 2017; Eyngor et al., 2014; OIE, 2017). Other lesions include lesions of the brain such as edema, focal hemorrhages in the leptomeninges and capillary congestion in the white and gray matter (Dinesh et al., 2017; Tattiyapong et al., 2017). Indicative signs in infected tilapia ponds include high mortality (20–90%), reduced appetite, discoloration and decreased movement (Eyngor et al., 2014; NACA, 2017). Higher mortalities can be recorded during co-infections like the case reported in Malaysia where *Aeromonas veronii* in co-infection with TiLV was seen to be fatal (Amal et al., 2018).

3.6. Detection of TiLV

A number of detection methods common to most viruses have been documented. One of the easiest detection methods for laboratories that do not have necessary biosafety level for virus isolation is a semi-nested RT-PCR (Dong et al., 2017c). The semi-nested RT-PCR protocol based on a previously described protocol (Eyngor et al., 2014; Tsofack et al., 2017) targeting the segment 3 of TiLV genome by omitting primer Nested ext-2. Sequencing results of amplicons from the first procedure of (Eyngor et al., 2014) demonstrated that primer Nested ext-2 was similar to a fish gene and lead to false positive results. Therefore, a semi-nested RT-PCR was employed where Nested ext-1 and ME1 are used in the first reaction and a new primer (7450/150R/ME2) coupled with ME1 were considered for the second PCR (Dong et al., 2017c). Moreover, a study on tilapia samples from Lake Victoria described an RT-PCR protocol with new primer sets targeting segment 2 of TiLV which efficiently yielded non-specific amplification of the fish genes (Mugimba et al., 2018). Other studies also described the development of novel and highly sensitive RT-qPCR for TiLV detection. The method was able to detect as low as two viral copies in large range of tissues including liver, gills, brain, kidney and spleen (Tattiyapong et al., 2018). More interestingly, a new study was able to detect TiLV from tilapia mucus using a RT-PCR from the segment 3 of the genome (Liamnimitr et al., 2018).

3.7. Current geographical distribution of TiLV

Countries that officially reported TiLV outbreaks when this paper is being written are eight. They are Ecuador (Ferguson et al., 2014), Israel (Eyngor et al., 2014), Colombia (Tsofack et al., 2017), Egypt (Fathi et al., 2017; Nicholson et al., 2017), Thailand (Dong et al., 2017b; Surachetpong et al., 2017); Taiwan (FIS, 2017), India (Behera et al., 2018) and Malaysia (Amal et al., 2018). In addition, subclinical infections have been reported in wild and farmed tilapia in the Tanzanian and Ugandan basins of Lake Victoria, being the first report of TiLV from

SSA (Mugimba et al., 2018). However, 43 other countries are currently at risk of occurrence of the disease and this include 10 SSA countries such as Burundi, Congo, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Togo, Uganda, and Zambia (Dong et al., 2017b), with confirmation in Tanzania and Uganda (Mugimba et al., 2018). Investigations of TiLV is lacking in most SSA countries and we do not know the actual distribution of the virus in the SSA region despite the only one and first report of TiLV infection in Lake Victoria (Mugimba et al., 2018). For instance, the etiology of mortality in tilapia in Ghana and Zambia in 2016 (OIE, 2017) have not yet been confirmed.

3.8. Prospective socio-economic impacts of TiLV disease in SSA

The fisheries sector in SSA is confronted with serious depletion of most wild captures because they either have reached their production limit or are over-fished (The World Fish Centre, 2009). Additional losses due to TiLV will certainly worsen the situation and subsequently cause poverty, malnutrition, unemployment and food insecurity in the region. The majority of small-scale fish farmers in SSA stock their ponds with fingerlings obtained from other local farmers (de Graaf and Garibaldi, 2014). Since TiLV is more virulent in early life stages of tilapia, a crucial fish scarcity is plausible with subsequent impact on fish availability among poor communities whose livelihoods depend on this activity. The impact on local fish/tilapia trade is expected to be significant in low-income settings although it might not be felt in the global fish market since the level of tilapia production in SSA is very low (The World Fish Centre, 2009). In Egypt for instance, the overall impact of mortalities observed in tilapia aquaculture in 2015, which was suspected to be caused by TiLV, was estimated at 98,000 tons of lost production at a value of USD 100 million affecting 37% of the country's fish farms (Fathi et al., 2017). Egypt is however, a leading aquaculture producer as compared to the entire SSA countries and even if the economy of most SSA countries does not heavily depend on tilapia farming, the economy of populations whose life directly depends on tilapia aquaculture and fisheries are likely to be severely affected.

According to FAO, the fisheries sector employs 12.3 million people in Africa as full-time fishers or full-time and part-time processors, representing 2.1% of Africa's population of between 15 and 64 years old (de Graaf and Garibaldi, 2014). Since tilapia is one of the main encountered fish species in the system especially from fresh waters, it is therefore predictable that the impact of TiLV that causes up to 90% mortalities could be serious in SSA. Nevertheless, most tilapia in SSA countries are wild caught (Handisyde et al., 2015) and this could reduce the impact because although wild tilapia is indicated susceptible to TiLV, most reports on TiLV outbreaks showed high mortalities in cultured tilapia (Del-Pozo et al., 2017; Dong et al., 2017b; Ferguson et al., 2014). Both wild and cultured tilapia are susceptible to TiLV (Bacharach et al., 2016; Eyngor et al., 2014; Mugimba et al., 2018) and could develop mortalities up to 90%. Moreover, there are unexplored possibilities of host switching and adaptation (Bandín and Dopazo, 2011) overtime where TiLV could reach other fish species in the marine and fresh water environments. If we hypothesize these possibilities together, we could estimate that if appropriate actions are not taken now, the worst may happen where the income source of at least 6 million people (half of the 12.3 million involved in the fisheries in SSA will be at risk. Based on this estimation, if we suggest for instance that each of these 6 million people supports three dependents, the livelihood of 18 million people including children is at risk of serious food insecurity in SSA. Such situation is susceptible to lead to social crisis such as theft and exodus towards the already crowded urban areas with all the associated health and environmental corollaries.

About 400 million Africans consume fish, including tilapia, which contributes essential proteins, minerals and micronutrients with annual demands for fish expected to increase by 2.6 million tons by 2030 (Allison, 2011; FAO, 2014; The World Fish Centre, 2009). Food availability and accessibility is therefore endangered. A disease that can make vulnerable the food source of over 400 million people (Africa alone) needs serious attention and consideration. So far, few initiatives e.g. from international organizations such as OIE and FAO (CGIAR, 2017; OIE, 2017) have considered locally adapted preventive measures in SSA countries to limit the emergence of the virus in the region.

In a situation when TiLV goes at global stage with the known mortalities of up to 90%, the worldwide tilapia production estimated at US$ 7.5 billion per annum could be endangered with highest impacts among top tilapia-producing countries (NACA, 2017). Ten SSA countries are already at high risks of emergence of TiLV and some of them have recorded suspicious mortalities in farmed tilapia (Dong et al., 2017a; OIE, 2017). Among them two, Tanzania and Uganda have confirmed infection (Mugimba et al., 2018). As TiLV is mainly transmitted horizontally through infected live fish (Eyngor et al., 2014; Liamnimitr et al., 2018), the spread from aquaculture systems to natural water bodies is very likely because the outlet water of most aquaculture ponds in SSA are connected to natural water bodies such as lakes and rivers. On the other hand, TiLV is confirmed at subclinical levels in Lake Victoria (Mugimba et al., 2018), one of the African great lakes and when this goes to a disease stage, it is likely to create serious unprecedented food insecurity and economic crisis on the continent especially among populations whose income depend on fisheries and small-scale fish farming. Further model-based risk assessment studies are needed to quantify and appreciate the possible losses that can be due to TiLV when it occurs in forms of outbreaks in natural waters in SSA. However, natural variations of wild Tilapia and quick adaptation of the virus may strike a balance and resistance to the virus as compared to cultured tilapia, though further studies are required to prove this point.

The Chilean Infectious Salmon Anemia (ISA) outbreak bankrupted the aquaculture industry in 2007 and left debts of US$1.8 billion (Bayliss et al., 2017). Low-income rural communities were particularly badly affected, and an estimated 13,000 jobs were lost (Bayliss et al., 2017). This is evidence that SSA countries, because of their poor disease control systems should begin active surveillance to prevent TiLV outbreaks in order to avoid such irreversible losses. Another example is the outbreaks between 2010 and 2014 of acute hepatopancreatic necrosis disease (AHPND) in shrimp culture which was estimated to have caused a US$1 billion annual loss to the shrimp farming industry (Bayliss et al., 2017). Therefore, TiLV should not be given such chance to worsen poverty, malnutrition and unemployment in SSA.

3.9. Challenges related to the management of TiLV disease in SSA

Control measures and biosecurity procedures are provided by FAO and OIE on TiLV management (CGIAR, 2017; Jansen and Mohan, 2017; OIE, 2017). However, these measures are yet to be applied in SSA because aquaculture in this region is still at small-scale level whereas the proposed solutions are based at commercial larger scale operations. The fear of global spread of TiLV together with the fact that most imports of fish products from commercial hatcheries are directed towards locations where TiLV has not been reported, have resulted in distorted solutions and policies in respect to disease management (OIE, 2017). Live fish imported for aquaculture should undergo screening and possibly be quarantined (OIE, 2017). However, experiences from the veterinary field have proven that such measures hardly work in SSA countries where farmers have inadequate resources and infrastructures to quarantine animals (Lupindu et al., 2012). Poor capacity in biosecurity remains a major obstacle to most agricultural trade in Africa and limits farmers' incomes. In SSA countries aquaculture production is still in the hand of rural farmers. Most farmers have limited resources, little or no knowledge of aquaculture health management and with inadequate opportunities to improve management skills and respond effectively to diseases. Moreover, most of them have little knowledge about symptoms of different diseases or when to apply treatments (Idowu et al., 2017). In a situation of total stamping out for containment when the virus emerges in a particular farm, there is typically no compensation policy for the farmers in SSA, making the solutions proposed by OIE and FAO difficult to apply in African settings. Moreover, "stamping out" often results in large numbers of fish being destroyed, which is unacceptable in most poor SSA countries (Thomson, 2009).

The transboundary nature of most water bodies in SSA countries is a serious vulnerability factor for the rapid continental spread as it exists both in aquaculture and natural environments. Since naïve tilapia get TiLV from infected ones (Liamnimitr et al., 2018), there is a high likelihood that infected fish from aquaculture systems and Lake Victoria (Mugimba et al., 2018) can get into other African great Lakes of southeastern Africa mainly Lake Tanganyika, Lake Malawi, Lake Kivu, Lake Edward, the Congo River, the river Nile and more. Nigeria on the other hand shares a basin with Lake Chad, another African great Lake of the continent. In the west, the Volta and Mono Rivers are at high risks of contamination by TiLV especially because Togo, which is declared at risk, is in this gulf.

Since some fish, especially adults (Fathi et al., 2017; Ferguson et al., 2014) have recovered from TiLV disease; vaccination was regarded as a possible prevention method besides sanitary prophylactic measures (Jansen and Mohan, 2017; OIE, 2017). Nevertheless, there are various challenges that can hamper the effectiveness of TiLV vaccination in SSA. First is the cost-effectiveness. Most aquaculture farms in SSA are small-scale and cannot afford expensive vaccines as reported in other animal diseases (Lupindu et al., 2012). The currently available vaccine (TV1 by KoVax in Israel made of attenuated strain of TiLV) requires some levels of technology and infrastructures as well as financial necessities that may limit its use in SSA countries. The required cold storage and vaccine delivery are constraints for field application of the vaccine. It is unlikely that vaccination will be possible for tilapia in natural water bodies like African great lakes.

Most SSA countries are characterized by poor laboratory services, which are hampering disease control. In many parts of the subcontinent, laboratories lack resources and expertise (Bankolé et al., 2015). As a result, they cannot keep up with diagnostic demands, and proper diagnosis and response is delayed (Mwabukusi et al., 2014). In SSA countries, most laboratories have no vital expertise and skills for fish diseases for several reasons. These include lack of capacity in this particular field, professionals retiring and emigrating. The consequence is a lack of mentorship and proper training for new experts. A further problem is that many veterinary and fisheries technologists have not kept up with current knowledge and new technologies.

TiLV disease can be classified as a trade-influencing transboundary animal disease (TAD) because it is able to spread quickly and affect a large number of animals (fish) over a wide geographic area in a short period of time and can affect trade of tilapia from countries that are declared infected. In SSA, the control of most TADs (including TiLV disease) is challenging for a variety of technical, financial and logistical reasons (Thomson, 2009). Sub-Saharan Africa is consequently confronted with a complex problem that contributes significantly to delayed rural development, which, in turn, obstructs poverty alleviation. Therefore, instead of adopting technologies from developed countries whose solutions are based on large-scale production, it makes more sense to conjugate efforts on managing the impact of TiLV using local realities because the contexts differ.

3.10. Preventive and control measures for TiLV disease in SSA and perspectives for further investigations

Effective control of TiLV in SSA countries should aim at preventing introduction of the disease or its propagation in case it occurs. Most diseases affecting fish including TiLV are stress related (Ferguson et al., 2014), thus affordable disease prevention and control practices should center on good husbandry (management) practices; good water quality management, nutrition and sanitation.

The use of locally produced larvae and fingerlings should be promoted from local and regional farmers or breeders known to have no record of mass mortality with acceptable safety levels controlled by mandated fisheries officers. Healthy fish obtained from such reputable sources must possibly be quarantined using locally available means before being released to culture ponds. Other local measures could include the use of mobile technologies, which are already proven great in timely disease reporting in SSA countries (Mwabukusi et al., 2014) to give alerts on occurrence of TiLV for prompt and adequate response. Innovations such as rapid field diagnostic tools for TiLV must be considered for SSA countries where special laboratory skills are scarce. Since TiLV is still a new virus, continuous capacity building is needed to train and strengthen laboratory technicians and field aquatic health officers in SSA to be able to detect and respond to TiLV outbreaks. At elementary level, a relatively disease-free water supply is of paramount importance. We suggest a rigorous control of introduction of organic matters to the pond and suitable feeding schedule. High stock density beyond required levels should be avoided as it may stress the fish and predispose them to infections. In addition, proper handling of fish is necessary to reduce the risk of surface injuries capable of rendering tilapia vulnerable to TiLV. Governments in SSA countries may impose and sponsor TiLV screening to all fish feed or fish products imported to the countries to minimize the risk. In a farm with many ponds and despite the limited resources available in the farms, it is advisable to have separate nets for each ponds. General prophylactic measures applicable at resource-limited levels include pond disinfection, which can prevent diseases in pond from being carried over to subsequent production year.

Vaccination against TiLV could be considered in SSA countries if the vaccines are thermostable, cost-effective, applicable at low dosage for small farms and cheap, accessible and affordable to low-income farmers. Sponsored vaccines by Governments or locally produced vaccines against TiLV are encouraged for the control of TiLV in SSA.

Governments of SSA countries and agricultural extension services are expected to take measures adapted to low-income settings such as local sensitization for awareness rising on the virus, elaboration of manuals with locally applicable Biosecurity rules and affordable containment procedures. Collaborations between SSA countries for contextualized solutions are needed for integrated and sustainable control and prevention of TiLV because the virus does not need a visa to cross borders. There is a need to protect fisheries and aquaculture trade by enhancing international collaboration in fighting TiLV via integrated holistic approaches like One-Health approach although human health is not at risk. It urges that SSA countries invest as soon as possible in prevention and control of TiLV by designing SSA-based (i) regional guidelines; (ii) national strategies on TiLV disease management; (iii) rapid diagnostics and therapy; (iv) Surveillance and reporting; (v) research; (vi) institutional strengthening and manpower development (education, capacity building and extension, diagnostic services). Possibilities should also explore natural product research for TiLV prevention and treatment because most animal diseases in Africa can be treated or prevented by means of locally available medicinal plants, which are freely accessible for farmers (Dougnon et al., 2017).

Moreover, OIE recommended strict restrictions on the movement of live tilapiines from farms and fisheries where the virus is known to occur (OIE, 2017). We encourage participatory strategies such as One Health approach involving at all stakeholders to enable rapid dissemination of outbreak information. Public-Private sectors Collaboration should be promoted to limit the impact of TiLV and other infectious diseases in fish farming.

Local cooperatives should be encouraged among fish farmers and fishers to organize themselves into groups or networks and respond adequately to outbreaks like TiLV.

We also encourage the creation of a Community-Based Fish Health Insurance funds (CBFHI) among small-scale farmers and fishers. The idea here is to make the CBFHI the main Fish-heath advocate center in the fishing and farmers communities, and its ultimate goal will be the effective protection of fish health. The CBFHI will be created by the community and run by the community itself. However, the platform will also depend on some traditional sponsors such as governments and NGOs as well as other sponsors who invest in food and nutrition security at large. The CBFHI is a proactive system that will have delegate fish health experts as technical support. Each fisher and fish farmer (> 18 years old) member of the community will subscribe to this Insurance with an amount that will be defined by the community and transparently handled by themselves. The CBFHI will also collaborate with University experts on aquatic health and food security to offer regular trainings to subscribers in local languages. Its activities will be highly beneficial to the society because it will be operating like a community center for fish health where involved stakeholders can themselves take decisions on outbreaks prevention and control with their saved funds before getting supports from other sources.

In summary Tilapia Lake Virus disease is devastating fish disease causing high mortality in Tilapia with subsequent losses in the fisheries sector mainly in aquaculture. It is a potential threat to tilapia farming and food security worldwide. Every government should support researchers to begin active surveillance of the virus for early detection and control. Based on local realities of SSA countries, awareness creation and capacity building among farmers, veterinarians, and laboratory staff and fisheries officers is highly needed for effective management of TiLV disease in these countries. Pond water and natural water bodies also need to be sampled and analyzed for thorough risk characterization.

Conflict of interest

None declared.

Acknowledgement

The authors acknowledge the DANIDA Funded IMLAF project, Innovations and Markets for Lake Victoria Fisheries and the African Centre for Health of Aquatic Resources for providing access to the internet and supporting data sorting and content analyses.

References

Adams, M.J., Lefkowitz, E.J., King, A.M.Q., Harrach, B., Harrison, R.L., Knowles, N.J., Kropinski, A.M., Krupovic, M., Kuhn, J.H., Mushegian, A.R., Nibert, M., Sabanadzovic, S., Sanfaçon, H., Siddell, S.G., Simmonds, P., Varsani, A., Zerbini, F.M., Gorbalenya, A.E., Davison, A.J., 2017. Changes to taxonomy and the international code of virus classification and nomenclature ratified by the international committee on taxonomy of viruses (2017). Arch. Virol. 162, 2505–2538. http://dx.doi.org/10.1007/s00705-017-3358-5.

Allison, E.H., 2011. Aquaculture, Fisheries, Poverty and Food Security | WorldFish Publications [WWW Document]. The WorldFish Center, Penang, Malaysia. URL. https://www.worldfishcenter.org/content/aquaculture-fisheries-poverty-and-food-security-0, Accessed date: 2 February 2018.

Aly, S.M., 2013. A Review of Fish Diseases in the Egyptian Aquaculture Sector: Working Report. WorldFish, Penang, Malaysia.

Amal, M.N.A., Koh, C.B., Nurliyana, M., Suhaiba, M., Nor-Amalina, Z., Santha, S., Diyana-Nadhirah, K.P., Yusof, M.T., Ina-Salwany, M.Y., Zamri-Saad, M., 2018. A case of natural co-infection of Tilapia Lake virus and Aeromonas veronii in a Malaysian red hybrid tilapia (Oreochromis niloticus × O. mossambicus) farm experiencing high mortality. Aquaculture 485, 12–16. http://dx.doi.org/10.1016/j.aquaculture.2017.11.019.

Bacharach, E., Mishra, N., Briese, T., Zody, M.C., Tsofack, J.E.K., Zamostiano, R., Berkowitz, A., Ng, J., Nitido, A., Corvelo, A., Toussaint, N.C., Nielsen, S.C.A., Hornig, M., Pozo, J.D., Bloom, T., Ferguson, H., Eldar, A., Lipkin, W.I., 2016. Characterization of a novel Orthomyxo-like virus causing mass die-offs of Tilapia. mBio 7, e00431-16. http://dx.doi.org/10.1128/MBio00431-16.

Bandín, I., Dopazo, C.P., 2011. Host range, host specificity and hypothesized host shift events among viruses of lower vertebrates. Vet. Res. 42, 67. http://dx.doi.org/10.1186/1297-9716-42-67.

Bankolé, H., Dougnon, V., Hounmanou, G., Sintondji, A., Aminou, A., de Souza, M., Boko, M., Baba-Moussa, L., 2015. Comparative study of infectious risks in diagnostic laboratories between public and private hospitals in Benin. J. Med. Microbiol. Diagn. 4. http://dx.doi.org/10.4172/2161-0703.1000205.

Bayliss, S.C., Verner-Jeffreys, D.W., Bartie, K.L., Aanensen, D.M., Sheppard, S.K., Adams, A., Feil, E.J., 2017. The promise of whole genome pathogen sequencing for the molecular epidemiology of emerging aquaculture pathogens. Front. Microbiol. 8. http://dx.doi.org/10.3389/fmicb.2017.00121.

Behera, B.K., Pradhan, P.K., Swaminathan, T.R., Sood, N., Paria, P., Das, A., Verma, D.K., Kumar, R., Yadav, M.K., Dev, A.K., Parida, P.K., Das, B.K., Lal, K.K., Jena, J.K., 2018. Emergence of Tilapia Lake virus associated with mortalities of farmed Nile Tilapia Oreochromis niloticus (Linnaeus 1758) in India. Aquaculture 484, 168–174. http://dx.doi.org/10.1016/j.aquaculture.2017.11.025.

CGIAR, 2017. Tilapia Lake Virus (TiLV): What to Know and Do? | WorldFish Publications [WWW Document]. URL. https://www.worldfishcenter.org/content/tilapia-lake-virus-tilv-what-know-and-do, Accessed date: 2 February 2018.

Del-Pozo, J., Mishra, N., Kabuusu, R., Cheetham, S., Eldar, A., Bacharach, E., Lipkin, W.I., Ferguson, H.W., 2017. Syncytial hepatitis of Tilapia (Oreochromis niloticus L.) is associated with Orthomyxovirus-like Virions in hepatocytes. Vet. Pathol. 54, 164–170. http://dx.doi.org/10.1177/0300985816658100.

Dinesh, R., George, M.R., John, K.R., Abraham, S., 2017. TiLV - a worldwide menace to tilapiine aquaculture. J. Entomol. Zool. Stud. 5, 605–607.

Dong, H.T., Ataguba, G.A., Khunrae, P., Rattanarojpong, T., Senapin, S., 2017a. Evidence of TiLV infection in tilapia hatcheries from 2012 to 2017 reveals probable global spread of the disease. Aquaculture 479, 579–583. http://dx.doi.org/10.1016/j.aquaculture.2017.06.035.

Dong, H.T., Siriroob, S., Meemetta, W., Santimanawong, W., Gangnonngiw, W., Pirarat, N., Khunrae, P., Rattanarojpong, T., Vanichviriyakit, R., Senapin, S., 2017b. Emergence of tilapia lake virus in Thailand and an alternative semi-nested RT-PCR for detection. Aquaculture 476, 111–118. http://dx.doi.org/10.1016/j.aquaculture.2017.04.019.

Dong, H.T., Siriroob, S., Meemetta, W., Santimanawong, W., Gangnonngiw, W., Pirarat, N., Khunrae, P., Rattanarojpong, T., Vanichviriyakit, R., Senapin, S., 2017c. A Warning and an Improved PCR Detection Method for Tilapia Lake Virus (TiLV) Disease in Thai Tilapia Farms.

Dougnon, T.V., Déguénon, E., Fah, L., Lègba, B., Hounmanou, Y.M.G., Agbankpè, J., Amadou, A., Koudokpon, H., Fabiyi, K., Aniambossou, A., Assogba, P., Hounsa, E., de Souza, M., Avlessi, F., Dougnon, T.J., Gbaguidi, F., Boko, M., Bankolé, H.S., Baba-Moussa, L., 2017. Traditional treatment of human and animal salmonelloses in southern Benin: knowledge of farmers and traditherapists. Vet. World 10, 580–592. http://dx.doi.org/10.14202/vetworld.2017.580-592.

Eide, K.E., Miller-Morgan, T., Heidel, J.R., Kent, M.L., Bildfell, R.J., LaPatra, S., Watson, G., Jin, L., 2011. Investigation of koi herpesvirus latency in koi. J. Virol. 85, 4954–4962. http://dx.doi.org/10.1128/JVI.01384-10.

Eyngor, M., Zamostiano, R., Kembou Tsofack, J.E., Berkowitz, A., Bercovier, H., Tinman, S., Lev, M., Hurvitz, A., Galeotti, M., Bacharach, E., Eldar, A., 2014. Identification of a novel RNA virus lethal to tilapia. J. Clin. Microbiol. 52, 4137–4146. http://dx.doi.org/10.1128/JCM.00827-14.

FAO, 2005. Cultured Aquatic Species Information Programme - *Oreochromis niloticus* (Linnaeus, 1758). Food and Agriculture Organization of the United Nations.

FAO, 2014. Economic Analysis of Supply and Demand for Food up to 2030—Special Focus on Fish and Fishery Products.

FAO, 2017. FAO - News Article: FAO Issues Alert Over Lethal Virus Affecting Popular Tilapia Fish [WWW Document]. http://www.fao.org/news/story/en/item/888884/icode/, Accessed date: 2 February 2018.

Fathi, M., Dickson, C., Dickson, M., Leschen, W., Baily, J., Muir, F., Ulrich, K., Weidmann, M., 2017. Identification of Tilapia Lake virus in Egypt in Nile tilapia affected by 'summer mortality' syndrome. Aquaculture 473, 430–432. http://dx.doi.org/10.1016/j.aquaculture.2017.03.014.

Ferguson, H.W., Kabuusu, R., Beltran, S., Reyes, E., Lince, J.A., del Pozo, J., 2014. Syncytial hepatitis of farmed tilapia, *Oreochromis niloticus* (L.): a case report. J. Fish Dis. 37, 583–589. http://dx.doi.org/10.1111/jfd.12142.

FIS, 2017. Tilapia Lake Virus Affects Seven Farms in Taoyuan [WWW Document]. Fish Information and Services. http://www.fis.com/Fis/Worldnews/worldnews.asp?monthyear=6-2017&day=19&id=92318&l=e&country=&special=&ndb=1&df=1, Accessed date: 2 February 2018.

Gomna, A., 2011. The role of Tilapia in food security of fishing villages in Niger state, Nigeria. Afr. J. Food Agric. Nutr. Dev. 11, 5561–5572.

de Graaf, G., Garibaldi, L., 2014. The Value of African Fisheries, FAO Fisheries and Aquaculture Circular. FAO, Rome.

Handisyde, N., Fridman, S., Bostock, J., 2015. Partnership for African Fisheries (PAF) Aquaculture Working Group: Environmental Strategies for Aquaculture: A Strategic Review on Environmental Capacity and Management, Climate Change Response/Adaptation and Aquatic System Health.

Idowu, T., Adedeji, H., Sogbesan, O., 2017. Fish disease and health management in aquaculture production [WWW document]. Int. J. Environ. Agric. Sci. 1 (1). https://bioaccent.org/environmental-agricultural-science/environmental-agricultural-science02.php, Accessed date: 2 February 2018 001. 6 pages.

Jansen, D.M., Mohan, C., 2017. Tilapia Lake Virus (TiLV): Literature Review. CGIAR Research Program on Fish Agri-Food Systems, Penang, Malaysia Working Paper: FISH-2017-04.

Kabuusu, R.M., Aire, A.T., Stroup, D.F., Macpherson, C.N.L., Ferguson, H.W., 2017. Production-level risk factors for syncytial hepatitis in farmed tilapia (*Oreochromis niloticus* L). J. Fish Dis. 41, 61–66. http://dx.doi.org/10.1111/jfd.12672.

Liamnimitr, P., Thammatorn, W., U-thoomporn, S., Tattiyapong, P., Surachetpong, W., 2018. Non-lethal sampling for Tilapia Lake virus detection by RT-qPCR and cell culture. Aquaculture 486, 75–80. http://dx.doi.org/10.1016/j.aquaculture.2017.12.015.

Lupindu, A., Ngowi, H.A., Dalsgaard, A., Olsen, J.E., Msoffe, P., 2012. Current Manure Management Practices and Hygiene Aspects of Urban and Peri-Urban Livestock Farming in Tanzania.

McBeath, A.J.A., Ho, Y.M., Aamelfot, M., Hall, M., Christiansen, D.H., Markussen, T., Falk, K., Matejusova, I., 2014. Low virulent infectious salmon anaemia virus (ISAV) replicates and initiates the immune response earlier than a highly virulent virus in Atlantic salmon gills. Vet. Res. 45. http://dx.doi.org/10.1186/s13567-014-0083-x.

Mugimba, K.K., Chengula, A.A., Wamala, S., Mwega, E.D., Kasanga, C.J., Byarugaba, D.K., Mdegela, R.H., Tal, S., Bornstein, B., Dishon, A., Mutoloki, S., David, L., Evensen, ø, Munang'andu, H.M., 2018. Detection of tilapia lake virus (TiLV) infection by PCR in farmed and wild Nile tilapia (*Oreochromis niloticus*) from Lake Victoria. J. Fish Dis. http://dx.doi.org/10.1111/jfd.12790.

Mwabukusi, M., Karimuribo, E.D., Rweyemamu, M.M., Beda, E., 2014. Mobile technologies for disease surveillance in humans and animals. Onderstepoort J. Vet. Res. 81 (5 pages). https://doi.org/10.4102/ojvr.v81i2.737.

NACA, 2017. Tilapia Lake Virus - An Emerging Threat to Farmed Tilapia in the Asia-Pacific Region [WWW Document]. Disease Advisory - Network of Aquaculture Centres in Asia-Pacific. https://enaca.org/?id=864&title=tilapia-lake-virus-edisease-advisory, Accessed date: 2 February 2018.

Nicholson, P., Fathi, M.A., Fischer, A., Mohan, C., Schieck, E., Mishra, N., Heinimann, A., Frey, J., Wieland, B., Jores, J., 2017. Detection of Tilapia Lake virus in Egyptian fish farms experiencing high mortalities in 2015. J. Fish Dis. 40, 1925–1928. http://dx.doi.org/10.1111/jfd.12650.

OIE, 2017. Tilapia lake virus (TiLV) - a novel Orthomyxo-like virus [WWW document]. In: Disease Information Cards. OIE - World Organisation for Animal Health. http://www.oie.int/en/international-standard-setting/specialists-commissions-groups/aquatic-animal-commission-reports/disease-information-cards, Accessed date: 2 February 2018.

Senapin, S., Shyam, K.U., Meemetta, W., Rattanarojpong, T., Dong, H.T., 2018. Inapparent infection cases of tilapia lake virus (TiLV) in farmed tilapia. Aquaculture. http://dx.doi.org/10.1016/j.aquaculture.2018.01.007.

Surachetpong, W., Janetanakit, T., Nonthabenjawan, N., Tattiyapong, P., Sirikanchana, K., Amonsin, A., 2017. Outbreaks of Tilapia Lake virus infection, Thailand, 2015–2016. Emerg. Infect. Dis. 23, 1031–1033. http://dx.doi.org/10.3201/eid2306.161278.

Tattiyapong, P., Dachavichitlead, W., Surachetpong, W., 2017. Experimental infection of Tilapia Lake virus (TiLV) in Nile tilapia (Oreochromis niloticus) and red tilapia (Oreochromis spp.). Vet. Microbiol. 207, 170–177. http://dx.doi.org/10.1016/j.vetmic.2017.06.014.

Tattiyapong, P., Sirikanchana, K., Surachetpong, W., 2018. Development and validation of a reverse transcription quantitative polymerase chain reaction for tilapia lake virus detection in clinical samples and experimentally challenged fish. J. Fish Dis. 41, 255–261. http://dx.doi.org/10.1111/jfd.12708.

The World Bank, 2013. Fish to 2030: Prospects for Fisheries and Aquaculture. (No. 83177). The World Bank.

The World Fish Centre, 2009. Fish Supply and Food Security for Africa | WorldFish Publications [WWW Document]. https://www.worldfishcenter.org/content/fish-supply-and-food-security-africa-0, Accessed date: 2 February 2018.

Thomson, G.R., 2009. Currently important animal disease management issues in sub-Saharan Africa. Onderstepoort J. Vet. Res. 76, 129–134.

Tsofack, K.J.E., Zamostiano, R., Watted, S., Berkowitz, A., Rosenbluth, E., Mishra, N., Briese, T., Lipkin, W.I., Kabuusu, R.M., Ferguson, H., del Pozo, J., Eldar, A., Bacharach, E., 2017. Detection of Tilapia Lake virus in clinical samples by culturing and nested reverse transcription-PCR. J. Clin. Microbiol. 55, 759–767. http://dx.doi.org/10.1128/JCM.01808-16.