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REVIEW ARTICLE

RNA VIRAL DISEASES OF FINFISH: A REVIEW

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ABSTRACT

Infectious diseases are associated with the most devastating problem in aquaculture sectors. In comparison to terrestrial farm animals and plants, aquatic animals require more attention in order to monitor and manage their health. Both farmed and wild fish are most susceptible to the various viral pathogens. Regrettably, viral diseases are more difficult to control due to lack of knowledge about pathogenesis and natural resistance to viral infections. Particularly, intensive aquaculture has brought more disease problems which leading to great economic losses. The outbreaks of both DNA and RNA viral disease are associated with significant losses of cultured and wild fish populations. In general, RNA viruses by far cause severe diseases in fish aquaculture and hence become economically important universally. RNA viruses including birnavirus, nodavirus, orthomyxovirus, rhabdovirus, reovirus, paramixovirus, retrovirus, coronavirus, togavirus, picornavirus etc. those are infectious for culture and wild fishes. The present review was built on RNA virus diseases affecting finfishes are menacing to the sustainable growth of aquaculture.

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INTRODUCTION

Aquaculture is the fastest growing industries in fish production contributing significantly to the global economy. Like a terrestrial animal, cultured and wild fish populations affected by viral diseases are considered as a major task to the sustainable growth of aquaculture globally. Significant losses of cultured and wild populations of fish occur every year due to viral diseases across the world. Both DNA and RNA viruses causing high mortality among commercially important cultivable fishes have been studied last two decades. Many RNA viral pathogens have been reported to cause mass mortalities of the fish population in cultured fish. Major RNA viral pathogens in aquaculture include Rhabdoviruses infectious hematopoietic necrosis virus (IHNV) infecting non-salmonids including European eel, herring, cod, sturgeon, pike, shiner perch and tube snout; spring viramia of carp virus (SVCV) mainly infects in common carp; viral haemorrhagic septicaemia virus (VHSV) can be caused infection in flounders, eels, mimmichiog, stickleback, brown trout and striped bass in Canada and Epizootic ulcerative syndrome rhabdoviruses in striped snakeheads and a freshwater eel in Northern Thailand and Myanmar]; Betanodavirus infecting over 40 species including barramundi, Japanese parrotfish, turbot, European seabass, redspot grouper and striped jack; Reovirus mainly causing potential lethal infection in grass carp in china; Birnavirus infectious pancreatic necrosis virus (IPNV) infection from several fish species including tropical fishes such as Giant snakehead, Snakehead and eye-spot barb; Sand goby virus isolating from sand goby with ulcer disease reared in freshwater cages in Thailand] (John and Sivasankar, 2016). Poor management practice is one of the ways to easy transmission of the virus from one farm to another. However, avoidance of viral disease outbreaks is one of the best preventive measures. Although, the effective control of infectious viral diseases without chemicals has become more and more important in the cultivation of aquatic organisms. The aim of the present review was to analyse RNA viral diseases affecting fish aquaculture.

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RNA viral diseases

Birnavirus

Aquabirnavirus is the largest and most diverse genus of the family *Birnaviridae*. The type species, infectious pancreatic necrosis virus (IPNV), was the first fish virus isolated in cell culture (Wolf *et al.,* 1960). The virus isolated from a disease outbreak causing around 50% mortality of rainbow trout fingerlings is the archetype IPNV strain VR-299 (Wolf, 1988).

Since then, a vast range of IPNV and IPN-like viruses have been isolated from a very wide host range of diseased and healthy salmonid and non-salmonid fish species (Hill and Way, 1995; Reno, 1999). McAllister and Owens, (1992) reported that IPNV can be transmitted by faeces of piscivorous birds, e.g. heron, crow, grackle, kingfisher, sparrows, mallards, egrets and ospreys. Yellowtail ascites virus (YAV) was the first aquabirnavirus isolated from marine fish, yellowtail (*Seriola quinqueradiata*) in Japan (Sorimachi and Hara, 1985). Marine birnavirus MABV have been detected in various marine hosts (Isshiki *et al*., 2004). Birnavirus has been characterized as non-enveloped icosahedrons of 60 nm in diameter, containing a genome consisting of two segments (A and B) of dsRNA. Segment A encodes a polyprotein which is post-translationally cleaved to form three viral proteins VP2, VP3 and VP4, with VP2 epitopes being responsible for serotype specificity and the target for neutralizing antibodies (Dobos, 1995). Segment B encodes VP1, an RNA-dependent RNA polymerase (Dobos *et al*., 1979).

Infectious pancreatic necrosis virus (IPNV)

IPNV is a birnavirus that infect both freshwater and marine fishes and also cause infectious pancreatic necrosis (IPN), a severe disease in farmed salmonid fish. IPN is a viral infection primarily of trout & salmon and the virus has also been isolated from a wide variety of other fish species. The viral infection is characteristically seen in trout as causing high mortality in fry and fingerlings. IPNV has been reported among freshwater fish (carp and gold fish) in Iran, Japan, Korea and Australia. Mortalities at this stage can be as high as 90% and infected fry may show typical signs such as a darkening of the skin colour, swimming high in the water column or lying on their side and hyperventilating (Roberts & Pearson, 2005). Desautels and MacKelvie (1975) recognized IPN as one of the major fish disease problems in the United States, Canada, and Europe. IPNV is a major concern to the Australian salmonid aquaculture industry. IPNV has been isolated from goldfish *(Carassius auratus)* and discus fish *(Symphysodon dis*cus) (Adair and Ferguson., 1981). The IPNV may cause high mortalities among non-salmonids but show no specific clinical signs (Adair and Ferguson., 1981; McAllister and Stoskopf., 1993). IPNV show vertical transmission among ornamental fish, which was shown experimentally in zebra fish *(Brachydanio rerio)* (Seeley *et al*., 1977).

IPNV can be grown in fish tissue culture cells at a temperature less than 24^{o} C (Malsberger, 1965). The virus replication occurs in cytoplasm and a single cycle of growth takes time between 16 and 20 hours (Malsberger, 1965). The structural proteins of IPNV may be classified into three size classes on the basis of molecular weight: (i) large, α (90,000); (ii) medium, β_1 (59,000), β_2 (58,000), and β_3 (57,000); and (iii) small, γ_1 (29,000), γ_{1A} (28,000), γ_2 (27,000), and γ_3 (25,000) (Dobos, 1977). The RNA and protein gel profile of Tellina virus (TV) is similar to that of IPNV, but only a very low level of antigenic relationship exists between the two viruses (Underwood, 1977). Currently at least three serogroups, A, B and C of IPNV has been recognised (Hill and Way 1995, John and Richards, 1999). IPN-like virus has been reported in marine tropical reef fish (McAllister and Stoskopf., 1993). Ørpetveit *et al*. have been found that IPNV is able to enter into a wide range of mammalian cells, and virus entry is most likely receptor mediated. They found no indication of IPNV replication in any of the mammalian cell lines tested (Ørpetveit *et al*., 2012).

Betanodavirus

The family *Nodaviridae* classified into two genera include Alphanodavirus and the Betanodavirus. Alphanodavirus infects the insect while betanodavirus causes disease outbreaks in hatchery-reared larvae and juveniles of a wide variety of marine and freshwater fish (Shetty *et al.,* 2012). Betanodavirus (Ball *et al.,* 2000) comes under the family of *Nodaviridae* and is the etiological agent of viral nervous necrosis (VNN), also known as viral encephalopathy and retinopathy (VER). The nodavirus has been reported to infect both freshwater and marine fishes (Munday *et al*., 2002). Betanodaviruses known to infect over 40 marine fish species worldwide, including populations in Australia, Asia, Europe, North America, Africa, and the South Pacific. Walker and Winton, (2010) recognised importance of betanodaviruses as emerging group of viruses.
The Betanodavirus disease was first reported in Barramundi (*Lates calcarifer*) farmed in Australia (Glazebrook *et al*., 1990; Munday *et al.,* 2002) and Japanese parrotfish *Oplegnathus fasciatus* (Yoshikoshi and Inoue, 1990) followed a year later in Turbot *Scopthalmus maximus* (Bloch *et al*., 1991), European sea bass *Dicentrarchus labrax* (Breuil *et al.,* 1991; Mori *et al*., 1991; Munday *et al*., 1992; Nguyen *et al*., 1994; Grotmol., 1995; Frerichs *et al*., 1996), Redspotted grouper *Epinephalus akaara* (Mori *et al*., 1991) and Striped jack *Pseudocaranx dentex* (Mori *et al*., 1992). The betanodavirus infected fish show abnormal swimming behaviour, encephalopathy and retinopathy in Japanese parrotfish (*Oplegnathus fasceatus*) and has been defined as viral nervous necrosis (VNN) (Yoshikoshi and Inouye, 1990). Viral encephalopathy and retinopathy (VER), fish encephalitis, encephalomyelitis or, striped jack viral nervous necrosis, caused high mortalities among larvae and juveniles of several species of marine fish in the Indo-Pacific region, the Mediterranean, France and Scandinavia (Essbauer and Ahne, 2001).

This disease is characterized by vacuolating necrosis of neural cells of the brain, retina and spinal cord and causes up to 100% mortality in larval and juvenile fish, and can cause significant losses in older fish. Munday and Nakai, (1997) reported nodaviruses showing vertical transmission. Betanodaviruses has been isolated in cell culture for the first time from European seabass and characterized using SSN-1 cell line (Frerichs *et al*., 1996). Nervous necrosis virus (Nodavirus), has been reported as the most important pathogen infecting grouper in the last decade (Hyatt *et al*., 2000).The striped jack nervous necrosis virus (SJNNV) reported in larvae of striped jack (*Pseudocaranx dentex*) (Mori *et al*., 1992) was characterized and classified under the genus Betanodavirus of *Nodaviridae* (van Regenmortel *et al*., 2000). The betanodavirus is characterized as having a small size of 25-30 nm in diameter, non-enveloped and icosahedral-shaped capsid that surrounds genetic material made up of single-stranded, positive-sense RNA (Gagne *et al*., 2004). Betanodavirus (ICTV 2009) are described to include four categories based on genetic analyses; these are a]. Striped jack nervous necrosis virus (SJNNV); b]. Barfin flounder nervous necrosis virus (BFNNV); c]. Tiger puffer nervous necrosis virus (TPNNV); and d]. Redspotted grouper nervous necrosis virus (RGNNV). Piscine nodaviruses can be propagated efficiently *in vitro* in the SSN-1 cell line derived from tissue of striped snakehead (*Ophicephalus striatus*) (Frerichs *et al*.,

1996; Iwamoto *et al*., 1999). The nodaviruses described as tentative species in the genus are the Atlantic halibut nodavirus (AHNV) and the Malabar grouper nervous necrosis virus (MGNNV) (van Regenmortel *et al*., 2000). Virions of nervous necrosis virus (NNV) are small (25–30 nm in diameter), spherical and non-enveloped with a genome consisting of two molecules (RNA1 and RNA2) of positive sense single standard RNA, the complete sequences of which have been determined (Tan *et al*., 2001). RNA1 encodes a non-structural protein and RNA2 encodes the coat protein (Mori *et al.,* 1992; Nagai and Nishizawa 1999; Skliris *et al*., 2001). Nodavirus has been reported in marine fish species (Gagne *et al*., 2004), marine ornamental fish (Gomez *et al*., 2006), live food organisms (Chi *et al.,* 2003) and freshwater fish (Bigarre *et al*., 2009; Jithendran *et al*., 2011). Nodavirus was also isolated in India from cultured sea bass and the Indian strain was characterised as LCNNV-In01 belonging to RGNNV serotype (John *et al*., 2012).

Orthomyxovirus

The family *Orthomyxoviridae* contains the genera influenzavirus A, influenzavirus B, influenzavirus C and thogoto-like viruses. Features of the family include spherical or pleomorphic virions of 80-120 nm diameter, having an envelope with surface projections. Infectious salmon anemia virus (ISAV), an *Orthomyxovirus*, is the causative agent of infectious salmon anaemia (ISA).

Infectious salmon anaemia virus (ISAV)

Infectious salmon anaemia virus (ISAV) is listed as a notifiable disease by the World Organization for Animal Health, and to this day, culling of infected cages or farms remains the current practice in many countries to mitigate the spread of the virus (Gagné and LeBlanc, 2017). ISAV has been isolated from Atlantic salmon (*Salmo salar*) in Norway (Falk *et al*., 1997), Canada (Mullins *et al*., 1998) and Scotland (Rodger *et al*., 1998). Lovely *et al*. (1999) reported ISAV to be associated with haemorrhagic kidney syndrome (HKS) in Atlantic salmon (*Salmo salar*). ISAV causes severe economic losses of Atlantic salmon and other fishes like Sea trout, rainbow trout and Atlantic herring. The virus can be transmitted by sea lice (*Caligus elongatus*, *Lepeophtheirus salmonis*); by coprophagy (Rolland and Nylund, 1998) and it does not seem to be transmitted vertically (Melville and Griffiths, 1999). OIE has been reported that there is no evidence of true vertical transmission, however eggs and embryos could be a risk of transmission if ISAV biosecurity measures are not adequate (Rimstad *et al*., 2011, Mardones *et al*., 2014, OIE, 2017). ISAV was grown in salmon head kidney cells (SHK-1) and in Chinook salmon embryo cells (CHSE-214) at 15°C (Dannevig *et al*., 1995; Bouchard *et al*., 1999). ISAV has a buoyant density of 1.18 g/ml in sucrose and caesium chloride gradients and is sensitive to chloroform, heat and low pH (Falk *et al*., 1997). ISAV contains four major polypeptides of 71, 53, 43 and 24 kDa and eight single-stranded RNA segments of 1.0-2.3 kb with total genome size of 14.5 kb (Mjaaland *et al*., 1997 and McCauley *et al*., 2011); in which, gene segments 5 and 6 encode the surface glycoproteins that are important for the pathogenicity of ISAV. The mortality of marine fish in net-cages due to ISAV rises slowly and can vary from 0 to 90% (OIE 2012). Significant mortality was noted from marine fish in net cage due to ISAV (Kibenge *et al.,* 2012).

Rhabdovirus

Rhabdoviruses by far are one of the largest groups of viruses isolated from teleost fish. The viruses are mostly associated with epizootics and heavy losses in piscine aquaculture (Wolf, 1988). The family *Rhabdoviridae* contains the genera *Vesiculovirus*, *Lyssavirus*, *Ephemerovirus*, *Cytorhabdovirus*, *Nucleorhabdovirus* and *Novirhabdovirus* (Essbauer and Ahne, 2001). Rhabdoviruses has been reported to cause acute disease in Rio Grande Perch (cichlid), also known in the North American (Mexican) Cichlid *(Cichlasoma cyanoguttatum)* (Malsberger and Lautenslager, 1980). These viruses are responsible for infections in a wide range of freshwater and marine fishes (*Anguilliformes, Clupeiformes, Cypriniformes, Gadiformes, Perciformes, Pleuronectiformes and Salmoniformes*) (Essbauer and Ahne, 2001). Infected fish show sign of lethargy leading to mortality within one week (Malsberger and Lautenslager, 1980). Striped snakehead skin ulcerative disease has been reported in striped snakehead *(Ophicephalus striatus)* in Burma and Thailand, which has caused large, deep ulcerations of the skin on the head and body of fish (Ahne *et al*., 1988; Frerichs *et al*., 1989). Several strains of rhabdoviruses have been isolated from this species.

The Rhabdovirus can be characterized as enveloped virions with the nucleocapsid (30-70 nm in diameter) containing a single molecule of linear, negative-sense ssRNA (Essbauer and Ahne, 2001). Rhabdoviruses generally have five structural polypeptides (polymerase, L; glycoprotein, G; nucleocapsid, N; phosphoprotein, P, and matrix, M) of which the N-, L- and P-proteins are associated with the nucleocapsid. The envelope containing the G-protein is connected with the nucleocapsid by the M-protein (van Regenmortel *et al*., 2000). Novirhabdoviruses can be distinguished from the piscine vesiculoviruses by a non-structural protein (12-14 kDa, 111 amino acids), the non-virion protein (NV-protein) (Kurath *et al*. 1997). The non-virion protein plays an important role in the viral replication (Nichol *et al*., 1995). The molecular biology of fish pathogenic rhabdoviruses has been reviewed (Enzmann, 2000). A rhabdovirus was isolated and characterised from an asymptomatic starry flounder (*Platichthys stellatus*) during a viral survey of marine fishes from the northern portion of Puget Sound, Washington, USA, (Mork *et al*., 2004).

Infectious haematopoietic necrosis virus (IHNV)

IHNV has been reported from Russia, Japan, Iran, China and Korea (AGDAFF-NACA, 2007; Crane and Hyatt, 2011). IHN is a highly contagious disease of salmon and trout (*Onchorhynchus*, *Salmo*) occurring at water temperatures between 8 and 15°C. IHNV is responsible for infectious haematopoietic necrosis, IHN. Young fishes are more susceptible to the IHNV and infected fishes were shown to have impairment of osmotic balance in connection with oedema which leads to mortality. IHNV epizootics occur usually in young *Salmoniformes*, and other fishes like *Acipenseriformes*, *Pleuronectiformes* and *Perciformes,* which are also susceptible to the virus (Winton, 1992). IHNV shares physicochemical characteristics of *Rhabdoviridae*, which has a single molecule of linear, negative sense ssRNA genome (11.1 kb). IHNV genome contains six genes (N-, P-, M-, G-, NV-, and L-genes) located from 3' to 5' (Kurath *et al*., 1985; Morzunov *et al*., 1995). IHNV is an economically important pathogen causing clinical disease and mortalities in a wide variety of salmonid species, including Atlantic salmon (*Salmo*

salar) and rainbow trout (*Oncorhynchus mykiss*) (Dixon *et al*., 2016).

Spring viraemia of carp virus (SVCV)

Spring viraemia of carp virus (SVCV) is the causative agent of spring viraemia of carp (SVC). The SVCV genome is composed of linear, negative-sense, ssRNA containing five genes in the order 3'-N-P-M-G-L-5', encoding a nucleoprotein, phosphoprotein, matrix protein, glycoprotein and RNA-dependent RNA polymerase, respectively (Ashraf *et al*., 2016). SVC has been reported in China, Iran and Northen hemisphere (Bernoth and Crane, 1995). The SVCV has been reported to infect both wild and culture fishes, but mainly affects common carp (*Cyprinus carpio*) in European aquaculture. SVCV has been reported as most important virus disease of ornamental and also wild and farmed carp (Southgate and Branson, 1992). The SVCV existence in large number of ornamental fishes has been reported in China (Zhang *et al*., 2009). SVCV infects several fishes of *Cypriniformes*, *Atheriformes*, *Salmoniformes* and Crustacea (Fijan, 1972; Wolf, 1988; Johnson *et al*., 1999; Stone *et al*., 2001). The SVC viral genome consists of one molecule of non-infectious linear single standard RNA (Hill *et al*., 1975). SVCV was isolated and identified from common carp and koi carp and was isolated and identified from coregonus, grass carp, pike, pseudorasbora, river trout, silver bream and tench (Ahne *et al*., 1998a).

The spring viraemia of carp virus show high pathogenicity for Pacific herring (*Clupea harengus pallasi*) (Kocan *et al*., 1997). SVCV can be multiplied in several fish, avian, mammalian and reptilian cells at 20-25°C (Clark and Soriano, 1974). Clinical signs of SVCV infected fishes include external and internal haemorrhages, peritonitis and ascites (Fijan, 1972). Additionally, these include lethargy, darkening of the skin, respiratory distress, exophthalmia, petechial haemorrhages of the skin and gills, pseudofeces, inflamed and protruding vent, and loss of balance (sometimes fish appear to stand on their heads or their tails) which lead to 30-100 % mortality. Internal signs include those typical of a viral septicemia with all organs affected, such as inflammatory oedema, necrosis in all organs (liver, pancreas, kidney, heart, brain, intestine, swimbladder), visceral haemorrhages and serosanguineous fluid in the abdominal cavity (Southgate and Branson 1992; McAllister 1993). The disease has been described as an endemic in Europe, America and several Asian countries, where it causes significant morbidity and mortality in affected fish (Ashraf *et al*., 2016).

Viral haemorrhagic septicaemia virus (VHSV)

VHSV causes high mortality rates (90-100%) usually among juvenile fish in trout aquaculture at 4-14°C. Marine fish and trout are most susceptible to VHSV and have been reported from Japan, Korea and Iran. VHSV can induce interferon in the early stage of infection (de Kinkelin and Dorson, 1973). Jorgensen, (1971) has reported that survivors are resistant to reinfection due to the development of neutralizing antibodies. In 1998, thousands of dead Pacific herring, Pacific hake (*Merluccius productus*) and walleye pollock (*Theragra chalcogramma*) were infected by the American strain of VHS in Alaska, (Meyers *et al*., 1999). The European VHSV and American VHSV could be clearly distinguished at the genomic level (Batts *et al*., 1993; Benmansour *et al*., 1997). VHSV was isolated from some of the marine fishes (*Clupea harengus, Sprattus sprattus, Gadus morhua, Rhinonemus cimbrius, Trisopterus esmarkii, Micromesistius poutassou, Merlangius merlangus, and Argentina sphyraena*) in the Baltic Sea and North Sea (Mortensen *et al*., 1999). VHSV has a non-segmented single standard RNA genome (SchuÈtze *et al*., 1999). Clinical signs of VHSV infected fish have been described as exophthalmia, darkened skin, bleeding around eyes and base of fin, skin ulceration and pale gill with haemorrhages (AGDAFF-NACA, 2007). Ito *et al*. have been described the differences of pathogenicity in rainbow trout between the virulent NO-2007-50-385 and the non-virulent 4p168 VHSV GIII isolates. The study suggested that substitutions of amino acids in positions 118–123 of the nucleo-protein are candidates for being related to virulence of VHSV GIII in rainbow trout (Ito *et al*., 2016).

Epizootic ulcerative syndrome rhabdoviruses

Epizootic ulcerative syndrome (EUS) causes high mortalities in fish. Epizootic ulcerative syndrome is caused serious infections noticed in the finfish of Asia-Pacific during the last three decades (John and George, 2012). In 16 countries, EUS of fish severely affected wild and cultured freshwater and estuarine - fishes (Frerichs, 1995). Two rhabdoviruses, ulcerative disease rhabdovirus (UDRV) and the snakehead rhabdovirus (SHRV) were isolated from freshwater eel (*Fluta alba*) (Frerichs *et al*., 1986) and snakehead fish (*Ophicephalus striatus*) (Wattanavavijarn *et al*., 1986) respectively in Thailand. EUS is listed as a notifiable disease by Office International des Epizooties (OIE) (OIE, 2001).

Reovirus

Reoviruses coming under the family *Reoviridae* have been isolated and reported from both freshwater and marine fishes. The first finfish reovirus (golden shiner virus, GSV) has been reported from golden shiner (*Notemigonus crysoleucas*) in the USA (Plumb *et al*., 1979). Chum salmon aquareovirus has been reported from kidney and liver of asyptomatic fish mention species (Winton *et al*., 1981). An aquareovirus was isolated from masou solmon fry in Japan (Yoshimizu, 1988) and in Taiwan (Hsu *et al*., 1989). Reovirus has been reported in EUS infected snakehead (*Channa striata*) fish in 1992 (Robert *et al*., 1994). These viruses replicate in several fish and mammalian cells at 15-25°C (Winton *et al*., 1987; Lupiani *et al*., 1995; Samal *et al*., 1998; van Regenmortel *et al*., 2000; and John *et al*., 2001). McPhillips *et al*., (1998) reported that the infectivity of the viruses can be increased by treatment with proteases. Grass carp reovirus (GCRV) was reported as highly pathogenic in grass carp (*Ctenopharyngodon idella*) in China (Chen and Jiang, 1984).

Aquareovirus has also reported from fancy carp and eel in Japan (Sano and Fukuda, 1987); tench (*Tinca tinca*) and chub (*Squlium cepalus*) in Germany (Ahne and Kolbe, 1987); Cultured turbo (*Scophthalamus maximus*) in Northwest Spain (Lupiani *et al*., 1989); Canadian smelt (*Osmerus mordex*) (Marshall *et al*., 1990) in east coast of Canada; Striped sea bass in Chesapeake bay, Maryland, United States (Baya *et al*., 1990); common carp (*Cyprinus carpio*) in China (Jiang *et al*., 1991) angel fish (*Pterophyllum scalare*) in United States (Varner and Lewis, 1991) and gilthead seabream in Northwest Spain (Bandin *et al*., 1995). Snakehead reovirus (SKRV) has been characterized as the presence of a double-stranded RNA genome with icosahedral symmetry, double capsid, average

size of 71 nm, buoyant density of 1.36 g ml^{-1} in CsCl and lacked a lipid-containing envelope (John *et al*., 2001). The virus has a ten segmented dsRNA genome and is the first orthoreovirus to be isolated from fish. Fingerling and yearlings are mostly affected by the grass carp reovirus, which caused haemorrhages in the skin and base of fin and in the eye and also exophthalmia and swollen abdomen (Jiang and Ahne, 1989). Fish reoviruses have been described as genus *Aquareovirus* of *Reoviridae* (van Regenmortel *et al*., 2000).

Paramixovirus

Viruses belonging to *Paramixoviridae* have been reported in chinook salmon (*Oncorhynchus tshawytscha*) in USA (Essbauer and Ahne, 2001). Paramyxovirus-like particles (100-300 nm) have been reported in rainbow trout (*Oncorhynchus mykiss*) and pike (*Esox lucius*) (Essbauer and Ahne, 2001). Virus has been characterized as an enveloped, pleomorphic RNA virus of 125-250 nm in diameter with one molecule of helical nucleocapsid. The paramyxovirus is sensitive to chloroform, and has a buoyant density of 1.20 g/ml in caesium chloride gradient. The virus replication was reported in several fish cell lines at 18°C (Winton *et al*., 1985). Miyazaki *et al*., (1989) detected paramyxovirus in the cytoplasm of necrotized epithelial cells of black sea bream (*Acanthopagrus schlegeli*) by electron microscopy.

Retrovirus

Retroviruses come under the genus *Epsilonretrovirus* of the family *Retroviridae*. Van Regenmortel *et al*., (2000) reported distinct species of fish retroviruses, i.e. walleye dermal sarcoma virus (WDSV), walleye epidermal hyperplasia virus type 1 (WEHV-1), and walleye epidermal hyperplasia virus type 2 (WEHV-2), and two tentative species, i.e. perch hyperplasia virus (PHV) and snakehead retrovirus (SnRV). Several retrovirus-like particles associated with proliferative conditions in fish (Bowser and Casey, 1993) have been reported. Epidermal papilloma of white sucker (*Catostomus commersoni*) have carried C-type retrovirus particles of 100 nm in diameter associated with transcriptase activity and C-type particles of110-150 nm have been found in Atlantic salmon (*Salmo salar*) with swim bladder neoplasia and epidermal papilloma. Hart *et al*., (1996) has analysed the complete nucleotide sequence of the snakehead retrovirus (SnRV), isolated from persistently infected striped snakehead (*Ophicephalus striatus*) cell line (SSN-1). Retrovirus-like particles have been isolated from several fishes such as coho salmon (*Oncorhynchus kisutch*), masou salmon (*O. masou*), rainbow trout (*O. mykiss*), iwana (*Salvelinus pluvius*) and ayu (*Plecoglossus altivelis*) (Oh *et al*., 1995).

Coronavirus

A coronavirus-like agent has been isolated from common carp (*Cyprinus carpio*) screeneding for erythematous skin and abdomen. The virus has been characterized to be enveloped, with an RNA genome and measured 60-100 nm in diameter. The agent tentatively classified as coronavirus, induced hepatic, renal and intestinal necrosis in fish by experimental infection (Sano *et al*., 1988). It has induced high mortality in common carp (*Cyprinus carpio*) in Japan.

Togavirus

Salmon pancreatic disease virus (SPDV)

Salmon pancreas disease virus, often referred to as salmonid alphavirus (SAV) (Weston *et al*., 2002; Skjold *et al*., 2016), is a highly contagious virus and the aetiological agent of pancreas disease (PD) in marine reared Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) (Nelson *et al*., 1995; Taksdal *et al*., 2007). The virus is also referred to as sleeping disease (SD) in freshwater reared rainbow trout (Boucher *et al*., 1994). Belonging to *Togaviridae,* SPV disease has been reported to cause up to 50% mortality among farmed Atlantic salmon (*Salmo salar*) in Europe and North America (Poppe *et al*., 1989). Nelson *et al*., (1995) identified the salmon pancreatic disease virus (SPDV) as a toga-like virus. SPDV transmission experimentally has been reported from some of the fishes including Atlantic salmon (*Salmo salar*) (to be highly susceptible), rainbow trout (*Oncorhynchus mykiss*) (less susceptible) and brown trout (*Salmo trutta*) (least susceptible) (Boucher *et al*., 1995). Horizontal transmission of SAV has been shown in both fresh- and seawater in experimental trials (Boucher *et al*., 1995; McLoughlin *et al*., 1996) and experimental challenges have shown that viral shedding typically precedes clinical PD (Andersen *et al*., 2010; Graham *et al*., 2011). SAV transmits horizontally from fish shedding virus into the water (Skjold *et al*., 2016).

Sleeping disease virus of rainbow trout (SDV)

SDV has been isolated from plasma of rainbow trout (*Oncorhynchus mykiss*) (Castric *et al*., 1997). SDV has been characterized as an enveloped virus of 55-65 nm and infected fish showed clinical signs of lying side up on the bottom of a tank, suffering from sleeping disease (SD) (Castric *et al*., 1997). SDV and SPDV induce similar histopathology; it is probable that both agents are related or undistinguishable viruses (Weston *et al*., 1999).

Erythrocytic inclusion body syndrome virus (EIBSV)

EIBS viral particles were detected in erythrocytes of salmonid fishes (*Salmo trutta fario*, *Salvelinus fontinalis*, *Oncorhynchus mykiss* and *Oncorhynchus clarki*). Erythrocytic inclusion body syndrome (EIBS) has been found to be caused by togavirus-like agents (Nakajima *et al.,* 1998a). Coho salmon *Oncorhynchus kisutch* were infected artificially with the virus that causes erythrocytic inclusion body syndrome (EIBS) (Piacentini *et al*., 1989). The cytoplasmic inclusions are either large, single inclusions (1-2 microm) or smaller multiple inclusions (0.5-1 microm) (Rodger, 2007). The virus is a single-stranded RNA, spherical virion morphology with an icosahedral core, average size of 70 nm (Rodger, 2007).

Picornavirus

Picornaviruses belonging to *Picornaviridae* have been detected in teleost fish species in America, Asia and Europe. Usually hatchery reared fish are more susceptible to the virus which exhibit corkscrew-like swimming often associated with mass mortalities (Essbauer and Ahne, 2001). Picornavirus has been reported as small non-enveloped, icosahedral RNA viruses measuring less than40 nm. Picornavirus-like particles have been detected in several economically important fishes including European seabass (*Dicentrarchus labrax*, Breuil *et al*., 1991), barramundi (*Lates calcarifer*, Glazebrook *et al*., 1990), smelt (*Osmerus eperlanus*, Ahne *et al*., 1990; *Osmerus mordax*, Moore *et al*., 1988), turbot (*Scophthalmus maximus*, Bloch *et al*., 1991) and salmonids (*Salmo trutta fario*, *Salvelinus fontinalis*, *Oncorhynchus mykiss* and *Oncorhynchus clarki*, Yun *et al*., 1989). Usually, hatchery reared fish are

affected by picornavirus which exhibit corkscrew-like swimming and with associated mass mortalities. Some picornaviruses have been isolated in fish cell cultures such as CHSE-214 *in vitro* at 10-20°C, inducing syncytia of infected cells (Hetrick and Hedrick, 1993). In 2001 an unknown virus has been isolated from a bluegill fish (*Lepomis macrochirus*) and it was identified as a picornavirus termed as bluegill picornavirus (BGPV) (Barbknecht *et al*., 2014). Under experimental infections of bluegills has been confirmed that BGPV can cause morbidity and mortality in bluegills (Barbknecht *et al*., 2014). A novel picornavirus from Baitfish has been identified and named as fathead minnow picornavirus (FHMPV) in the USA (Phelps *et al*., 2014). Based on complete polyprotein analysis, the FHMPV was shared 58% (P1), 33% (P2) and 43% (P3) amino acid identities with BGPV and shared less than 40% amino acid identity with all other picornaviruses (Phelps *et al*., 2014).

Conclusion

Aquaculture with high stocking density is associated with risks of disease emergence and spread. Particularly viral diseases are major constraints to the aquaculture sectors. Many RNA viruses such as birnavirus, nodavirus, orthomyxovirus, rhabdovirus, reovirus are caused infectious diseases among the important cultivable fishes resulting in great economic losses of aquaculture. Prophylactic measures in aquaculture like prebiotics, probiotics, vaccines and immunostimulants have found to be the effective tool for preventing the risk of infectious diseases. Several experimental types of research on effective prophylactic health management have been carried out by many researchers, however, more attention is required to approach at field level for successful aquaculture production. In addition, best management practice is more essential to minimize the risk of disease causing organism particularly virus pathogen which would help to achieve affluent production in the aquaculture sector.

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