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

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SUMMARY

Tilapiais a traditional and favorite dish in almost all countries of Sub-Saharan Africa (SSA) and the second most produced fish worldwide. A deadly viral disease caused by Tilapia Lake Virus (TiLV) currently threatens tilapia production. This study aimed to describe TiLV disease, discuss its related socio-economic impacts in SSA, and envisage preventive measures applicable in SSA countries. PubMed, Web of Science, Scopus, Google Scholar and Research Gate were searched. Results reveal that TiLV is an RNA virus causing the disease of over 90% mortalities in tilapia. It attacks early developmental stages of tilapia, transmitted horizontally between fish, and is a potential trade-influencing transboundary animal disease. It is currently confirmed in six countries: Ecuador, Israel, Colombia, Egypt, Thailand and Taiwan. 10 SSA countries have likely imported TiLV infected tilapia fingerlings from hatcheries in Thailand and Tanzania, Burundi, Congo, Mozambique, Nigeria, Rwanda, South Africa, Togo, Uganda, and Zambia are suspected infected with TiLV. Approximately 6 Million jobs with subsequent 18 million livelihoods are expected to be affected. Food insecurity is likely to hit over 400 Million lives in the course of TiLV disease. An estimate of US$ 3 billion per year could be lost in SSA countries due to TiLV. In SSA, technologies to achieve effective control of TiLV based on measures suggested by OIE, and FOA do not exist. There is a crucial need for capacity building among farmers and technical personnel on prompt diagnostic procedures and effective remedial action and establishment of outbreak response systems.

Keywords: Tilapia; fish diseases, aquatic health, aquaculture, food security

INTRODUCTION

Globally, fish currently represents16.6% of animal protein supply and 6.5% of all protein for human consumption (World Bank, 2013). Tilapines, is a generic term for edible fish belonging to the family Cichlidae and commonly known as tilapia. They are fast growers, efficient food convertors and relatively disease-resistant (Nicholson *et al.*, 2017). These assets render them most suitable for farming and their demand is growing as populations grow (Lem *et al.*, 2014). Tilapia are farmed worldwide and serve as an important protein source, because of their affordable price, omnivorous diet, and tolerance to high-density farming methods (Tsofack *et al.*,2016). Tilapia serve as the second most important group of farmed fish worldwide with an annual production of 4.5 million tons and the current global tilapia trade has value of more than USD 7.5 billion (Dinesh *et al*., 2017).

In Africa, Egypt ranks first and second after China worldwide with regard to global tilapia output (Nicholson *et al.*, 2017). Cultureof 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.*, 2014).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 peryear (De Graaf and Garibaldi, 2014).

Most disease reports in tilapia implicate bacterial pathogens, e.g. *Aeromonas hydrophila* and *Streptococcus* species with fewer reports of viral diseases (Nicholson *et al.*, 2017). Viral pathogens in tilapia include betanodavirus, iridovirus, and herpes-like virus (Surachetpong *et al*., 2017). At the time this paper is being written, six countries have reported a new viral disease named “Tilapia Lake Virus” (TiLV) disease. The affected 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; Surachetpong *et al*., 2017) and Taiwan (FIS, 2017). Outbreak reports and experimental studies with TiLV have demonstrated mortalities from 10% to 90% and up to 100% during co-infections with other microorganisms (Dong *et al.*, 2017b; Surachetpong *et al.*, 2017; Tattiyapong *et al.*, 2017).Cohabitation trials by Tattiyapong *et al.* (2017) demonstrated that the disease is contagious and can spread from one fish to another and that under controlled conditions mortalities occur within few days post-infection, leading to the death of 80-100%. Recent updates from Dong *et al.* (2017a) reveal 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. These records suggest that many countries have been translocating tilapia fry/fingerlings prior to and even after the first reports of TiLV in Thailand (Dong *et al.*, 2017b).

Besides the six already confirmed countries, it seems that 43 countries, 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 (Dong *et al.*,2017a). Although the TiLV disease has not yet officially been detected and reported in any of these SSA countries, the Food and Agriculture Organization (FAO) has raised alertsand called for awareness and active surveillanceof TiLV worldwide (FAO, 2017). 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 aimedto review the available literature on TiLV and discuss the potential socio-economic impact and disease control and management challenges faced by SSAcountries where disease control is known to be difficult compared to other countries in the world.

MATERIAL AND METHODS

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 Scholaras well as ResearchGate. The search was performed in English during 25 June to 25July 2017with 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 sourceson 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.

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. Reference lists of full-text publications and textbooks were also examined to identify studies not retrieved by the original 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.

Results and Discussion

Current research on TiLV

A total of 42 scientific papers, 13 books, reports, and six webpage 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, none of these studies was conducted in Sub-Saharan Africa, nor did they address SSA specific matters. They were concentrated on large-scale commercial fish production rather than small-scale fish farming with proposed solutions that can hardly be implemented in low-income countries in SSA.

Description of the causative agent of TiLV disease

Tilapia lake virus (TiLV) disease is caused by a novel RNA virus in the family Orthomyxoviridae (Eyngor *et al.*, 2014; Bacharach *et al*., 2016; del-Pozo *et al.*, 2016). 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 and10, 323 kb total length (Dong*et al*., 2017b; Tattiyapong *et al*., 2017). Electron micrographs of the TiLV are shown in Figure 1 (Tattiyapong *et al.*, 2017). In its segmented genome, the largest segment (segment 1), contains an open reading frame with weak sequence homology to the influenza C virus PB1 subunit, while the other nine segments show no homology to other viruses but have conserved, complementary sequences at their 5' and 3' termini, consistent with the genome organization found in other Orthomyxo viruses (Bacharach *et al*., 2016). Genetic information of the virus can be found trough the GeneBank accession numbers provided in the NCBI database by the authors. Available sequences from Israel include KJ605629 (clone 7450, ORF) (Eyngor *et al*. 2014) and KU751814 to KU751823 (whole genome, segments 1 to 10) (Bacharach *et al.*, 2016). Thailand strains include KY615742 (segment 1), KY615743 (segment 5) and KY615744 to KY615745 (segment 9) (Dong *et al.*, 2017a), as well as KX631921 to KX631930 (whole genome, segments 1-10) and KX631931 to KX631936 (segment 1, originating from different Thailand provinces) (Surachetpong *et al.*, 2017).

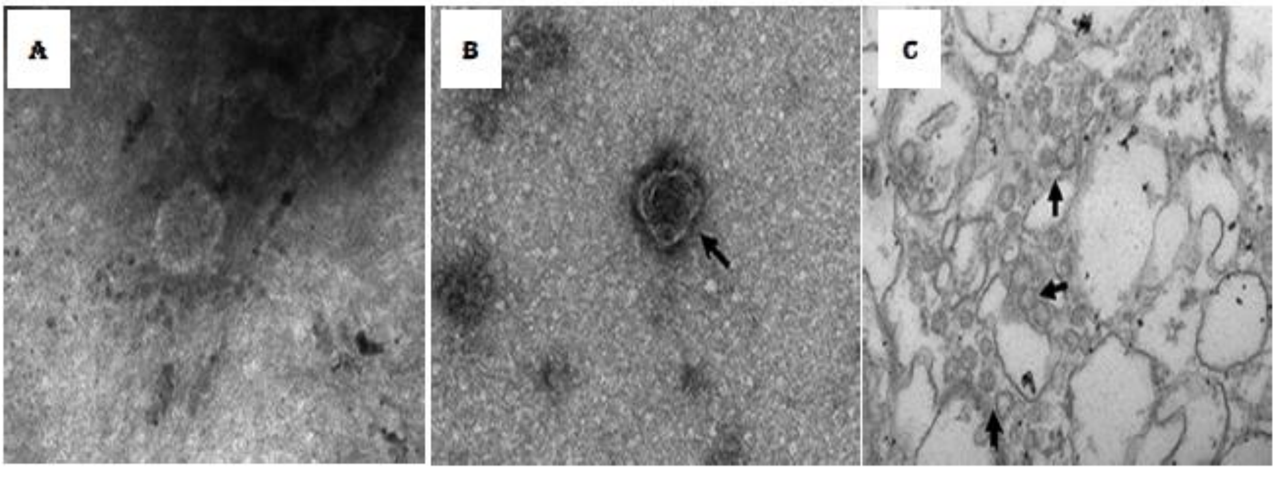

Figure 1. Transmission electron micrograph of infectedE-11 cells and ultrathin sections of infected tilapiabrain tissue. (A and B) High magnification of a freevirion showing a round enveloped viral particle with60 to 80 nm diameter. (C) Ultrathin section of infected tilapia brain showing multiple viral particlesin the cytoplasm of infected cells marked with black arrows (Source: Tattiyapong *et al.*, 2017)

Habitats and hosts 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*, farmed tilapia (*Oreochromis niloticus*) and commercial hybrid tilapia (*Oreochromis niloticus* X *Oreochromis aureus*) (Bacharach *et al.*, 2016; Ferguson *et al.*, 2014; Eyngor *et al.*, 2014). Thus, TiLV has a narrow host range infecting only tilapines while other species which are reared with tilapia remain unaffected (Dinesh *et al.*, 2017). Although only tilapines have been shown to be susceptible to date, it is possible that other species will be found susceptible since the virus can undergo mutations. Nevertheless, it is still not clear why only tilapines are infected and what are the specific receptors of the virus in tilapia compared to other fish species. The only controversial report in terms of species affected so far is from Egypt, where mortalitiesaround 9% due to TiLV were observed in medium to large sized Nile perch, whichbelong to the Latidae and not the Cichlidae as reported by the World Organization for Animal Health (OIE, 2017). Additional, studies are needed to confirm that Nile perch is also susceptible to TiLV.

TiLV tropism and susceptible host age

The virus has a multiple tissues tropism including liver, brain, kidney, spleen, gills and connective tissues of muscle (Dong *et al.*, 2017a). 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). It is possible that the pathogenic agent can also be found in musculature of infected fish (OIE, 2017).

Outbreaks and experimental studies have indicated that TiLV affects mainly early developmental stages of tilapia, i.e. fertilized eggs, yolk-sac larvae, fry and fingerlings (del-Pozo *et al.*, 2016; Dong *et al.*, 2017b; Tattiyapong *et al.*, 2017). Surachetpong *et al.* (2017) 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. TiLV disease is frequently reported within one month after fry or juvenile tilapias have been moved from hatcheries to the grow-out cages (Tattiyapong *et al*., 2017; OIE, 2017). The affected age group brings suspicions of possible vertical transmission ornonspecific absorption of viral particles on these life stages, an issue that 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.

Ferguson *et al.* (2014) noted that a strain of tilapia (genetically male tilapia) incurred a significantly lower level of mortality (10-20%) compared to other strains. This was concluded by the OIE (2017) as evidence those certain genetic strains of tilapia are resistant to TiLV. Moreover, Dinesh *et al.* (2017) noticed no more outbreaks in the same pond once the initial mortality ceased. 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, since TiLV infects very early developmental stages of tilapia (fertilized eggs, fry, and fingerlings) when fish immune system is not fully developed, the use of vaccines may not be an effective control approach.

Mode of transmission of TiLV

The main transmission route of TiLV is horizontal through cohabitation giving a high likelihood for disease transmission via water and transport of live fish (Tattiyapong *et al.*, 2017). Nicholson, *et al* (2017) noticed that the Egyptians strains of TiLV have high nucleotide identity with Thai and Israeli strains. Similar observations were made by Dong *et al*. (2017a) who concluded that TiLV strains circulating in Asia are all genetically related, confirming the risk of cross country and cross continents spread of the virus. Nevertheless, there are possibilities of vertical transmission since the virus is present in early developmental stages of fish such as larvae, fries and fingerlings (Dong *et al.*, 2017b). It could 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. There is limited information about TiLV biophysical properties and the risks associated with aquatic animal products. Since biophysical characteristics of the virus are not well described, it is unclear to determine the significance of indirect transmission by fomites (OIE, 2017). Infected populations of fish, both farmed and wild, are the only established reservoirs of infection but the original source of TiLV is not known (Ferguson *et al.*, 2014; Dong *et al.*, 2017b). The most important risk factors are associated with stress (Ferguson *et al.*, 2014) but no studies have provided evidence on other physico-chemical risk factors such as temperature, salinity, Ph, etc.

Current geographical distribution of TiLV

Countries that officially reported TiLV disease when this paper is being written 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; Surachetpong *et al.*, 2017) and Taiwan (FIS, 2017). 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.*, 2017a). Investigations of TiLV are lacking in most SSA countries and we do not know the actual distribution of the virus in the SSA region. For instance, the etiology of mortality in tilapia in Ghana and Zambia in 2016 (OIE, 2017) have not yet been confirmed.

Clinical manifestations of TiLV disease

Natural and experimental infections of fish by TiLV display the same clinical signs that reflect the tropisms of the virus. Ferguson *et al.* (2014) and del-Pozo *et al*. (2016) described TiLV disease as a syncytial hepatitis because of its liver related symptoms. However, other authors reported liver and brain affected symptoms in TiLV infected fish (Dong *et al.*, 2017a; Tattiyapong *et al.*, 2017). Symptoms comprising lethargy, endophthalmitis, skin erosions, renal congestion, and encephalitis were reported by Dinesh *et al*.(2017).General clinical manifestations of TiLV disease include black discoloration, skin abrasions, and ocular alterations like opacity of the lens (cataract), ruptured lenses with endophthalmitis accompanied by swelling of the eye ball with occasional perforated cornea and shrinkage and loss of ocular functioning in advanced cases (OIE, 2017; CGIAR, 2017).Other lesions include skin erosions and moderate congestion of the spleen and kidney as well as lesions of the brain such as edema, focal hemorrhages in the leptomeninges, and capillary congestion in both the white and gray matter (Dinesh et al., 2017; Tattiyapong *et al*., 2017). Indicative signs in infected tilapia ponds include mass mortality (20-90%), loss of appetite, pale color, gathering in the bottom, slow movement, and stopped schooling prior to death (Eyngor *et al.*, 2014; NACA, 2017). Figures 2 and 3 illustrate clinical signs of TiLV disease.

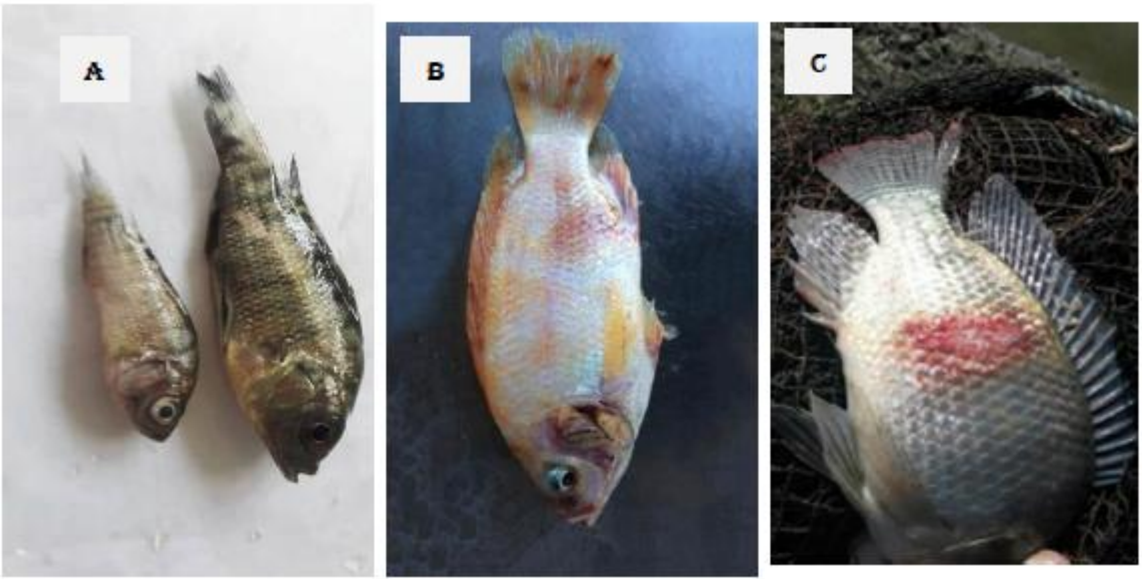

Figure 2. (A) Naturally TiLV-infected Nile tilapia revealed discoloration, and scale protrusion; (B) Naturally TiLV-infected red tilapia juveniles with congestions; (C) Skin lesions in TiLV-infected tilapia. (Source: Jansen and Mohan, 2017).

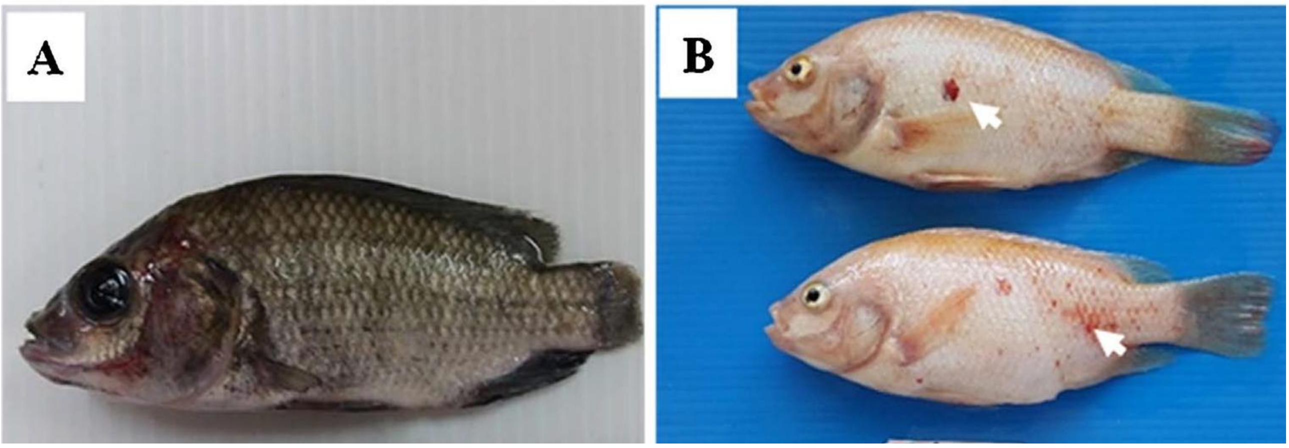

Figure 3. (A) Experimentally TiLV-infected Nile tilapia with skin erosion, hemorrhage and ocular alterations**;** (B) Experimentally infected Red tilapia with skin hemorrhage (arrow), mild exophthalmos and abdominal swelling. (Source: Tattiyapong *et al.,* 2017).

Detection methods for TiLV

Several detection methods are available and range from isolation of the virus to molecular techniques. Reported molecular methods for TiLV detection include nested RT-PCR, semi-nested RT-PCR, SYBR (Synergy Brand) quantitative RT-PCR and *in situ* hybridization (Bacharach *et al*., 2016; Dong *et al*., 2017a; Tsofack *et al.*, 2017). Moreover, electron microscopy (Tattiyapong *et al*., 2017), high nucleotide sequencing, unbiased high-throughput sequencing (UHTS), Northern hybridization and mass spectrometry (Dinesh *et al.*, 2017) were reported efficient in TiLV diagnosis. Isolation of the virus is feasible by propagation in E-11 cells lines, a continuous cell line from snakehead fish *Ophicephalus striatus* (Tsofack *et al.*, 2016; Tattiyapong *et al.*, 2017). Advanced detection methods include viral metagenomics with the potential to identify novel viruses without prior knowledge of their genomic sequence data and may provide a solution for the study of uncultivable viruses (Munang'andu *et al.*, 2017). Currently, the easiest detection method for laboratories that do not have necessary biosafety level for virus isolation is the alternative semi-nested RT-PCR described by Dong *et al*. (2017c). It is an improved semi-nested RT-PCR protocol based on a previous protocol described by Eyngor *et al*. (2014) and Tsofack *et al*. (2017) targeting TiLV genome segment 3 by omitting the primer Nested ext-2. Actually, sequencing results of amplicons from the first procedure of Eyngor *et al*. (2014) demonstrated that the primer Nested ext-2 was similar to a fish gene and lead to false positive results. Since the error was likely to be from that primer Nested ext-2, Dong *et al*. (2017c) then developedan alternative semi-nested RT-PCR in which the primer Nested ext-1 and ME1 are employed in the first round amplification, then 7450/150R/ME2 and ME1 are used in the second round PCR. With this new protocol, heavily infected samples generate two amplicon bands of 415bp and 250 bp while lightly infected samples generate a single 250-bp amplicon band (Dong *et al*., 2017c).

Prospective socio-economic impacts of TiLV diseasein 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 (World Fish, 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 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 (World Fish, 2009). In Egypt for instance, the overall impact of mortalities observed in tilapia aquaculture in the summer of 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 aquaculture and fisheries are likely to be severely affected. The value added by the African fishery sector as a whole in 2011 was estimated at more than US$ 24 billion, 1.26% of the GDP of all African countries (De Graaf and Garibaldi, 2014).

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 the second most encountered fish in this system, it is therefore predictable that the impact of TiLV that causes up to 90% mortalities could be catastrophic in SSA. Nevertheless, most tilapia in SSA countries are wild caught (*Handisyde et al.*, 2014) and this could reduce the impact because although wild tilapia is indicated susceptible to TiLV, most reports on TiLV disease showed high mortalities in cultured tilapia only (Ferguson *et al.*, 2014; del-POZO *et al*., 2016; Dong *et al.*, 2017a). However, if we stick to the fact that both wild and cultured tilapia are susceptible to TiLV (Eyngor *et al.*, 2014; Bacharach *et al*., 2016) and can develop mortalities up to 90%,we could estimate that the income source of at least 6 million people (half of the 12.3 million involved in the fisheries in SSA is 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, predominantly tilapia, which contributes essential proteins, minerals and micronutrients with annual demands for fish expected to increase by 2.6 million tons by 2030. (World Fish, 2009, World Fish, 2011; Lem *et al.,* 2014). 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 OIE (2017) and FAO (CGIAR, 2017) has considered locally adapted preventive measures in SSA countries to limit the emergence of the virus in the region.

The global economic impact of TiLV is estimated at US$7.5 billion per annum, especially among the top tilapia-producing countries (NACA, 2017). According, to Dong *et al*. (2017b), 10 SSA countries are already at high risks of emergence of TiLV and some of them have recorded suspicious mortalities in farmed tilapia (OIE, 2017). As TiLV is mainly transmitted horizontally through infected live fish (Eyngor *et al.,* 2014), 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. If TiLV gets into African great lakes and rivers, it will 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 natural waters in Africa.

Baylis *et al.* (2017) reported that the Chilean Infectious Salmon Anemia (ISA) outbreak bankrupted the aquaculture industry in 2007 and left debts of US$1.8 billion. Low-income rural communities were particularly badly affected, and an estimated 13,000 jobs were lost (Baylis *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 (Baylis *et al.*, 2017). Therefore, TiLV should not be given such chance to worsen poverty, malnutrition and unemployment in SSA.

Challenges related to the management of TiLV diseasein SSA

Control measures and biosecurity procedures are provided by FAO and OIE on TiLV management (OIE, 2017; CGIAR, 2017; Jansen and Mohan, 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 of disease management and trade in fish products (OIE, 2017). According to OIE (2017), live fish imported for aquaculture should undergo screeningand possibly be quarantined. 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 of the virus when it jumps from aquaculture to natural environment and becomes hard to control. There is a high probability that infected fish from aquaculture systems in Burundi, Tanzania, Congo, Mozambique, Uganda and Zambia can get into the African great lakes of southeastern Africa mainly Lake Victoria, 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 (Ferguson *et al.,* 2014; Fathi *et al.,* 2017) have recovered from TiLV disease; vaccination was regarded as a possible prevention method besides sanitary prophylactic measures (OIE, 2017; Jansen and Mohan, 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 retarded rural development, which, in turn, impedes poverty alleviation. The fact is that the epidemiology of most TADs, not to mention performance characteristics of vaccines and other control mechanisms, preclude any realistic SSA-based prospect of success for effective control. 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 TiLVusing local realities because the contexts differ.

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 orits 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 ongood 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 vital. Introduction of organic matter to the pond water must be controlled. Proper and appropriate feeding schedule should be ensured. Maintaining a suitable stocking density is also necessary as overcrowding stress fish and eventually predispose them to infections. In addition, proper handling of fish is necessary to reduce the risk of surface injuries capable of predisposing fish 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 pond so that TiLV outbreak in one is prevented from being transferred to the others. General prophylactic measures applicable at resource-limited levels include pond disinfection by fallowing and liming, which can prevent diseases in pond from being carried over to subsequent culture 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 TiLVdisease 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 tilapines from farms and fisheries where the virus is known to occur (OIE, 2017). To facilitate rapid dissemination of information, participatory approaches at all stakeholder levels should be encouraged. Collaborative programs between theprivate sector and relevant governments should be promoted to limit the impact of TiLV and the associated disease.
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 serious 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.

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